THE EFFECTS OF THE 1955–56 DROUGHT ON
EXOTIC TREE SPECIES IN NORTH CANTERBURY
AND THE IMPLICATION OF THESE FOR SITE
EVALUATION

K. W. PRIOR, W. J. WENDELKEN, A. CUNNINGHAM*

SYNOPSIS

Damage to exotic trees in North Canterbury caused by severe
drought conditions during 1955–56 is reviewed. The effects are dis­
cussed under five headings, from slight foliage injury to death of trees.
The species concerned are listed under six drought-damage categories;
these in turn are related to site differences based on soil type, topo­
graphy, rainfall, and other variables. It is shown that in many places
in Canterbury a deficiency of soil moisture influences tree growth and
survival.

Broad recommendations are made for assessing the potentialities of
sites in the area, and emphasis is placed on the role hardwoods can
play in afforestation on the drier sites.

Introduction

The 1955–56 drought caused widespread damage to exotic tree
species throughout North Canterbury. The purpose of this paper is to
record the main facts relating to this damage, in particular the nature
and extent of the damage suffered by different species. The influences
of site factors and the significance of these in connection with species
siting is discussed.

The Area Investigated, the Topography and the Soils

The area most intensively investigated is located between the
Waimakariri River in the south and the Waiau and Conway Rivers in
the north. The exotic State Forests of Balmoral, Ashley, Eyrewell, and
Omihi are situated within this area. In addition the Hanmer district,
with Hanmer Forest, was intensively investigated.

Approximately half of the surveyed area comprises relatively flat
alluvial plains of which about 75% are located at altitudes of up to
500 ft and the remaining 25% at 500–1,000 ft. Rolling downs to steep
hill country occupy the remaining half of the area investigated.

The majority of the inspected occurrences of species are located
close to roads at altitudes mostly less than 1,000 ft and only occasion­
ally at altitudes more than 1,500 ft. Opportunities for investigations of
exotic species located in the steep foothill and mountainous country
to the west are unfortunately limited.

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Napier respectively, N.Z. Forest Service.
The soil pattern has of course developed under the influence of the environment. Brown-grey soils, typical of a semi-arid region, occur in one area. The seasonally dry yellow-grey soils and the yellow-brown soils, which occur in more humid areas, are both strongly represented. Stony soils, which are described by Taylor as being closely related to yellow-grey earths, cover much of the plains. The gley soils of the plains are widespread and limestone soils and recent alluvial plains soils cover large areas.

Climate of the Area and Descriptions of Drought

The average annual rainfall for most of the area varies from just under 25 in. to a little over 40 in. but is, for about 60% of the localities investigated, no more than 30 in. Along the coast the rainfall increases from about 25 in. at the Waimakarikari River to just over 40 in. at the Conway River in the north. Although in general the rainfall is lowest at the coast a 25–30 in. rainfall area extends inland in a broad belt through Balmoral Forest. A similar low-rainfall belt straddles the lower reaches of the Waimakariri River. The areas with a rainfall of 60 in. or more, in the mountainous region to the west, fall largely outside the drought-survey area. Seelye recorded that, for a broad coastal belt throughout Canterbury, there was a total of from over 20 to more than 30 autumn months with a rainfall less than 1 in. for the 30-year period from 1911 to 1940.

Föhn-type north-westerly winds, frequently of gale force, are an important feature of the climate. These winds tend to be far more frequent in inland districts than near the coast. In summer months the humidities are far lower in the inland than in the coastal districts.

In summer and autumn months evapotranspiration could exceed rainfall. At Lincoln, for the months of November to February inclusive, the average evaporation from a free water surface is more than 3 in. per month. In inland districts the amount would be greater.

In November 1955 the rainfall over most of North Canterbury was appreciably below normal. From 30 November to 19 March at Balmoral Forest there was no effective fall. The drought was widespread throughout North Canterbury, as the following data from four stations show.

