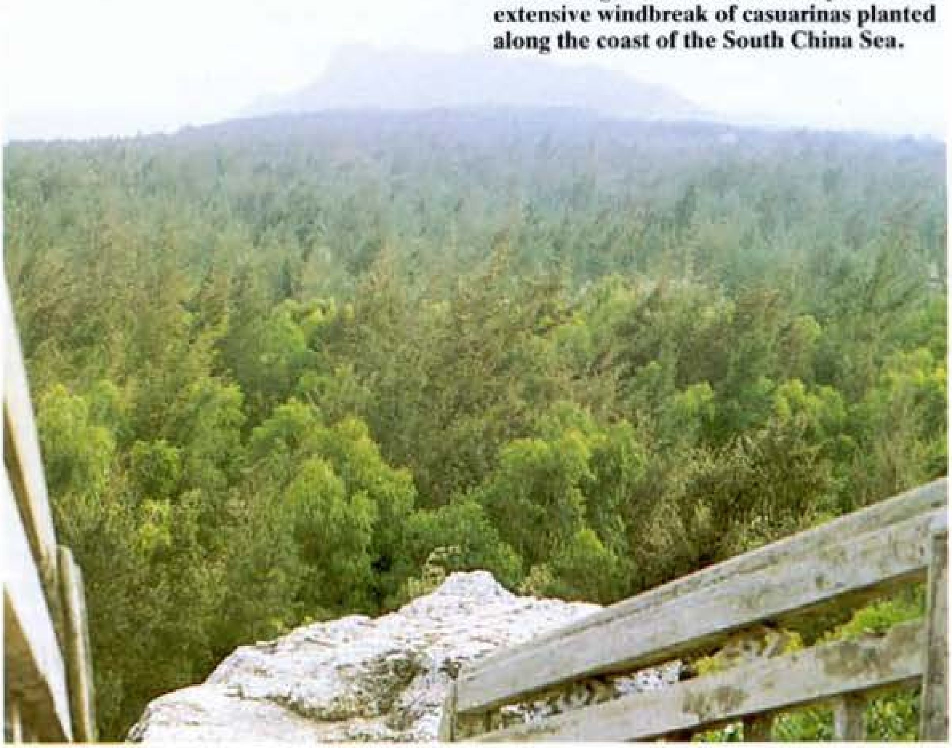
Boosting casuarinas around the world

The other great wall of China — part of the extensive windbreak of casuarinas planted along the coast of the South China Sea.



In his 'Maxims for Revolutionists', George Bernard Shaw wrote 'no man manages his affairs as well as a tree does'; his comparison could well have been based on the resourceful casuarina. This tree — so-called because its filamentous branches resemble the plumage of the cassowary, *Casuaris* sp. — is hardy, adaptable, and vigorous, and has colonized coastal dunes, swamp and salt-water habitats, and arid soils around the globe.

Casuarinas, also commonly known as she-oaks, grow rapidly and are often easily propagated vegetatively. They need little care, are fairly resistant to pests, and suffer few major diseases. Most species also tolerate extreme heat: one central Australian species grows in summer temperatures of up to 47°C.

They naturally reseed themselves very well in open, disturbed areas — think of the many tree stands along Australian roads. They compete successfully with weeds, particularly the tenacious imperata grass in Asia, and can thrive in poor soils such as beach sand, salt-marsh, or black cracking clay. She-oaks even colonize sterile tin tailings in Malaysia, and in Hawaii grow well on volcanic ash and pumice.

What's the secret of their success? Part of the answer lies in the unusual symbiosis the tree has with the filamentous *Frankia* bacteria. The symbiosis allows the casuarina to use gaseous nitrogen directly from the atmosphere, rather than from nitrates and ammonium salts in soil solutions. The genus *Frankia* belongs to a group of organisms, collectively known as actinomycetes, that help at least 170 species of woody plants to fix atmospheric nitrogen.

Nodules

Infection by *Frankia* occurs in the tiny hairs of fine casuarina roots, causing the formation of swellings or nodules there. These may be numerous and small (1–4 mm in diameter), or may form large spherical conglomerates up to 10 cm in diameter. Although long-lived, they eventually decay and release *Frankia* spores. The nodules form the enzyme nitrogenase, which catalyses the reduction of nitrogen from the atmosphere to ammonium ions within the plant. In return for the nitrogenous compounds, the host plant provides the bacterial symbiont with sugars and possibly with other organic substances.

