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ROOT CLUSTERS OF WESTERN AUSTRALIAN PLANTS: A CURIOSITY IN CONTEXT

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Western Australia was a part of Gondwanaland, and some of the most ancient parts of the Earth's crust can be found here. The rocks are up to 3.6 billion years old, with some of the sediments being as old as 4.3 billion years. Other parts of the Western Australian landscape originated more recently from calcareous marine deposits. This explains why our soils are amongst the most heavily leached and nutrient-impoverished in the world. Phosphorus is one of the least available nutrients, at least for plants that are not adapted to the Western Australian soils. It is an essential nutrient for all living organisms, including our native plants. Micronutrients (e.g., copper, manganese, zinc) are also scarcely available on ancient weathered soils; micronutrients are also essential for life.

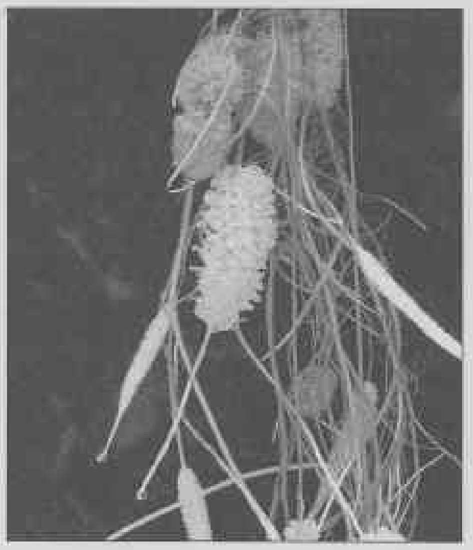

Fig. 1: Simple cluster roots of *Hakea prostrata*, grown in nutrient solution in the glasshouse at UWA.

The nutrient-impoverished soils of the southwest of Western Australia harbour one of the world's 25 hotspots of biodiversity. The Proteaceae (e.g. *Banksia*, *Grevillea*, *Hakea*) represents the top most species-rich plant family in Australia, and has a very long geological association with the continent, beginning 65 million years ago. Cyperaceae (sedges) are also an important component of the Western Australian flora. Therefore, both the Proteaceae and the Cyperaceae offer a unique opportunity to study plant adaptations to nutrient-poor soil conditions. We have grabbed that opportunity, to learn more about our highly biodiverse flora and to search for traits that would be desirable for crop plants grown in Western Australian soils.

A relatively large proportion of the species from the nutrient-poor soils in Western Australia, including almost all Proteaceae and Cyperaceae, cannot produce a symbiotic association with a mycorrhizal fungus. That is paradoxical, because mycorrhizas are widely considered an adaptation to phosphorus-impoverished soils. Moreover, it is widely accepted that all ancestors of the Proteaceae and Cyperaceae were once mycorrhizal. Therefore, during the course of millions of years of evolution, most of the species belonging to the Proteaceae and Cyperaceae must have lost their ability to be colonised by symbiotic mycorrhizal fungi. Instead, many species belonging to these plant families in Western Australia produce **root clusters**. In the Proteaceae we find 'proteoid' or 'cluster' roots (Figures 1 and 2). In Cyperaceae 'dauciform' or 'carrot-shaped' roots are common. Root clusters also occur in several other species belonging to different families that are common in Western Australia, e.g., in *Viminaria juncea* (native broom), *Casuarina* (sheoak), *Jacksonia* and *Kennedia* species. Other forms of root clusters can be found in Restionaceae (rushes), another non-mycorrhizal family.

The functioning of the root clusters of Proteaceae and Cyperaceae is a major component of our current investigations in the School of Plant Biology at the University of Western Australia. Once it was believed that their adaptive significance was to enhance the roots' surface area, and hence allowed the roots to 'scavenge' for nutrients. However, the individual rootlets and root

continued on page 4

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continued from page 1

hairs of the root cluster would all be competing with each other for the same molecules in the soil, and hence do not make this a very effective scavenging structure.

We have recently discovered that these root clusters release vast amounts of organic acids, especially citric acid, during just a couple of days in their very short existence. Cluster roots live for about 3 weeks only; dauciform roots live for less than 2 weeks. Citric acid effectively mobilises phosphorus and micronutrients that are 'locked up' in the soil, pushing these vital nutrients in solution for the roots to take up. Therefore, root clusters actively 'mine' the soil. This is a costly process because of the large quantities of organic acids that have to be produced and released. However, the root clusters are very successful where roots that lack this ability to 'mine' the soil, including mycorrhizal roots, would fail. Ideally, crop plants would have similar adaptations of efficient nutrient acquisition, to perform well on the soils in Western Australia, and this is the subject of our further investigations. Some lupin species, e.g. white lupin and blue lupin, have traits that are very similar to those of the Proteaceae and, consequently, these crop plants do better on phosphorus-impoverished soils, when compared with wheat.

