



## Why do forest sands become less fertile?

We all know that, if you grow wheat or cabbages in the same place year after year, you must take special precautions if yields are not to decline. Is the same true of timber forests?

The obvious way to find out is to measure the yields from successive crops in a plantation — but you must be very patient. Each rotation of Australia's most popular and successful commercial tree — the introduced radiata pine, the Monterey pine of California — lasts about 50 years. This means that, after planting your first trees, you must wait the best part of a lifetime before you can compare two successive plantings.

The best place to make such comparisons is in the oldest forests. Australia's first radiata pine plantings were made in South Australia in the 1860s, and in 1879 the State's Woods and Forests Department introduced the pine to the Mount Gambier region of South Australia.

Here the Department maintains permanent yield plots where it measures the growth rates of trees, and thus assesses each site's productivity. When trees are 9–10 years old, their sizes are compared with those of trees of the same age in the

previous rotation, to see whether productivity has fallen.

Unfortunately, it has. The phenomenon of 'second-rotation productivity decline' was first identified in the 1950s, when the decline was assessed at 25–30%. Scientists from the Woods and Forests Department and three CSIRO Divisions (Soils, Forest Research, and Mathematics and Statistics), co-ordinated by Mr Bob Boardman of the Department, applied themselves to the problem, and prescribed a combination of fertilizers (particularly nitrogen and phosphorus), weed control, and site preparation.

The medicine helped considerably, but did not effect a complete cure; the productivity of second-rotation sites that receive the prescription is still about 10% below that of first-rotation sites that have been similarly treated.

The sandy soils of the State's southeast grow bigger trees than they did a few decades ago, but something is prevent-

A grapple skidder at work during clear-felling near Mount Gambier. Low-pressure tyres and flexible tracks are increasingly used to minimize the impact of machinery on soils.

ing maximum yields — something that, as one soil scientist puts it, 'can't be solved out of the fertilizer bag'.

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*You must wait the best part of a lifetime before you can compare two successive plantings.*

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The mystery factor is probably the soil's physical condition — in particular the extent to which it has become compacted. Several pieces of evidence point to this conclusion. For example, if you dig up the soil from a number of sites and transfer it to pots, you often find that seedlings grow equally well in soils from first- and second-rotation sites. This suggests that the lower productivity of second-rotation soils depends on their physical properties in the forest.

An even simpler observation brings compaction under suspicion. When a gardener digs over part of his vegetable patch, the soil seems to expand, and the surface ends up above its original level. The Mount Gambier soils are different. Dig a pit then refill it, and you are sometimes left with a hole! This shows that, in the natural state, the local sands have a very open structure.

Just how they acquired this structure is not known. The soils probably developed on wind-blown coastal dunes, and perhaps some of their original components have been leached out over the centuries. Whatever the cause, they are extremely light and therefore easy to compact.

### Probing the problem

To find out just how badly some forestry soils have become compacted, a team of three scientists measured the force required to push a special probe into the ground at different sites. Using this instrument, called a penetrometer, Dr Roger Sands and Dr Bill Greacen, of the CSIRO Division of Soils, and Dr Cleve Gerard of the Texas Agricultural Experiment Station found that some soils in radiata pine plantations were markedly more compacted than others.

**A radiata pine plantation in South Australia.**



Is this compaction likely to affect the growth of pines? Dr Sands and his Soils Division colleague Dr Glynn Bowen sowed radiata pine seeds in pots of Mount Gambier sand packed to three densities within the range found in plantations.

Five months later, the scientists harvested the seedlings and found that the more compacted soils had markedly stunted the plants' growth. Seedlings from the compacted sands had smaller roots and shoots, and the dry weight of pines grown in the most compact sand (1.60 g per mL) was little more than half that of the plants grown in the loosest sand (1.35 g per mL).

In this experiment the roots did not lack water or air, and the scientists concluded that pine roots, like the experimental probe, found it harder to push their way through the denser soils. Even the very form of the root system was affected: in more compact soils the main root was broader and it bore more side-branches.

In plantations the sand is not evenly packed, as it was in the experimental pots. Using their field penetrometer, Dr Sands, Dr Greacen, and Dr Gerard charted the degrees of compaction of soils, rather as meteorologists map atmospheric pressures. The result was a diagram of a 'vertical slice' through the soil at each site, with isobars (lines joining points of equal pressure) showing the distribution of soil density.