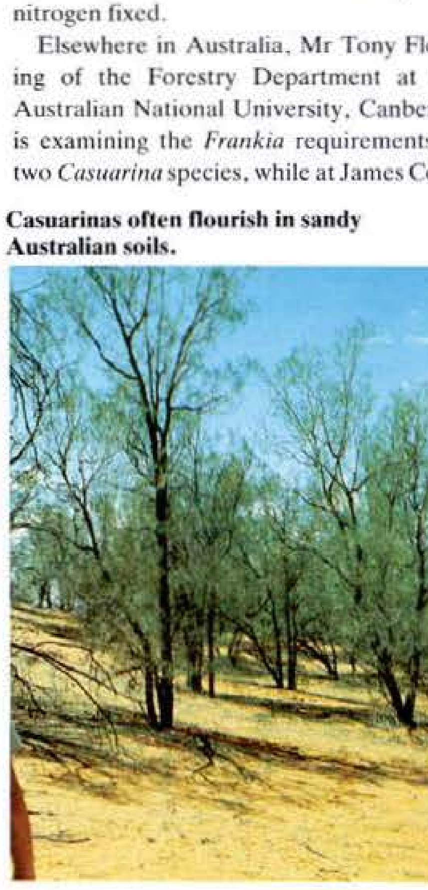
The amount of nitrogen fixed by nodulated trees is comparable to the amounts fixed by legumes with *Rhizobium* symbionts. For example, in sand dunes in the Cap Vert peninsula of Senegal, where casuarinas have been planted to consolidate coastal sands, nitrogen in the soil around casuarinas has increased annually at rates of about 60 kg per hectare.

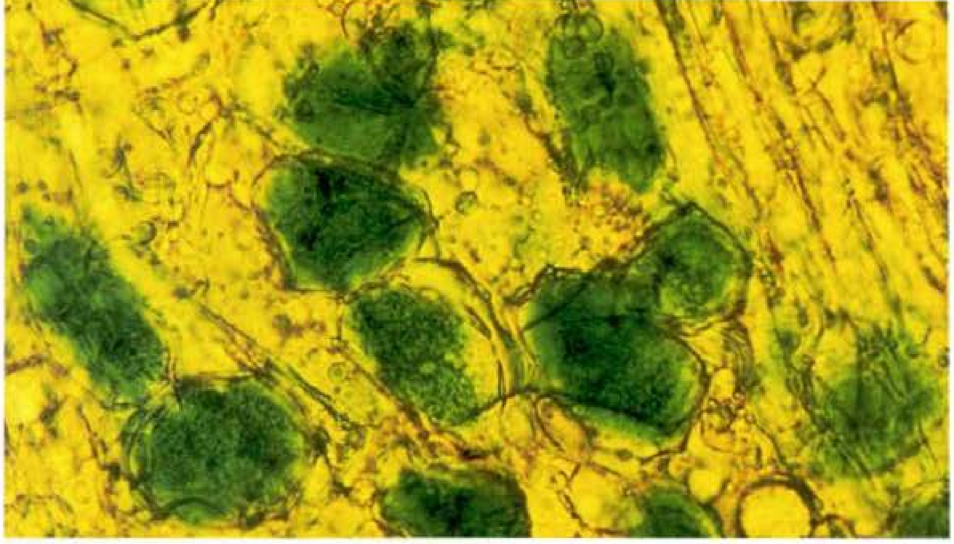
Scientists first isolated a *Frankia* — similar to the one that inhabits root nodules of casuarinas — from a related Northern Hemisphere tree, the alder, as recently as 1978. Culturing of pure strains of the bacterium from casuarinas in artificial media did not begin until 1983 and still presents difficulties.

Until recently, research into factors affecting nodulation and nitrogen fixation has been largely neglected. In Australia, Dr Glynn Bowen and a small team of researchers from the CSIRO Division of Soils in Adelaide have been studying the *Frankia*–casuarina symbiosis for 4 years. The research covered two main areas: host specificity (whether the one *Frankia* strain is suitable for nitrogen fixation by all casuarinas) and soil factors affecting nodulation and the amounts of atmospheric nitrogen fixed.

Elsewhere in Australia, Mr Tony Fleming of the Forestry Department at the Australian National University, Canberra, is examining the *Frankia* requirements of two *Casuarina* species, while at James Cook

Casuarinas often flourish in sandy Australian soils.





A nodule under the microscope. *Frankia*-infected cells are stained green.

University in Townsville, Dr Warren Shipton is studying *Frankia* growth and nitrogen fixation in laboratory media.