RAINFALL DATA—NOVEMBER 1955 TO FEBRUARY 1956

<table>
<thead>
<tr>
<th>Station</th>
<th>Nov</th>
<th>Dec</th>
<th>Jan</th>
<th>Feb</th>
<th>Total</th>
<th>Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Christchurch</td>
<td>1.40</td>
<td>0.51</td>
<td>1.84</td>
<td>0.54</td>
<td>4.29</td>
<td>8.4</td>
</tr>
<tr>
<td>Highfield</td>
<td>2.56</td>
<td>1.27</td>
<td>0.75</td>
<td>1.54</td>
<td>6.12</td>
<td>11.0</td>
</tr>
<tr>
<td>Balmoral</td>
<td>1.56</td>
<td>0.17</td>
<td>0.99</td>
<td>0.59</td>
<td>3.31</td>
<td>8.8</td>
</tr>
<tr>
<td>Hanmer</td>
<td>2.38</td>
<td>1.36</td>
<td>1.09</td>
<td>1.09</td>
<td>5.92</td>
<td>14.3</td>
</tr>
</tbody>
</table>

Summer droughts of severity were also recorded for 1943–44, 1934–35, 1932–33, 1931–32, 1925–26, 1916–17 and 1907–08. Thornthwaite (1) concluded that the water need of a crop is dependent chiefly on temperature and length of day. The rainfall for November
to February inclusive, for four warm and dry periods, is shown below. (The summers of 1943–44, 1932–33, 1931–32 and 1925–26 were not unusually warm.)

RAINFALL FOR THE MONTHS OF NOVEMBER TO FEBRUARY INCLUSIVE

<table>
<thead>
<tr>
<th></th>
<th>1955-56</th>
<th>1934-35</th>
<th>1916-17</th>
<th>1907-08</th>
<th>Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Christchurch</td>
<td>4.29</td>
<td>4.43</td>
<td>4.74</td>
<td>2.09</td>
<td>8.4</td>
</tr>
<tr>
<td>Highfield</td>
<td>6.12</td>
<td>8.67</td>
<td>5.93</td>
<td>2.95</td>
<td>11.0</td>
</tr>
<tr>
<td>Balmoral</td>
<td>3.31</td>
<td>3.57</td>
<td>—</td>
<td>—</td>
<td>8.8</td>
</tr>
<tr>
<td>Hanmer</td>
<td>5.92</td>
<td>8.22</td>
<td>11.10</td>
<td>4.19</td>
<td>14.3</td>
</tr>
</tbody>
</table>

The mean temperatures at Christchurch recorded for the four unusually warm dry periods are recorded below.

MEAN TEMPERATURES AT CHRISTCHURCH FOR FOUR UNUSUALLY WARM PERIODS OF DROUGHT

<table>
<thead>
<tr>
<th></th>
<th>Nov</th>
<th>Dec</th>
<th>Jan</th>
<th>Feb</th>
</tr>
</thead>
<tbody>
<tr>
<td>1955-56</td>
<td>58</td>
<td>62</td>
<td>67</td>
<td>62</td>
</tr>
<tr>
<td>1934-35</td>
<td>59</td>
<td>64</td>
<td>66</td>
<td>64</td>
</tr>
<tr>
<td>1916-17</td>
<td>59</td>
<td>64</td>
<td>64</td>
<td>61</td>
</tr>
<tr>
<td>1907-08</td>
<td>57</td>
<td>63</td>
<td>63</td>
<td>60</td>
</tr>
<tr>
<td>Average 1864-1955</td>
<td>56</td>
<td>61</td>
<td>61</td>
<td>61</td>
</tr>
</tbody>
</table>

The data available concerning the frequency of north-westerly winds are limited. The Wigram data suggest that of the three driest months during the 1955–56 drought (December to February) January was the only one in which north-westerly winds were a little more effective than normal. Wigram observations cannot, however, be considered as representative of many parts of the area.

If the potential evapotranspiration for December to February of 1955–56 at Lincoln were to be assumed for Balmoral, it would exceed the rainfall by more than 9 in.

The drought was followed by a very warm and favourable growing period, the April of 1956 being the warmest on record.

The 1955–56 drought was undoubtedly one of the most severe on record. In South Canterbury, for the seven-month period from September to March, the rainfall was the lowest in 60 years of record. It is possible however that, in North Canterbury, the 1907–08 drought was at least as severe as that of 1955–56. Occurrences of drought damage to tree species in Canterbury are by no means isolated. Damage to exotic tree species was recorded by Adams for droughts as early as 1886 and 1897–98.

