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SOIL LIFE INFLUENCES PLANT GROWTH

Unearthing the secrets of the soil

Every square metre of a layer of soil is inhabited by a community of worms and insects, kilometres of fungal hyphae and millions of nematodes and bacteria. Research is producing more and more insight into the precarious balance under the ground, and the extent to which it is influenced by life above ground. This is leading to new strategies for crop protection.

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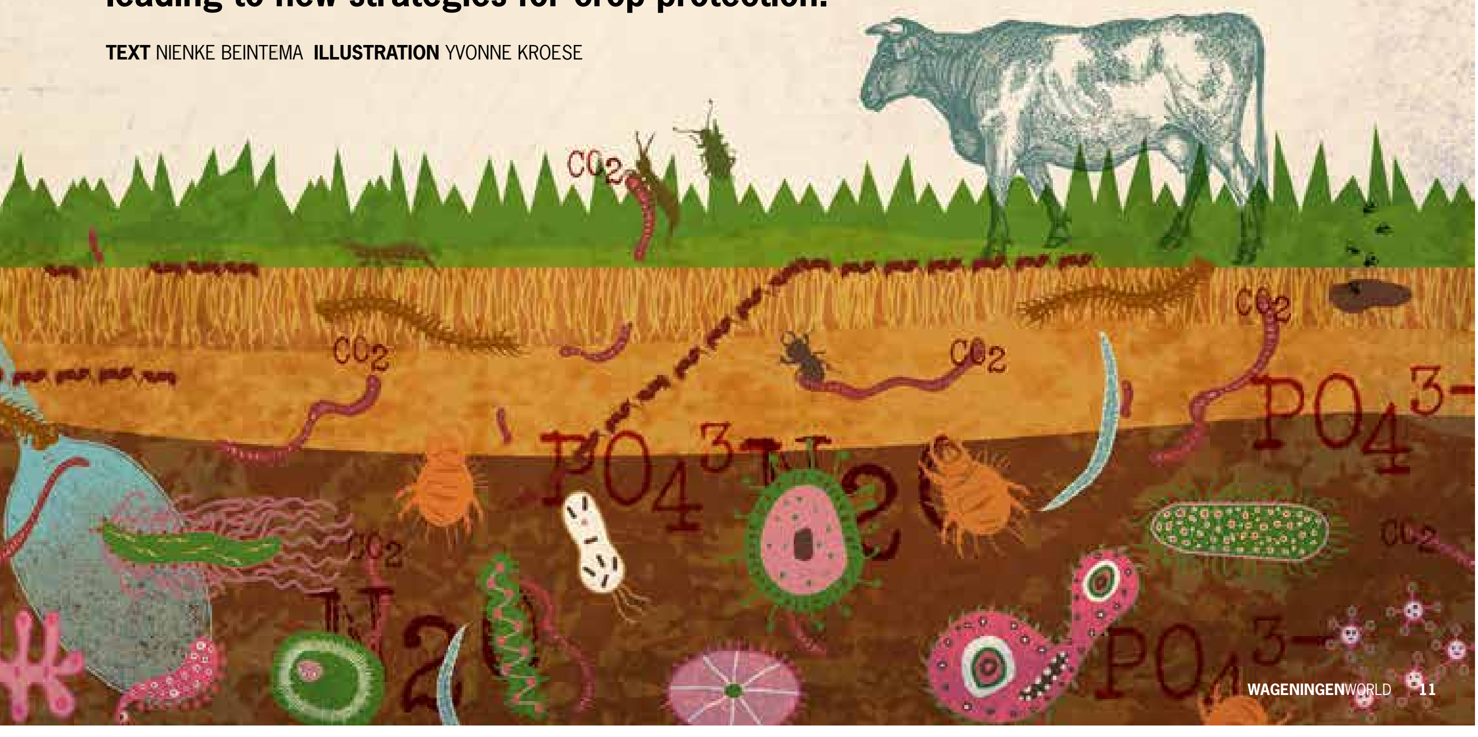


It is no news to farmers, horticulturalists and gardeners: worms are good for the soil. They recycle dead matter and keep the soil aerated so that water can drain away better and the soil can 'breathe'. Plants grow much better when there are worms present in the soil. But there is a flip side to this. 'Soils full of earthworms emit at least 30 percent more greenhouse gases that soils without worms,' says Jan-Willem van Groenigen, associate professor in the Soil Quality department at Wageningen UR. 'This is partly because carbon dioxide is released when that dead plant matter is broken down. And another explanation is the use of artificial fertilizer containing a lot of nitrogen. Soil bacteria convert that nitrogen into laughing gas, which is a greenhouse gas. The worms create conditions in which that happens faster.'
Worms also change the phosphate balance in the soil. This is of interest in view of the increasing global scarcity of phosphate fertilizer. The problem, says Van Groenigen, is that phosphate accumulates in the soil in a chemical form which is of little use to plants. 'Earthworms make that phosphate available to plants again. It would be tremendous if we could stimulate that through soil management that benefits earthworms. Using organic fertilizer, for instance.'

