

ENLISTING SOIL BACTERIA

MICROBIOLOGY

Enlisting bacteria and fungi from the soil to support crop plants is a promising alternative to the heavy use of fertilizer and pesticides

By Richard Conniff



TOMATOES FRESH FROM A ROADSIDE STAND, SLICED, GLISTENING, and served with nothing more than salt, pepper and a drizzle of olive oil—a sacred pleasure of summer. To die for? Possibly so.

Almost every year for the past decade or so, public health investigators on the East Coast have tracked down one or two *Salmonella* outbreaks and identified local tomatoes as the culprit. These outbreaks are typically small, affecting 10 to 100 people. Yet for the very old and very young, they can mean hospitalization and even death.

A few years ago Eric Brown, director of microbiology at the U.S. Food and Drug Administration's Center for Food Safety and Applied Nutrition, began to wonder: Why East Coast tomatoes? The *Salmonella* bug probably gets onto tomato fields from surface water and the droppings of seagulls, turtles, poultry, and other animals. So why aren't West Coast tomatoes contaminated, too?

The answer to Brown's question came from a close inspection of the community of bacteria, viruses and fungi living in and around all plants—what scientists call the microbiome. West Coast tomatoes, it turned out, grow in the company of soil bacteria that inhibit and even kill *Salmonella*. When researchers went to hunt for similar strains back East, they found them but in smaller numbers. Thus, in a pilot study in Virginia, the FDA has been brewing up populations of one of these local bacteria, *Paenibacillus*, spraying them onto tomato seedlings and getting the same anti-*Salmonella* effect on the crop. Brown expects to move the process out to commercial tomato growers in 2014 or 2015.

Adding bacteria to a crop to prevent human disease could be the start of a whole new path to food safety, possibly extending beyond tomatoes to cantaloupes, spinach, sprouts and other crops that have made *Salmonella* and *Escherichia coli* headlines. The tomato project fits into a far more dramatic shift in how we



grow our food, based on a new understanding of microbes in the soil and of the many ways plants and microbes depend on one another.

It is almost the opposite of the green revolution, which dramatically boosted agricultural productivity in the mid-20th century with massive inputs of fertilizer, pesticides and water. The microbial revolution aims instead to take advantage of what is already there: as many as 40,000 microbe species in a gram of soil. Until recently, this microbial community—what might be called the “agribiome”—was largely a mystery. But over the past decade low-cost DNA sequencing and other technologies have opened up the secret world of microbes. Botanists can now identify every member of the microbial community that surrounds a plant. By doing so, they have begun to understand how various microbes behave in different seasons and soil environments and have even started devising ways to tweak them to help plants grow better.

Soil scientists must come to grips with so much new information, in fact, that Andrea Ottesen, the FDA microbiologist who cracked the tomato *Salmonella* case, describes it, with a sigh, as “kind of a huge rabbit’s hole at this point.” But sorting out that wealth of new information to help farmers grow better crops seems particularly urgent, given the vast challenges that agriculture now faces: the global water shortage; extreme and unpredictable weather events such as last summer’s devastating drought in the U.S. corn belt; worries over the sustainability of nitrogen fertilizer produced with fossil fuels; and the prospect of having to feed an extra two billion people by midcentury.

New research suggests that microbes could provide an alternative to existing agricultural methods and genetic engineering in alleviating some of these problems. For instance, sunflowers and some other plants naturally produce the sugar trehalose, which helps to stabilize plant cell membranes and to reduce the damage from cycles of drying followed by rehydration. Other plants, including corn and potatoes, have been genetically engineered to manufacture trehalose. Yet molecular biologist Gabriel Iturriaga in Mexico hopes to eventually treat crops without any genetic modification by using the trehalose-producing bacterium *Rhizobium etli*, which is found around the roots of bean plants. An earlier experiment with a genetically altered version of the bacterium improved yields by 50 percent in normal conditions—and saved half the crop during a drought.

Microbial methods also give farmers more flexibility. One problem with plants that have been genetically engineered for drought resistance is that they do poorly in wet years. Thus, farmers have to try to predict the weather when they select seeds at the start of the growing season. But a cocktail of microbes may enable plants to adapt even when growing conditions suddenly shift.

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Russell Rodriguez and Regina Redman of Adaptive Symbiotic Technologies in Seattle have been working with a plant fungus that appears to make a range of food crops more tolerant of salinity, drought, and extreme heat or cold. The fungus thrives in panic grass, which survives soil temperatures as high as 70 degrees Celsius around thermal pools at Yellowstone National Park. The grass can stand the heat only if this particular fungus is present and only if the fungus contains a crucial virus that serves as a kind of on/off switch for heat tolerance. The researchers have gone on to collect root fungi in a range of high-stress environments, from sand dunes to alpine slopes. The ambition, Rodriguez says, is to achieve a blend that reliably boosts yields by 10 to 15 percent in an increasingly unpredictable range of conditions.

PHOSPHATE WARS

OTHER RESEARCHERS are tweaking the agribiome to help deliver crucial nutrients to plants. Farmers have, of course, recognized for thousands of years that soybeans, peanuts and other legumes have an almost magical power to fertilize the soil. Further, scientists have known for more than a century that it is not, in fact, the plants that manage the trick of pulling nitrogen out of the air, it is the rhizobial bacteria living in nodules on their roots.

Plants also require phosphate, which is exceptionally low in the soils of many tropical nations. Farmers in developing countries often depend entirely on the international market for phosphate fertilizer. In 2007 and 2008 prices for phosphate and other fertilizers spiked, contributing to food riots from Mexico to Bangladesh. In some countries, farmers now just skip phosphate fertilizer altogether and take their chances with starvation.

