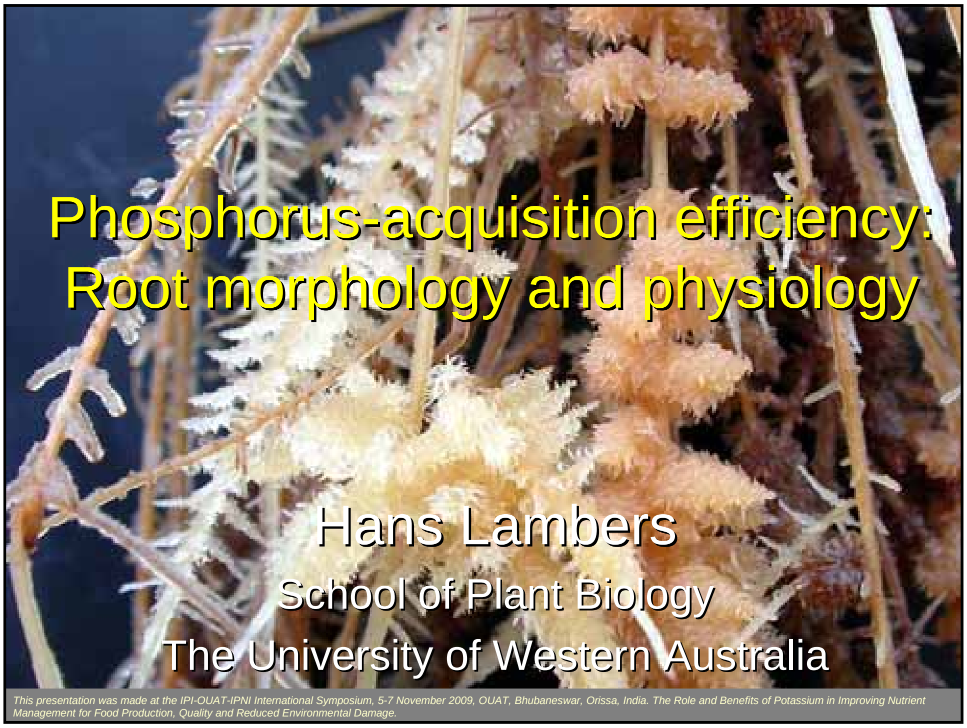
Phosphorus-acquisition efficiency:
Root morphology and physiology
Hans Lambers
School of Plant Biology
The University of Western Australia
This presentation was made at the IPI-OUAT-IPNI International Symposium, 5-7 November 2009, OUAT, Bhubaneswar, Orissa, India. The Role and Benefits of Potassium in Improving Nutrient Management for Food Production, Quality and Reduced Environmental Damage.


Soils and plant species in Western Australia
• Soils in Western Australia are the most nutrient-impoverished in the world
• Plant species richness is amongst the highest in the world
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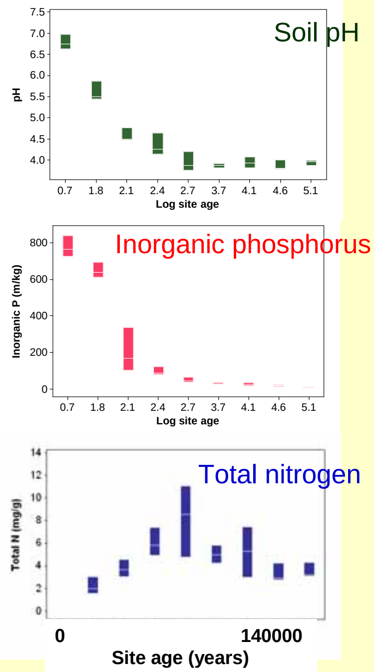
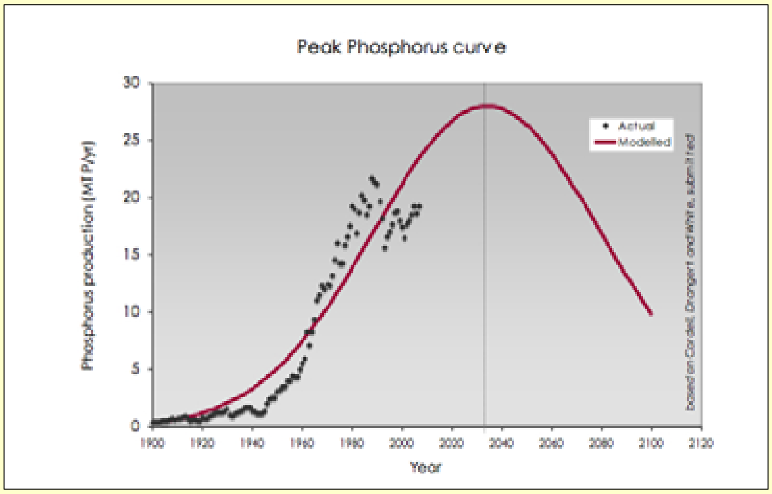


Summary of mineral soil properties along the Franz Josef soil chronosequence, New Zealand: P availability declines with increase in soil age

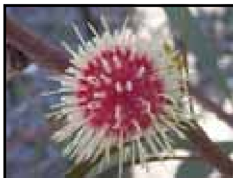
(Box plot symbols:
horizontal lines are the median;
bars give 25 and 75% percentiles)

Richardson, S.J. Peltzer, D.A., Allen, R.B., McGlone, M.S. & Parfitt, R.L. 2004. *Oecologia* **139:** 267-276.