Nature and Extent of Injuries

The most obvious symptoms of drought damage in order of severity are (1) wilting of foliage, (2) necrosis and death of individual leaves and needles, (3) death to young growth and branchlets, (4) die back from main laterals and terminals and (5) death of trees. In addition to these there are a number of less obvious symptoms. Needles and leaves were often reduced in size and paler than normal. In one area, in addition to being smaller and paler, the needles of Pinus coulteri
were shed six months earlier than is usual. Buds of some species, for example *P. nigra* (laricio), were often reduced in size and produced excess quantities of resin.

An interesting form of needle damage occurred in 6–12-ft-high *P. radiata* saplings located at Balmoral Forest. A short section near the sheath, of the new season’s needles, turned yellow. Although many of the affected needles finally died, a few continued to live with only the slight yellowing near the base to indicate that damage had occurred.

For any one species the severity of the injuries varied with age and height. Mortality to recently planted seedlings was often heavy and young trees up to 5 ft high were frequently severely damaged. Relatively healthy and vigorous trees, between say 35 ft and 60 ft high, appeared to be least affected. Beyond a certain point, however, the damage appears to have increased with further increase in age and height. In one area, where two 75 ft *Chamaecyparis lawsoniana* were closely associated with several younger 35 ft specimens, the taller stems suffered severe die back of laterals and terminals, whereas the younger trees remained unaffected. In several localities, where large overmature *P. radiata* adjoined young and vigorous specimens, similar behaviour was observed.

With some species, including *Chamaecyparis* spp., *Thuja* spp. and *Pseudotsuga taxifolia* the top levels were usually the first to die. With *Pinus* spp., although terminal leaders were frequently killed, death took place as a result of die back which occurred at all levels on the crown more or less simultaneously. In the case of *Araucaria araucana* the lower branches were the first to die and, in two areas, only the top few whorls of branches and the leader remained green.

Some deciduous species shed foliage early with little autumn colouring. In the case of *Fagus sylvatica* and *Acer pseudoplatanus* all leaves had turned brown by March but were not shed for at least another month. *Betula pendula*, *Larix decidua*, *Quercus petraea* and *Quercus robur* shed some foliage early but in March and April produced new leaves approximately half the normal size. In autumn several species of ornamental shrubs produced unseasonable flowers which soon aborted.

Increment borings at Eyrewell indicated that *P. radiata* increment was reduced by about a third. *Larix decidua* produced practically no earlywood and only a very narrow, dense band of latewood. *Pinus coulteri* produced a ring of near-normal width but one which included a high proportion of summer wood. In many species an additional or “false ring” was produced during the mild conditions immediately following the drought.

The lateral and terminal shoots in many coniferous species became dormant early and produced resting buds. In the mild conditions immediately following the drought, the terminal buds opened and further growth took place, but most of the whorls of lateral buds continued resting. When terminal growth ceased with the approach of more severe winter conditions, new terminal and lateral buds were produced. This resulted in the presence of more than one whorl of
buds on most shoots. This behaviour was observed in uninodal as well as multinodal species.

In most hardwood species the length of terminal growth was less than normal. As a consequence the leaves, and the buds which are subsequently produced in the axils of these leaves, were spaced more closely than usual.

In *Thuja plicata*, longitudinal strips of inner bark on the stems were found to be abnormally discoloured and presumably overlay dead cambium. Similar but less marked effects were observed in *P. taxifolia* and *C. lawsoniana*. In *Thuja plicata* and *Abies grandis* longitudinal cracks, which penetrated through the outer bark deep into the wood, were observed. Although there is still some doubt as to whether drought was responsible for these injuries, they were observed in much greater numbers at this time than before or after the drought.

Close inspections at Eyrewell Forest revealed that the roots of *P. radiata*, *P. muricata*, *P. murrayana*, *P. banksiana*, and *Pseudotsuga taxifolia* had suffered considerable die back. The lateral roots furthest from the stem were the first to die. Similarly, the lateral roots nearest the surface of the soil died before those which penetrated more deeply. Of the small vertical roots which arise from the lateral roots, it would appear that those which are short and peg-like and which bear heavy mychorrhiza were more severely injured than those which are long and deep.

