Old MacDonald Was an Ant

She knew about manure, herbicides, weeding, and—maybe—raiding a neighbor's garden

By SUSAN MILIUS

Ulrich G. Mueller, who belongs to a species that has only recently gotten the hang of agriculture, has been studying some of the planet's more experienced farmers.

True, the University of Maryland evolutionary biologist's own species has managed some good tricks in the mere 10,000 years or so since several hunter-gatherer groups around the globe took up farming. *Homo sapiens* can bask in the glory of taming more than 100 wildling plants, including such grasses as the rice, wheat, and corn that have powered states and nations, not to mention such miracles as chocolate and coffee that power whole states of existence.

There is, of course, the matter of breeding a tomato that withstands impact as well as most compact car bumpers—and tastes about as good—but agriculture is a relatively new venture for humanity. In contrast, the New World tribe of ants called attines started farming some 50 million years ago. They had already developed the basic techniques—planting, fertilizing, pruning, and using herbicides to zap weeds—when people were still grubbing for their meals among the shrubbery.

Ancient ant farmers had also domesticated a wild species, at least once. Researchers have puzzled, however, over how often the ants tamed new species and whether they shared their successes.

Now, Mueller, Ted R. Schultz of the Smithsonian Institution in Washington, D.C., and Stephen Rehner of the University of Puerto Rico in San Juan are bringing molecular genetic analysis to bear on the question. Their most recent work suggests that, once again, ants' achievements look similar to people's, and the ants got there first.

More than 200 ant species belong to the attine tribe, and all run farms. The tropics hold the richest array of species, but farmer ants can live as far north as New Jersey.

The tribe reaches its peak of specialization in the notorious leaf-cutter ants. These colonies send out great streams of workers along ant highways to snip out and retrieve bits of fresh leaves or other plant parts, which yet more workers process into the equivalent of topsoil for planting. Biologists marvel at the efficiency and coordination of the many precise steps in the process. Human farmers, on the other hand, tend to focus on the several million dollars' worth of leafy crops they lose each year to ants.

Photos: Mueller

Leaf-cutting ants Atta cephalotes *carry their booty down a tree during a night's work collecting raw material for their fungus farm in Costa Rica.*

Leaf-cutters and all the other attines cultivate various kinds of fungi for colony members to eat. Schultz says the fungus "looks like a very thick, white fuzz." Instead of planting flat fields, the ants garden in three dimensions, creating lumps of fungus that they lace with passageways and tunnels.

Each of these ant farms may resemble a crumbling bath sponge, but "it's true agriculture," Schultz says firmly. Entomologists have long recognized among the attines the basic components of the human family farm.

For one thing, ants don't just happen upon the fungus they tend. Ants actually plant their gardens. A reproductively mature female takes a bite of the fungus in the nest where she grew up, settles it into a pouch inside her mouth, and leaves for a once-in-a-lifetime orgy of airborne sex. Harvard University entomologists Edward O. Wilson and Bert Hölldobler describe the event for leaf-cutting *Atta* ants: "With furiously beating wings, the heavy virgin queens labor upward into the air, where they meet and mate with as many as five or more males in succession."

The researchers estimate that each flying female accepts some 200 million or more sperm, which she stores internally to last the rest of her life. A queen may live up to 14 years. Her mates expire within a day or two of the nuptial flight.

When the female comes down to earth, her wings break off, ending her flying days. She burrows into the ground and hollows out a chamber to start farming. She spits out the fungus snippet and starts laying eggs. Until her first offspring mature and get to work, in some 40 to 60 days, she tends both farm and eggs by herself. She does not eat the fungus during that period but sustains herself by metabolizing fat and the now useless wing muscles.

Like human farmers, the queen draws on the power of manure. Every hour or two, she pulls off a bit of the growing fungus glob and holds it against the tip of her abdomen. She wets it with a droplet of yellowish or brownish liquid waste and then settles the enriched fragment back into the garden.

Schultz points out that the ants have evolved into little fertilizer factories. When they eat the fungus, they do not metabolize the enzymes it uses to break down plant material. These enzymes concentrate in the insects' wastes, so ant manure provides a jolt of feeding power. "It helps the fungus get a head start," he says.

Ant farmers encounter the same miseries that plague their two-legged counterparts. "There are always weed molds trying to get in," Schultz observes. So, ants evolved weeding. They patrol the passages, worming their way through the lump of crop fungus, antennae wiggling to catch whiffs of

Researchers found this free-living Leucocoprinus *mushroom to be closely related to a fungus grown by ants—a hint that the insects domesticated their crop recently.*

any invading molds.

When an ant worker detects a mold, she plucks it out and hurries to a dump. Ants pile this debris away from their gardens, often in a separate chamber or even outside the nest. After a close encounter with a weed, the ant cleans herself, reducing the chance of carrying contaminants back into the garden.

Ants may also weed out spent fungus, Schultz says. Once a lump of fungus has exhausted the food supply it grows on, it falters, getting less productive and falling prey to infections. Yanking out bits of useless old fungus may take less effort than humans expend pulling out tree stumps, but the principle is similar.