MITES AND SPRINGTAILS

Worms are by no means the only underground organisms to influence life above ground. They share the upper stratum of soil with an astonishing variety of nematodes, mites and springtails, ants, beetles and millipedes. Not to speak of the life forms that are invisible to the naked eye: countless fungi and bacteria. Some of these are useful for the growth of plants: earthworms and fungi improve the soil structure while many 'good' nematodes, fungi and bacteria keep pathogens under control. Others, however, can cause plant diseases. All these organisms benefit directly or indirectly from substances excreted by the plants. This is a delicate balance on which little research has been done yet.
'The Wageningen Centre for Soil Ecology is changing that,' says Wim van der Putten, head of Terrestrial Ecology at the Netherlands Institute for Ecology (NIOO-KNAW) and professor of Functional Biodiversity at Wageningen University. In 2010 he helped set up this centre, a collaboration between Wageningen UR and NIOO-KNAW. It was the first institute in the world to bring together ecologists, agronomists, chemists and hydrologists to study how the soil functions and how that influences plant growth. 'It is becoming clearer and clearer how important that soil is,' says Van der Putten, 'but what we know is still only the tip of the iceberg.' This is why the United Nations designated 2015 the Year of the Soil. A great initiative, says the professor. 'A better understanding of the soil is badly needed to help us tackle both the global food problem and the environmental problem in agriculture, as well as to restore nature areas.'

FIFTY SHEEP

First a few dry facts. The top decimetres of each square meter of soil harbours about 400 earthworms as well as about 20 million nematodes. One teaspoon of soil contains hundreds of metres of fungal filaments and as many as 10 billion bacteria of perhaps 10,000 different strains. 'Imagine a hectare of land with five sheep grazing on it,' says Wietse de Boer, senior researcher of microbial ecology at NIOO-KNAW and special professor of Soil Quality at Wageningen UR. 'That is a standard sheep density. Under the ground the density of micro-organisms is equivalent to 30 or 40 sheep.'
How scientists see that soil life traditionally very much depends on the context: agriculture or nature. 'Nature managers see

pathogens as useful in principle,' says Van der Putten. 'They prevent certain fast-growing species from getting the upper hand, thus increasing biodiversity. But in agriculture we see pathogens as a negative factor because they are a threat to crops.'
Currently the perspectives of scientists from these two fields are coming closer, says Van der Putten. 'This cross-fertilization is delivering important new insights.'
The example he gives is the phenomenon of invasive exotic species in the Netherlands: the infiltration of plant and animal species that did not originally belong here, such as the wild black cherry. In America this bush is nicely distributed through the forest, kept under control by the fungal pathogen Pythium, an oomycete which causes root rot. Pythium is not found in the Netherlands, so the fast-growing shrub can spread unchecked. 'This illustrates the important of a natural soil life for the balance above the ground,' says Van der Putten. 'In a natural environment those defences are well arranged, but in our intensive agriculture it is disrupted by ploughing, fertilization, drainage and pesticides. It seems as though the natural defences stay more intact on organic farms. We would very much like to know why that is.'
At the same time, experimental soil management practices from agriculture are now being tried in the context of nature management too. One example is the 'grafting' of soil from elsewhere in order to introduce a complete community, including soil life. One of the places where this has been done is Reijerscamp nature area near Wolfheze, not far from Wageningen. Once a heath, this land was then used for many years for crop farming. Turf from heath elsewhere was placed on the now abandoned field, with all its soil fauna, micro-organisms and plant seeds. Within five years the area had returned to heathland. Van der Putten: 'Our research showed that the soil life in 'new nature' is far more developed after these kinds of transplants than it is if you don't do anything. We had already demonstrated with greenhouse experiments that that soil life promotes the development of the vegetation.'

NEMATODES DROWN

The less soil life there is, the more vulnerable the soil is to opportunistic pathogens. That is a fact affecting farmers in the flower bulb-growing region of the Netherlands. Besides using pesticides as a strategy for combatting nematodes that damage bulbs, they have recently started flooding their bulb fields every so often,

> 'What we know is still only the tip of the iceberg'

in order to drown the pathogens. Soil microbiologist Wietse de Boer: 'The disadvantage of that is that the useful soil organisms are wiped out too.' These include the bacteria and fungi which promote a natural immunity, or which make nutrients available to the plants. 'Over time, the original composition of micro-organisms is restored and the natural immunity comes back too. So the soil has a self-renewing capacity. But three months after flooding the fields, the useful organisms have not usually returned yet. It would be nice if we could speed up this process, and if we could slow down the establishment of opportunistic pathogens by introducing useful organisms.' This is not happening yet, but according to De Boer it is a serious possibility. >

> **‘The crux is that organisms have their effect in interrelation to one another’**

In fact, farmers have been using ‘ecological’ methods of combatting pathogens for centuries. The best-known example is crop rotation: farmers do not grow the same crop on a plot of land year in year out. This is because many pathogens are species-specific so they will disappear from the soil if ‘their’ crop is not grown there for a while. But this is not a panacea, notes De Boer. After asparagus has been harvested, for instance, pieces of root often stay in the soil for 20 years, complete with harmful fungi. ‘So you need pesticides as well as crop rotation in order to stay on top of the pathogens,’ says De Boer. Up to now these are mainly chemical, but the EU guidelines for the use of chemical pesticides are getting stricter and stricter. That is why we are looking for organic alternatives.’

