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PINE NUTRITION

An Account of Investigations and Experiments in connection with the Growth of Exotic Conifers in Western Australian Plantations

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FOREWORD.

Although the major activities of the Forests Department of Western Australia since its establishment twenty years ago have been directed towards the protection and rehabilitation of the valuable indigenous hardwood forests of Jarrah and Karri, other phases of forest production have received considerable attention. Among these has been the establishment of plantations of pines with the object of supplying local softwood requirements, and, in the course of this work, efforts have been made to develop a technique which will enable areas of waste land in proximity to the larger centres of population to be used for this purpose. The successes which have been achieved in establishing healthy plantations of great promise on the poor soils available have been due in a large measure to an intensive study of problems of pine growth, the more important of which are dealt with in this report.

It is proposed that this publication form the first of a series of technical papers dealing with the scientific investigations which have been carried out and are still proceeding as an essential part of our extensive reforestation programme.

J. C. WILLCOCK,
Premier and Minister for Forests.

Perth, 14th March, 1938.

SUMMARY.

With the object of providing for future local requirements of softwood timber in Western Australia, the Government has planted 11,400 acres of pines during the past 15 years in 16 different centres. The majority of these plantations, consisting of P. radiata and P. pinaster, have shown rapid and uniform growth.

In common with all plantations of exotic conifers in Australia, certain areas of irregular and abnormal growth have developed. With a view to discovering possible remedial measures and to avoid further planting on sites not likely to give satisfactory results, a detailed study has been made of the factors affecting the growth of pines in plantations, and numerous experiments carried out. This publication is in the nature of a progress report on the main aspects of the work.

The geology and soils of the region concerned are briefly described. Emphasis is placed on the importance of detailed soil survey based on the whole soil profile as a first step in the study of plantation problems, and on virgin soils close correlation has been established between soil type and pine growth. Anomalies due to site changes following intensive cultivation and pasture establishment are discussed.

The depth, physical properties and moisture-retaining capacities of soils have been found to be of very minor importance in determining the suitability of sites for the growth of either P. radiata or P. pinaster, but the investigations have shown that P. radiata requires a soil containing a considerably higher percentage of essential plant nutrients than is needed for the successful growth of P. pinaster.

The paramount importance of the fertility factor in determining the value of soils for different pines is postulated and the P_2O_5 content of Western Australian soils is stated to be a valuable indicator of the suitability of different soil types for P. radiata and P. pinaster respectively, provided such soils have not been intensively developed for pasture or crop purposes.

Remedial measures to restore to normal growth areas of young pine affected by various disorders are described and discussed. The most important corrective treatments applicable to the pine crop on a large scale are cultivation, the application of dressings of superphosphate at the time of and after planting, and spraying very young pines with a solution of zinc salts.

PINE NUTRITION

An Account of Investigations and Experiments in connection with the Growth of Exotic Conifers in Western Australian Plantations.

Chapter 1.

INTRODUCTION.

In Western Australia the principal forests of commercial importance are located in the south-western portion of the State. In this region a continental plateau with an elevation of 1,000 to 1,500 feet extending from the centre of the continent continues practically to the seaboard. The fault scarp which marks the western edge of this plateau has become much rounded and worn, and is dissected by the many short rivers which flow through narrow valleys before entering the plain below. This eroded escarpment parallel to the coast line is known as the Darling Range.

The geological formation of this Range, on which the good quality forests of Jarrah and Karri are situated, is igneous, being composed of granite and gneiss. Dykes of basic rock occur throughout and give rise to the more fertile soil conditions found in certain localities. The characteristic feature of the Range, however, is heavy lateritic capping which occurs generally and is present in every stage from cemented boulder formations to heavy accumulations of rounded gravel or disintegrated pisolotic laterite.

A coastal plain some 20 to 30 miles wide, on which the capital city of Perth is situated, extends from the foothills of the Darling Range to the Indian Ocean. On the seaward side this plain is characterised by extensive sand dunes. Some of these have long since been fixed by vegetation and now support in many places forests of some economic value. Along the shore line more recent dunes have invaded the older formations. Occurring sporadically at varying depths in the dunes is a rock formation known locally as coastal limestone. It is of aeolian origin, having resulted from a consolidation of lime-bearing sands, and there is a wide variation in the proportion of lime and sand. On the inland side of the plain occur extensive beds of detrital material from the peneplain above, partly consolidated as sandstone and shales. These have given rise to the clay flats and sandy ridges of the eastern fringe of the plain.

The fault responsible for the formation of the Darling Range does not extend to the extreme south-west corner of the continent, where a trough fault 20 to 30 miles in width occurs, leaving a narrow outlier of the main plateau extending from Cape Naturaliste to the Leeuwin. A fringe of calcareous sandstone of similar origin to that described above has been formed above sea level on the surface of the granite facing the sea.

EXAMPLES OF NORMAL STANDS ON GOOD SITES.

P. radiata.

Age 14 years. Height 75 feet. Planted 7ft. x 7ft.
Present stocking 350 per acre.
Present volume O.B. 4,000 cubic feet.
Removed as thinnings 2,000 cubic feet.
Greystones Plantation, Mundaring Division.

P. pinaster.

Age 11 years. Height 26 feet. Planted 7ft. x 7ft. Total volume O.B. 1,025 cubic feet
Collier Plantation, Metropolitan Division.

25 cubic feet

The climate is characterised by a regular winter rainfall spread over the cooler months from April to September, with only occasional rain storms during the summer. In the extreme south-western section the average annual rainfall reaches in places a maximum of 60 inches, but it diminishes rapidly from the coast to the interior. The climate is equable and severe frosts are rare even in midwinter.

The best of the indigenous hardwood forests are found in the region between the 35-inch and 60-inch isohyets. Within this region of moderately high and regular winter rainfall there are extensive areas on which the indigenous Eucalypt forests, although of considerable height growth, are of low commercial value and, with the object of supplying as far as practicable future local requirements of softwood timber, large areas have been cleared and plantations of pine established by the Forests Department as an adjunct to its extensive reforestation operations in the valuable hardwood forests. For some years past pine-planting has been restricted to less than 1,000 acres per annum, and the area of effective plantations established to date is 11,400 acres, consisting of 3,374 acres of Pinus radiata, 7,582 acres of P. pinaster, and 444 acres of other species of conifers.

The development of single trees and rows of pines planted on farms and orchards for shade and windbreak purposes has shown that, climatically, the region is well suited to the growth of a number of coniferous species, chief among which are Pinus radiata and P. pinaster. General experience throughout Australia has shown that P. pinaster is more adaptable with regard to soil conditions than P. radiata, and therefore the latter species has been given the benefit of the better soils available for afforestation purposes.

Other pines tried include P. halepensis, P. canariensis, P. Coulteri, P. muricata, P. Lambertiana, P. Jeffreyi, P. ponderosa, P. patula, P. laricio, P. longifolia, P. rigida, P. clausa, P. Torreyana, P. densiflora, P. Massoniana, P. luchuensis, P. strobus, P. Banksiana, P. sylvestris, P. echinata, P. taeda, P. palustris and P. caribaea. Of these the only species, apart from P. radiata and P. pinaster, which so far shows any promise of making a stand on a variety of soil types under ordinary plantation conditions hitherto existing is Pinus caribaea.

In the south-west of Western Australia the growth of pine stands on selected sites is very good, P. radiata reaching a height of 100 feet in fifteen years. Volumes up to 7,500 cubic feet per acre over bark in stands planted at 8 feet by 8 feet have been recorded in the same period. The rapid growth made by P. radiata and the quality of its timber make it a very valuable tree in a country so deficient in softwood.

Twenty years ago the opinion was held generally throughout Australia that the demands of Monterey Pine upon the physical and chemical composition of the soil could be readily satisfied by the poorest of soils. This mistaken idea was largely responsible for the establishment of plantations in most States of the Commonwealth on coastal sands which were useless for any other purpose, and the results have been generally unsatisfactory.

More recently many foresters have postulated that the physical characters, moisture-holding capacity, soil depth and ease of root penetration in heavy subsoils were the important considerations to be studied, while a minority have stressed the importance of factors affecting soil fertility including questions of the presence and availability in sufficient quantities of essential nutrients.

Australian foresters, in considering problems of pine establishment, have tended to overlook the intensive measures found necessary to secure the satisfactory growth of plantations on the coastal sands of some Western European countries, the moorlands and heaths of England, and the poor soils of Central Europe. This is understandable when it is realized that, with few exceptions, the pine crop in

Australia has been planted on sites which are known to have carried forests of Eucalypts. In very many instances the Eucalypts were trees of considerable height growth, although the timber they produced may have been of little or no commercial value. Experience in Western Australia has shown that the height growth of the indigenous Eucalypt crop is a most unreliable index to the value of any site for the growth of exotic conifers. Examples of unsatisfactory pine growth are to be seen in experimental plots and arboreta on sites which carried indigenous forests of various species, including Jarrah-Marri associations ranging from 80 to 120 feet in height and Karri-Marri associations from 150 to 250 feet in height. It is interesting to note that these sites, although giving only indifferent results when planted with exotic conifers, appear to be well suited to the growth of other Eucalypts not endemic to Western Australia. Experimental plots of species such as Eucalyptus Muelleriana, E. pilularis, E. microcorys, E. saligna, and E. resinifera have shown extremely rapid and healthy development in contrast to the indifferent growth of pines on adjoining plots.

In the conversion of the Eucalypt forest to pines the treatment preparatory to planting has been limited, for the most part, to clear felling followed by burning of the fallen debris. In this process the ground flora is burnt back to the ground and the smaller limbs of the felled trees are disposed of, but the larger branches and logs remain on the planting site. The high cost of removal of the logs to permit ploughing has led to the general practice of planting without cultivation other than a small amount of hand-digging around the actual planting spots.

Despite the good growth made by Pinus radiata as ornamental and shelter trees around homesteads and on pastures in Southern Australia, foresters in many instances have been unable to secure satisfactory growth in the same localities under plantation conditions. In some of the plantations a yellow chlorotic condition has developed in the early years. This has occurred frequently on soils which have been judged on agricultural standards the equal of those already supporting satisfactory pines of the same species singly or in groups in the same locality. Such disorder may not affect the whole of a plantation, but more often occurs sporadically in patches of varying extent.

On extensive areas of plantation in all parts of the Commonwealth where the growth of the pines is unsatisfactory, very little attention has been given in the past to possible remedial measures. On many sites there occurs a gradual improvement in Pinus radiata stands, which in their early stages showed alarming symptoms and without any special treatment grow on to form fair-quality crops. This is one of the most interesting features of certain plantations, but unfortunately there are others in which the pines fail to recover and the extent of these failures is sufficient to make a comprehensive study of the behaviour of pine stands on different sites one of the most important economic problems in Australian forestry today.

Considerable attention has been given to all aspects of the problem for a number of years in Western Australian plantations and, as a result, the improvement of unsatisfactory areas by various corrective treatments involving such measures as cultivation, the use of fertilisers, spraying with zinc solution, etc., has now in this State a considerable background of accomplishment. A brief summary of the work done to March, 1936, appeared in "Australian Forestry," Vol. I., No. 1, entitled "Plant Nutrients and Pine Growth," by Kessell and Stoate. This report deals more fully with developments up to the end of 1937.

It will be many years before the correctness of deductions made from certain experimental data now available can be fully established and before the final test of financial results of treatment undertaken can be applied to the plantations. Experiments laid down during past years will continue to be assessed periodically,

and further work is proposed to clarify many points which are still obscure, particularly questions relating to the effect on the pine crop of combinations of various treatments. In the course of these studies of pathological phenomena, information is being obtained on many other aspects of plantation work which is adding to our total knowledge of the silvicultural characteristics of pine species which are of great importance in Australian forestry practice. For example, in the course of these experiments, attention has been focussed repeatedly on the importance of racial strain in relation to bole form, branching habits, resistance to insect attack, root and shoot development, periodicity of growth, and bark and needle shed.