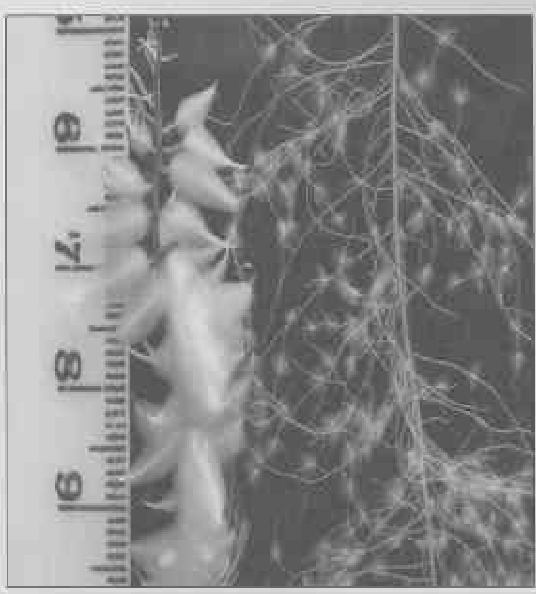

Fig 2: Dauciform roots of two WA sedges grown in the glasshouse at UWA. Grass-like sedges are very common elements in the WA flora, but are often overlooked. Very few ecophysiological studies have been done on this fascinating part of our flora. Many sedges make 'dauciform' or 'carrot-shaped' roots, which live for less than two weeks. As with cluster roots, dauciform roots release large quantities of organic acids (eg citrate) during a brief period (1-2 days only) when mature.

Fig 3: Phosphorous toxicity in *Hakea prostrata*. In the early stages of P-toxicity, affected leaves become 'blotchy', and white crystal-like material can be found on both sides og the leaves. The crystals emerge on the leaf surface through stomatal pores. The exact composition of the crystals is not known, but we do know it is not phosphorous, which hyperaccumulates in cells inside the leaves. Later the leaves turn yellow and die. In the end, the entire plant succumbs to phosphorous poisoning.

Many Proteaceae, including *Banksia* and *Hakea* species, are readily killed by phosphorus fertilisation; they are highly sensitive at slightly enhanced soil phosphorus levels (Figure 3). Even at slightly elevated levels of phosphorus in soil, many Proteaceae tend to 'hyperaccumulate' phosphorus in their leaves, building up toxic phosphorus concentrations. Other plants rarely achieve such high concentrations in their leaves, even when heavily fertilised with phosphorus. That is because most plants have the capacity to reduce the rate at which phosphorus is taken up when the phosphorus supply in the soil exceeds the plant's demand for phosphorus. That is, they "close the doors through which phosphorus enters the roots when a big crowd of phosphorus molecules is waiting to move in". We have recently discovered that the extreme sensitivity of harsh hakea, *H. prostrata*, is due to its severely impaired capacity to reduce its phosphorus-uptake rate at elevated phosphorus levels in the soil. Some time, during the course of millions of years of evolution on severely phosphorus-impoverished soils, this capacity diminished. To conserve our precious biodiverse flora, we have to respect these millions of years of evolution, and ensure that phosphorus-sensitive plants are not exposed to elevated soil phosphorus levels.

Having discovered the physiological cause of the phosphorus sensitivity of harsh hakea, we made a wider survey of related species. Interestingly, the close relative *Grevillea crithmifolia*, also belonging to the Proteaceae, does not suffer from phosphorus toxicity, even when exposed to phosphorus levels that are much higher than those that kill some *Hakea* or some *Banksia* species. We found that roots of this grevillea "close the doors through which phosphorus moves in" when supplied with a lot of phosphorus. These new findings offer enormous potential for breeders who are keen to develop new cultivars in the Proteaceae. It should not be too difficult to cross phosphorus insensitivity into new cultivars, which could then be grown without the risk of phosphorus poisoning in our gardens. One of our colleagues in the School of Plant Biology at UWA, Dr Guijun Yan, is working to achieve that aim.

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