Lifetime of phosphorus reserves

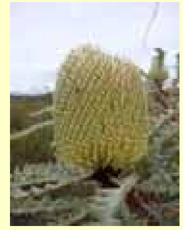
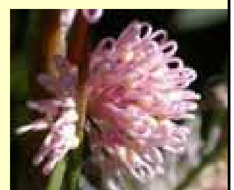


Cordell *et al.* 2009. The story of phosphorus: Global food security and food for thought. *Glob. Environ. Change* **16:** 292-305.



Proteaceae

- Highly diverse family, with many representatives in Western Australia
- Almost all have **‘proteoid’** or **‘cluster’** roots
- Almost all are **non-mycorrhizal**
- Many species are very sensitive to **P toxicity**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Cyperaceae

- Worldwide distribution
- Many representatives in Western Australia
- Many have **‘dauciform’ roots**
- Almost all are **non-mycorrhizal**

Many Australian species are very sensitive to **P toxicity**


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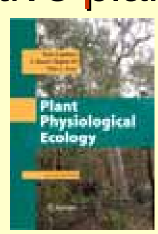
The aims of this presentation

- Explore traits of native species that occur on severely nutrient-impoverished soils
- Explore how these traits can be useful in crop and pasture systems

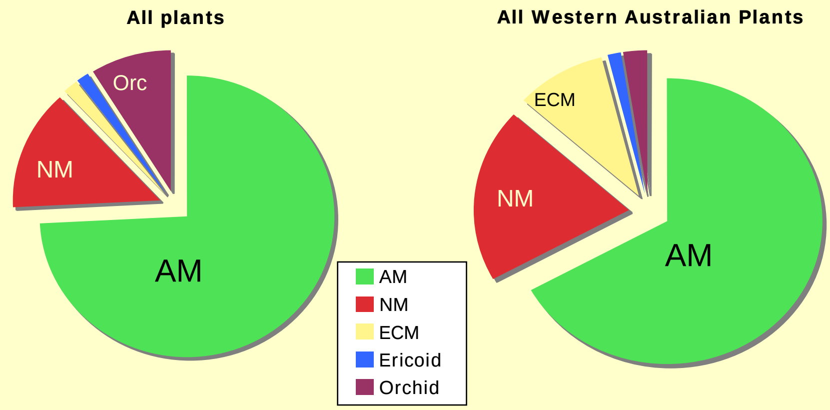
Root structures involved in phosphorus acquisition in Australian and South African native plants



Lambers, H., Chapin III, F.S. & Pons, T.L. 2008. Plant physiological ecology, 2[nd] edition. Springer, New York.

This presentation was made at the IPI-OUAT-IPNI International Symposium, 5-7 November 2009, OUAT, Bhubaneswar, Orissa, India. The Role and Benefits of Potassium in Improving Nutrient Management for Food Production, Quality and Reduced Environmental Damage.

Proportions of species with different nutrient-acquisition strategies

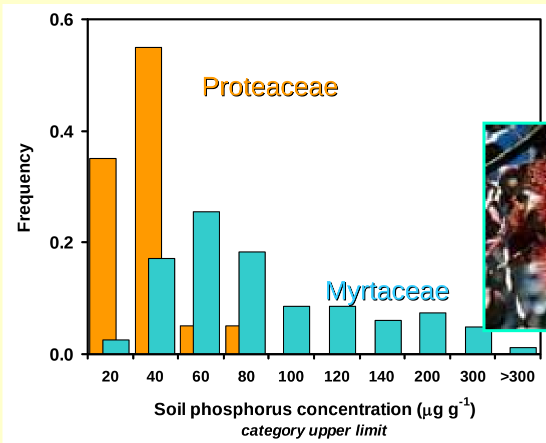


Brundrett, M.C. 2009. Mycorrhizal associations and other means of nutrition of vascular plants: Understanding the global diversity of host plants by resolving conflicting information and developing reliable means of diagnosis *Plant Soil* **320:** 37-77.

In the rest of the world, plants on nutrient-poor soils plants tend to live symbiotically with mycorrhizal fungi

- The mycorrhizal fungi acquire phosphorus for the plants, in exchange for carbon
- Mycorrhizas also occur in Western Australia, but this symbiosis is relatively less common

Phosphorus status of the soil supporting non-mycorrhizal Proteaceae (with cluster roots) and mycorrhizal Myrtaceae in Western Australia



Lambers, H. *et al.* 2006.
Ann. Bot. **98:** 693-713.

This presentation was made at the IPI-OUAT-IPNI International Symposium, 5-7 November 2009, OUAT, Bhubaneswar, Orissa, India. The Role and Benefits of Potassium in Improving Nutrient Management for Food Production, Quality and Reduced Environmental Damage.

What special features allow the non-mycorrhizal plants in Western Australia to acquire nutrients from very poor soils?