Chapter II.

TYPES OF IRREGULAR GROWTH.

Throughout these investigations attention has been directed to the study of pine stands rather than individual trees. Owing possibly to climatic conditions pine plantations in Western Australia are remarkably free from diseased conditions which can be directly ascribed to any fungus or insect attack. Chermes occurs to a limited extend on Pinus pinaster, but most trees recover without showing any serious effects. In practically all cases where parts of plantations are found to be in an unhealthy condition, it would appear that the primary cause can be attributed to some physiological upset.

As a first step towards the recognition of specific disorders, the morphological characteristics of the abnormal features of growth exhibited by stands in an unhealthy condition have been described. Each set of descriptions deals with members of a stand growing on the same site. In some instances considerable variation exists in the extent to which symptoms are shared by all members of the stand, and it is difficult to decide how far these differences are due to the same set of causative factors. The belief that in the majority of cases such variations may be attributed to different intensities or different phases of a single disorder is supported by the fact that, where a response to a given treatment has been obtained in a stand growing under uniform site conditions, all abnormalities of growth have disappeared.

The Commonwealth Forestry Bureau, Canberra, has undertaken an anatomical study of the organs of normal pines, diseased pines and pines which have been restored to normal growth, by remedial treatment. In a lengthy communication on the subject (unpublished), Mr. C. E. Carter has drawn attention to certain peculiarities of leaf structure in affected pines and to variations in starch content.

Although many differences may be noted in making detailed descriptions of symptoms of disorders occurring in stands of both P. radiata and P. pinaster in different localities, or on different sites in the same locality, it has been found convenient to group types of irregular growth having certain characteristics in common into a few broad classes under descriptive names.

Local variations within these broad classes are referred to by the name of the plantation on which the conditions occur. It would appear that no good purpose is to be served by setting out these local variations in detail, and, in consequence, only the main classes of plantation sicknesses are described in a general way hereunder.

The age and size of pine stands when symptoms of certain disorders become apparent are greatly influenced by the treatment the site has received prior to planting. The prior establishment of pasture or thorough ploughing before planting will assist early growth of the pine stand to an extent that disorders usually associated with a particular soil type may not develop until many years later than anticipated, or may never show up.

Considerable changes in the colour of the foliage with the seasons is a characteristic of pine stands which are not in a completely normal and healthy condition. In Western Australia improvements in the general colour of the needles take place during the late winter and early summer. About the end of January the appearance of certain stands will begin to deteriorate, and "yellowing" and similar disorders will show up to the greatest extent during the months of April to July.

Pinus radiata.

In every stand of P. radiata, including those growing under the most favourable conditions, a close examination will show a percentage of trees of bad form. To an extent this will be found to be due to the death of the leading shoot of poor form trees at different stages in the development of the stand. Although this may happen to 10 per cent. or more of the trees, the condition of the stand as a whole continues satisfactory, and such minor complaints of individual trees are not intended to come within the scope of the disorders of the stand referred to hereunder.

1.—*Rosetting.*

This name is applied to a disorder or group of disorders which develop in very young plantations. Immediately following planting, growth is healthy and vigorous. The first signs of disorder become evident at the end of the first growing season, although it may not develop to a serious extent until two or three years later. In affected trees there is a marked reduction in the amount of foliage, and both side branches and needles are much shorter than normal. The short side branches 1 foot or less in length tend to stand at an acute angle with the main stem. The needles are generally under 2 inches in length and the foliage is scanty, owing to the shedding during early winter months of not only all the previous season's needles but also of the first formed or lower needles of the current season's growth. The branches thus become bare except for a bunch of foliage around the leading shoot of the main stem, and the terminal buds of the short side branches. In extreme cases, the side branches die after developing to a length of two to three inches only and the tree becomes devoid of needles except for a tuft three to four inches in depth at the top of the main stem. The general appearance of the stand is chlorotic and the colour of the needles varies from a moderately good green to a bright yellow. The individual needles are not irregularly variegated or mottled but shade off to more intense yellow or even brown colour towards the tip. At certain seasons tufts of dead needles immediately below the main or side terminal buds give a characteristic reddish brown colour to affected patches of pines.

Some pines make no height growth and carry very few green needles after the condition first develops, while other pines in close proximity may show nearly normal height growth, colour and general development. All intermediate stages between these extremes tend to occur scattered over the whole of the affected area. Many affected pines may continue to grow for a considerable period of years carrying tufts of short stiff needles around the terminal bud of the leading shoot and at the end of otherwise bare branches.

The disorder as a whole may be described as alarming stagnation and malformation occurring in a large proportion of very young pines following healthy growth for at least twelve months after planting. The condition appears to be peculiar to a few localities and in these to areas newly cleared, on which the pines have been planted in the winter following the "burn."

2.—*Yellowing.*

This name, which has been adopted to describe a general condition of unthriftiness in early life, appears to be the first phase of two very different complaints. Further knowledge may render it possible to distinguish between the two conditions, but at present, on the symptoms apparent in the stand itself, we are not able to decide whether the condition known as "Yellowing" will develop into one or other of the disorders described hereunder as "Dead Top" and "Thin Crown." Towards the end of any summer during the first few years after planting, young stands of P. radiata may show a general deterioration in colour of the foliage. When first noticed the condition may be confined to yellowing of needle tips, which will tend to disappear in the following winter only to reappear in a more serious form the following summer. In addition to the colour change, general signs of unthriftiness may be noted throughout the portion of the plantation affected: height growth is below normal, the foliage becomes sparse and the needles shorter. As the condition develops, the whole area varies between a pale green colour in spring and early summer to a characteristic yellow in late summer and autumn months. Only two seasons' needles, and, in extreme cases, only one season's needles, are retained on the tree.

The reduced height growth, comparatively short side branches, and sparse foliage all contribute to prolonged delay in forming canopy, with the result that the bottom branches tend to remain alive for much longer than in normal stands.

Stands affected by Yellowing are recognised as being generally unthrifty in growth and poor in colour. Practically all trees are affected, but dead tops are rare and there is no serious malformation apparent in individual trees.

3.—*Dead Top.*

In certain stands where P. radiata has been planted on very inferior sites, the condition described above as Yellowing steadily becomes more acute and passes into the condition of complete stagnation known as "Dead Top." This development occurs usually between the sixth and fifteenth years after planting, when the average height of the stand is between 15 and 30 feet. A characteristic feature shared by many trees is the multiplication and relatively greater development of the secondary branch system, producing trees of shrub-like appearance with a central dead shoot. The needles developed on the upper branches of badly affected trees are extremely short. Odd trees may send out a new leader, but the terminal bud will generally die after one or two seasons' growth. Areas in this condition must be regarded as complete failures, and no instances of any general recovery with or without treatment have been recorded, although odd trees may continue to develop for a period of years.

4.—*Thin Crown.*

In contrast to acute forms of Yellowing on sub-marginal soils which develop into Dead Top, other areas on somewhat better soils which develop Yellowing to an alarming extent may recover and form stands which will yield a considerable volume of marketable log timber. At some stage—usually between the tenth and fifteenth years, when the stand is 25 to 35 feet high—a considerable improvement is noted in the colour and density of the foliage. The annual height growth in-

creases and, as the canopy improves, the general condition of the stand becomes more normal. As the name implies, the density of the crown does not compare with average trees in a normal stand, and it is probable that on such sites the physical rotation of the crop will prove to be short. If the capacity of a site to maintain a crop in a condition of "Thin Crown" can be established when the plantation is young, artificial aids to assist growth may prove a sound investment.

5.—*Die-back.*

This is a disorder which occurs usually between 4 and 8 years of age. It is, perhaps, best described as a complaint of early years which passes off to leave permanent bole malformation of some members of the stand but, in many instances, sufficient trees of good shape remain to form a satisfactory forest.

After fairly normal growth and good colour in the early years, the leading shoot and sometimes the upper whorl of branches of a number of trees die back. The lower branches continue to carry a heavy canopy of normal needles of good colour. Subsequently many die-back trees develop a new leader and again grow vigorously and some form satisfactory crop trees, particularly where the "Die-back" occurred at a low height. A proportion of the trees in the stand show normal development throughout.

This disorder is very restricted in occurrence in Western Australian plantations. It is, however, very distinctive. A feature is that good stands may result at 12 or 15 years of age, despite the fact that the symptoms at 4 to 8 years may have been alarming.

6.—*Autumn Brown-top.*

This, as the name implies, is a condition appearing in autumn in stands of any age after canopy is formed. The intercalary growth which is frequently made at this time of the year results in an elongation of the leader. In some years the needles carried on the top foot or so of the leading shoot may die, resulting in a brown-top appearance of a varying proportion of trees. This short top section of the leader may be killed, or may continue growth with the early rains and become clothed in green needles except for the short length which suffered the autumn check.

It is possible that Autumn Brown-top is closely related to the condition described as Die-back, but in the present state of our knowledge it is considered desirable to give the complaints separate names. They share the important characteristic that the foliage below the affected top sections retains a good colour but, whereas Die-back may seriously affect a large proportion of young trees during one or two growing seasons and not reappear, Autumn Brown-top is a condition which may occur repeatedly in older stands. A further important distinction is that in Autumn Brown-top only the leading shoot loses its colour and it is seldom, even in severe cases, that the top whorl of branches is affected.

7.—*Needle Fusion.*

For some unknown reason, this disorder in which the needles on the dwarf shoots do not separate is very rare in Western Australia, although comparatively common in many parts of the Eastern States. A description of the condition and of its occurrence throughout Australia, by Ludbrook, has recently been published as Pamphlet No. 72 of the Commonwealth Council for Scientific and Industrial Research.

Pinus pinaster.

Although many variations occur in functional disorders of Pinus pinaster, it is not easy to draw any very definite line between the conditions occurring in different localities.

The generic name of "Short Needle" has been adopted in Western Australia for a disorder of widespread occurrence on extremely poor soils. In the majority of cases the first symptom of a disorder may be noticed in the yellowing of the foliage towards the end of the first summer after planting. This discoloration may disappear in the following spring to reappear the next summer in a more acute form, following which the pine assumes an appearance of general unthriftiness. The needles are very much shorter than normal, and, in bad cases, only the current season's needles are retained. In consequence of this and the extremely short annual shoots, the pine develops an appearance of bare limbs with small tufts of needles at the ends of the branches.

Short Needle in P. pinaster may be divided into three important sub-classes, one in which the pine stagnates early when 18in. to 36in. in height, losing all foliage except a few needles at the tips of the uppermost whorl of branches, a second in which the pine continues to grow slowly in a stunted condition without any sign of dead tops appearing, and a third in which stunted growth is associated with a proportion of dead tops, though the length of leader killed is quite short, being restricted generally to a few inches of the tip.

Chapter 3.

GEOLOGY AND SOILS.

A careful examination of geological conditions and soils has been made on all plantation areas to decide in the first instance the species to be planted. On those plantations where areas of unsatisfactory growth have occurred, soil survey work has been intensified in an endeavour to correlate the behaviour of the pines with soil type and to provide a proper basis for fertiliser experiments and field trials of a similar nature. Marked difference in responses to treatments of various kinds has been noted on closely related soil types which superficially have a very similar appearance. One general observation emerging from the work carried out is the paramount importance of a detailed soil survey according to the whole soil profile as a basis for any investigations of plantation problems.