**Species Affected**

The species are listed in six drought-damage categories. The range of sites on which some species were observed was limited and a number of species, in which no damage was observed, were found on favourable sites only. The classification has accordingly been arranged to allow for this discrepancy in field data. To indicate the number of data on which the classification is based, the number of inspected occurrences is given in brackets after the species name. A single occurrence consists of either a plantation, a woodlot, a shelterbelt, several trees, or a single tree.

**Category 1 species**

Nearly all occurrences in this category were unaffected or only lightly affected on even the most difficult of sites.

*Pinus nigra* (laricio) (30+). Some slight die back was apparent but most stems have subsequently fully recovered. Corsican pine is vigorous, healthy, and of good form on a wide range of dry and exposed sites and is thus one of the most important species grown in Canterbury.

*Pinus radiata* (100+). In most cases no die back was apparent either during or immediately after the drought. But one year later, lateral and terminal die back was widespread. Subsequently, in 1957 and 1958, *Sirex noctilio* has caused heavy mortalities throughout a number of stands. It cannot be stated with absolute certainty that these
delayed symptoms were due to the drought, but nevertheless the implications are sufficiently relevant to warrant consideration. Although *P. radiata* can apparently thrive on relatively dry sites it lacks vigour, is unhealthy, and is subject to wind throw both on the stony plains soils and on shallow soil on dry exposed faces and ridge tops in hill country. *Pinus radiata* is a valuable species in forests, woodlots, and shelterbelts in Canterbury but due allowance must be made for its requirements.

*Pinus pinaster* (30+). None of the occurrences inspected showed any apparent effects of the drought but the provenances present lack vigour and are of poor form on all sites.

*Cedrus deodara* (30+). As specimen trees this species has performed extremely well on a wide range of dry sites and is now being more widely planted for farm forestry. No symptoms of drought damage were observed in any area. Perhaps the most outstanding aspect of the behaviour of this species was the high survival rates on newly planted areas.

*Cedrus atlantica* (30+). *Betula pendula* (40+). These two species do reasonably well on the driest sites and showed little damage.

**Category 2 species**

Nearly all occurrences in this category were unaffected or only lightly affected on a wide range of sites but the species were not found in sufficient numbers on the most difficult sites to justify their listing under category 1.

*Sequoiadendron giganteum* (40+). Specimen trees in homestead plantings are undoubtedly the most magnificent exotic trees present in Canterbury. On moderately poor sites, although lacking vigour, this species showed little apparent effects of drought.

*Pinus sylvestris* (30+). On most sites, although not obviously affected by drought, this species is stunted and of poor form. The only fair specimens observed are located well inland at 1,500 ft in a 60 in.+ rainfall area.

*Libocedrus decurrens* (17). On a wide range of sites specimen trees were largely unaffected by drought. This species is healthy and vigorous on favourable sites and in one area is more than 100 ft high and approximately 5 ft d.b.h.o.b. *Libocedrus decurrens* regenerates freely on some sites.

*Pinus coulteri* (9). Some die back was apparent on one particularly difficult site at Eyrewell Forest. Although healthy specimens, up to 80 ft high, are found on favourable sites, this species lacks vigour on the poorer soils.

*Cupressus lusitanica* (10). Although showing no apparent symptoms of drought damage on even the most difficult sites *C. lusitanica* in Canterbury lacks vigour on all sites.

*Cupressus arizonica* (10). This species can apparently tolerate severe drought, even at the recently planted seedling stage. As most occurr-
rences in Canterbury are relatively young, the full potentialities have still to be determined.

_Picea smithiana_ (1). One vigorous and healthy specimen, unaffected by drought, was observed on a site which would grow only sickly and stunted _Picea abies_ and _Picea sitchensis_.

All the underlisted species were largely unaffected and might, if more observations had been made on the difficult sites, have been listed under Category 1.


The species listed below, apparently for the most part unaffected on relatively dry sites, require fair to good sites for reasonable growth and could possibly be listed under Category 3.