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*Dig a pit then refill it, and you are sometimes left with a hole!*

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These diagrams strikingly illustrate the difference between pots and forests. In plantations, densely packed regions at depths of 40–100 cm may be separated by vertical channels of much looser sand. These channels are typically 10–20 cm wide.

Pine roots clearly 'seek out' these pathways of least resistance. The scientists showed this by counting the numbers of roots at different points in their 'vertical slices' (each 'slice' was a vertical pit-face 1 m wide and 1 m deep) and found that roots were clearly more numerous where the soil was loosest.

When the researchers compiled diagrams on which lines joined points having the same root frequency, each



**The penetrometer in action.**

diagram strikingly resembled the corresponding plot of penetrometer readings for the same site: the denser the soil, the scarcer the pine roots.

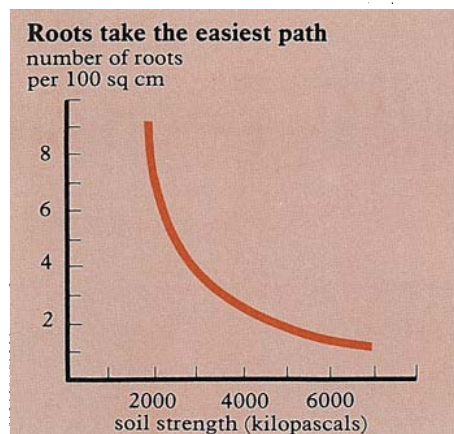
From these field investigations it seems that the roots have particular difficulty growing into soil compacted more than a critical amount, corresponding to a penetration resistance of about 3000 kPa (kilopascals) — about 15 times the pressure inside a typical family car tyre. In Mount Gambier forests, the researchers sometimes encountered higher resistances than this only 50 cm below the surface.

Whether a pine tree can grow satisfactorily in soils as compacted as this depends on a number of circumstances. If water and nutrients abound, the tree can satisfy its needs without penetrating the whole volume of the soil, but where there are shortages or where the soil is shallow, the patterns of compaction found by the researchers will restrict growth. Because rainfall fluctuates, trees may in practice grow well some years and not others.

### Changes in land use

Are all the soils in the Mount Gambier region as compacted as those in the forestry plantations? The researchers took

their penetrometer into local pastures and native scrub, and found that they almost always had less-densely packed soils than adjacent pine forests. The only exception was the top 20 cm or so of intensively managed pasture, which had been compressed by generations of animal hooves.



**Very few radiata pine roots penetrate soils whose strength exceeds 3000 kPa.**

The sandy soils of the Mount Gambier district, therefore, are not intrinsically compact; they have become denser with changes in land use, particularly from native vegetation to forestry plantations. At all the first-rotation sites that the researchers examined, the soils gave higher penetrometer readings than in adjacent native scrubland.

About half the second-rotation sites had even more compacted soils than neighbouring first rotations; at the other sites first and second rotations gave more or less the same readings. Some soils, it seems, are especially prone to compaction and continue to pack more tightly after the second-rotation pines have been planted.

Scientists cannot yet say exactly what causes compaction. Tall trees swaying in

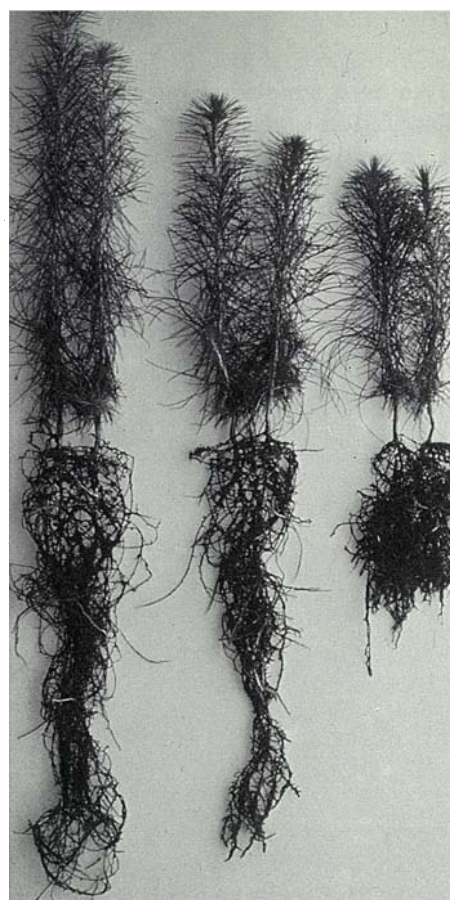
the wind cause shear forces in soils — particularly wet soils containing little organic matter — and these could lead to compaction. Heavy harvesting machinery may contribute.