In addition to the numerous mechanical analyses which are required as a basis for this work, partial chemical analyses have been made of a great number of important soil types, and these in the first instance appeared to have a value to indicate only that the majority of soils available for plantation purposes contained a very low percentage of the main recognised plant nutrients. It was only after the work had been in progress for a considerable time that an attempt was made to schedule and compare these chemical analyses from a number of plantations on which the pines had reached an age which gave some reliable indication of their response to the site, with the result that it has proved possible to establish some correlation between the figures supplied by the analyst and pine growth. As explained later in this chapter, the phosphate (P_2O_5) content of soils of the South-West premises to provide a most valuable indicator of the value of various soil types for the growth of P. radiata and P. pinaster

respectively, and to give a lead to the responses to be anticipated from cultivation with or without the use of fertilisers in restoring backward areas to normal growth.

Before proceeding to briefly describe the geological formation and soil conditions in the two main regions, it is desirable to point out that the portion of the Australian Continent dealt with is a very old land mass, the soils of which have been exposed to weathering and leaching throughout long geological eras, and this fact, associated with the comparatively low mineral content of the extensive masses of granite which underlies nearly the whole area, is responsible for the occurrence over very large areas of soils low in recognised plant nutrients according to accepted agricultural standards.

The Darling Range.

The underlying rock of the Darling Range is essentially Precambrian granite which exhibits both massive and gneissic characteristics. Narrow dykes of dolerite are numerous in this mass. Associated with the occurrence of the intrusive material are zones of shearing. The whole has been covered by a comparatively thick deposit of laterite which in places may reach six to eight feet in thickness. The laterite occurs both as heavy outcrops on the surface and as a hardpan formation overlaid by several feet of ironstone gravel.

These soils may be readily grouped on the basis of geological origin, primary soils associated with igneous rocks being generally of heavier texture than those of the lateritic and alluvial groups. The surface soils are for the most part sandy loams and contain a high percentage of coarse sand.

Soils of the basic association occur in comparatively narrow bands on the tops of ridges, or on the upper slopes, being associated with narrow basic dykes. They are readily distinguished by the chocolate-brown to red-brown colour of the surface soils.

The granitic series is usually associated with rock outcrops and consists of coarse, gritty yellow-brown sands and sandy loams. A characteristic feature is the underlying acid granite which gives rise to sandy clay loams and yellow gritty clays in the lower horizons. Contamination of the surface soils by laterite gravel or by basic material may occur in areas lying immediately below outcrops of these rocks.

The most extensive formation of the laterite type is to be found on the ridge tops, where it represents the remnant of the laterite plateau, while small areas occupy an intermediate position on the slopes. Very heavy laterite gravel (60-80%) commonly occurs in yellow-brown sands to lighter sandy loams, which become slightly heavier at depth to overlie a heavy laterite hardpan. Where laterite rock outcrops it appears to be merely an exposed and weathered form of the cemented laterite hardpan.

The alluvials are generally very immature and reveal only slight changes in texture with depth; although, in some cases, a tendency towards a profile development is apparent.

In the Darling Ranges pine growth is very good on soil derived from the more basic rocks, dolerites of the Darling Range type and basic segregations of the gneissic granite. Growth at least in the early stages of the stands is unsatisfactory on the granitic soil types and most alluvials, except on the banks of streams. On the lateritic soils development is in most cases extremely poor.

The Coastal Plain.

Geologically the coastal plain is of the Cainozoic Series with sands of recent and tertiary origin on its seaward edge. It is in these sands that the plantations of the coastal plain are situated. The soils are essentially of dune formation inter-

spersed with flats characterised by an indurated coffee-brown horizon. These coastal soils are deep coarse sands of grey or yellow and sometimes brown colour. They do not reveal any definite profile but frequently include at depth thin layers of small pebbles of cemented sand of deep yellow colour. They fall naturally into three main groups:—

1. Sand ridges or sand dunes. These consist essentially of medium to coarse sands of grey or yellow and sometimes brown colour. The brown sands contain much ilmonite and zircon. In the more northerly plantations in the vicinity of Perth, the outstanding feature is the very high coarse sand fraction, which in the surface soils reaches 96%.

2. Flats between the dunes. Most frequently these are composed of grey to dark grey coarse sands overlying an indurated coffee-brown horizon known locally as "coffee-rock," which rather closely resembles the Alios of the Landes, France. The beds, which are at shallow depths of 4 to 7 feet, are sometimes of 15 inches in thickness. In some plantations the more typical coffee rock is replaced by an iron-stained sandstone with a small amount of coffee-coloured cementing material.

3. Limestone hills and sands overlying limestones at shallow depth. The limestone is generally a rock formation of sea sand cemented into a compact rock with carbonate of lime, and is of aeolian origin. It occurs in the form of small pebbles to boulders. Sometimes the lime-bearing sands have formed comparatively high hills in which the limestone occurs as floaters in brown surface sands, while, in other cases, the limestone may be covered by sands of several feet in depth. These are characteristically brown sands overlying varying shades of yellow or yellowish-grey sands passing to limestone.

Chemical Analyses.

The plant nutrients of the plantation soils of Western Australia are low according to agricultural standards. A considerable number of partial chemical analyses have been made by the Government Chemical Laboratory, Perth, in conjunction with soil surveys undertaken by the Forests Department. Owing to the small quantities of certain important elements present in many of the soils, it has been necessary to develop a special technique of analysis which gives an accuracy of parts per million.

From a careful study of a large number of analyses giving for different horizons the phosphorus, nitrogen, calcium and potassium present the value of the phosphate (P_2O_5) figures as an indicator has emerged. The realisation that any useful lead might be obtained from these figures was delayed owing to apparent anomalies which were later traced to areas which had been previously used for agricultural or orchard purposes. On certain of these areas, generally referred to as "old cultivations," the early development of the pine crop has been very much better than the growth of pines planted on the same soil type immediately following the removal of the Eucalypt stand by the usual clearing methods explained elsewhere in this publication. In some instances the effect of this site change brought about by farming practices is sufficient to enable good stands to be grown on soils which, using the P_2O_5 content as an indicator, would appear hopeless. The further investigation of this problem offers scope for a very interesting research project.

In the following tables typical analyses are given of a number of soils with notes on the development of the pine crop which has been planted on them. All are soils from which the indigenous forest was cleared immediately prior to planting. Some are soils on which extensive areas of pine have been established, others are carrying only experimental plots of a few acres in extent, but in all cases the pines are growing under ordinary plantation conditions.

CHEMICAL ANALYSIS OF SOILS GROWING PINUS RADIATA.

Soil Type.	Locality.	Sample. No.	Horizons Sampled.	P_2O_5.	N.	CaO.	K_2O.	pH.	Condition of Pine.
			inches.						
Dandaya Sandy Loam, Rocky Phase	Greystones ...	282	0–17	·131	.319	.430	.110	5.75	Good
Portagabra Sandy Loam	Helena	228	0–6	·089	.197	.212	.066	5.87	Good
Byfields Loam	Helena	195	0–10	·060	.158	.897	.166	5.94	Good
Haywonup Loam	Harvey ...	133	0–9	·056	.203	.787	.386	5.35	Good
Dandaya Sandy Loam	Helena	205	0–6	·050	.183	.289	.046	6.18	Good
Portagabra Sandy Loam, Phase 5 ...	Greystones ...	118	0–8	·050	.196	.283	.118	5.26	Good
		119	8–15	·029	.062	.111	.120	5.17	
Woodarra Sandy Loam	Harvey	146	0–14	·050	.136	.428	.187	5.56	Good
Dandaya Sandy Loam	Greystones ...	245	0–7	·050	.165	.118	.075	6.08	Good
		246	7–30	·031	.045	.044	.057	6.18	
		247	30–54	·031	.021	.023	.097	6.11	
Haywonup Loam	Harvey	138	0–10	·042	.176	...	.243	5.40	Good
Greystones Sand	Greystones ...	252	0–8	·037	.162	.203	.095	6.11	Good
Burrayang Sand	Helena	167	0–7	·035	.059	.116	.062	5.51	Good
Portagabra Sandy Loam, Phase 4 ...	Greystones ...	105	0–9	·033	.137	.232	.135	4.97	Good
		106	9–15	·031	.084	.184	.163	5.17	
Warrawing Sandy Loam	Helena	218	0–9	·030	.195	.227	.084	5.65	Good
		221	36–54	·025	.050	.138	.091	5.42	
Boonoona Sandy Loam	Helena	223	0–4	·051	.251	.308	.061	6.19	Very poor
		224	4–18	·025	.112	.146	.077	6.32	
		225	18–27	·011	.047	.073	.060	6.22	
		226	27–42	·010	.025	.023	.092	6.19	
		227	42–60	·009	.010	.014	.043	5.88	
Ransomup Sand	Harvey	142	0–3	·040	.165	.109	.031	6.04	Poor
		143	3–15	·023	.055	.044	.020	6.08	
		144	15–27	·021	.063	.049	.033	6.14	
Koonawarra Sandy Loam	Helena	267	0–9	·036	.095	.183	.088	6.14	Very poor
		268	9–15	·024	.036	.073	.070	6.38	
		270	20–30	·018	.021	.112	.077	6.68	
Sand Type 5A	Pardelup ...	402	0–9	·031	.280	.095	.032	5.91	Poor
		403	9–15	·024	.127	.005	.011	5.73	
Helena Sandy Loam	Helena	271	0–8	·029	.070	.020	.096	5.82	Poor
		272	8–16	·023	.060	.020	.098	5.82	
		273	16 –	·017	.038	.003	.109	5.59	

	272	8–16	·023	.060	.020	.098	5.82	Poor
	273	16+	·017	.038	.003	.109	5.59	

CHEMICAL ANALYSIS OF SOILS GROWING PINUS RADIATA—continued.

Soil Type.	Locality.	Sample No.	Horizons Sampled.	P_2O_5.	N.	CaO.	K_2O.	pH.	Condition of Pine.
			inches.						
Pardelup Sandy Loam	Pardelup ...	825	2–9	·0158	·084	·1247	·0153	5·73	
		826	9–21	·0138	·038	·0325	·0155	6·01	Poor
		827	21–26	·0204	·041	·0194	·0194	5·86	
Boonderoo Gravelly Sand	Helena	201	0–5	·026	.097	.146	.047	6.08	
		203	12–33	·023	.031	.081	.075	6.01	Poor
Helena Gravelly Sandy Loam ...	Mudros	859	0–11	·0211	.092	.121	.074	5.48	
		860	11–23	·0153	.035	.050	.075	5.75	
		861	23+	·0195	.028	.040	.056	5.82	Very poor*
Wonnerup Sand	Wonnerup ...	238	4–30	·02	.02	...	.01	6.2	Poor*
Helena Sandy Loam	Helena	336	0–6	·02	.07	.235	.159	5.64	
		337	6–21	·017	.039	.162	.169	5.74	Poor
Arumup Sand	Boranup ...	613	0–12	·019	.090	.142	.024	6.95	Poor*
Boonderoo Gravelly Sand	Helena	210	0–4	·018	.112	.355	.011	6.04	Poor
Sandy Loam	Big Brook ...	692	0–14	·017	.105	.284	.020	6.84	
		695	40–50	·006	.018	.008	.009	6.17	Poor
Sand, Type 3A	Big Brook ...	676	0–4	·012	.062	.045	.005	6.03	
		679	36–46	·007	.010	.011	.008	6.10	Poor
Sand, Type 2B	Pardelup ...	835	0–9	·0047	.074	.0598	.0078	5.47	
		836	9–17	·0012	.011	.0042	.0006	5.25	
		837	17–24	·0032	.021	.0014	.0031	5.64	Very poor
Sand, Type 1A	Myalup	765	0–6	·0018	.0294	.0643	.0025	5.55	Very poor†
Yarrup Sand	Coolilup	778	0–5	·0005	.020	.0589	.0024	5.97	
		779	5–17	·0008	...	.0137	.0012	5.45	Very poor†
		780	17–62	·0005	...	.0032	.0002	5.09	
Fogarup Sand	Coolilup	775	0–4	·0002	.022	.0269	.0045	5.95	
		776	4–80	·0003	.004	.0008	.0033	6.09	Very poor†
		777	80–96	...	.004	.0001	.0042	6.12	

* P. pinaster very good.