Many have cluster roots, as illustrated here

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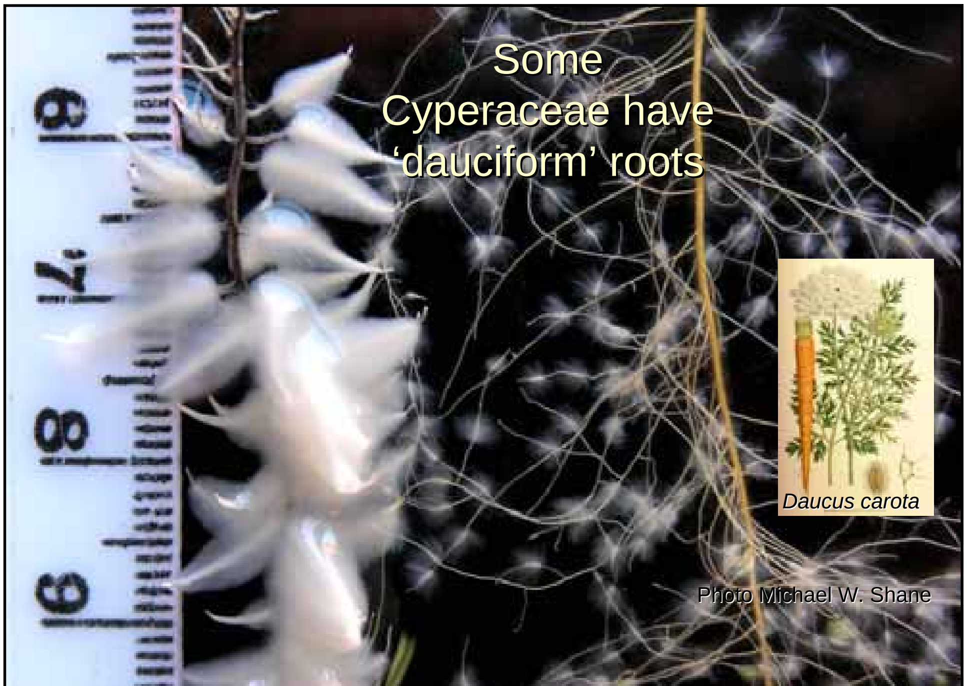
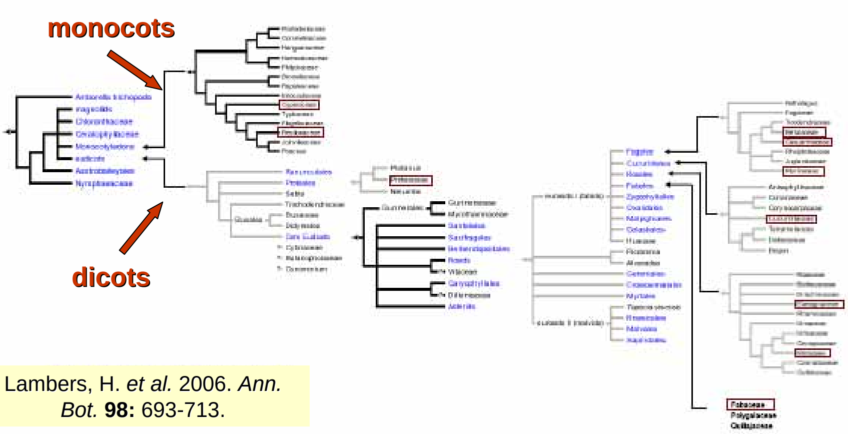
Some Cyperaceae have 'dauciform' roots



This presentation was made at the IPI-OUAT-IPNI International Symposium, 5-7 November 2009, OUAT, Bhubaneswar, Orissa, India. The Role and Benefits of Potassium in Improving Nutrient Management for Food Production, Quality and Reduced Environmental Damage.

Root cluster roots occur in several families throughout the plant kingdom



Lambers, H. *et al.* 2006. *Ann. Bot.* **98:** 693-713.

