What lies beneath

More creatures live in soil than any other environment on Earth. But what are they all doing there? **Amber Dance** reports on the world's widest biodiversity.

Ecosystems aren't green; they are black and brown, at least in the colour palette favoured by Diana Wall. Wall, a soil ecologist at Colorado State University in Fort Collins, spends her days digging into the world's underground ecosystems. These beiges, ochres and charcoals reflect a three-dimensional mosaic of micro-environments, each with its unique set of inhabitants.

But very little is known about these inhabitants. Understanding soil is a matter of rising urgency. A July report from the US National Research Council listed soil quality as the biggest barrier to higher crop yields for farmers in sub-Saharan Africa and south Asia. And knowing what myriad organisms live in the soil, and how they interact, is crucial to creating a healthy ecosystem.

For those scientists who are willing to crouch down and dig, the diversity of soil denizens beats any above-ground system, even that of a tropical rainforest. A handful of soil from one spot may house a very different community from soil just a metre away, because of variations in the availability of water or nutrients. For example, the ground under a decaying plant or animal is a different environment from soil lacking such enrichment. And around plant roots, specialized organisms inhabit the rhizosphere, a thin layer where roots and soil organisms interact in myriad ways. Large animals such as moles contribute, changing and aerating the underground landscape by tunnelling. Even a small clump of soil has a gradient of oxygen from its edges to the centre, and each oxygen concentration may make the perfect habitat for different kinds of creatures. "It is the most incredible zoo," says Wall.

Take that view to a larger scale, and it is possible to appreciate just how complicated the world's soil ecosystems are. In one ongoing study, not yet published, Wall and her colleagues scooped soil cores from two sites in Alaska, one in the tundra and one in the taiga forest. Although the sites were only 400 kilometres apart, the species living there were radically different: only 18 invertebrate taxa out of an estimated 1,300 appeared in both locations. "That just blew me away," says Wall.

And that's just looking at invertebrates, not including microbes. "As far as I know, there is no environment on Earth that is more biologically diverse, per unit area, than soil," says Eric Triplett, a microbiologist at the University of Florida in Gainesville. Thanks to faster, cheaper DNA sequencing, scientists are now getting a grip on what is down there and what those organisms might be doing. That information, in turn, could help improve soil management for agriculture and forest management for conservation.

"My dream is that you take a DNA sample from the soil, and then explain what species are there, and what benefits."
— Wim van der Putten

At this point, scientists don't even agree on how many creatures they are looking for. The first DNA-based estimate of soil microbial biodiversity, published in 1990, counted about 4,000 different bacterial genomes per gram of soil[1]. Since then, various studies and models have pushed the number up as high as 830,000 species per gram[2], down to 2,000 (ref. 3), and back up again. Most recently, Triplett and his colleagues ran 139,000 individual sequences — more than other studies have used — and came up with an estimate of 10,000 to 50,000 species per gram of soil[4]. Complicating the matter is the fact that, because so few of these species have been described, researchers have to group similar organisms within 'operational taxonomic units', which correspond roughly but not precisely to species designations.

EYE OF SCIENCE/SPL

A. SYRED/SPL

Valuable species

Quantifying such diversity illustrates just how much remains to be discovered, and soil scientists are teaming up to tackle the challenge. The Tropical Soil Biology and Fertility (TSBF) Institute, run by the International Center for Tropical Agriculture and headquartered in Nairobi, has united more than 300 scientists in seven countries to survey soil organisms. The project, which began in 2002, aims to identify living indicators for fertile or poor soil, and has already identified some novel organisms that could be useful to humans.

In the Veracruz rainforest, for instance, Mexican scientists have discovered *Acaulospora*, a mycorrhizal fungus that entwines with lily roots and provides water and mineral nutrients. Last spring the researchers injected *Acaulospora* into the soil of test lily plots in Benigno Mendoza, a community in Veracruz where lily bulbs are an important cash crop. As a result, this year's harvest consists of big, first-quality bulbs that match the yields gained through using inorganic fertilizer with none of the downsides of chemical treatments. Isabelle Barois, a soil ecologist at the Institute of Ecology in Xalapa and coordinator of the

TSBF Mexican team, says that the fungus could eventually help replace the expensive nitrogen fertilizer and harsh agrochemicals that farmers apply to their land five or six times a year.

Global soils contain a bounty of unusual and potentially useful organisms such as *Acaulospora* — more, theoretically, than they should. Although some species are common, there are also countless taxa found in vanishingly small numbers. Many species also seem to be redundant, eating the same foods and fulfilling the same ecosystem jobs, so scientists don't quite understand why they're there at all. "There is some debate about how many species need to be present in the soil to make an ecosystem," says Wim van der Putten, an ecologist at the Netherlands Institute of Ecology in Heteren.