† P. pinaster very poor.

CHEMICAL ANALYSES OF SOILS GROWING PINUS PINASTER.

Soil Type.	Locality.	Sample No.	Horizons Sampled.	P_2O_5.	N.	K_2O.	CaO.	pH.	Condition of Pine Crop.
			inches.						
Wonnerup Sand	Wonnerup ...	237	0-4	·02	.08	.01	...	6.4	Good
		238	4-30	·02	.02	.01	...	6.2	
		239	30-72	·01	.01	.03	...	6.1	
Arumup Sand	Boranup ...	613	0-12	·019	.09	.024	.124	6.95	Good
		614	12-27	·012	.015	.011	.029	6.81	
		615	27-72	·005	.004	.009	.006	6.60	
Helena Sandy Loam	Helena	271	0-8	·029	.07	.09	.020	5.82	Good
		272	8-16	·02	.06	.09	.020	5.82	
Portagabra Sandy Loam	Greystones ...	118	0-8	·050	.196	.118	.283	5.26	Good
		119	8-15	·029	.062	.120	.111	5.17	
Sand, Type 1D	Harvey Weir ...	497	0-8	·015	.116	.068	.267	6.25	Good
Pardelup Sandy Loam	Pardelup ...	825	2-9	·0158	.084	.0153	.1247	5.73	Good
		826	9-21	·0138	.038	.0155	.0325	6.01	
		827	21-26	·0204	.041	.0194	.0194	5.86	
Pardelup Sandy Loam	Pardelup ...	824	2-18	·0121	.048	.0099	.0244	5.60	Good
Badgerup Sandy Loam	Pardelup ...	844	0-2	·0222	.192	.0138	.2627	5.92	Fair
		843	2-19	·0083	.049	.0091	.0253	5.65	
		842	19-25	·0075	.052	.054	.0095	5.51	
		841	25-32	·0066	.017	.0060	.0042	5.35	
Sand, Type 2A	Pardelup ...	838	3-16	·0005	.021	.0002	.0113	4.85	Poor
		839	16-19	·0005	.013	.0006	.0076	5.57	
		840	19+	·0028	.035	.0136	.0042	5.62	
Sand, Type 2A	Pardelup ...	821	4-29	·0021	.028	.0060	.0317	5.81	Poor
Sand Type 2A (1)	Pardelup ...	822	0-15	·0062	.091	.0081	.0550	4.60	Poor
		823	24-33	·0004	.010	.0008	.0011	4.88	
Sand, Type 5A	Pardelup ...	831	2-10	·0045	.043	.0093	.0030	6.10	Poor
		832	15+	·0051	.036	.0101	.0030	5.25	
Sand, Type 1B	Myalup	762	0-48	·0003	.0056	.0015	.0172	4.84	Poor
		763	48-132	·0000	.0000	.0013	.0006	4.72	
		764	132-192	·0003	.0042	.0025	.0034	5.46	
Sand, Type 1A	Myalup	765	0-6	·0018	.0294	.0025	.0643	5.55	Poor
		766	6-48	·0008	.0028	.0016	.0028	5.45	
		767	48-120	·0014	.0028	.0027	.0023	5.58	
		769	144-156	·0017	.0014	.0040	.0027	5.58	

CHEMICAL ANALYSES OF SOILS GROWING PINUS PINASTER—continued.

Soil Type.	Locality.	Sample No.	Horizons Sampled.	P_2O_5.	N.	K_2O.	CaO.	pH.	Condition of Pine Crop.

		766	6–48	·0008	.0028	.0016	.0028	5.45
		767	48–120	·0014	.0028	.0027	.0023	5.58
		769	144–156	·0017	.0014	.0040	.0027	5.58

Poor

CHEMICAL ANALYSES OF SOILS GROWING PINUS PINASTER—continued.

Soil Type.	Locality.	Sample No.	Horizons Sampled.	P_2O_5.	N.	K_2O.	CaO.	pH.	Condition of Pine Crop.
			inches.						
Fogarup Sand	Coolilup	775	0–4	·0002	.022	.0045	.0269	5.95	
		776	4–80	·0003	.004	.0033	.0008	6.09	Poor
		777	80–96	·0000	.001	.0042	.0001	6.12	
Yarrup Sand	Coolilup	778	0–5	·0005	.020	.0026	.0589	5.97	
		779	5–17	·0008	.000	.0012	.0137	5.45	Poor
		780	17–62	·0005	.000	.0002	.0032	5.09	
Tuart Sand	Myalup	855	0–2	·0026	.038	.0031	.0735	6.19	
		856	2–5	·0024	.024	.0014	.0427	6.22	Poor
		857	5–15	·0010	.010	.0002	.0104	6.09	
		858	15–30	·0009	.007	.0016	.0148	6.07	

From the above tables it will be seen that the P_2O_5 figures are consistently higher for the soils on which the condition of the pine crop is described as good. In the case of P. radiata, the line of demarcation between the P_2O_5 content of satisfactory and unsatisfactory sites appears somewhat less definite than in the case of P. pinaster.

In using the P_2O_5 figure in practice the percentage present in the surface soil is taken as an indicator unless the A_0 horizon is less than 4 inches, when reference is made to the corresponding figure for the sub-surface soil. When the surface or sub-surface soil has a P_2O_5 content approaching the figure regarded as a safe limit, the rate at which the corresponding figures fall off with increasing depth becomes important.

As a general guide in considering afforestation proposals and problems the following standards have been tentatively adopted:—

FOR P. RADIATA, A P_2O_5 CONTENT OF 400 PARTS PER MILLION IS REQUIRED IN THE SURFACE AND SUB-SURFACE SOILS. 300 PARTS PER MILLION MAY BE SATISFACTORY IF THIS CONTENT IS MAINTAINED FOR A DEPTH OF TWO TO THREE FEET.

FOR P. PINASTER a P_2O_5 CONTENT OF NOT LESS THAN 150 PARTS PER MILLION IS REQUIRED IN THE SURFACE AND SUB-SURFACE SOILS.

In this connection it would appear desirable to stress the following points:—

(a) The P_2O_5 content is suggested as an indicator figure only and it is not intended to imply that the amount of phosphorus present in the soil is in itself the limiting factor affecting the development of the pine sand.

(b) The P_2O_5 content ceases to be a useful indicator in the case of areas which have been cultivated previously for agricultural purposes. In other words, by means not properly understood, the fertility of any site can be increased by methods such as intensive cultivation without any corresponding increase in the P_2O_5 figure obtained by analysis.

(c) The stands on which these observations are based are for the most part very young. Of the 17 areas on which work has been carried out, only two carry plantations older than 15 years.

(d) It is not suggested that figures showing the phosphate content of soils in other countries will serve as an indicator in a similar manner.

Analyses available of soils of other countries show that even those classed as poor heath soils in England and Europe have a P_2O_5 content approaching the best of the soils tabulated above, and the following extract from Comber [1] provides an interesting commentary on the very low phosphorus content of Western Australian plantation soils:—

> "The amount of phosphorus present in soils varies very much; 0.15 per cent. (1500 parts per million) indicates the order of the amount of P_2O_5 commonly found in average loams. Some chalk soils, as is to be expected from their origin, contain higher amounts (0.2-0.3 per cent.) in very infertile areas the percentage may fall to something in the third decimal place."

(1) "An Introduction to the Scientific Study of the Soil," by Norman M. Comber (Edward Arnold & Co., London, 1932).

Chapter 4.

OTHER SITE AND GROWTH FACTORS INVESTIGATED.

Mention has been made already of a number of factors affecting soil and subsoil conditions, the presence or absence of which has been advanced from time to time to explain the failures which occur sporadically in the plantations of Southern Australia. The more carefully these problems of irregular growth are investigated the more apparent does it become that no single reason is likely to explain the cause of unsatisfactory growth over a wide region. Despite the extreme complexity of the factors involved which may render a full understanding far distant, the results already obtained give reason to hope that empirical investigations may lead in a number of cases to the discovery of comparatively simple remedial measures.

Canopy.

The history of the development of a number of Australian plantations shows that care should be taken to avoid wholesale condemnation of land as unsuitable following unsatisfactory early growth of pines.

A noticeable feature of the development of P. radiata stands in Western Australia is the improvement in vigour of stands on certain sites when canopy is formed, contrasting with the impoverished condition of the comparatively widely spaced pines in their early years.

Many other instances can be quoted of remarkable improvement in the condition and growth of pine stands in different parts of Australia when they have finally taken full possession of the site, formed canopy and suppressed the native vegetation.

Such examples direct attention to the need for caution in deciding the treatment which should be given to plantations in a Thin Crown condition. An ill-considered diagnosis may lead to the suggestion that thinning is needed, whereas a careful study of the past growth of the stand will show that the reverse is the case and that canopy is being established after a long struggle, with definite improvement in the general vigour of the pines.

The use of shelter or cover crops, which are removed when the more valuable species they are designed to assist, are about to form canopy is well known in European practice. Shelter given by the fast-growing Acacia pycnantha sown at time of planting the pines and by natural Eucalypt coppice, which is encouraged where not overtopping a pine, is believed to have resulted in improved growth of P. radiata in certain local plantations.

Soil Moisture.

In a few isolated cases extensive clearing of the indigenous tree growth prior to pine planting operations has caused a rise in the subsoil water-table during the winter months and, as a result, small areas of plants on low-lying ground have been adversely affected.

Excess of ground water is seldom a problem in this region of low summer rainfall, but there is always the possibility that drought conditions may have an important influence on the health and growth of plantations of exotic conifers.

There is ample evidence in many inland centres in Southern Australia that both P. radiata and P. pinaster are remarkably drought-resistant species and that they can be grown successfully on suitable soils with an annual winter rainfall as low as 22 inches. On the other hand, the better growth of pines in valleys and depressions on certain plantations has led to the suggestion that these sites are better suited on account of the moisture which drains into them, associated with the better moisture-retaining capacity of the sub-soils of such sites. It is evident, however, that these same conditions may lead to variation in soil types and consequently in soil fertility, and this explanation of the better growth is equally plausible.

In examining portions of plantations where growth is unsatisfactory, the soil moisture factor has been carefully considered in each instance, but attempts to correlate areas of abnormal growth with contour, soil depth, depth to free water level or moist soil in summer, have all given negative results. In many parts of the South-West of Western Australia the underground water to be obtained by sinking wells is highly mineralised, but it has not proved possible to associate any type of Dead Top or Die-back in pines with fluctuations known to occur in the level of the subsoil water-table, whether such water is fresh or brackish.

Clearing Methods.

To assess the effect of any of the methods used in the past to remove the Eucalypt crop before planting the pines is a difficult matter. On reasonably fertile land, clear felling followed by intense clearing fires appears to have little effect on the subsequent growth of any pine crop planted. On certain poorer soil types there is reason to suspect that heavy burns in the course of clearing operations may be the cause of temporary site changes which affect the pine crop in its very early years, leading to the development of functional disorders such as Rosetting.