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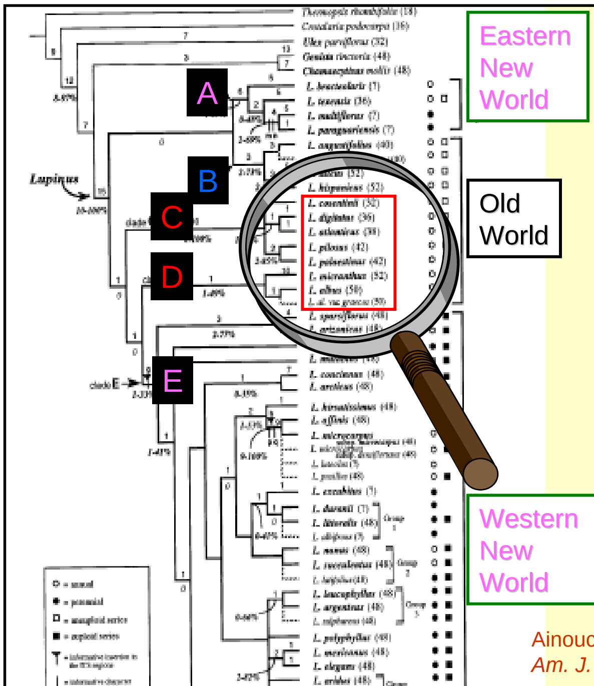
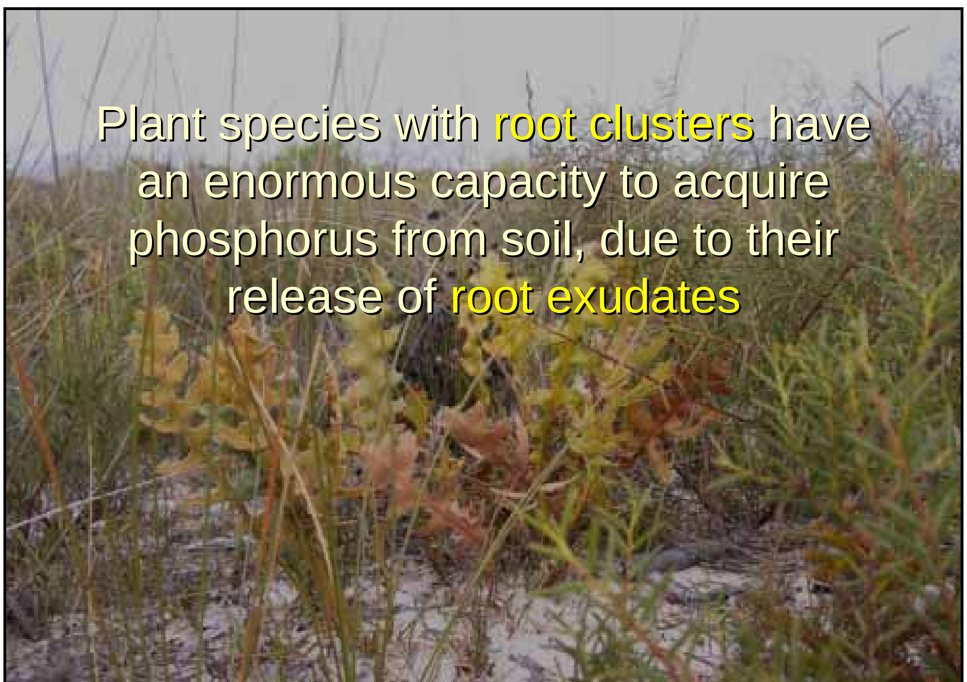


The genus *Lupinus*

Ainouche, A.-K. & Bayer, R.J. 1999. *Am. J. Bot.* **86:** 590-607.



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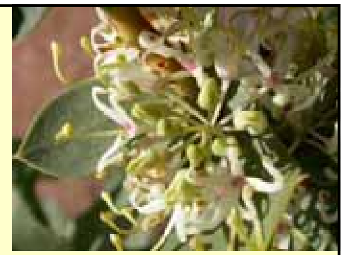
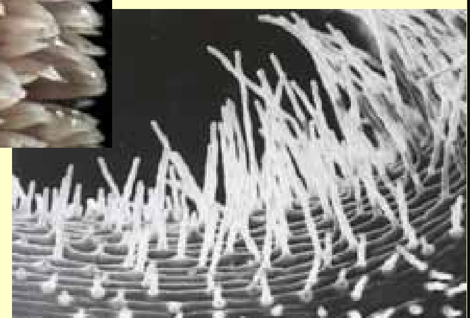
Simple cluster roots of *Hakea prostrata*





Photos Michael Shane

Cluster roots: ecological/agronomic significance of their morphology

- Cluster roots release organic compounds ('exudates') into the soil
- Increased surface is ideal to locally enhance the concentration of the 'exudates'
- Increased surface for nutrient absorption?
- Absorptive surface is enormous, but far greater than functional: overlapping depletion zones!

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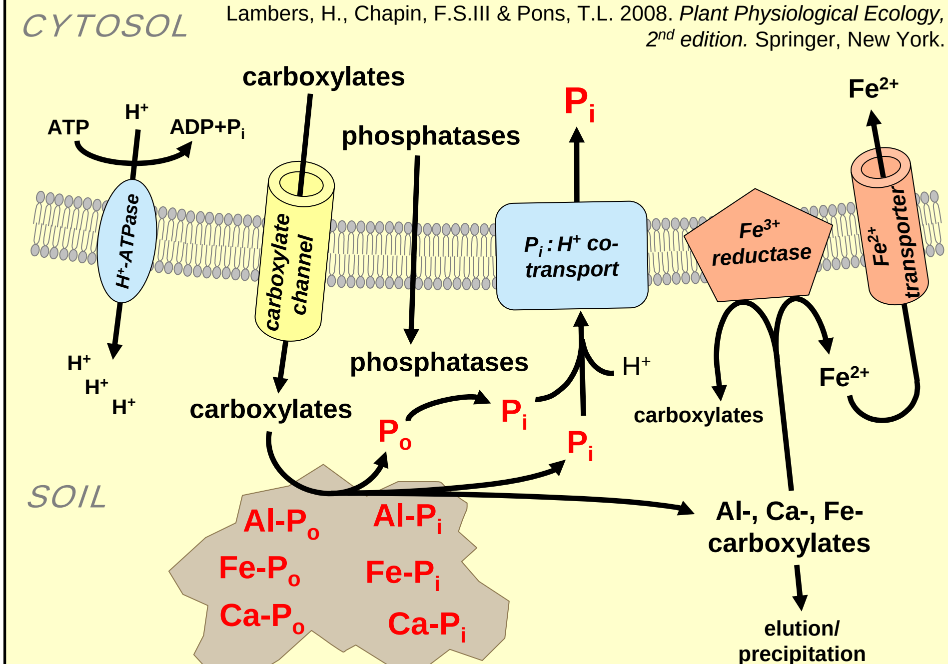
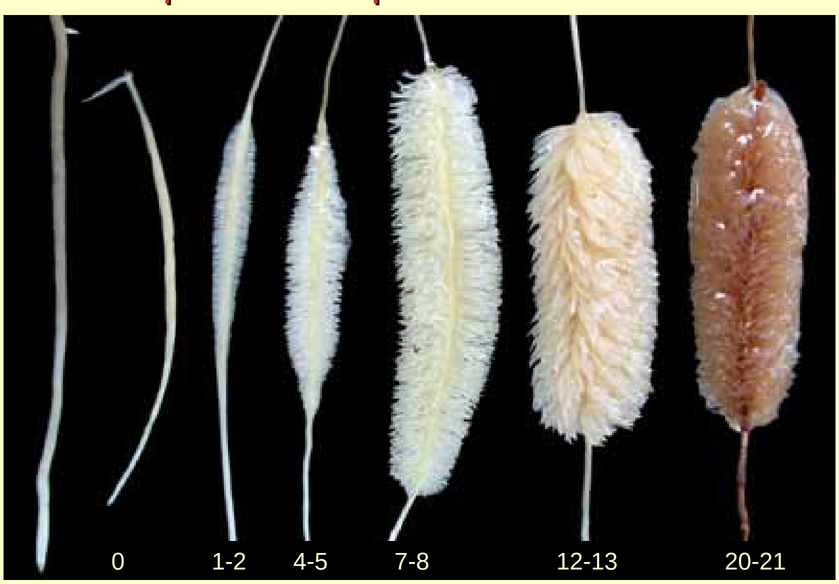
Lambers, H., Chapin, F.S.III & Pons, T.L. 2008. *Plant Physiological Ecology, 2nd edition.* Springer, New York.