_Abies concolor_ (4), _A. pinsapo_ (14), _A. nordmanniana_ (5), _Araucaria araucana_ (10), _Cupressus sempervirens_ (12), _Taxus baccata_ (11), _Ginkgo biloba_ (10), _Eucalyptus obliqua_ (3), _E. viminalis_ (6), _E. fastigata_ (2), _Pinus densiflora_ (2), _Pinus muga_ (2), _Populus tremula_ (3), _Populus nigra_ (6), _Populus nigra_ var. _italica_ (30+), _Acacia melanoxylon_ (10). Excellent specimens of _A. pinsapo_, _A. nordmanniana_, _E. obliqua_ and _Populus nigra_ are found on favourable sites.

Category 3 species

Nearly all occurrences in this category were at the most only lightly damaged on a number of fairly dry sites.

_Cupressus macrocarpa_ (100+). Although few occurrences were affected by drought the vigour is poor when this species is grown on shallow-rooting gravelly soils or on dry slopes and ridge tops.

_Larix decidua_ (20+). This species is seldom found on the driest sites, where the form is poor and the growth stunted, but even on these hard sites only a small amount of die back was apparent. As already recorded, there was early shedding of foliage followed by the production of some new foliage in autumn.

_Pinus muricata_ (20+). On even favourable sites terminal and lateral die back was widespread but few stems were killed. In view of the poor form and the lack of vigour on most sites there is little to commend this species.

_Pinus contorta_ (10+) and _Pinus banksiana_ (7+) exhibited moderately severe die back on the poorest sites. In general _Pinus banksiana_ was more severely affected than _Pinus contorta_.

_Pinus nigra_ (austriaca) (8), although not severely damaged on most sites, appeared to be somewhat more susceptible to drought injury than did _Pinus nigra_ (laricio).
Sequoia sempervirens was lightly to moderately damaged on a wide range of sites. In most cases the health and vigour of this species, which is exacting in its soil requirements, were poor.

Die back, although widespread, was not severe in the underlisted species: Quercus petraea (20+), Quercus robur (40+), Castanea sativa (10), Acer pseudoplatanus (4), Betula pubescens (10), Pinus lambertiana (2), Pinus cembra (2), Chamaecyparis nootkatensis (5).

Category 4 species

A large proportion of the occurrences in this category were severely affected by drought. Pseudotsuga taxifolia (40+). Of the species which are important in exotic forests in Canterbury, this was the one most severely damaged by drought. Lateral and terminal die back were widespread and frequently trees up to 30 ft high were killed. Although this is a valuable species in Canterbury, careful siting is essential.

Chamaecyparis lawsoniana (30+). Die back and death were widespread on difficult sites; careful siting is again essential.

Pinus ponderosa (15+). Die back in this species was frequently severe. In spite of this, however, individual stands of the species are among the finest and most vigorous of any species investigated. Provided timber quality proves to be satisfactory, there will continue to be a place for suitable strains of P. ponderosa in Canterbury.

Picea abies (15+) and Picea sitchensis (15+) suffered severe die back in several localities. In the majority of occurrences the health and vigour are extremely poor. In one area only, at 3,200 ft on a site which would be unsuitable for most other species grown in Canterbury, Norway spruce is reasonably promising.

Cryptomeria japonica (20) and Chamaecyparis pisifera (21+) were by far the most spectacularly affected of all species. It is probable that 25% to 50% of all trees of these two species present in North Canterbury were killed by drought.

The species listed below were all moderately to severely affected on relatively dry sites.

Abies balsamea (1), A. procera (2), A. alba (8), Thuja plicata (30+), T. occidentalis (3), Thujopsis dolabrata (5), Fagus sylvatica (7), Fraxinus excelsior (15).

Category 5 species

All occurrences in this category were unaffected or lightly affected, but were found only on the favourable sites.

Abies grandis (1), Pinus griffithii (1), P. strobos (10), Larix leptolepis (1), Chamaecyparis obtusa (1), Cupressus goveniana (1), Picea glauca (1), Pinus patula (6), P. monticola (10), Tsuga heterophylla (3), T. mertensiana (2). In two localities where they occurred together T. mertensiana had a much healthier appearance and colour than T. heterophylla.
Category 6 species

Nearly all occurrences in this group were unhealthy specimens but did not show apparent effects of drought. *Eucalyptus globulus* (40+), *Podocarpus totara* (2), *Thuja orientalis* (7).

