A Phosphate Fix

by Nicole Kresge

[1] If you hop into a car in the border town of Eagle Pass, Texas, and drive south for four hours, past stunted mesquite and blinding white gypsum dunes, you'll reach an isolated corner of the Chihuahua Desert called Cuatro Ciénegas, or Four Marshes. It's not your typical desert. Nestled among the white dunes is an oasis of wildlife centered around a series of pools whose hues of blue and green appear in stark contrast to the monochromatic desert sand.

[2] Fed by underground springs percolating up through the desert floor, the pools, or pozas, are home to creatures found nowhere else in the world. Groups of grass shrimp populate zones rich with algae and schools of inch-long pupfish thrive in the hot, salty water. HHMI Senior International Research Scholar Luis Herrera-Estrella is most interested in *Pseudomonas stutzeri*WM88, a bacterium that may hold a key to plant survival, as the world's easily accessible phosphorus supply runs dry.

[3] Herrera-Estrella and his lab team have managed to tap into the bacterium's ability to thrive in the pools, where phosphate—a salt form of phosphorus that occurs in natural environments—is rare.

[4] Plants need phosphorus. It's an essential component of their DNA. Most plants obtain phosphorus from phosphate in the soil, but nearly 70 percent of the world's soil is phosphate deficient, so farmers must use a lot of fertilizer to help their crops grow. And the phosphorus supply is shrinking.

[5] "Phosphorus is a non-renewable resource," explains Herrera-Estrella, a plant biologist at the Center for Research and Advanced Studies of the National Polytechnic Institute in Irapuato, Mexico. "The planet has a certain amount of phosphorus, and we are using it very rapidly. We are consuming about 40 to 50 million tons per year." At this same rate, phosphorus stores will be depleted and unavailable for agriculture and industrial use in the next 70 to 200 years, according to estimates.

[6] Phosphorus is the seventh most abundant element in Earth's crust, but its chemical properties are its downfall. It is highly reactive with soil, quickly forming insoluble compounds that plants can't use. As a result, as little as 20 to 30 percent of the phosphate applied as fertilizer is actually taken up by cultivated plants. The rest ends up as agricultural runoff, eventually making its way to rivers and oceans where it is absorbed by algae, resulting in toxic algal blooms.

[7] Phosphate is also in short supply in the soil because every organism living there needs it to grow. "Microbes, weeds, fungi, and crops all compete for phosphorus," says Herrera-Estrella. He spent 15 years trying to engineer crops that use less of the resource by looking at how plants adapt to low-phosphate conditions. "We've had some advances but nothing that could really improve efficiency of phosphorus use," he says. "So we went to a very radical approach. We decided to search for organisms that use other chemical forms of phosphorus."

[8] This search ended at the pools of Cuatro Ciénegas. Scientists believe the pools are relics of an ancient sea that contained lots of dissolved oxygen but not a lot of phosphate. To survive in the pools, organisms evolved to use alternative ways of acquiring phosphate. *P. stutzeri* WM88 did this with an enzyme called phosphite oxidoreductase (ptxD), which converts phosphite—abundant in the pools—to phosphate by adding an oxygen molecule.

[9] To see if they could encourage plants to use phosphite to meet their phosphate needs, Damar López-Arredondo, then a graduate student in Herrera-Estrella's lab, inserted the *ptxD* gene into the genome of *Arabidopsis,* a model plant commonly used in research labs. Herrera-Estrella is no stranger to adding genes to plants. He was one of the first people to make a transgenic plant in the early 1980s, and he's been using that knowledge to improve agricultural crops, especially the ones in his native Mexico.

[10] "Our first results were amazing," says López-Arredondo. Normal phosphate-using plants died under the same conditions in which the transgenic *Arabidopsis* thrived. Moreover, the transgenic plants needed half the normal amount of phosphorus fertilizer, when applied as phosphite, to achieve maximum yield. And phosphite's chemical properties are ideal for fertilizer—it is highly soluble and not very reactive with soil components—two attributes that ensure most of it is taken up by the transgenic plants rather than ending up as agricultural runoff. As a bonus, weeds and microbes can't use phosphite, so they don't compete for the molecule and, therefore, the system reduces the need for herbicide.

[11] Tests showed that phosphite levels in the transgenic plants were minimal, suggesting that most, if not all, the phosphite taken up by the plants was indeed converted to phosphate. The scientists published their findings in the September 2012 issue of *Nature Biotechnology*. Herrera-Estrella is excited about the potential of the team's discovery, pointing out that a reduction in fertilizer and herbicide use for food production could have a positive ecological impact and would help produce food less contaminated by agrochemicals.

[12] "The outcome of what Luis and his colleagues have done is nothing short of fantastic," says HHMI-Gordon and Betty Moore Foundation Investigator Jeff Dangl, a plant biologist at the University of North Carolina at Chapel Hill. "One of the things that limit corn growth in Mexico and Central America is phosphate-depleted soils. Now you have the ability to add phosphite to those soils and to make transgenic corn that can use that phosphite. This increases the overall fertility of the system and allows you to grow more corn." Herrera-Estrella and López-Arredondo have formed a company called StelaGenomics to develop their system and have started field testing the *ptxD* gene in corn and soybeans. They also have a small grant from the Bill & Melinda Gates Foundation to develop the technology for corn strains that grow in Africa. Their plan is to make the transgenic system available to everyone.

[13] "I am convinced that the phosphite technology has great potential and could promote many changes in agriculture worldwide," says López-Arredondo. "I want to be part of those changes."