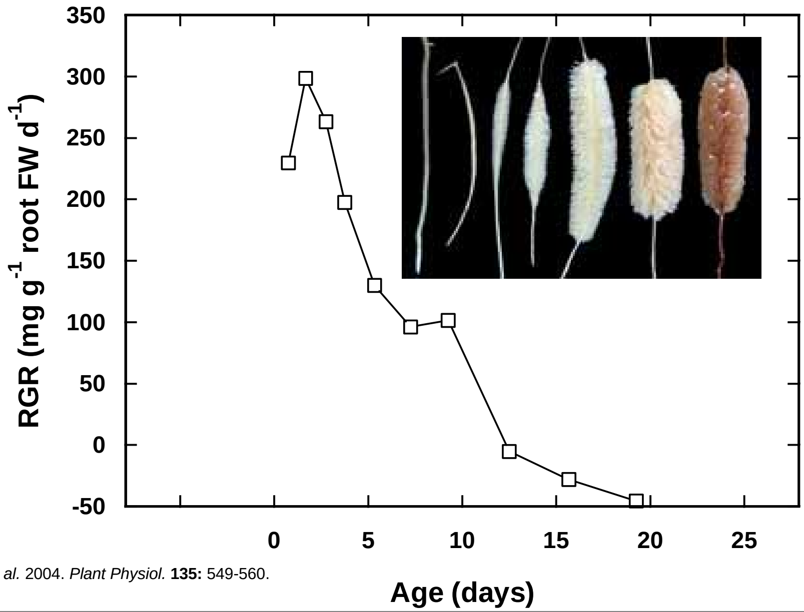
Developmental aspects of cluster roots



Shane, M.W., Cramer, M.D., Funayama-Noguchi, S., Cawthray, G.R., Millar, A.H., Day, D.A. & Lambers, H. 2004. *Plant Physiol.* **135:** 549-560.

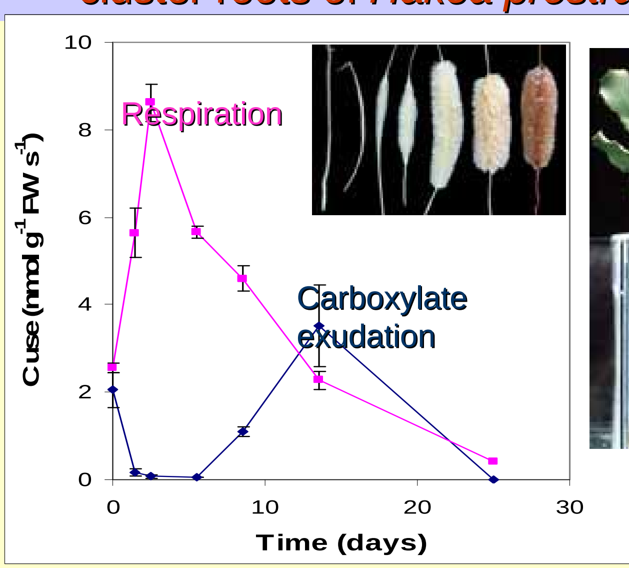
This presentation was made at the IPI-OUAT-IPNI International Symposium, 5-7 November 2009, OUAT, Bhubaneswar, Orissa, India. The Role and Benefits of Potassium in Improving Nutrient Management for Food Production, Quality and Reduced Environmental Damage.

Growth



Shane *et al.* 2004. *Plant Physiol.* **135:** 549-560.