On many plantations places where heaps of lop debris or logs have been burnt are distinguishable for many years both by variations in pine growth and by examination of surface soil conditions. It is remarkable how many years elapse before grass or other undergrowth becomes established on these ash beds, although, if there are seed trees on or around the area burnt, Eucalypt regeneration will develop freely on them.

Generally speaking, the growth of young pines on or around "ashbeds" tends to be faster and better than the general average of the plantation.

On the other hand, in certain plantations where the general effect of ash beds is to give increased growth, instances are to be seen where chlorosis or malformation of the young pines occurs first among these faster grown specimens. The malformations first apparent on the seemingly strong pines on ash beds may within twelve months become evident on adjacent areas.

Pastures.

With minor exceptions the forest regions of the South-West of Western Australia have a ground flora composed of woody perennials and characterised by an absence of grasses. As Eucalypt forest conditions are replaced by conditions which favour the growth of clovers and grasses, some subtle changes take place which render the site more suitable for the growth of pines.

Adjacent to compartments on Pardelup plantation which, following initial good growth for twelve to twenty-four months, showed serious disorders, an interesting experiment has been carried out by planting plots of P. radiata on established pasture on the same soil type. Pines from the same nursery were planted in the same year on recently cleared land in five stages of pasture development. Paddocks on

which pasture had been established by topdressing with superphosphate and sowing with seed of clovers and grasses one, two, three, four and five years previously were selected. In all instances the young pines, after four years, show vigorous and healthy growth without any signs of chlorosis.

Whatever the explanation may be, numerous observations support this conclusion that any land which has once been well cleared and cultivated, whether for orchard crop or pasture purposes, may be expected to carry much better stands of pines than similar soil types newly cleared by chopping down the Eucalypt crop and burning the debris. It is interesting to note that this same drastic clearing treatment does not appear in most instances adversely to affect the site for the growth of Eucalypts, whether planted or sown.

As a method of hastening the development of grass conditions leading to better pine growth, grazing by dairy cattle has been encouraged wherever possible in young plantations. Scrub cattle will not serve the same purpose, as they are liable to cause considerable damage by browsing the young pines.

Nitrogen Cycle.

The better growth of pines planted on old pastures, cattle camps and along cultivated firebreaks suggested that considerable advantage might accrue from measures designed to increase the nitrogen content of the soil. It has been found difficult to establish soiling crops of lupins and subterranean clover without heavy dressings of artificial fertilisers, and no conclusive results have been obtained from these attempts. The natural spread of the Blue Lupin (Lupinus varius) at Stirling has not improved growth beyond that shown on grassed land and has adversely affected survival of pines during the first summer to a serious extent.

The nitrogen cycle of the soil has been suggested by some workers as a possible general index of potential soil fertility. A study was conducted at two centres, Myalup and Applecross, of the nitrogen cycle in coastal sandplain plantation soils with special reference to late autumn yellowing of pines. The residual available nitrogen in the soil in the form of nitrate was determined at intervals of six weeks. Samples were taken at depth of 0in.-6in. and 6in.-30in. from virgin Eucalypt forest, ploughed land, stands of good colour and stands of poor colour. The results showed no great differences in the nitrogen content in the separate conditions studied on the same soil types in each plantation and the low content indicates the extreme poorness of the soil types under observation. The maximum nitrate supply in the surface soil (0in.-6in.) is from 13 to 16 parts per million and occurs between January and April. During the peak period the nitrate supply in the virgin forest slightly exceeds that on which pines of good colour were growing by from 1 to 3 parts per million. From April to December the supply in the surface soil (0in.-6in.) varies from 3 to 12 parts per million and during this period the supply in soils supporting the good colour pines exceeds that in the virgin forest by from 1 to 5 parts per million.

Analyses of Ash of Pines.

Another line of investigation followed has been a chemical examination of the ash of leaves, bark and wood of healthy and unhealthy trees. Specimens were obtained from Pardelup where areas of P. radiata plantations have developed very unhealthy symptoms in early years, owing apparently to serious metabolic disturbances, while on similar soil types on adjoining farms, single specimens and windbreaks of the same species, have grown very well indeed. These comparative analyses showed no striking or consistent differences in the percentage of the following minerals present in the ash, viz., Lime (CaO), Magnesia (MgO), Potash

(K_2O), Phosphate (P_2O_5), Manganese (Mn). Only in the case of sodium did there appear to be any relation between the percentage present in the ash and the condition of the pine. The soda figures varied from 1.02% to 4.55%, being consistently higher in the needles from well grown specimens. No further work has been done on this aspect apart from a few analyses of soda content of healthy P. radiata needles from other localities which showed considerable divergence from the Pardelup figures.

Attempts have been made by the Government Chemical Laboratory to trace possible excesses or deficiency of elements in the ash by spectrographic methods. Spectrographic analysis of the ash of needles from healthy trees, zinc sprayed trees, and unhealthy trees, 3 years of age from the same year's planting and the same soil type at Stirling gave the following results in parts per million: Zinc 10:5:1, Manganese (by chemical anlayses after detection by the spectrographic examination) 2.16%:0.31%:0.30%.

Mycorrhiza.

Investigations into the cause of failure of pine seedlings in new nurseries during the years 1924 to 1926 led to certain conclusions concerning a missing biological factor particulars of which were published in the Empire Forestry Journal Vol. 6, No. 1, 1927, in an article entitled "Soil Organisms—The Dependence of Certain Pine Species on a Biological Soil Factor" (Kessell).

Following this work all new nursery sites were inoculated by the application of a dressing of soil taken from under the trees in established plantations which had formed canopy, and large quantities of the slime ball fructifications of Rhizopogon luteolus were used for the same purpose. In this way the fungus population of the soil was rapidly built up to a satisfactory extent, as shown by the improved growth of nursery stock and the presence of swollen root hairs exhibiting the characteristic coralline formation associated with mycorrhizal infection of the pine root system.

No difficulty has ever been experienced in conveying the infection from the nursery beds to the planting site which is rapidly infected by the hyphae and inoculated soil adhering to the roots of the pine. In early investigations in connection with the unsatisfactory development of pines soon after planting, particular attention was given to the possibility of disorders arising from the failure of the mycorrhizal fungus to develop satisfactorily. This explanation cannot be lightly dismissed in considering the primary cause of disorders such as Rosetting, but it is very difficult to trace the association of fungi with pine roots under field conditions on any basis aiming at quantitative measurements, and, even if practicable, involves a technique possible only to a well equipped and generously staffed experimental station.

Chapter 5.

CORRECTIVE TREATMENTS AND GROWTH RESPONSES.

A considerable period of years must elapse before response to corrective treatments can be given in terms of increased mean annual increments, and in much of the experimental work referred to hereunder initial results must of necessity be based on observations of increased vigour of the trees coupled with a restoration of normal colour, needle length and habit of growth.

Whether or not an improvement in vigour will last long enough to result in the development of a marketable stand with or without further treatment has yet to be determined in the majority of cases.

The first indication of a response to treatment usually is a needle colour change followed by increased length of new needles and increased length of new shoots.

The development of a prominent leading shoot and bark splitting, bark shed, and bark colour change resulting from fast diameter growth become noticeable at a later stage.

New needles and shoots are developed en masse once a year between June and December, although some shoot extension through intercalary growth takes place and some needles may be produced in the other months. Normally needles are retained on a tree for three years before being cast.

Colour change may become apparent as early as three weeks after treatment when alteration or deepening of the colour of the current season's needles may take place. No change in length of needles or shoot already developed occurs and increased length of these parts refers to the longer needles and shoots produced in subsequent seasons. These increased lengths both result ultimately in greater foliage production since more dwarf shoots are produced on the longer shoots. Where a symptom of disorder is an early shedding of needles a third factor, the retention of three seasons' needles, operates to increase crown density.

When an unthrifty pine with short needles is stimulated by superphosphates large needles are produced in the spring following application of the fertiliser, but the shoot is short, resulting in half a dozen to twenty dwarf shoots on each branch or leader. In the following spring, provided the stimulus continues or another application of manure is given, shoots and needles of normal length are borne and after two more growing seasons the pine will have its three sets of normal shoots and needles. Hence four years must elapse from the time of first application of fertiliser before the pine can be brought to a healthy vigorous condition, and it may then be necessary to wait for a further period before the stimulus is fully reflected in terms of diameter increment.

Zinc and phosphorus, the two elements which have caused such striking colour changes, produce different shades of green. Zinc develops in P. radiata a rich dark green and in P. pinaster a blue or steel green. The use of phosphorus, on the other hand, results in a light or golden green in both species. This shade difference is more noticeable in P. pinaster than in P. radiata.

Where the unthrifty pines are yellow the colour change to a green is very obviously an improvement, but in cases where unthrifty P. pinaster has retained a deep green colour the use of phosphate may in spring appear to have had an adverse effect owing to the development of the characteristic lighter golden green colour of a phosphate response referred to above.

The effects indicated by general vigour, needle length and colour and density of foliage may be very striking qualitatively and readily measurable in terms of needle and shoot length, and sometimes in young pines of total height. Many of the unsatisfactory patches of pine, despite their chlorotic and unthrifty condition, continue to make height and diameter increment which, though below normal, is still considerable. This necessitates wider margins than might be thought necessary when using such measurements for differences to become significant. In fact the growth continued to be made by some of the stands of P. radiata affected by Thin Crown which attain a height of 80 feet, and a volume of 3,000 cubic feet over bark per acre at 20 years, is an interesting feature of their behaviour. A very much higher volume of timber is produced than would be expected from the general unthrifty appearance of the stand.

Difficulties are met with also in determining the effects of a second or third factor, for example of added nitrogen or potash, since the response to phosphate may be so striking as to mask the possible beneficial effects of other plant nutrients used in addition.

The treatments which have been productive of beneficial results are:—

1. *Cultivation.*

The improved growth in the outer row of trees along so many cultivated firebreaks in Southern Australia has drawn attention to the possibility of the beneficial effect of cultivation on pines. Break or edge trees have the advantage not only of additional space but also of repeated cultivation from the time of establishment. Cultivation may exercise an important influence on such diverse factors as soil water content, soil tilth, crumb structure, activity of micro-organisms, processes of nitrate formation and many others.

The entire absence of edge effect along firebreaks in some compartments of the plantations of the coastal sands in Western Australia showed soil type may cause a marked variation in the response of pines to cultivation.

Ploughing is done with two-disc stump-jump ploughs to a depth of 10 to 12 inches. Multi-disc ploughs cannot be operated efficiently on the stump infested plantation areas. The aim in ploughing is that it should be thorough enough to eradicate scrub and give a bare fallow.

Cultivation of the ground by ploughing prior to planting has increased survivals in the first summer, bringing about an almost complete "take." Where satisfactory establishment, due largely to severity of scrub competition, is particularly difficult, ploughing prior to planting has been included as standard practice to aid establishment.

Cultivation has been found also to stimulate development subsequent to planting, particularly after the first summer. As an indication of the increased growth on ploughed land the following measurements of P. radiata, 1935, taken two years after planting, are given:—

Average height on ploughed land	.. ..	48.5 inches.
Average height on unploughed land	.. ..	33.0 inches.
	$P > .01$.	

In some plantations the improvement due to prior ploughing is merely transitory and a chlorotic condition may develop a few years after planting.

The beneficial influence of cultivation for P. radiata has been shown most clearly on the lateritic soils of the Darling Range of which the P_2O_5 content is of the order of 100 to 200 parts per million, and for P. pinaster on those sandplain soils which have a P_2O_5 content of 15 to 20 parts per million These soils are regarded as marginal for the species concerned. When tried as a remedial measure

in the case of pines established for some years on such sites without cultivation, and already showing symptoms of unsatisfactory growth, thorough cultivation repeated several times has resulted in some improvement but has not restored the trees to normal growth.