The ants also treat their gardens with herbicides, Mueller notes. Special glands on the sides of their bodies secrete substances that suppress other fungi but don't hurt their own crop. Recent research has suggested that ants' salivary glands also secrete antibiotics, and many species mix saliva into the mush they prepare for the fungus to live on.

Melanie Bass of Trinity College in Wales and her colleagues have demonstrated that ants have developed their own version of pruning. When researchers removed the ants tending to it, the growth of the fungus garden slowed. However, the researchers were able to boost the growth by nicking out bits here and there with a needle, mimicking the ants' steady nibbling.

The most advanced fungus farmers, the leaf cutters, achieve farming on a scale worthy of the most sweeping high-tech agro-empires. Wilson and Hölldobler report that a colony of *A. sexdens* may grow to 5 to 8 million members.

One nest in Brazil branched into more than a thousand chambers, and the ants excavating it had lugged approximately 44 tons of loose soil to the surface. The researchers calculate that the nest building required more than a billion ant loads, each four or five times the weight of a worker. The ants hauled these burdens up shafts that, if they were scaled up to an equivalent length for a human, would stretch as far as a kilometer.

Naturalists have known since the middle of the 19th century that ants cultivate fungi. "What couldn't be easily studied was the nature of the fungus," Mueller says. One blob of fuzzy, asexual fungal tissue looked pretty much like another, and inside the ant nests, fungi do not sprout the reproductive bodies that a mycologist uses for identification. Scientists weren't sure what the fungi were, much less where they came from.

Four years ago, Mueller and a group of collaborators characterized some of the mystery fungi as varieties in the family of parasol mushrooms and began the task of tracing the history of its domestication. One possibility was beautifully simple: Ants had domesticated one fungus and passed it as a keepsake from mother queen to daughter queen. As new ant species split off from an ancestral form, the fungi they once shared also diverged over time.

Nice idea, but it didn't work like that, the researchers realized after their initial analysis. The fungal pedigree didn't match their ants' pattern of ancestry.

Mueller could envision two explanations for the complexity. Perhaps, after the first breakthrough in domesticating a fungus, descendant lineages of ants went back to the wild again to tame new fungal crops. People, after all, have brought many wildlings into cultivation.

Alternatively, the ants might have borrowed or stolen crops from the neighbors, just as even very early human agriculturists did. By the time Columbus stumbled upon the Americas, the sweet potato, which had originated in the Andes, was growing in Polynesia, and East African farmers were tending Asian bananas and rice.

Mueller and his colleagues approached the puzzle by slogging through Panama in the fungus-friendly rainy season to collect both free-living parasol mushrooms—the reproductive stage of the fungi—and the ants' crops. The researchers genetically screened 309 of the wild species and 553 samples from the same region's ant farms. Then, they sequenced two genes from 27 of the wild species and 57 of the ants' crops.

From the degrees of similarity among those genes across the fungi, Mueller and his colleagues constructed a family tree with three main branches. The closer an ant-fungus sits on the tree to a free-living relative, the more likely it is that domestication was recent, Mueller argues. In the new family tree of fungi, published in the September 25 SCIENCE, he sees evidence of five independent ant successes in domesticating a wild fungus.

"I've just been in one tiny patch in Panama," he says. "I would not be very much surprised if there are hundreds of independent evolutionary domestications."

The family tree also convinced Mueller that ant colonies occasionally did pick up crops from their neighbors. One of his students is working to unravel just how such exchanges might happen. In the laboratory, the researchers pair colonies of fungus-growing ants and then remove the fungus garden from one colony.

"We're really intrigued that sometimes they all join and make one big happy family," Mueller reports, cautioning that these rare collaborations need to be observed for longer to see if they eventually splinter.

More often, however, "neighbors are very, very defensive of their gardens—they do not like to give up parts thereof," he emphasizes. Attempts to refurbish a missing garden can lead to tremendous fights, in which one colony perishes.

In the same issue of SCIENCE as Mueller's fungal family tree, Jared Diamond compares crop domestication in ants and people. Diamond, a physiologist at the University of California, Los Angeles, traced the world-changing consequences of crop domestication in his Pulitzer Prize–winning book, *Guns, Germs, and Steel* (1997, Norton, New York).

Adopting a crop that somebody else tamed certainly lies at the heart of human food production. Just check a McDonald's restaurant, Diamond advises. Beef originated in the Fertile Crescent, chickens in China, potatoes in the Andes, and kola nuts (the inspiration for Coca Cola) sprang from tropical West Africa.

People, however, have largely ceased pulling crops from the wild, Diamond observes. In contrast, ants may be continuing the process. Mueller found two wild mushrooms growing in modern Panama that are nearly identical genetically to strains in an ant garden, evidence for very recent domestication.

"You'd think, after 50 million years, they don't need to go to the wild anymore to pick up new domesticants," Mueller says. Yet he's convinced that they still do. "Maybe there's a message that it's not that easy to liberate yourself from biodiversity if you're an agriculturist."

Preserving biodiversity could also be very valuable to the human food supply, he says. He's just passing along the hint from some old hands at farming. □

A microscopic view of strands of the fungus that ants grow. They harvest the swollen ends, rich in protein and sugars.