Respiration and carboxylate exudation in cluster roots of *Hakea prostrata*



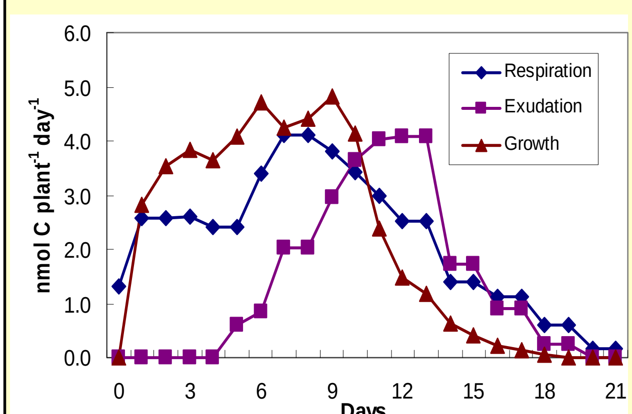
Shane *et al*. 2004. *Plant Physiol*. **135:** 549-560.

Clusters of white lupin avoid microbial decomposition of released carboxylates

- Drastic pH decrease during the exudative burst: reduces bacterial activity
- Excretion of phenolic compounds, mainly isoflavonoids, during exudative burst: fungal sporulation
- Release of antifungal cell-wall degrading enzymes, prior to exudative burst: chitinase and glucanase

Weisskopf, L., Abou-Mansour, E., Fromin, N., Tomasi, N., Santelia, D., Edelkott, I., Neumann, G., Aragno, M., Tabacchi, R. & Martinoia, E. 2005. *Plant, Cell Environ.* **29:** 919-927.

Estimated carbon costs of cluster roots in *Hakea prostrata*: 52-100% of daily produced photosynthate



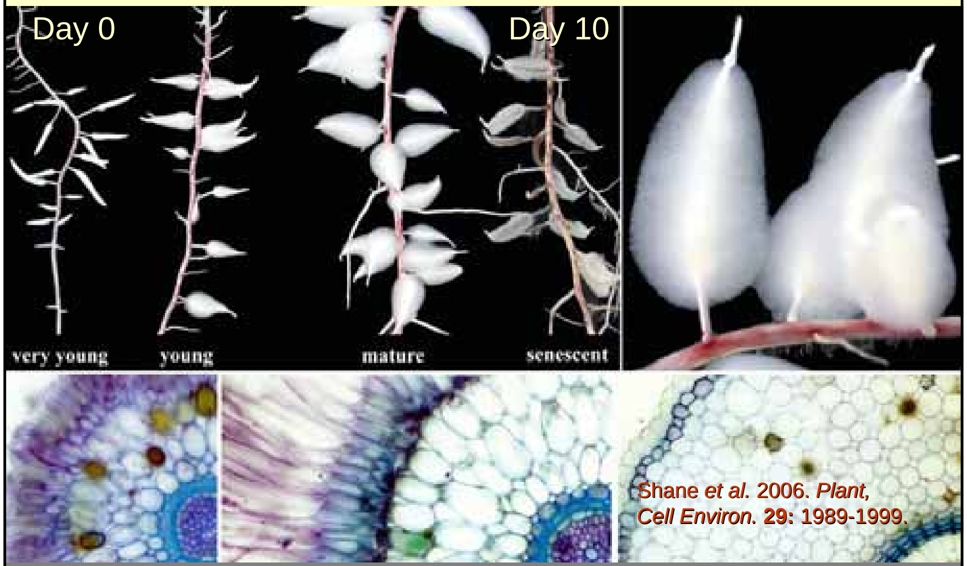
- The clusters are only active during the wet season, i.e. 2-3 months per year
- They are probably also responsible for most of the (organic) nitrogen and micronutrient uptake

Lambers, H. *et al.* 2006. *Ann. Bot.* **98:** 693-713.

Conclusions *re* phosphate acquisition in *Hakea prostrata*

- Respiration peaks before 'exudative burst'
- Clusters release vast amounts of malate and citrate
- Carbon costs (growth, respiration, exudation) of clusters are high
- Carboxylates mobilise phosphate

Dauciform root development in a Western Australian sedge, *Schoenus unispiculatus*



Shane *et al*. 2006. *Plant, Cell Environ*. **29:** 1989-1999.

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Similarities between Proteaceae (and *Lupinus albus*) and Cyperaceae

- Both have specialised root clusters
  - Proteoid or cluster roots
  - Dauciform roots
- Development of their specialised roots is suppressed by high leaf phosphorus concentrations
- They release exudates in an 'exudative burst'

Why would the non-mycorrhizal habit of Proteaceae be more successful in the most P-impoverished habitats?