Heikki Setälä, an ecologist at the University of Helsinki, took on this question with experiments in which he controlled the number of animal or microbial species in artificial ecosystems. In one study[5], he set up soil microcosms in glass jars and added fungal species: only one in some jars, and up to 43 in others. Diverse systems decomposed more organic matter — demonstrated by higher carbon dioxide production — and produced more nitrogen compounds in the soil. But that relationship held true only at the lower end of the spectrum. Six species were better than one, but 43 weren't any better than six. "It was kind of a bummer," Setälä says. "It would be nice to tell the audience that we need all the species to make the planet green and sustain it."

The explanation for the wealth of soil biodiversity, then, remains an open question. Maybe the multitudinous creatures are simply adapted for niches that humans don't yet understand. Alternatively, they could literally be waiting for a rainy day; some organisms spring into action after a storm, fire or other disturbance, and so make the ecosystem more resilient. Or perhaps those organisms are truly redundant. "We know virtually nothing about what controls the diversity of soil communities," says soil ecologist Richard Bardgett of Lancaster University, UK.

Triplett disagrees. "I don't think it's a vast unknown," he says. "I think there are some dominant genera out there that we could learn about pretty fast." In a follow-up to his soil biodiversity survey[6], Triplett and his colleagues found that up to around 65% of the DNA samples from soil microbes fell into known genera, which makes those genera prime candidates for further study. For example, *Chitinophaga* was prevalent in the four distinct soils tested, from Canada, Illinois, Florida and Brazil. But a PubMed search for the genus finds only ten papers on the genus (and one of those is Triplett's), highlighting the lack of work that has been done in this area.

"My dream for the future would be that you would just take a DNA sample from the soil, and then explain what species are there, and what benefits," van der Putten says. But this kind of quick DNA test is years in the future.

LONDON SCHOOL HYG. TROP. MED./SPL

Setting microbes to work

For some scientists, just defining the diversity isn't enough. Triplett, for instance, wants to alter it. He envisions harnessing the nitrogen-fixing power of bacteria that form nodules on the roots of some plants, such as legumes, and convert nitrogen from the air into a form the plants can use. He thinks he could insert some of the nitrogen-fixing (nif) genes from the bacteria into agricultural crops — which could then collect their own nitrogen from the atmosphere and eliminate the use of artificial nitrogen fertilizer. It has already been shown that some nif genes can function in plants[7]. A nitrogen-fixing plant would require at least ten new genes, making the task difficult, Triplett says, but not impossible.

Policy-makers are slowly starting to pay attention to the problem of soils. In 2006 the European Union agreed that soils need protection from erosion, landslides and salinisation, but has not yet finalized the laws that would ensure this happens. Some countries, including France, would prefer to see individual countries regulate soil. "I'm pretty confident that the politicians will swallow the hook sooner or later," Setälä says.

Avoiding that hook comes with a price tag: one estimate valued the free services provided by the world's soil biota at US$1.5 trillion or more each year[8]. Soils are also important as a carbon sink; soil stockpiles 1,500 gigatonnes of organic carbon, more than Earth's atmosphere and all the plants on the planet, according to the United Nations Food and Agriculture Organization. If soils remain degraded and their many denizens disappear, the world might lose access to organisms that improve crop yields, degrade toxins, or make useful by-products such as drugs — before they're even discovered. ■

Amber Dance is a freelance science writer based in the Los Angeles area, and a former News intern with *Nature*.

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B. P. KENT/PHOTOLIBRARY.COM

J. DE MEESTER/ARDEA.COM

Rare greenhouse gas adds to climate concerns

Scientists are recommending that a rare but potent greenhouse gas should be included in future climate agreements after confirming that the gas is about four times more abundant than previously believed.

Nitrogen trifluoride (NF_3) is commonly used to etch microcircuits in plasma-screen televisions and other flat-panel displays. As a greenhouse gas, NF_3 is about 17,000 times more efficient at trapping heat than carbon dioxide, but very little was thought to escape into the atmosphere.

A team led by Ray Weiss of the Scripps Institution of Oceanography in La Jolla, California, confirmed that atmospheric concentrations have risen more than 20-fold during the past 30 years after analysing air samples from coastal stations in California and in Tasmania, Australia.

The scientists reported that in 2008 some 5,400 tonnes of NF_3 were present in the atmosphere (R. F. Weiss *et al. Geophys. Res. Lett.* doi:10.1029/2008GL035913; 2008).