**Drought Damage in Relation to Site**

Under this heading it is necessary to evaluate not only the broad geographic and climatic influences but the more local influences of topography and soil. As would be expected the local influences were frequently of overriding importance.

For the area located between the Ashley and Conway Rivers a record has been kept of the locations of the different coniferous occurrences encountered during the survey. It is thus possible to demonstrate quantitatively the effects of rainfall and of soil. In all cases records of rainfall were obtained from isohyets. Soil types were determined from the 4-miles-to-inch soil maps.

As would be expected the species susceptible to drought damage were far more strongly represented on favourable sites than on difficult sites. The category 4 species only (the species most subject to injury) were therefore used as a basis for comparing the respective sites. Similarly it was found that a much better comparison could be made if percentages were computed for the severely damaged occurrences only and not for the lightly damaged ones—with tall trees the light damage could possibly have escaped notice and thus not be recorded.

In table 1 the effects of rainfall are evaluated.

<table>
<thead>
<tr>
<th>TABLE 1: EFFECTS OF RAINFALL</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Total Number and the Number and Percentages which were Damaged by Drought</td>
</tr>
<tr>
<td>Less than 30 in.</td>
</tr>
<tr>
<td>Number Percentage</td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td>Severely damaged</td>
</tr>
</tbody>
</table>

In the less-than-30 in. rainfall area 55% of the occurrences, as compared with 36% and 16% of the occurrences in the 30 in. to 40 in. and the more-than-40 in. rainfall areas respectively, were severely damaged by drought.

It is clear that, other things being equal, damage should have been less severe in coastal districts, where humidities are higher and NW winds less frequent, than in inland districts. To demonstrate that damage was in fact less severe nearer the coast the percentage of severely damaged occurrences located within 10 miles of the coast are compared in table 2 with that of occurrences located more than 10 miles from coast. These observations are for the less-than-30 in. rainfall areas.
TABLE 2: SIGNIFICANCE OF THE LOCALITY

<table>
<thead>
<tr>
<th></th>
<th>Within 10 miles of the coast</th>
<th>More than 10 miles from coast</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Percentage</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Severely damaged</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Where the rainfall is less than 30 in., 29% of the occurrences within 10 miles of the coast, as compared with 69% of the occurrences more than 10 miles from the coast, were severely damaged by the drought. With further increase in rainfall, however, the difference between the severity of the damage in coastal districts and that in inland districts becomes less marked. This is demonstrated by the fact that most of the occurrences in the 40 in. + rainfall areas, given in table 1, occur well inland, but only 16% of these were severely damaged.

In table 3 are listed, for the different broad soil groups, the number of occurrences and the percentages of these which were severely damaged by drought.

TABLE 3: EFFECTS OF SOIL

<table>
<thead>
<tr>
<th></th>
<th>Severely damaged occurrences</th>
<th>Total number of occurrences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number damaged</td>
<td>Percentage damaged</td>
</tr>
<tr>
<td>On brown-grey soils</td>
<td>2</td>
<td>40</td>
</tr>
<tr>
<td>On yellow-grey soils under dry coastal climate</td>
<td>26</td>
<td>43</td>
</tr>
<tr>
<td>On yellow-grey soils under damp coastal climate</td>
<td>4</td>
<td>31</td>
</tr>
<tr>
<td>On yellow-brown soils</td>
<td>4</td>
<td>19</td>
</tr>
<tr>
<td>On recent soils of the plains</td>
<td>13</td>
<td>32</td>
</tr>
<tr>
<td>On gley soils</td>
<td>8</td>
<td>73</td>
</tr>
<tr>
<td>On limestone soils</td>
<td>6</td>
<td>40</td>
</tr>
</tbody>
</table>

Listed under yellow-grey soils are certain plains soils which are described by Taylor as being closely related to yellow-grey soils.