Host specificity

Although a few introduced species of *Casuarina* have performed well in overseas countries, some of the transplants have been puzzling failures. One of the explanations offered by scientists is that the *Frankia*–casuarina association may be highly specific, and that foresters have not been selecting the right combination for trees to nodulate readily and fix nitrogen.

Earlier studies at the Australian National University had pointed to the existence of specificity in nodule production. Dr Bowen and Dr Paul Reddell, also of the Division of Soils, began their research by extensively examining species of *Casuarina* from different parts of Australia. They noted that the degree of nodulation varied between species and soils, and they inoculated 15 species with nodules obtained from a wide range of casuarinas.

Recently, Dr Lawrence Johnson of the Royal Botanic Gardens in Sydney subdivided the genus *Casuarina* into four genera. In Dr Reddell's and Dr Bowen's glasshouse experiments, casuarinas belonging to one of the genera, *Allocasuarina*, nodulated less frequently than those remaining in the *Casuarina* genus. The scientists also found that *Frankia* from the genus *Casuarina* only occasionally nodulated species of *Allocasuarina* and *vice versa* — evidence of host specificity.

However, the ability to form nodules is only one part of the symbiotic process. What really matters is whether all of the nodulating *Frankia* on a plant are equally effective in fixing nitrogen. The two scientists next examined the effects of 15 strains of *Frankia* on two important and widespread *Casuarina* species — *C. equisetifolia* and *C. cunninghamiana*.

The results showed large differences in nitrogen-fixing effectiveness between *Frankia* strains. Some *Frankia* sources nodulated plants well but fixed almost no nitrogen; some strains were very effective, while others had a moderate effect. Plants with highly effective strains produced 10–15 times the growth of uninoculated plants. A further important finding was that strains highly successful on one species were ineffective on the other.

Scientifically, the findings of the specificity studies provide a basis for finding out how nodules develop. Practically, they demonstrate the need for carefully selecting the right *Frankia* strain for each species, and possibly provenance, of casuarina.

Selecting the right Frankia *strain is critical to the success of plantations overseas.*

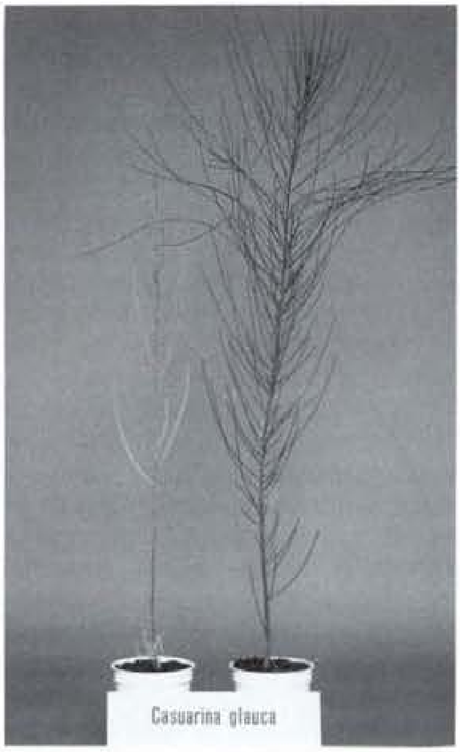
Not only is this critical to the success of plantations overseas, but it opens up the possibility of improving on naturally occurring *Frankia* strains in some parts of Australia. Because many eucalypt communities depend largely on nitrogen fixed by neighbouring casuarinas, their productivity may be determined by the effectiveness of the naturally occurring *Frankia* at the site. The introduction of highly effective *Frankia* to such communities could, theoretically, improve plant productivity and species composition.

Planting a nursery trial at Gympie, Qld.

A successful hybrid

The selection of the right *Frankia* for optimum casuarina growth has important consequences for several developing countries that have serious fuelwood shortages. ACIAR — the Australian Centre for International Agricultural Research — has commissioned Dr Bowen, together with Miss Trish Rosbrook and Mr Ian Francis, both of the Division of Soils, to select highly effective *Frankia* for each of several casuarinas being tested to help solve this crisis, and to develop a relatively simple inoculation technology.

In Papua New Guinea, the highland people use casuarinas for fencing, as well as for fuelwood, in building, and as shade trees in coffee plantations.



Uninoculated and inoculated casuarinas in nitrogen-deficient soil.