Yet researchers have known for decades of a possible remedy. Soil microbes called arbuscular mycorrhizal fungi form spores and filaments inside and around a plant’s roots and help them acquire phosphate. There has never been a good way to mass-produce and deliver the stuff. Soil containing the spores that form new fungi can, in fact, be shipped from one country to another, but the environmental impact of introducing foreign fungi as exotic species remains uncertain. And the spores of the fungi are so thinly concentrated that a farmer planting a crop like cassava needs to apply the enriched soil at a rate of a metric ton per hectare.

With the help of new technologies, a few companies can now mass-produce the fungi in culture and market it in a highly con-

IN BRIEF

Microbes in and around food crops do not just cause human disease. In certain cases, they do exactly the opposite, acting as sentinels of food safety and furnishing an environmentally sound alternative to massive inputs of fertilizers and pesticides.

Spreading bacteria on crops became a strategy for researchers in Virginia who sprayed anti-*Salmonella* soil bacteria on tomato seedlings. The scientists hope the approach might prevent annual outbreaks of food poisoning from raw tomatoes grown on the East Coast.

Applying fungi to cassava plants, a project of researchers in Colombia, helps the roots acquire phosphate without the need for expensive fertilizers, a boon in tropical nations where the amount of nutrient that can be obtained from the soil is particularly low.

centrated gel. A farmer can carry enough to cover a hectare in a soda bottle. Research teams can collect local strains of the fungi, test which ones look most promising, then deliver them to a manufacturer for production. Ian R. Sanders of the University of Lausanne in Switzerland and Alia Rodriguez of the National University of Colombia began field studies last year focusing on cassava, a root crop that is a staple food for much of the developing world.

In the field, a farmer dilutes the gel in a bucket of water and dips a mesh sack of cassava stems in the bucket for a few seconds before planting them. In the first season of testing, that treatment cut phosphate use in half and boosted yields by 20 percent. Sanders and Rodriguez are now crossbreeding multiple fungus strains on the three or four common cassava varieties. They are also testing the strains in Africa and, if successful, will expand this program to half a dozen countries there, thus enabling the technology to benefit subsistence farmers.

Another promising path to agricultural symbiosis involves studying the chemical signals that microbes use to communicate with one another. Researchers monitor this everyday chit-chat to identify which bacteria may be suited to the task of supplying plant nutrients or to find weaknesses in pathogens. This strategy has given rise to a potential weapon against *Xylella fastidiosa*, the bacterium that causes Pierce's disease, which is killing off vast swaths of California grapes. The bacterium is quiescent until its insect host (the glassy-winged sharpshooter) feeds on a grape plant. It wakes up inside the plant but later becomes quiescent again when it is time to be acquired by another insect.

"Basically, the lifestyle that it takes on to be transmitted by an insect is incompatible with its ability to move in the plant," says Steve Lindow of the University of California, Berkeley. Lindow took genes that the pathogen uses to signal quiescence and spliced them into the grape genome. When the pathogen arrives, the plant's transgenes tell it to behave as if it were about to be acquired by an insect, rendering it harmless.

UNMET PROMISES

IN THE PAST new microbial methods in agriculture have often failed to yield the promised results in the field, in part because of a lack of funding to translate basic research into practical applications. Molecular biologists also often lack the inclination to transfer their know-how to farmers. "It's a tale of two worlds," says Ken Giller of Wageningen University in the Netherlands, who works in Africa on improving use of rhizobial bacteria for nitrogen-fixing legumes. The molecular work on the genetics of nitrogen fixation has been "an absolutely fascinating story," he remarks. Meanwhile farmers continue to treat their plants with bacterial strains first isolated 30 years ago. "And it's largely because the scientists doing this are hell-bent on finding the next finer detail," Giller says. "A lot of interesting discoveries aren't being picked up and taken through to the point of application."

Many products that do make it into the field are ineffective because they have not been adequately tested or because they are manufactured carelessly, perhaps fraudulently. The International Institute of Tropical Agriculture (IITA) in Nigeria has tested 106 different farm products, most of them microbial. All but five failed because they did not contain the active ingredi-



CHECKING THE CASSAVA: A student in Colombia inspects a plant treated with a fungi-laden gel that promotes the uptake of phosphate, an essential nutrient.

ent on the label, they did not have enough of it, or they were not effective in greenhouse and field trials.

Many of the flawed products come from Europe, the U.S. and Japan. Rather than taking on the manufacturers, IITA is training regulators in the target countries to do their own quality testing. The institute is also developing a seal of approval to let buyers know when a product meets reasonable standards. The program aims to help farmers understand not just which microbial products work but where and under what conditions.

Getting farmers to understand the new rules of the agribiome is "going to be incredibly complicated," says Ann Reid, director of the American Academy of Microbiology, but it will also be "very cool." It means convincing farmers that their work is not a simple business of inputs and outputs—some water here, some pesticides there. Instead it means waking up to what farming has always been—a collaboration with the vast community of microbes. If farmers and scientists together can get that right, we will have come a step closer to feeding a hungry world. ■

MORE TO EXPLORE

Trehalose Accumulation in *Azospirillum brasilense* Improves Drought Tolerance and Biomass in Maize Plants. Julieta Rodríguez-Salazar et al. in *FEMS Microbiology Letters*, Vol. 296, No. 1, pages 52–59; July 2009.

Microbes Helping to Improve Crop Productivity. Ann Reid in *Microbe Magazine*, Vol. 6, No. 10; October 2011. <http://bit.ly/1aLQBDX>

SCIENTIFIC AMERICAN ONLINE

Watch an animation showing how fungi can help a plant obtain an essential nutrient at ScientificAmerican.com/sep2013/microbial