SCIENCE

Shh . . . they're thinking

Groundbreaking research shows that plants keep time, count and know themselves

POLITICAL REVOLUTIONS come and go with the seasons, but in science, they take longer. In the long march to establish that plants are intelligent, it has been eight years and counting. "You have to wait for the old generation to die," says Frantisek Baluska, a plant biologist at University of Bonn, with a grim jocularity.

Most of us, if we think about plants at all, consider them to be mindless organisms, automata evolutionarily tuned to react to wind, rain, sun, the attacks of the herbivores and they add up to—that plants think—remains as radical a notion to most biologists as it is anathema to vegans. Those who accept it frequently invoke the names of the giants of science who travelled this path before: Jagadish Chandra Bose, the Indian polymath physicist and biologist, measured electrical signals in plants in the 1920s; Charles Darwin wrote in *The Power of Movement in Plants*, in 1881, that the tips of plant roots, which spread through the soil in a fine network, function as a brain-like organ. Mancuso and Baluska the chemistry of grapes to fingerprint the best flavours from the 35,000 compounds that a plant produces at any given time. But she has mainly been fascinated by the chemical connections between plants and human brains. Both make and use the same compounds.

Murch was the first to publish (in *The Lancet* in 1997) that feverfew and other plants like St. John's wort produce hormones such as melatonin and serotonin, which humans use to modulate sleep and mood. This paper drew the rapt attention of the international press

gardeners with black thumbs. Yet, as Baluska's colleague, Stefano Mancuso, professor of horticulture at the University of Florence argues, plants (99.9 per cent of the planet's biomass) actually behave as animals do. In a series of published experiments, Mancuso, Baluska and other plant scientists have demonstrated that plants keep time, know themselves, count, distinguish kin from strangers and competitors, explore for the best patches of soil and sun, and chemically warn of (and ward off) enemies–all while luring dumb animals like us to do their sexual bidding. Although they are modular (each cell much like every other) and lack central nervous systems, they display intelligence in myriad ways as they deal with environments from which they cannot run away.

Though hundreds, perhaps thousands, of peer-reviewed articles attest to these facts, what are convinced that this is where plant cognition happens—that roots act like a distributed information-processing network, similar to the neural networks that organize information in computers.

The international Society for Plant Signaling and Behavior, through which these startling arguments are being put forward, held its first North American meeting this July in the Irving K. Barber Learning Centre at the University of British Columbia. (Barber, who founded Slocan Forest Products, made his fortune from B.C.'s forests.) The organizer was Susan Murch, associate professor of chemistry at UBC-Okanagan, and Canada research chair in natural products chemistry. Murch is well-known for her practical work: cloning breadfruit from single cells to produce 50,000 trees a year for food-challenged places like Haiti, and deconstructing (even *Penthouse* magazine, to the dismay of Murch and her colleagues). Both plants had long been used to combat human depression. She asked: Why would plants manufacture these compounds? To make humans feel good? She thought it might be a case of "same chemical, different role," and wondered if the hormones help shape plant development. To test that hypothesis, she suppressed their production in St. John's wort as it grew in her lab. She fed the plants 39 different human pharmacological products that interfere with serotonin and melatonin, including selective serotonin reuptake inhibitors (SSRIs). Prozac (an SSRI) was one of eight that disturbed the plants' development.

This work attracted the attention of Mancuso, Baluska and their colleague Anthony Trewavas, a senior plant scientist at the University of Edinburgh who had begun to write

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about plant intelligence in the early 2000s. Baluska had started to note work showing that plants produce painkillers such as ethylene (well known as a plant stress hormone) and ether. Both compounds reversibly render humans and animals unconscious, and make plants unresponsive to stimuli. For Baluska, that means plants normally have their own kind of consciousness. Murch calls the chemical signals generated by wounded plants "screams." (Remember that, the next time you rip a carrot out of the garden.)