The CSIRO team — in collaboration with the Division of Forest Research in Canberra, the Queensland Department of Forestry, and scientists in developing countries such as Thailand and Zimbabwe — have set up field trials in Gympie, Queensland, involving 12 different species of *Casuarina*. The results of this study will be useful in Australian soil conservation and rehabilitation.

To expand the present range of species available for plantation use around the world, Dr Bowen collected nodules from two *Casuarina* species — *C. oligodon* and *C. papuana* — in Papua New Guinea, and from species in Thailand. The people of Papua New Guinea have a number of uses for the two casuarinas: for fuelwood, fencing, and building piles; as windbreaks; as shade for plantation coffee bushes; and in land reclamation. In the highlands, the government encourages local people to grow *C. oligodon* by distributing free seedlings. But outside Papua New Guinea, the two species are little known.

In 1900, a sterile hybrid of two other species (*C. junghuhniana and C. equisetifolia*) was introduced into Thailand as an ornamental plant. Through vegetative propagation, the tree soon became established as a plantation species because of its fast growth, good stem form, and adaptability to difficult environments. The hybrid trees are used in land reclamation after mining, and as fuelwood and pilings.

The hybrids could be of use to Australia. Dr Bowen visited Thailand to investigate the possibility of Australian collaboration in developing a nursery and inoculation program for the hybrid. The program would benefit the Thai people by providing them with information on how effective present strains of *Frankia* are. It would also benefit those countries that wished to introduce this hybrid for fuel plantations or other purposes.

Soil factors

Dr Reddell and Dr Bowen also looked at how soil factors — particularly phosphates, temperature, and salinity — affect nodulation and nitrogen fixation. They found that — in field studies — *Allocasuarina* species nodulated poorly compared with species of *Casuarina*, and this seemed to be related to soil phosphate levels. *Allocasuarina* species grew more often in phosphate-deficient soils. They also found that, for one fast-growing species of *Casuarina*, the application of phosphate to soil stimulated plant growth, nodulation, and nitrogen fixation.

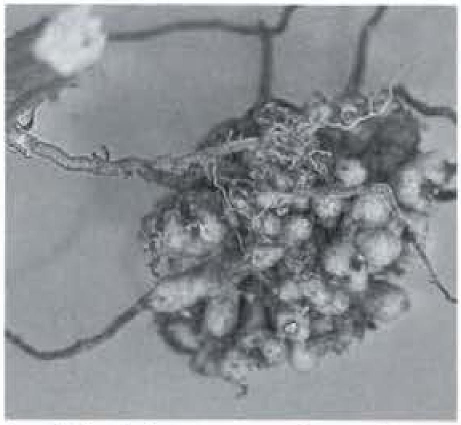
Phosphate uptake is another symbiotic operation managed nicely by the astute casuarina. Casuarina roots form associations with soil fungi called mycorrhizas ('fungus-roots'), which can either cover the root surface or invade its cortex and the root cells themselves. These fungi help the trees scavenge mineral nutrients — including phosphates — from the soil.

Plants with highly effective Frankia *strains produced 10–15 times the growth of uninoculated plants.*

Dr Reddell and Dr Bowen observed that such mycorrhiza infections stimulated nitrogen fixation by *Frankia* via stimulation of phosphate uptake. Other micro-organisms stimulate casuarinas to form 'cluster' or 'proteoid' roots, which also assist in phosphorus uptake.

The two scientists, together with Professor Alan Robson of the University of Western Australia in Perth, studied the effects of soil temperatures between 15°C and 30°C on plant growth, nodulation, and nitrogen fixation in seedlings of a *Casuarina* species inoculated with *Frankia* from two different sources. The test plants dependent on symbiotically fixed nitrogen grew best at a soil temperature of 25°C.

At the lowest soil temperature of 15°C, however, nodulation was poor and nodule function became impaired, preventing

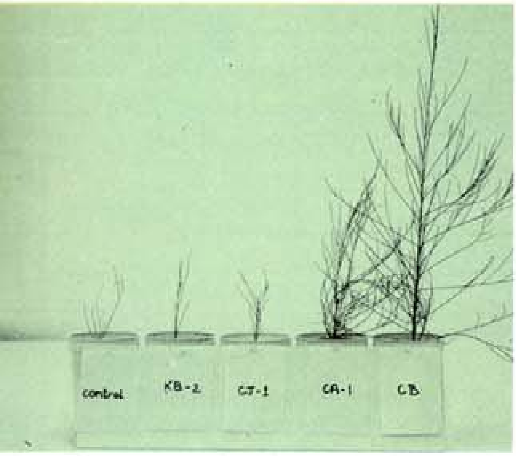


A nodule cluster on a casuarina root.

plant growth. Control plants treated with inorganic nitrogen grew reasonably well at this temperature. This may explain why the distribution of those *Casuarina* species reliant on *Frankia*-fixed nitrogen appears to be confined to areas where soil temperatures exceed 15°C for the major part of the growing season.