Puffball in the Pilbara

- Cluster roots are able to mobilise P that would be unavailable for other plants
- Some ectomycorrhizal plants and other non-mycorrhizal plants also release carboxylates, but ….
- Root clusters combine structural and biochemical specialisations

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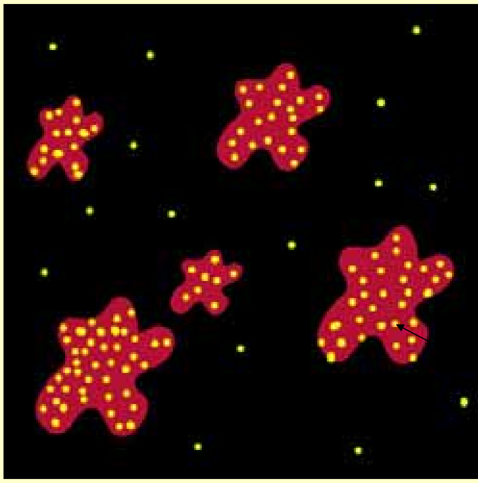
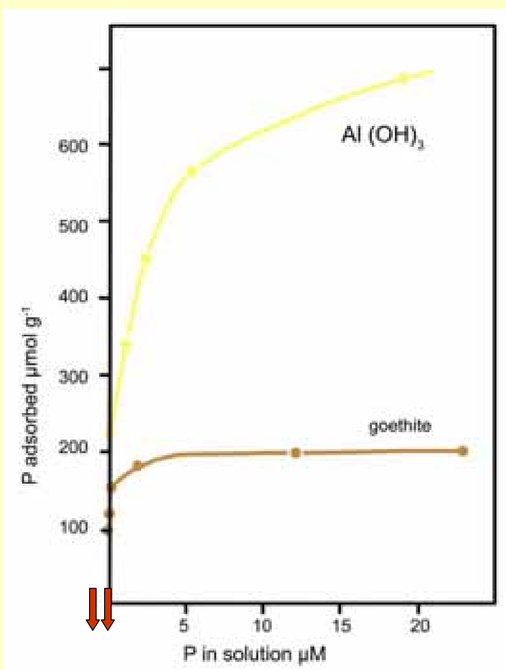


Soil looks a bit like this – with only a few phosphate ions in solution

The dots on the oxide particles represent phosphate on the soil surface

Courtesy: Dr Jim Barrow



- No P available for ryegrass, until 40% of goethite is 'covered'
- Maximum P availability when [P] in solution is 2 µM, at about 75% 'coverage' on goethite
- Mycorrhizas increase availability of P at about 0.5-2 µM P (60-70% coverage of the goethite surface)

Parfitt, R.L. 1979. *Plant Soil* **53:** 55-65.

Shoot mass of wheat and white lupin, grown in mixed culture in a way that either their roots remained separated or they could mix

P supply	Root system	Shoot dry mass (g) wheat	lupin	together
No extra phosphate supplied	separated	20	33	54
	mixed	38	29	66
Rock phosphate supplied	separated	24	27	51
	mixed	40	25	64

Horst, W.J. & Waschkies, C. 1987. *Z. Pflanzenernähr. Bodenk.* **150:** 1-8.

Crop rotation: dry matter production, P and N concentration of shoots of wheat grown in pots for 49 days as affected by the preceding crops (wheat or white lupin)

Preceding crop	Shoot dry mass mg plant^{-1}	Concentration µg g^{-1} dry mass P	N
Wheat	360	1.1	49
Lupin	690	1.3	43

Kamh *et al.* 1999. *Plant Soil* **211:** 19-27.

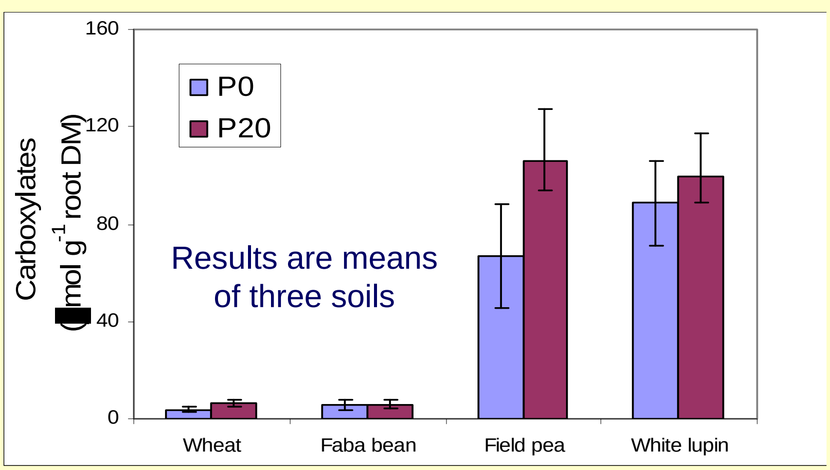
Crops at 55 days after sowing, grown with and without applied P

Field pea

Nuruzzaman, M., Lambers, H. & Veneklaas, E.J. 2005. *Plant Soil* **271:** 175-187.

Faba bean

Rhizosphere carboxylates of different crop plants, grown with low (P0) and high (P20) P supply



Nuruzzaman, M., Lambers, H. & Veneklaas, E.J. 2005. *Plant Soil* **271:** 175-187.