Whatever the cause, the phenomenon can be quite severe, especially under certain conditions. Dr Sands, Dr Greacen, and Dr Gerard investigated these conditions in the laboratory by applying various loads to soil samples in an instrument called a consolidometer, which measures the resulting compaction.

They found that soils saturated with water were severely compacted, even by light loads. The soil's organic content also affected its behaviour, although less spectacularly; the more humus a soil contained, the better it resisted compacting loads.

Can these research findings help foresters to minimize soil compaction? They can, but the problem may not be serious in all forests. The sands of the Mount Gambier region are quite different from most Australian soils. They have much lower densities than most sands, and, unlike other soils, once compacted they stay that way; clays and loams both shrink and expand, and in this way can recover naturally.

Forestry plantations on sandy soils of the Mount Gambier type occur on the coastal plains of Western Australia and south-eastern Queensland (where different pines are grown), in western Victoria, and in parts of Gippsland. In these places, the research suggests that foresters would be well advised to avoid logging and using heavy machinery when the soil is very wet, and to exercise particular care on soils containing little humus.

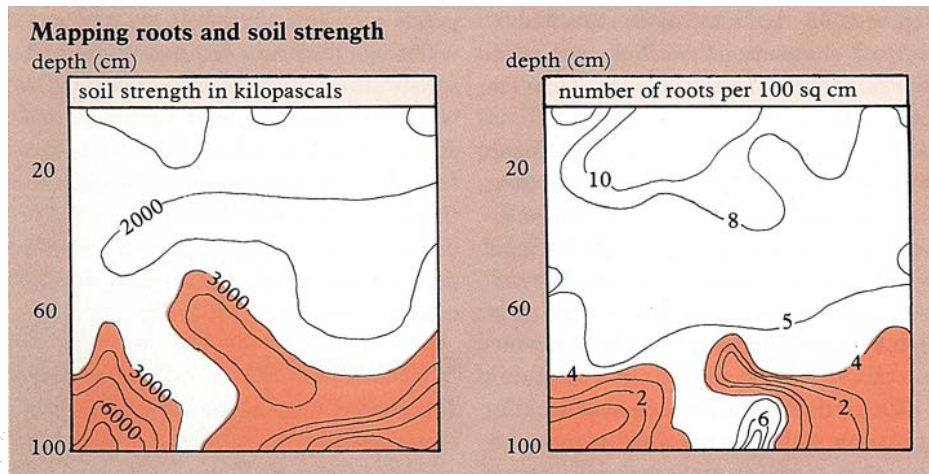


**Soil compaction stunts the growth of radiata pine seedlings.** These specimens grew in pots of soil with density 1.35 g per mL (left), 1.47 g per mL (centre), and 1.60 g per mL (right): a typical density range in plantations.

Since organic matter helps protect soils against compaction, any measures that conserve humus would be welcome. The scientists suggest, for example, that leaf litter should not be burnt; that deep ploughing could help incorporate organic matter into the soil's deeper levels; and that lime could be applied, to speed up litter decomposition. These measures have already been shown to improve pine growth. A further tactic may be to grow legumes or other pasture plants between pine rotations.

*John Seymour*

Each chart shows the vertical side of a pit dug in radiata pine forest near Mount Gambier. *Left*: isobars of soil strength, measured by penetrometer. *Right*: map of root frequency. The chart shows that most roots grow in soils of strength below 3000 kPa.



#### More about the topic

Compaction of sandy soils in radiata pine forests. I. A penetrometer study. R. Sands, E. L. Greacen, and C. J. Gerard. *Australian Journal of Soil Research*, 1979, 17, 101–13.

Compaction of sandy soils in radiata pine forests. II. Effects of compaction on root configuration and growth of radiata pine seedlings. R. Sands and G.D. Bowen. *Australian Forest Research*, 1978, 8, 163–70.

Compaction of forest soils. A review. E.L. Greacen and R. Sands. *Australian Journal of Soil Research*, 1980, 18, 163–89.