On yellow-grey soils under dry coastal climate 43% of the occurrences were severely damaged, whereas on yellow-grey soils under damp coastal climate 31% and on yellow-brown soils 19% of the occurrences respectively were severely damaged. As the environment, and in particular the rainfall, controls soil development, it is probable that these differences do no more than reflect the differences shown in table 1 for rainfall.

Only 32% of the occurrences located on the recent soils of the alluvial plains were severely damaged, compared with 43% of the occurrences located on yellow-grey soils under dry coastal climate (which includes a large proportion of the plains soils investigated) that were similarly severely damaged. Although too much reliance cannot be placed on this difference, the figures do support the very strong impressions formed during the survey that damage was less severe on the recent soils. In general the “pans” which are typical of
yellow-grey soils are lacking in recent soils where the roots can, as a consequence, penetrate more deeply.

The competition from the grasses for the available soil moisture has resulted in severe losses on newly planted areas, particularly on the recent soils. In a number of areas the losses have been substantially reduced by planting the trees in ploughed furrows.

Most of the limestone soils investigated are associated with yellow-grey soils under a dry coastal climate. On the limestone soils 40% of the occurrences were severely damaged, compared with 43% of the occurrences on yellow-grey soils under dry coastal climates. In the field, the impression was formed that damage was in fact similar for the two groups. Occasionally an interesting chlorotic condition is found in P. radiata trees located on limestone soils. Although the primary cause of this condition may not be drought, the symptoms become apparent only on the more shallow pockets of soil which dry out more rapidly.

On gley soils there were numerous occurrences (in some cases of excellent trees) which were severely damaged by drought. It was found that, because of the high level of the water tables on many gley soils, the rooting systems were shallow and particularly susceptible to injury. The water tables throughout Canterbury were substantially lowered by the 1955–56 drought and damage was, as a consequence, severe. This damage, due to the lowering of the water tables, was severe not only on the gley soils of the plains, but also on the low-lying gravels adjoining the main rivers and at the points of seepage on hill slopes where soils are usually wet.

Normally it would be expected that soil texture would have some influence on the severity of drought damage. In a few areas damage was in fact less severe on deep clayey loams than on adjacent deep sandy loams. In many cases, however, the texture of the soil was of negligible importance compared with its depth or with the relative abundance of large rocks present in the soil. Damage was obviously likely to be more severe on shallow soils overlying either the river gravels on the plains, or on solid rock on steep hill slopes, than it would be on much lighter, but deeper soils. In Canterbury, soil depth is one of the most important criteria of a site.

In many areas, die back was frequently spectacular in Nothofagus cliffortioides forests. The distribution of this damage demonstrated the significance of aspect and exposure in Canterbury localities. Damage was most severe on stony ridge tops and on exposed westerly to northerly slopes.

To illustrate further the effects of aspect, the results of investigations carried out at Hanmer in 1956 in connection with the rate of growth of P. nigra (laricio) are quoted. The area selected for study provided a variety of aspects. Mean top height was used as the indicator for site. It was found that the aspects in the quarter between west and north are the least favourable. Aspects towards the east are favourable. At Hanmer, altitude does not have a marked affect on
site below 2,000 ft, but above this it appeared to exaggerate the effects of aspect.

An excess of soil moisture is, surprisingly, one of the main causes of mortality in Canterbury. Possibly, under a higher rainfall, the soils concerned would be permanent swamps, but in Canterbury they are, on the average, flooded only once every 2 to 5 years. This causes tree mortality. A close inspection of the mottled layers is often necessary to reveal the true nature of these soils. *Thuja plicata* has shown promise on these soils.

**Implications of the Effects of the Drought for Site Evaluation**

There are four main reasons for assessing the potentialities of sites in Canterbury. Occasionally it is necessary to assess the potentialities of large blocks of land for afforestation purposes. Secondly, the siting of species into compartments is required. Thirdly, and perhaps most frequently, comes the need for selecting species for woodlots and shelterbelts. Finally, on certain sites, e.g., in semi-arid regions, special establishment measures are necessary.

The drought demonstrated that on many sites the available soil moisture is a major factor limiting the growth of exotic species. It could be said that, on the basis of available soil moisture, the sites in Canterbury vary from those which are favourable for a wide range of species, to those which are submarginal for all but the least exacting. There is, however, no single criterion on which to judge site.