Mancuso, a well-respected plant physiologist, wisely waited until he had tenure before actively pursuing these questions. In 2004, he talked a Florentine bank into putting some of its legally required community donations into science projects, such as his, instead of the city's museums. He used the grant to set up the provocatively titled International Laboratory of Plant Neurobiology and to kick-start a society of the same name. He and Baluska invited 250 scientists to the first symposium on plant neurobiology in Florence in June 2005. About 100 came, among them, Susan Murch.

renamed Plant Signaling and Behavior.

Murch was disappointed. She thought the original title pointed to better research questions. Baluska argued that, if they'd stuck with it, few would attend their conferences. In conservative Germany, Baluska can't get direct funding because, as he says, "they think this is nonsense."

Yet Mancuso has attracted strong financial support from the European Space Agency and the European Commission. He is developing robots modelled on plant signalling and behaviour (with a major Swiss robotics group), and new forms of plant-style computation (with a British group). He even opened an outpost of his Laboratory of Plant Neurobiology in Japan in February; it will focus on plant-like robots. Perhaps following Darwin's lead (Darwin was remarkably astute about getting his ideas into the world), Mancuso is prolific and welcomes the interest of the press. Five journalists came to the Vancouver conference (attended by 100 scientists), including American author Michael Pollan.

The first two days of the Vancouver conference focused mainly on standard biological science, heavy on gene and protein interactions. Many papers parsed seemingly mindless Rube Goldberg-esque systems, such as those that permit a Venus flytrap to distinguish prey from a random raindrop, to snap shut and slowly digest it without brain, mouth, muscles or stomach. Few presenters directly addressed memory, selfhood or intentionality, and how these phenomena could arise in life forms organized differently than we are.

But on the last morning, Mancuso went to the barricades. First, he paced the lecture hall, reminding the attendees about Leonardo da Vinci's inventions based on plant mimicry, including his failed attempts to build a glider that could fly the way plant seeds do. There was something Harry Potter-like about him, gentle yet steely, as he introduced colleagues who design robots that can reshape themselves, modelled on how seeds and roots penetrate soil (one looks just like a penis). Then he introduced Monica Gagliano of the University of Western Australia.

Gagliano asked: Do plants learn? Learning means that an organism can distinguish one kind of event from another, that it can remember, and adapt its behaviour. We once thought only humans learn, but animal behaviour scientists have shown otherwise. Gagliano applied to plants test methods devised to study animal learning. Mimosa plants curl their leaves instantly if touched by something they interpret as a threat. She trained mimosa plants to recognize that being dropped from the lab bench was no threat. She dropped each plant 60 times, then introduced a new de-habituating threat (a vigorous shake) to be sure they distinguished one type of event from the other. Then she dropped the plants 60 times more. She found they stopped curling their leaves after about four drops and remembered the lesson up to 50 days later. Although some of the questions from the Rube Goldberg signallers in the

Do plants learn? *One researcher trained mimosa plants not to curl their leaves*

Although the group's early publications were generally ignored, eventually a protest letter signed by 36 plant scientists appeared in *Trends in Plant Science*. The main objection was to the society's use of the word "neurobiology" in its name, as plants have no neurons. But when Mancuso's lab reported in the peer-reviewed journal *Proceedings of the National Academy of Sciences* in 2009 that they had recorded spontaneous, not reactive, spiking-action potentials in plant roots (electrical signals characteristic of neurons), implying brain-like behaviour, the pushback got ugly. In a non-peer-reviewed online article titled "Intelligent Plants or Stupid Studies," they were accused of failing to measure plant signals properly and of using influence to get published (charges an outraged Mancuso denies). To reduce the flak and attract more scientists, the society, and its journal, were

crowd were unfriendly, her evidence seemed solid. But: "The paper is not published," warned Murch.

Gagliano confirmed she had sent it to the top 10 science journals in the world (*Nature*, *Science*, etc.) and they had refused to even send it out for review. Why? "I put the words 'plant learning' in the title," said Gagliano. She won't take them out, either, because she's convinced that is what she demonstrated. And no, she's not about to give up. You have to persist when leading a science revolution.

"That's what I tell my students," said Murch. "You have to be brave." **ELAINE DEWAR**

Dewar's book, Smarts, *will be published by Goose Lane in 2014*