The term "subsequent cultivation" is used to refer to the practice of cultivating or ploughing between the rows of pines during the period between time of planting and the development of full canopy. In conjunction with other remedial measures such as the application of phosphate and the use of zinc, subsequent cultivation has been used with some measure of success in this State on the poorest soils, but no further planting is being carried out on these soil types.

In plantations where subsequent cultivation is considered desirable, provision should be made at the time of planting to lay out the rows of pines in such a manner as to facilitate ploughing operations. The cost of ploughing is not, in itself, excessive, being usually from 16s. to £1 per acre, but the cost of preparation by the removal of all logs remaining from the Eucalypt forest may often be prohibitive.

2. *Fertilisers.*

The increased growth of pines on "ash beds" or areas on which limbs and logs, rather than the smaller branches, of trees had been burnt, indicated a possible effect of some fertiliser, in addition to the recognised effect of heat on the soil particles, soil micro-fauna, eradication of scrub, etc.

The following example gives some measurements of comparative growth of P. pinaster on the Wonnerup Sand, a soil type on which this species has shown uniformly satisfactory growth:—

Height at 3 years of age:

On ash beds	36.23	± .996 inches	P > .01
Not on ash beds	24.85	± .604 inches	

Girths at 11 years of age on another compartment:

On ash beds	15.22 inches	P > .01
Not on ash beds	10.21 inches	

The ash of several Eucalypts was examined with a view to determining a constituent of the ash possibly responsible for the faster growth rate. An analysis of the ash of the Tuart (Eucalyptus gomphocephala) which, with Peppermint (Agonis flexuosa), forms the climax association on the Wonnerup Sand gave the following percentages data:—

SAMPLES DRIED AT 115° C.

	Main Trunk.	Young Tree.	Branch.
Carbon	0.12	0.07	0.12
Sand	0.58	0.25	0.12
Silica	0.84	0.37	0.14
Iron Oxide and Alumina, Fe_2O_3, Al_2O_3 ...	1.90	0.62	0.38
Lime, CaO	54.48	46.06	38.49
Magnesia, MgO	3.97	5.10	9.83
Manganese Oxide, MnO	1.74	1.53	1.59
Phosphoric Acid, P_2O_5	2.41	1.65	1.20
Sulphuric Oxide, SO_3	2.31	1.12	1.19
Soda, Na_2O	3.29	2.93	3.68
Potash, K_2O	3.24	6.96	9.93
CO_2, Cl. and loss	25.12	33.34	33.32

Following this analysis it was recommended that sulphate of potash and lime be applied as a fertiliser, but in the case of both young Tuart and young pines the results were negative. A dressing of two pounds of dry wood ash per tree has not had any beneficial effect on P. pinaster transplants in Ludlow plantation.

In an endeavour to determine whether the heating of a soil is alone responsible for the better results on ash beds, a series of experiments were carried out in 1935 and 1936. Wood fires were kept burning for four hours in iron drums 2ft. 6in. in diameter. Pines were later planted on these spots while the ash in the drums was spread around another set of pines as a second treatment. Neither of these treatments stimulated growth beyond that shown by pines planted on ordinary ground, a condition which is a sharp contrast to the increased vigour of pines on "ash beds" caused by the burning logs or crowns of trees. The spots subjected to heat alone, however, showed like the "ash beds" a higher percentage of "takes," due probably to the absence of grass competition for a few years after planting. These results confirmed similar tests carried out a few years earlier with Tuart seedlings. The soil beneath "ash-beds" formed by burning of heaps of logs resulting from felling of the indigenous Eucalypt forest is, however, subjected to heat in some cases for two or three days, and a thick covering of ashes may result from the burning of the debris. The creation of parallel conditions is not practicable in an experiment of the type described.

(a) *Phosphate.*

It is generally recognised that the soils of Southern Australia exhibit a low phosphate content, and it was considered by the writers that the response to superphosphate shown by agricultural and horticultural crops provided a lead worth testing in silvicultural practice, particularly in relation to the growth of exotic conifers.

Phosphate has been applied chiefly in the form of acid superphosphate, which is the standard manure of agricultural practice, and is also cheaper than other fertilisers containing phosphate, such as blood and bone manure and basic phosphate. The ordinary commercial grade of superphosphate used contains 22% P_2O_5 (20.5% water soluble).

In order to establish which constituent of superphosphate was responsible for the improved growth of pines, special experiments were conducted on two plantations with di-calcic phosphate, gypsum, calcium chloride, and di-hydrogen sodium phosphate. Mono-calcic phosphate was unobtainable. It was shown that of the various major constituents of superphosphate it is the water-soluble phosphate which is responsible for its beneficial effects.

Results obtained on different soil types have been by no means uniform, and it is difficult to understand why light dressings of superphosphate on poor sand should give remarkable results on one plantation, while very much heavier applications are necessary to secure similar results on another plantation on which the soils according to analytical results should be equal or even much better.

In view of the possibility of the change of the water-soluble form of phosphate into insoluble forms such as iron and aluminium phosphate, trials were made with special mixtures to overcome this. Basic phosphate in which the greater part of the mono-calcic phosphate has been changed to the dicalcic or non-water-soluble form by the addition of 15 parts of slaked lime to 100 parts of superphosphate, was used. Superphosphate was mixed with molasses. No indications were obtained of any advantages possessed by these mixtures over the ordinary commercial grade of acid superphosphate.

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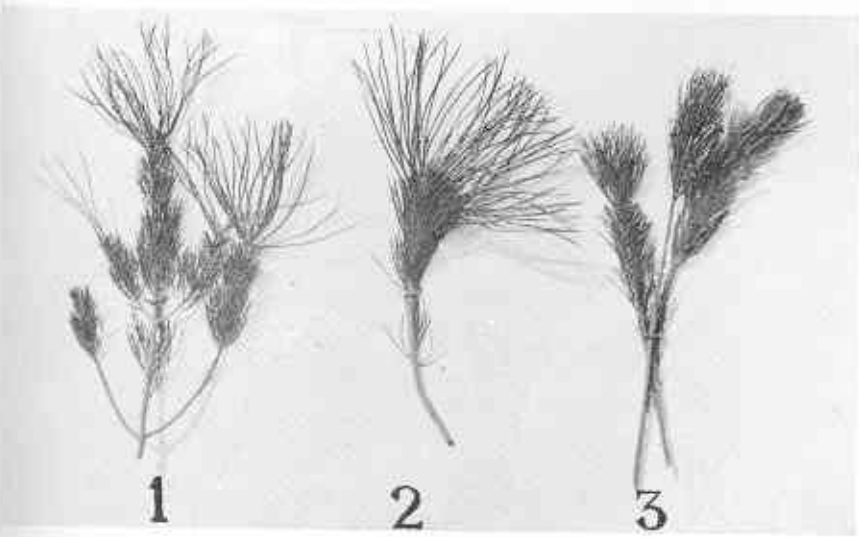
SUPERPHOSPHATE RESPONSES—P. PINASTER.

P. pinaster on poor coastal sand plain, Gnangara Plantation, Metropolitan Division. Ploughed and planted 1933. Treatment uniform except that rows of tall pines on left given dressings of superphosphate at rate of one cwt. per acre in 1933, 1935, and 1937. Rows of unmanured pines on right barely discernible in photograph, except specimen marked by hat.



Needles of P. pinaster from 12-year old pines affected with "short needle," Coolilup Plantation.

(1) and (2) show needles of normal colour and length produced on the end of branchlets 12 months after the application of superphosphate at the rate of 1 cwt. per acre.

(3) Continued development of short needles on branchlets of "control" pines.

Another factor requiring investigation was the time of application. If applied in the period of heaviest rainfall or to water-logged soil, the whole of the phosphate is quickly dissolved, perhaps hastening, it might be thought, the chemical change to the insoluble forms. On well drained soils, or in periods of light rainfall, a superphosphate particle might be supposed to be not completely dissolved, the inner portion being retained in a state of balance with an external solution in the form of a film which is available to the pines. For these reasons trials were made with the application of fractional quantities of superphosphate at regular fortnightly and monthly intervals, making in the aggregate a dressing equal to a single heavy application at one time. In all cases a better result was secured from the heavy dressing at the one time than from the frequently repeated applications.

The best time of application appears to be the winter in the months of July and August.

Superphosphate must be applied close around the base of the tree. Curiously enough there is no side-effect apparent for some years. It is known that in a plantation of P. pinaster with 7ft. spacing the roots of three-year-old trees have a spread of up to 21 feet, yet superphosphate applied to one row of trees does not affect those in the next row seven feet away. Broadcast mannrings of 8 cwt. per acre at Coolilup on plots of P. pinaster grown from broadcast sowings produced striking responses which ceased abruptly on the borders of the plots and did not affect trees three feet outside those borders.

In most plantations, however, a gradual improvement in the adjoining trees takes place after an interval of two years and at four years after treatment three outside rows at 7ft. spacing will show an improvement in vigour. On the other hand a case is known with 14ft. spacing of no side effect after repeated applications for four years.

Blood and bone has, on some soil types, produced responses equal to, though never exceeding, those from superphosphate, but has often failed to cause a stimulus where superphosphate has been successful. On account of its high cost it is not used for general application.

A response to superphosphate applied in August may be observed within six weeks. In only one plantation is there a delayed action with superphosphate and the reason for this is not known. At Pardelup dressings of one to 20 cwt. per acre have no effect on P. radiata in the first year after application, but one cwt. per acre produces a marked response in the second year.

Superphosphate has been used in most plantations of the State and on a great many soil types and ages and conditions of crops. The results of only a few typical cases can be given here.

P. pinaster.

It is with this species that the most striking results from superphosphate have been obtained. On the sands north of Perth, at Gnangara, P. pinaster without fertiliser stagnates at a height of 18 inches to three feet according to soil type. With light dressings of superphosphate repeated at intervals of two to three years stands of this pine have now reached a mean height of 27 feet, and are in vigorous condition, at 11 years.

Further south on the coast at Myalup, this pine has been restored to healthy condition after stagnating at a height of four to five feet for 10 years. Curiously enough, dressings of two to four cwts. per acre are required for stagnant pines

at Myalup on soils with a P_2O_5 content as low as two or three parts per million, whereas, on sands with the same low content at Gnangara, one cwt. dressings produce a striking response.

In new plantings on the coastal sandplain it is now standard practice to apply dressings of one to two cwts. of superphosphate at time of planting. The fertiliser is distributed along the shallow furrows in which the pines are planted, and the quantity per acre within the above limits is varied with the soil type. Further dressings at the rate of one cwt. per acre have been applied by broadcasting at intervals of three years up to the ninth year, when canopy is formed, but the most desirable practice for each soil type is being worked out by extensive series of sample plots. On compartments which have suffered no check in growth, no advantage has been gained by the use of dressings greater than two cwts per acre.

On soils with a P_2O_5 content of 200 parts per million, which include many of the lateritic soils and certain of the coastal sands in the extreme South-West, P. pinaster forms satisfactory stands without fertilisers. It is a characteristic of this species on these soils that growth in the early years is comparatively slow. No improvement in rate of growth, or appearance of the pine has been effected by applications of superphosphate on these soils in quantities as high as 24 cwts. per acre.

P. radiata.

With the exception of small experimental plots no P. radiata has been planted on coastal sands towards the northern end of the Coastal Plain in Western Australia during the past 20 years. Fertiliser experiments on these small plots have shown P. radiata will show important responses to dressings of superphosphate on these poorer coastal sands.