Within Canterbury the 10 in. difference between the upper and lower extremes of the 25–35 in. rainfall can have a profound effect on tree growth. But in spite of this, providing the local soil and topography are favourable, a wide range of exacting species will grow in the lowest-rainfall areas that are available. As already shown, this 10 in. difference in rainfall is of less significance near the coast than in inland districts.

The effects of soil, of soil depth, and of aspect and exposure have been dealt with in the previous section. In Canterbury, perhaps more than in most other localities in New Zealand, it is necessary to evaluate the moisture regime of the soil in order to determine the merits of the site. Although the use of individual species of vegetation, as indicators of site, has not been worked out in detail for Canterbury, the vegetation does reflect the extent to which the soils are subject to drought or flooding and can be of assistance when evaluating sites.

Throughout Canterbury certain plant species are usually found on sites subject to flooding. Locally, other species are useful indicators of site. For example, on the shingle soils in areas occupied mainly by sweet vernal and browntop, the occurrence of cocksfoot indicates that locally the soils are probably deep and the site favourable. The growth form of certain species, for example *Discaria toumatou*, varies from place to place according to the moisture regime of the soil. Frequently, for instance with *Leptospermum ericoides*, the health and vigour of the vegetation are of value for ascertaining the merits of a particular
site. Where the vegetation can be kept under observation for several seasons, the extent of the wilting and the time at which this occurs can be of value, as can the rate of regrowth on recent burns. The marked change in site, from gullies to ridge tops, is usually reflected by an equally well marked change in the vegetation.

In Canterbury the broad floristic pattern, the development of which is largely controlled by the environment, can frequently be used to help assess the suitability of large areas for afforestation purposes. Due allowance must be made for the repeated burning and grazing which have been carried out in the past.

The dominant species in some of the driest areas are frequently grasses and herbaceous weeds. Xerophytic shrubs and tussocks are scattered throughout. A striking feature of these areas is the similarity of the vegetation in the gullies to that on the ridge tops. A typical example occurs in the westerly slopes immediately to the east of Balmoral Forest, in the 25–30 in. rainfall area. Here the slopes are moderately steep and exposed, and rock outcrops, which indicate that the soils are shallow, are numerous. In spite of the fact that these soils are considered to be fertile, the area is submarginal for afforestation purposes. Some 16 miles north, in the 40 in. + rainfall area, *L. ericoides* and *L. scoparium* occupy the gullies. Numerous pockets of beech forest and odd podocarp remnants are present. This area obviously has a climate favourable for the growth of trees. Numerous other examples of a transition from an unfavourable to a favourable environment are to be seen in Canterbury and can be recognised with the aid of the flora.

**Conclusions**

In many places in Canterbury a deficiency in soil moisture influences tree growth. This fact was forcefully demonstrated by the drought, which caused severe damage to exotic tree species.

Although *P. radiata* can apparently tolerate relatively dry sites, it lacks vigour, is unhealthy and is subject to wind throw on exposed sites and on shallow soils. Douglas fir does best on deep, well drained soils in sheltered sites and, in North Canterbury, on the easterly aspects; it is liable to be injured by drought and exposure. Larch needs deep-rooting, well drained soils on sloping ground and requires access to adequate soil moisture, but if these requirements are met it can apparently withstand severe drought. Of the several coniferous species which withstood the drought reasonably well and are vigorous and healthy on a number of sites, *Cedrus deodara*, *Sequoiadendron giganteum*, *Libocedrus decurrens*, *Abies nordmanniana*, and *Abies pinsapo* are outstanding.

The excellent behaviour of hardwoods during the drought indicates the need for greater use of these species when tree planting is necessary on the most difficult sites.

The 10 in. difference between the lowest (25 in.) and the highest (35 in.) rainfall frequently has a marked effect on tree growth. This
10 in. difference in rainfall is of less significance near the coast. There is, however, no single criterion by which to evaluate the merits of individual sites. Allowance must be made, not only for the broad climatic and geographical influences, but also for the more local influences of topography and soil.

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