Casuarinas are often pioneer colonizers of saline soils. One Western Australian species, *C. obesa*, grows in soils containing chloride at concentrations of up to 28 000 parts per million. The CSIRO's Adelaide work indicated that highly salt-tolerant strains of *Frankia* co-exist with such trees.

Three-year-old trees of the casuarina hybrid that has made its mark in Thailand.



The same species of casuarina inoculated with five different strains of *Frankia*. The need to match *Frankia* and casuarina is clear.

In one study, salt-tolerant casuarinas nodulated with salt-tolerant *Frankia* still grew when provided with water containing 15 000 p.p.m. of chloride — about half the salinity of sea-water. The same species, supplied with inorganic nitrogen, could not grow at concentrations beyond one-tenth of this.

Together with Dr Ralph Foster, an electron microscopist with the Division, the soils team discovered that somehow the *Frankia*-containing nodule cells keep out salt, thus protecting the nitrogen-fixing system. These findings are especially applicable to the reclamation of salt-affected soils, a serious problem in Australia.

A 'high-performance' tree

At the moment, a few private firms, based mainly in southern Australia, are supplying seed of a few well-known *Casuarina* species to markets in North Africa, the Middle East, and North America.

Complementing the Adelaide research are studies on casuarinas by the Division of Forest Research in Canberra. Dr John Turnbull and Mr John Doran have been identifying new species and provenances that could grow on the often barren and infertile soils of developing countries, and have sent teams to collect seed from lesser-known trees in more remote parts of the country. A recent expedition collected seed and nodules from 18 sample sites, ranging from the south coast of New South Wales to Cooktown in northern Queensland, for use in testing the effectiveness of *Frankia* on different provenances of the river oak, *C. cunninghamiana*.

These casuarinas next to a road in Papua New Guinea are controlling erosion.

Their observations on the specificity of *Frankia* to casuarina hosts have confirmed Dr Bowen's findings. Since *Frankia* is not transmitted with seed but in nodule material or in the soil as spores, one of the main challenges to be overcome in applying the CSIRO findings is developing an efficient mass inoculation technique for casuarina seeds and seedlings.

Because of the difficulty in growing *Frankia*, inoculation methods so far have consisted of crushing nodules in water, which can be applied to the seedling roots. Either fresh or dried nodules are used, and the Division of Soils is raising selected strains on casuarinas for experiments in Australia and in developing countries. Dr Bowen believes that an inoculum, mass-produced in the laboratory, is not far off.

The successful establishment of seed is critical in countries where the population relies heavily on casuarina trees. Because the wood is very dense, it burns slowly and efficiently as a fuelwood. But one of the tree's most successful uses is as a windbreak.

Shelterbelts in North and West Africa, Yemen, Somalia, the Middle East, India, and southern China protect not only crops but humans and farm animals from damaging winds. Casuarina forests have stabilized thousands of square kilometres of coastal sand dunes in southern China, Egypt, and Mexico.

This young casuarina in Zimbabwe, which had not been inoculated with *Frankia*, shows evidence of nitrogen deficiency a year after planting.

With the present global depletion of forests focused in the very countries that can least afford to lose wood, improving the growth efficiency of a 'high-performance' tree like the casuarina may help counteract the loss. Through CSIRO's work on testing *Frankia* strains, developing inoculation technology, and increasing the range of the *Casuarina* species resource, Australia can ensure that the tree's potential is realized in those countries where wood sustains human life. And in Australia, where the land itself is endangered, casuarinas improved by new *Frankia* strains could take a leading role in agroforestry, and in soil conservation and rehabilitation.

Mary Lou Considine

More about the topic

Frankia source affects growth, nodulation, and nitrogen fixation in *Casuarina* species. P. Reddell and G. Bowen. *New Phytologist*, 1985, **99** (in press).

The effects of soil temperature on plant growth, nodulation, and nitrogen fixation in *Casuarina cunninghamiana*. P. Reddell, G. Bowen, and A. Robson. *New Phytologist*, 1985, **99** (in press).

The management of nitrogen fixation by *Casuarina*. G. Bowen and P. Rosbrook. Report to Australian Centre for International Agricultural Research, 1985.