On the better sands in the extreme South-West, with a P_2O_5 content of the order of 200 parts per million, and on the Pardelup soils with a similar phosphate content, P. radiata has shown some responses to superphosphate which, when applied at time of planting, has prevented the development of Rosetting. It is only at Pardelup, however, that this fertiliser has had any effect in improving the condition of rosetted pines. As explained elsewhere zinc is used to restore rosetted pines to a normal condition.

On most of the lateritic soils of the Darling Range which have a P_2O_5 content of the order of 200 parts per million, and notably at Mundaring, no response is shown by P. radiata to heavy dressings of superphosphate, of up to 24 cwt. per acre, when applied to stands showing Yellowing.

In no case has the use of this fertiliser yet been adopted as standard practice in connection with areas planted or to be planted with Pinus radiata in Western Australia.

(b) N.P.K. Mixtures.

Mixtures with phosphate, potash and nitrogen are prepared as complete (N.P. & K.) and incomplete (N. & P.) manures by the fertiliser companies. There are a number of combinations containing these three elements which are made up as ordinary proprietary mixtures and known as potato manures, orchard manures, super and ammonia mixtures, etc. Trials have been made with these, in view of the possibility that the pines may be unable to take advantage of one particular plant nutrient because another element is lacking. In order to try another quality of nitrogen, special manures have been applied using nitrate of soda, since the proprietary mixture contains nitrogen only in the form of sulphate of ammonia. The use of basic phosphate in these compound

fertilisers introduced another variation. In no instances have positive results yet been obtained of an improvement on the results that would have accrued from using by itself the superphosphate contained in the mixture.

Both nitrate nitrogen and ammonia nitrogen have had a deleterious effect on young stands of P. radiata on the poorer coastal sands.

3. *Minor Elements.*

Pathological conditions associated with a deficiency of the so-called minor elements in the nutrient supply are now known as soil deficiency diseases.

Parallel with the experiments with the major nutrient elements and cultivation, experiments to test the effect of the addition of the minor elements were initiated.

Three methods of treatment have been used (a) by spraying or pouring a solution on the foliage and limbs; (b) by application in solution or as a solid to the ground around the plant; (c) by injection in solution or as a solid into the plant itself. The injection method which is not practicable on the large scale in silvicultural practice has been used for diagnostic purposes only.

Fifteen elements, namely Zinc, Copper, Nickel, Cobalt, Manganese, Iron, Magnesium, Boron, Chromium, Cadmium, Iodine, Sulphur, Sodium, Arsenic and Molybdenum, in water soluble salts have been used in a number of plantations.

Positive results have been obtained with Zinc and Nickel in the form of sprays, and with Zinc applied as a solid to the ground around the tree.

It is of interest that phosphate which produces such striking results as an ordinary fertiliser has had no effect when sprayed on the foliage.

In the early experiments chemically pure Chloride of Zinc was used in a 1% solution as a spray, but subsequently, for general application as a practical treatment, commercial zinc sulphate has been substituted. Zinc chloride was used in the anhydrous form containing 45% of Zinc. Commercial Zinc Sulphate about 95% pure is obtainable with 3, 5 and 7 molecules of water. The form used was $ZnSO_4$ 7 H_2O containing approximately 33% Zinc. Thus 1¼% Zinc Chloride solution is the equivalent of 2½% Zinc Sulphate.

A slag or residue from the Superphosphate works and composed of approximately Iron Oxide 60%, Silica 20%, Zinc Sulphate varying from 1 to 10% and Copper Sulphate 1 to 10% has caused colour responses from dressings of 7 lbs. and upwards per tree.

It appears that Zinc Chloride and Zinc Sulphate are equally effective provided the same amount of metallic zinc is used. The results obtained from applying Zinc Sulphate as a solid have been conflicting. The action of Zinc in the solid form appears to be a slow one except where comparatively heavy dressings are used. On the coastal sands a minimum of 4 ounces per tree for trees of 3-4 feet in height is necessary to produce a stimulus in the first year, but there are indications now that ½ oz. per tree gives a similar stimulus in the second year. Quantities of 1 lb. per tree and upwards were required to stimulate growth in the first year on one lateritic soil and no response to smaller quantities on this soil has yet been noted. On account of cost of the salt, approximately 60s. per cwt., the application of Zinc in the solid form is impracticable. The noteworthy character of the response here is that unlike the behaviour of Superphosphate there is a marked side effect with Zinc and trees under 10 feet in height situated 21 feet away from the treated pine have benefited immediately. The effect is much more pronounced on the side of the tree nearest the point of application of the salt.

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ZINC RESPONSES—P. RADIATA.

P. radiata, Boranup Plantation, 3 years after planting

(1) Pine showing recovery six months after spraying with 1% solution of Zinc Chloride. Before treatment, the description and measurements of this pine corresponded very closely with the control pine in the adoining photograph.

(2) "Control" badly affected by Rosetting.

P. radiata, Stirling Plantation, 3½ years after planting.

(1) Pine on left treated with 1¼% solution of Zinc sulphate in February, 1936. Quantity applied ½ pint. Photographed January, 1938. Height 88 inches.

(2) Control, showing Rosetting on right, similar in size and condition at time Zinc solution applied in 1936. Photographed January, 1938. Height 22 inches.

Nickel has been used as a chemically pure chloride in 1% and 2½% solutions as a spray. In October, 1935, one half pint of 1% solution did not damage the needles but produced by January, 1936, a striking colour response which was, however, quite transitory and had disappeared three months later. In October, 1936, one half pint of 2½% solution killed most of the needles but caused later a colour change to normal green with the development of some new season's needles of normal length. This effect was still pronounced at January, 1938. Used in combination with ferrous sulphate the effect was not so striking.

Zinc has undoubtedly produced more spectacular results than any other corrective treatment. This is due to its quick action in reclothing with green needles the most misshapen and yellowed pines, providing such sharp contrasts with adjoining untreated pines.

Its importance in silvicultural practice is due to two causes:—

(a) Its quick action in producing healthy growth in the most abnormal pines;

(b) The cheapness of the treatment. Costs have ranged from 4s. per acre including the cost of the zinc salt, in the case of very small pines, using three fluid ounces of 1½% solution per tree, to £1 per acre for pines of twelve feet in height, using half a pint of 2½% solution per tree.

Zinc cannot, however, be used on trees which are too tall to be reached with a spray, as the cost of application of a zinc fertiliser in the ordinary way is prohibitive unless very small amounts of solid are found to be sufficient.

P. radiata.

Spraying with zinc sulphate has been adopted as standard practice in preventing the development of, and correcting in the 2 to 5-year-old stands, "Rosetting" on the sands with a P_2O_5 content of 200 parts per million, and on the lateritic soils in the extreme South-West.

Stands affected with Yellowing or Dead-Top on the lateritic soils, with a similar phosphate content at Mundaring, in the Darling Range, have shown no response to zinc.

An interesting analogy to these results is contained in the following extract from an article on "Zinc as a Nutrient for Plants," by W. H. Chandler, which appeared in Vol. 98, No. 4, of the "Botanical Gazette," 1938:—"It is interesting that the most dependable symptoms (of zinc deficiency) on deciduous trees are the rosettes of small, stiff, nearly sessile leaves in the first flush of growth in spring."

P. pinaster.

Spraying with zinc sulphate has produced some remarkable responses on marginal soils with phosphate contents below 50 parts per million at Pardelup, and on sub-marginal coastal stands at Myalup. In both these centres dead-tops are an important symptom of the Short Needle disorder.

It is curious that zinc has had no effect in alleviating Short Needle disorders on sub-marginal sands at Coolilup, though in this plantation, as at Myalup, superphosphate has an important restorative action. Dead tops, however, which are so prevalent at Myalup, do not occur as a symptom of the Short-Needle condition at Coolilup.

Chapter 6.

GENERAL DISCUSSION OF CONCLUSIONS AND THEIR PRACTICAL APPLICATION.

Although the investigation and experiments dealt with in this publication have been in progress for more than ten years, a great deal more work remains to be done before any claim can be made to a full understanding of the problems of pine growth in Western Australian plantations. Views expressed are in the nature of tentative conclusions which may have to be modified from year to year as the results of further measurements and experiments become available, but a stage has been reached when it is possible to narrow down the lines of investigations and to design experiments with the object of obtaining, in a minimum of time, data of practical value in large scale plantation work.

On reasonably fertile forest soils the problems of unsatisfactory pine growth discussed in this publication do not arise. It is, however, seldom that good quality soils are available for plantation purposes, and the forester is called upon to use for pine planting inferior soils rejected for agriculture. The popular misconception current in Australia that pines prefer poor soils dies hard, and in previous papers and reports the authors have pointed out the doubtful economy of expending public funds in seeking to grow softwood plantations on extremely poor soils. It is desired to stress again this viewpoint. At the same time it is necessary to consider carefully what measures, if any, can be adopted to improve the condition of plantations which have already been established on inferior soils. Another allied problem worthy of careful investigation is the possibility of establishing successful softwood plantations on areas of poor waste land in proximity to large centres of population. This may be rendered possible by the adoption of an improved technique in the establishment and tending of plantations which takes full advantage of modern scientific developments such as the cheap production of artificial fertilisers.

1. *Soil Mapping.*

As a basis for the investigation of problems of the growth of pine stands in any locality, a detailed soil survey based on the whole soil profile has been found essential. This work is necessary also before any field experiments in connection with possible remedial measures can be undertaken.

The study of the soil in situ is a comparatively new science in which few foresters have had a thorough training. It is important that the field work, particularly in the early stages, be supported and checked by a large number of mechanical analyses carried out in a chemical laboratory on standard lines. Until the principal soil types have been classified and described for each locality, the services of a trained pedologist to supervise the work will be found very desirable.

In Western Australia a close correlation has been established between pine growth and soil types in each plantation where detailed soil surveys have been made. Some difficulty in reconciling the early development of pine stands with the growth to be expected on certain soil types may be anticipated where plantations have been established on abandoned or repurchased farm lands. This is due to the better development of young pines on all land which has been intensively cultivated or converted to clover and grass pasture for a period of years prior to planting.

Apart from the generalisation that soils derived from basic rocks or basic segregations in granites and gneisses are of better quality and carry the best stands of pine, it has not been found possible in Western Australia to associate the growth of the pine crop with the mechanical condition or depth of the soil or such factors as moisture-retaining capacity of soil or subsoil or depth to free water level.

In soil survey work in Western Australian plantations a detailed list of plants occurring on each soil type has been made. To a limited extent it has been possible to make use of certain members of the ground flora consisting of perennial woody shrubs as plant indicators of the distribution and boundaries of distinct groups of soil types. To date no plant indicators have proved sufficiently reliable to be used as substitutes for the more laborious methods of systematically traversing the area along parallel lines and sinking test holes at frequent intervals. For detailed soil surveys of plantations to provide a basis for experimental work it has been found necessary to run lines three chains apart and to sink test holes at intervals of three chains along each line.

2. *Soil Fertility.*

With few exceptions the soils available to date for pine-planting purposes in Western Australia are all regarded as low in plant nutrients according to accepted agricultural standards, and this has been borne out by numerous partial chemical analyses which have been made.

By comparing a large number of analyses of soils carrying pines and eliminating from the schedules soils which have been used intensively for pasture, farming or orchard purposes, before being planted, the conclusion has been reached that the P_2O_5 content may be used as a valuable indicator in the case of these so-called virgin soils.

The figure representing the P_2O_5 content is regarded as an indicator of comparative fertility and when used in this way the results obtained have supported the contentions based on numerous observations throughout Australia, firstly that P. radiata requires a soil richer in essential plant nutrients than P. pinaster, and, secondly, that there are soils in Australia too poor even for the growth of P. pinaster without artificial aids.