For a longer version of this story, see http://tinyurl.com/6a6gta

India makes history with launch of Moon mission

India's first lunar spacecraft is set to swing into orbit round the Moon on 8 November.

The Indian Space Research Organisation (ISRO) successfully launched Chandrayaan-1 (pictured) on 22 October from the Satish Dhawan Space Centre in Sriharikota, southern India.

The craft is carrying six foreign and five Indian scientific instruments designed to create a three-dimensional map of the Moon and study the lunar soil, among other things. The spacecraft will also search for frozen water and measure the abundance of helium-3.

The ISRO is now planning Chandrayaan-2, which would take a Russian-built rover to the Moon's surface by 2012. The agency also aims to send two Indians into space by 2015, in a mission that will cost roughly 120 billion rupees (US$2.4 billion).

ISRO/AP

Rice pathogen is added to list of bioterror agents

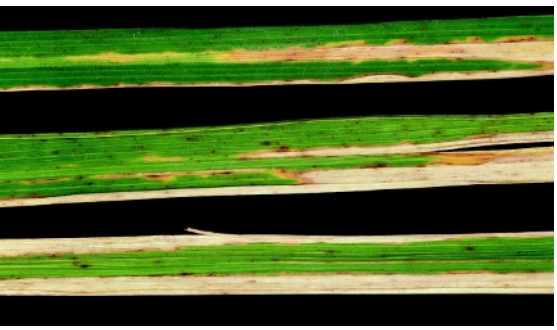
The US Department of Agriculture (USDA) this month added a rice pathogen to its national security watch list, despite objections from several prominent scientists.

USDA's Animal and Plant Health Inspection Service has listed the bacterium *Xanthomonas oryzae* pv. oryzae, which causes leaf blight, as a 'select agent' that could be used for bioterrorism.

Several researchers who work with the microbe argued against the listing, saying that it would have difficulty establishing itself in the United States, and that those labs working with it have perfect safety records dating back more than 20 years.

Researchers have until 17 November to notify the government if they possess the pathogen, and until 14 April 2009 to come into full compliance with the regulations.

"That's not a lot of notice," says Pamela Ronald, a rice researcher at University of California, Davis, who opposed the listing. "All the labs are scrambling to find out what it means to their research programmes."



N. CATTLIN/FLPA

Blight in rice caused by *Xanthomonas oryzae*.

Fall in profits prompts major job cuts at Merck

Pharmaceutical giant Merck is to cut 7,200 jobs, or roughly 12% of its workforce. Around 40% of the cuts will be in the United States, many of them from management as Merck trims the number of senior and mid-level executives by 25%. The company, based in New Jersey, also plans to close basic-research sites in Tsukuba (Japan), Pomezia (Italy) and Seattle (Washington).

These cuts come on top of the axing of 10,400 positions announced in 2005, which Merck says was "substantially complete" as of last month.

Merck's third-quarter profits were down 28%, and spending on research and development (R&D) dropped by 19% compared with 2007, to $1.2 billion. But the company says that R&D spending actually rose by 2% if expenses from restructuring efforts and the 2007 acquisition of NovaCardia are taken into account.

Swedish basic research receives funding boost

The Swedish government has announced a record investment in basic research, much of which will be directed to fields such as stem cells, climate modelling and nanotechnology.

Introduced on 23 October, the bill provides almost 15 billion Swedish krona (US$1.9 billion) for research and innovation between 2009 and 2012. Sweden currently spends 25 billion krona a year on research; that figure is expected to rise by 20% by 2012.

Most of the new funds will be distributed to universities through a merit-based system. Gunnar Öquist, head of the Royal Swedish Academy of Sciences in Stockholm, says that although the initiative would reverse years of declining research budgets, he worries that its narrow focus could stifle creativity.

The bill will now be taken up by the parliament, and is expected to pass early in 2009.

NASA clamps down on conference attendance

NASA has put a moratorium on participation in conferences in an effort to comply with an authorization bill recently enacted by Congress.

Signed into law by President Bush on 15 October, the act limits conference spending to US$5 million in the 2009 fiscal year. That figure represents more than a two-thirds reduction from conference spending in 2008.

The moratorium, announced earlier this month, covers sponsorship of conferences, as well as travel and admission fees. It applies to NASA staff and some contractors, such as employees at the Jet Propulsion Laboratory in Pasadena, California. Scientists receiving NASA grants or sponsorship have not been affected so far.

Correction

The News Feature 'What lies beneath' (*Nature* **455,** 724–725; 2008) incorrectly stated that nitrogen-fixing bacteria are 1–2 millimetres in length. They are, in fact, 1–2 micrometres long.