Exploring the roots of the problem: How a South American tree adapts to volcanic soils

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Left, small seedling (ca. 5 mo&#8211old) collected in Reserva Nacional Cerro Castillo, Chile, with its noticeable cluster roots holding soil. Right, one young cluster root; notice that they are simple cluster roots (i.e., bottle-brush-like structures). Credit: Left by Frida Piper; right by Mabel Delgado.

Soils of southern South America, including Patagonia, have endured a high frequency of disturbances from volcanic eruptions, earthquakes, landslides, and erosion. In addition, massive fires in the mid-20th century were set to forests in the region in an effort to promote colonization. In 2010, another 17,000 acres of Patagonia burned, fueling an international reforestation effort. Although the young soils of southern South America may contain high phosphorus levels, the element is tightly bound to the soil, offering limited phosphorus available to plants.

So how can plants in this area take root and access that phosphorus?

According to a recent article published in the *American Journal of Botany*, scientists have identified a mechanism enabling a native tree species access to this limiting nutrient. As a result, the Chilean fire bush (Proteaceae, *Embothrium coccineum*), a tree endemic to Chile and Argentina, could have an important role in the reforestation of Patagonia. In the wild, *E. coccineum* colonizes highly disturbed land where other tree species rarely occur. Proteaceae species, common in the southern hemisphere, are known for a root structure adaptation that increases phosphorus acquisition from weathered, phosphorus-poor soils. The greater surface area of cluster roots increases root exudates of organic acids and phosphatases. These exudates enhance plant phosphorus acquisition from unavailable forms in the soil.

"I was particularly curious of the ecological role of this root adaptation," explained Frida Piper, a terrestrial ecosystem ecologist at the remote research center Centro de Investigación en Ecosistemas de la Patagonia (CIEP) in Coyhaique, Chile. Piper designed a field study to better understand the role of cluster roots of *E. coccineum* across a natural precipitation and phosphorus gradient in its native habitat. How does the production of cluster roots in this Proteaceae enable successful establishment in young volcanic soils of South America?

Small and large *E. coccineum* seedlings and topsoil were collected at four sites in the Aysén Region of Patagonia, Chile, in 2010-2013. Seedlings were assessed for number and biomass of cluster roots, plant size and growth, and foliar phosphorus levels. Soil samples were analyzed for pH, total nitrogen (N), available phosphorus (P) and organic matter. Based on biomass and chemical analyses, four dominant factors were identified: soil P, soil N, foliar P, and seedling age. A suite of generalized linear mixed–effect model regressions were fitted to the data.

In contrast to previous studies of Proteaceae in Australia and South Africa, the best-fit model for predicting the number of cluster roots in this study did not contain any soil P factor; foliar P levels correlated with cluster root formation. The number of cluster roots was significantly higher in large seedlings, yet biomass investment in cluster roots was greater for small seedlings.

Piper found that cluster roots mediate a decoupling of foliar P from soil P concentrations for small seedlings. This enabled small seedlings to maintain adequate foliar P levels, critical to their ontogenetic growth. The relative investment in cluster roots was directly linked to both low soil N and leaf P. Seedlings from sites with lower total soil N had more cluster roots, regardless of other soil characteristics. The cluster root adaptation is very sensitive and highly expressed at low total soil N levels but rapidly disappears as soil N levels increase. The investment in cluster roots declines after seedling establishment, most likely as aerial growth is increasingly important for light competition.

Embothrium coccineum may have an important role in reforestation of Patagonia as an early successional species. Cluster roots have been identified in other plant species, including some agronomic crops in the Cucurbitaceae. "The biotechnology potential of these traits is being studied now," Piper says. Piper's research clarifying the mechanism of seedling establishment success for *E. coccineum* in conditions with limited availability of N and P may lead to advantageous root adaptation in other plants.

Piper is already exploring further research to understand how *E. coccineum* benefits neighbors by providing increased nutrient availability from root exudates or leaf litter decomposition. As a result of this study, nitrogen status of soil and plants, in addition to phosphorus, will always be included in Proteaceae studies by Piper. "Proteaceae can do something no other plant can do," Piper explains. "They are accessing nutrients that no other plants can access."

More information: Piper, Frida I., Gabriela Baez, Alejandra Zúñiga-Feest, and Alex Fajardo. 2013. Soil nitrogen, and not phosphorus, promotes cluster-root formation in a South American Proteaceae, Embothrium coccineum. American Journal of Botany 100:2328-2338. DOI: 10.3732/ajb.1300163

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