In addition to serving as an indicator of the soils in Western Australia which may be expected to grow normal crops of P. radiata and P. pinaster respectively, the P_2O_5 content figure can be used as an indicator in plantations suffering from various types of irregular growth of the probability of securing satisfactory growth following various remedial treatments. As explained later, the P_2O_5 content is a fairly reliable index of the response that may be expected to cultivation on marginal soils, but in the present state of our knowledge it is not possible to forecast the response which will result from any application of fertilisers in respect to either composition or quantity.

In the following tabular statement an attempt is made to indicate the lines on which it is proposed to use data obtained from partial chemical analyses of soils rather than to establish final standards. As soil surveys in plantations are extended and additional areas reach an age when the pines are old enough to give a reliable indication of their future development, more figures are becoming available which will enable the border-line between the classes to be determined with greater certainty. At the same time it is necessary to recognise that other factors may have an important influence on border-line soils, and, in consequence, no sharp

line can ever be established between site classes by a single indicator figure of this nature.

For P. radiata plantations.

Site Class.	P_2O_5 Content (Parts per million).	Condition of Pine Stand.
A	Over 400 ...	Good normal growth.
B	150–400	Growth irregular without special treatment.
C	Under 150	Growth very unsatisfactory, responses to treatment only transitory.

For P. pinaster.

Site Class.	P_2O_5 Content (Parts per million).	Condition of Pine Stand.
A	Over 150 ...	Good normal growth.
B	20 to 150 ...	Growth irregular without special treatment in early years.
C	Under 20 ...	Growth very stunted without continuous treatment.

The P_2O_5 figures quoted are for surface and sub-surface soils. High phosphate figures in shallow A_0 horizons may prove very misleading, and sub-surface soils are used in these cases. In soils approaching the limits for the class the rate at which the P_2O_5 content decreases with depth becomes important. If the gradient is steep the site should be viewed with suspicion. If the falling off is very gradual, the site may give results approaching that expected from the higher class. In Western Australia the height growth of the indigenous Eucalypt crop is not a useful indicator of comparative fertility or of the value of a site for the growth of pines.

3. *Establishment and Tending Methods.*

Clearing, establishment and tending methods have very little influence on the general health of the pine crop planted on good quality soils referred to in the previous section as "A" Class sites. On all such sites uniformly good growth may be confidently anticipated. The difficulty in the past has been to recognise sites of satisfactory quality for pine planting prior to the commencement of planting operations and, as previously explained, the height and general development of the indigenous Eucalypt forest has proved valueless as an indicator in Western Australia.

In practically all plantations established throughout Australia 25 to 30 years ago or earlier, the land was intensively cleared at great expense and thoroughly ploughed. As an economy measure this practice was generally discontinued and extensive areas of pines have since been established successfully and are growing into valuable forests. Other plantations on marginal or sub-marginal soils in every State of the Commonwealth have shown, in whole or in part, very unsatisfactory development, and, apart from recent work in Western Australia, the general practice has been to leave these stands to struggle on in an unthrifty condition or to stagnate as the case may be.

Extensive experimental work has indicated three methods of treatment which under certain conditions are productive of striking results and which are economically applicable on a large scale in practice. These are discussed under the headings of "Cultivation," "Superphosphate" and "Zinc Spraying." In considering the application of any of these treatments separately or in combination, it is important to realise that there are sub-marginal sites coming within "C" Class referred to on page 41 on which some response may be obtained, but, despite any assistance which may be given to the young pines, the land may prove too poor to carry the crop to a size when it can be marketed at a profit. On the other hand, on marginal or "B" Class sites, some assistance in early years may convert a poor stand of weedy trees into a plantation, the returns from which will cover the cost of accumulated charges including establishment, remedial measures and tending.

(a) *Cultivation.*

The beneficial influence of cultivation on marginal soils may be seen along firebreaks, cultivated annually, in many plantations throughout Australia. The cost of preparation of the planting site for ploughing by rolling up and burning the logs felled in clearing the indigenous Eucalypt crop is very great, varying from £3 to £7 per acre in different plantations in Western Australia. Once the pines have been planted among the debris from the native forest the cost of clearing to permit subsequent ploughing between the rows is prohibitive.

If soils are near the upper limit of the "B" Class, ploughing and cross ploughing to a depth of 9 or 10 inches before planting may be sufficient to carry the stand through until canopy is formed, when satisfactory development may be expected. Although very little information is available concerning the effect of pine litter on the soil, it is reasonable to anticipate that, provided forest conditions are preserved by sound silvicultural management, the quality of future pine crops will improve. If this contention is correct, it would appear unfair to charge high establishment costs arising from the necessity for burning up logs and ploughing wholly against the first rotation.

Where the soils are near the lower limits of the "B" Class, it is regarded as desirable to make provision at time of planting for subsequent cultivation between the rows if this is likely to become necessary before canopy is formed. This involves planting in reasonably straight and parallel lines with a sufficient distance between rows to allow a two-furrow plough to operate. In practice a minimum spacing of 8 feet between rows has been found satisfactory for this purpose.

The lack of response to cultivation alone is a distinctive feature of the behaviour of pines on the most infertile or "C" class sites, such as certain sands of the Coastal Plain, and is exemplified by the absence of improvement in the edge trees of cultivated firebreaks on these soils.

The use of cultivation as a cultural or remedial measure is limited by the high cost of preparatory clearing on many sites, to which must be added the cost of ploughing itself, usually about £1 per acre. For this reason the possibility of using other artificial aids such as those referred to in the following paragraphs is deserving of careful study and experiment with the idea of substituting such measures for cultivation at a much lower cost.

In this connection it should be noted that ploughing prior to planting may serve an important purpose in regions having a long dry summer by assisting the young pines to become established and survive the first summer after planting. This is another phase of the subject not directly related to problems of pine nutrition, and therefore outside the scope of this publication.

(b) *Superphosphate.*

The remarkable growth responses obtained by the application of comparatively light dressings of superphosphate to young stands of P. pinaster established on both "B" and "C" class sites has opened up a big field of investigation into the possibilities of the establishment of plantations of this species on poor coastal sands. Dressings of 1 cwt. of superphosphate per acre repeated at two or three-year intervals have stimulated the growth of Pinus pinaster to attain an average height of 27 feet in eleven years on sites on which stagnation would occur at three to five feet without artificial aid. These fertilised stands show healthy normal growth with good crowns, and are now forming heavy canopy. Where stagnation was reached before remedial measures were undertaken, heavy dressings of 4 cwt. per acre have been necessary to produce a stimulus on some sites, although on others 1 cwt. per acre has proved sufficient. Up to the present it has not proved possible by an examination of the physical or chemical properties of soils coming within "B" or "C" classes referred to on p. 41, to determine the growth responses which might be expected from the application of superphosphate in varying amounts with or without cultivation, and experiments are necessary on each soil type before treatment is undertaken.

On plantations on the coastal sandplains, with the exception of a few of the best soil types, it is standard practice to apply dressings of superphosphate at the time of planting P. pinaster. The fertiliser is distributed by a specially adapted drill along shallow furrows in which the young pines are planted, the quantity used varying from one to two cwts per acre with the site. Pending the results of experiments now in progress, the need for subsequent applications of superphosphate is determined by observations of the general vigour of the young pines, and, in particular, by the length and colour of the needles. As a general rule, it has been found that, even on the poorer soil types, dressings of one cwt. per acre broadcast at intervals of not less than three years are sufficient to maintain normal vigorous growth up to the time canopy is formed in the ninth or tenth year.

Superphosphate delivered on West Australian plantations costs approximately 3s. per cwt. and the cost of application at any stage up to the time canopy is formed amounts to approximately 3s. to 4s. per acre according to the quantity applied.

Where P. radiata has been planted on marginal and submarginal soils, applications of superphosphate have not given the same promising results as in the case of the P. pinaster plantations referred to above. On only one plantation has superphosphate shown promise as a useful remedial treatment for a disorder of P. radiata, namely in restoring to normal growth Rosetted pines at Pardelup. Some temporary growth responses have been noted when superphosphate has been applied to young P. radiata planted experimentally on poor coastal sand, but no improvement has been brought about by this fertiliser when applied to stands in the Darling Ranges affected by Yellowing.

In general it can be stated that, despite extensive experiments using superphosphate alone and in combination with other treatments, no practical economical method has been found of stimulating the growth of P. radiata planted on "C" class sites to a stage when the plantations will produce saleable timber.

(c) *Zinc.*

Zinc applied as a weak solution of zinc sulphate has been successful on three plantations in restoring young P. radiata suffering from Rosetting to normal needle colour and growth. Having recovered from Rosetting, the further growth of the

stands depends on the quality of the site. On comparatively satisfactory sites approaching the upper limit of "B" class, the plantations may then develop in a normal manner, but on poorer soils Yellowing, Dead Top, or other types of irregular growth may occur unless the pines can be assisted by the use of fertilisers or cultivation.

In stands of P. pinaster zinc, where effective as it is notably with "Short Needle" with dead top, has a quicker action than superphosphate in restoring a severely malformed tree to a vigorous condition. On some soils zinc, superphosphate, and cultivation have been found equally effective when used separately, but the best treatment to use or the best combination of these treatments can not be determined until the duration of the response to a given treatment is known.

Zinc spray is applied by the use of orchard type packsprays carried on the operator's back and holding approximately four gallons of solution. The treatment should be carried out in the autumn and winter months and the quantity necessary for each tree depends on the age of the plantation, the cost varying from 4s. to £1 per acre.

The development of Rosetting can be prevented by the application of zinc spray 12 months after planting, on sites on which experience on adjoining areas indicates that this condition will develop unless treatment is given.

It is interesting to note that dressings of superphosphate have been found to give some growth responses on all sites where zinc has been effective in restoring normal growth, although the phosphate responses sometimes take much longer to appear and are less spectacular than that obtained by the application of zinc spray. On the other hand, there are sites on which Pinus pinaster responds to superphosphate applications where zinc has given no results.

4. *Strain.*

There are many types of P. radiata with different habits of growth, and work is urgently required to determine the extent to which desirable forms breed true to type. In practically all young stands of this species the proportion of poor form, heavily branched trees is relatively high and this is an important factor influencing the number of trees found desirable to plant per acre. With improved methods of seed selection it is probable that wider spacing could be adopted with advantage on many sites leading to savings in establishment costs and eliminating the need for early unprofitable thinning.

Varieties of P. pinaster in different parts of Europe have been described by a number of authors, and plantations grown from seeds from different regions are to be seen in Australia and South Africa. There is a remarkable difference between the form and height growth of extreme types of this species, and seed supplies obtained from a French source between 1918 and 1925 have been responsible for the establishment of a very inferior strain in certain Western Australian plantations. It is important that workers studying the growth of this species in plantations should be able to distinguish these strains in order to avoid incorrect deductions arising from confusion between the effects of strain on rate and habit of growth and the effects of soil type and treatment.

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References cited:

Comber, N. M. "An Introduction to the Scientific Study of the Soil" (Edward Arnold & Co., London, 1932).

Ludbrook, W. V. "Needle Fusion of Species of Pinus in Southern New South Wales" (C.S. & I.R Pamphlet 72, Melb. 1937).

Kessell and Stoate. "Plant Nutrients and Pine growth," "Australian Forestry," Vol I., No. 1, 1936.

Kessell, S. L. "Soil Organisms—The Dependence of Certain Pine Species on a Biological Soil Factor." "Empire Forestry Journal," Vol 6, No. 1, 1927.

Chandler, W. H. "Zinc as a Nutrient for Plants," "Botanical Gazette," Vol 98, No. 4, 1938.

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