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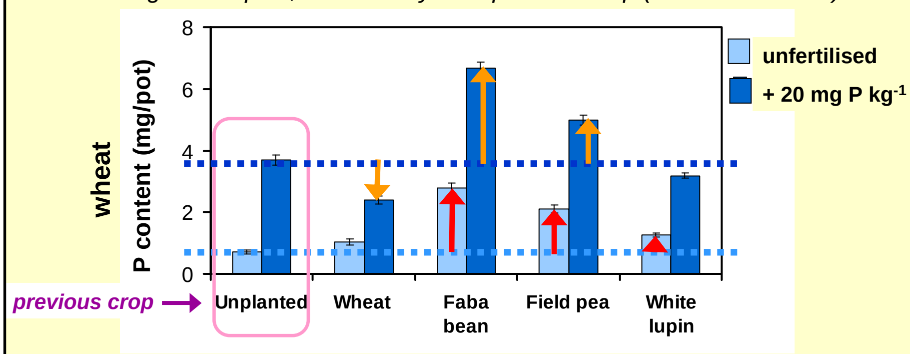
Wheat as an indicator of legume-enhanced P availability

wheat grown in pots, immediately after previous crop (means for 3 soils)



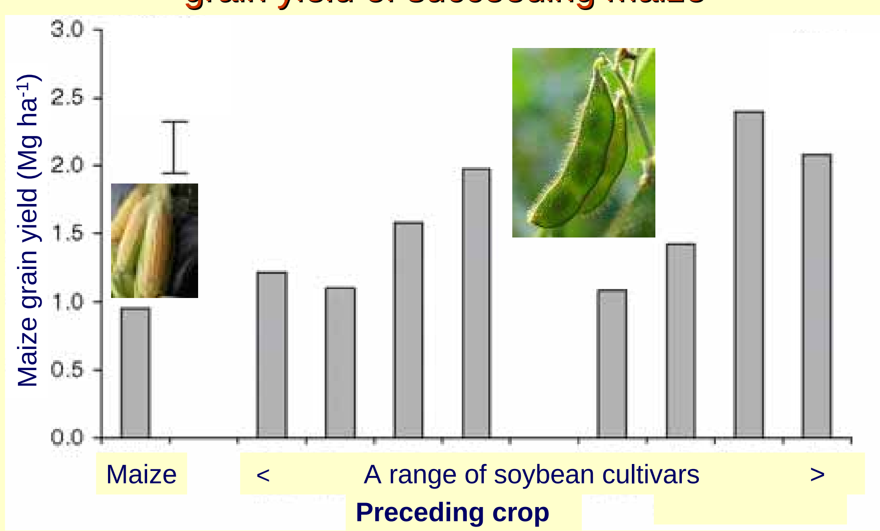
With no previous crop, added P has a large positive effect on P uptake

On unfertilised soil, legumes enhance P uptake by subsequently grown wheat

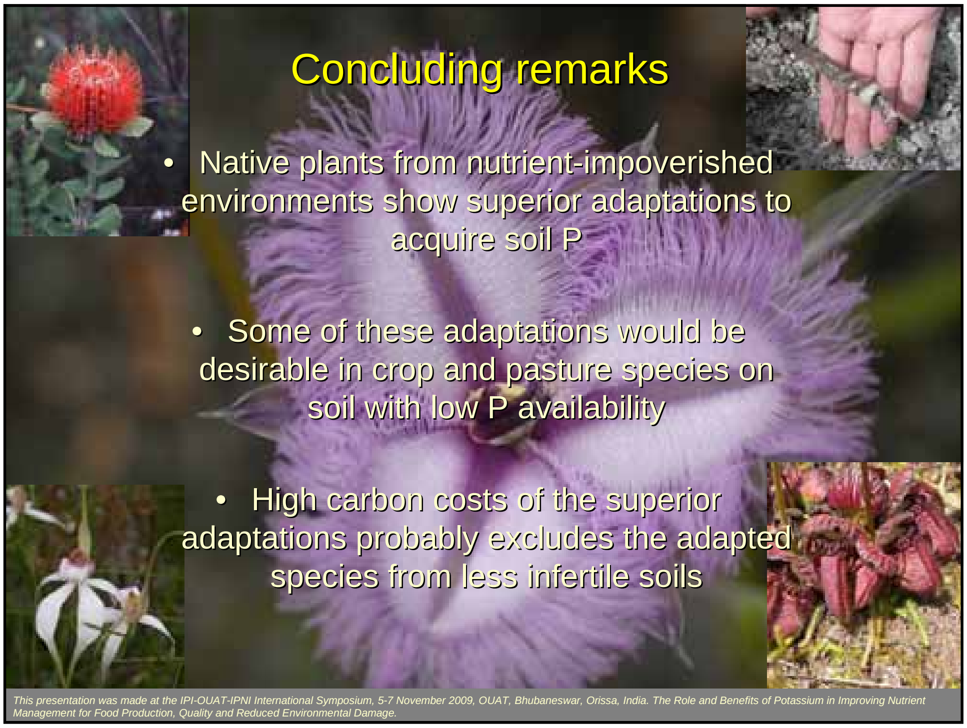
Legumes can also make previously added P more available - but the effect is greatest for the least-exuding species ...

Nuruzzaman, M., Lambers, H. & Veneklaas, E.J. 2005. *Plant Soil* **271:** 175-187.

Effect of preceding crop species and genotypes on grain yield of succeeding maize



Jemo, M., Abaidoo, R.C., Nolte, C., Tchienkoua, M., Sanginga, N. & Horst, W.J. 2006. Phosphorus benefits from grain-legume crops to subsequent maize grown on acid soils of southern Cameroon. *Plant Soil* **284:** 385-397.


Concluding remarks
• Native plants from nutrient-impoverished environments show superior adaptations to acquire soil P
• Some of these adaptations would be desirable in crop and pasture species on soil with low P availability
• High carbon costs of the superior adaptations probably excludes the adapted species from less infertile soils
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