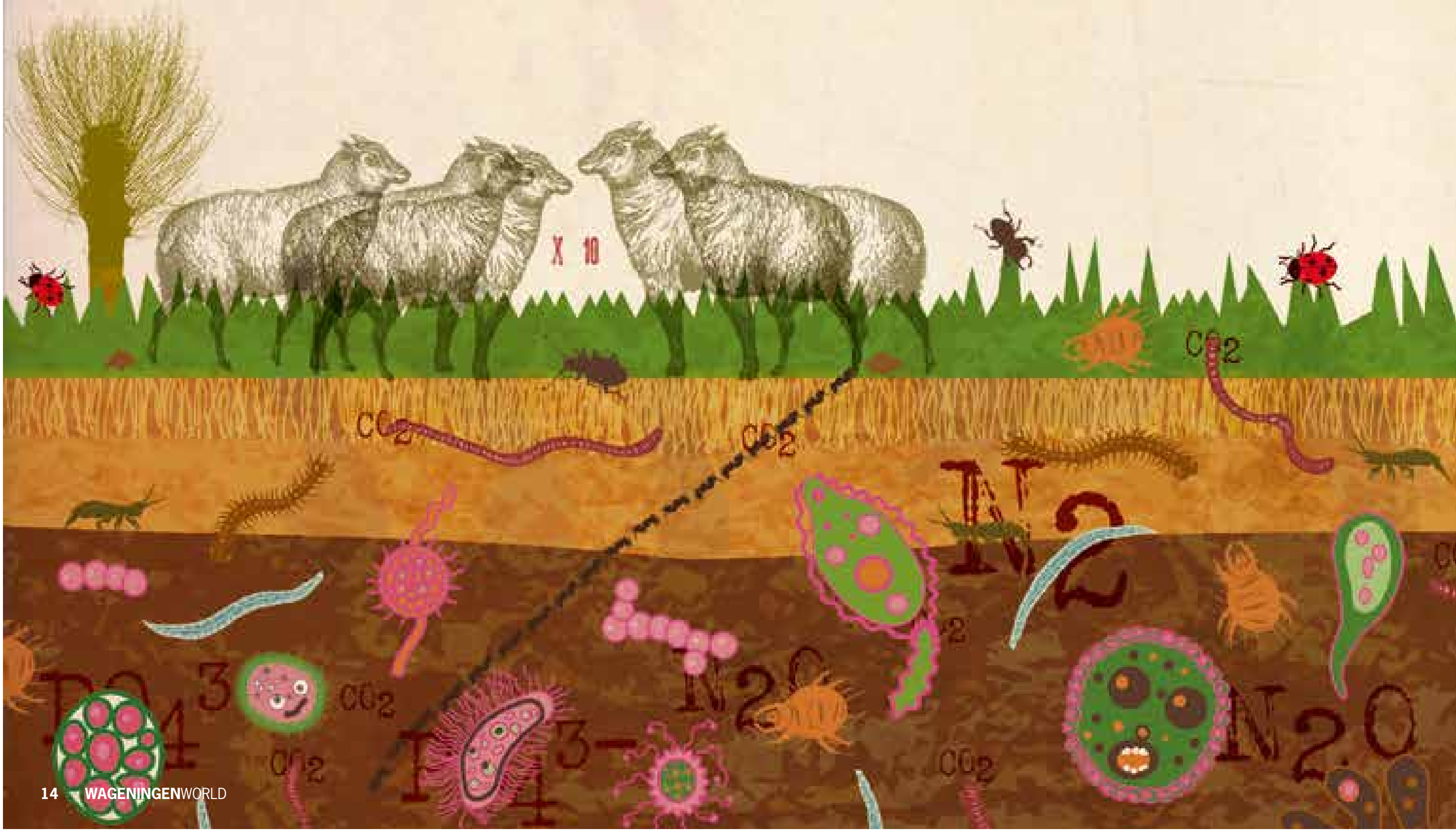
There are already some microbiological pesticides on the market, says De Boer. One of these is Mycostop, which contains an actinomycete, a fungus-like bacterium which produces antibiotics with which it suppresses pathogenic fungi. This substance is applied to the roots of young cucumber, tomato and bell pepper plants, for instance, when they are potted. De Boer: ‘But in the long run, these kinds of products often do not work well. The micro-organisms which are introduced do not seem able to fend for themselves in that underground battlefield.’

He thinks there is a more promising approach: stimulating the useful micro-organisms already present on the soil. ‘You could do that through very targeted fertilizer application, for instance,’ he says. ‘That makes it possible to create a kind of natural shield of useful bacteria and fungi around the crop’s roots.’ This principle was successfully tested recently by Applied Plant Research (PPO), part of Wageningen UR in Lelystad. Fertilizer containing ground shrimp waste, which contains a lot of chitin, proved to stimulate bacteria which break down chitin. Chitin is present in many damaging fungi as well. And this worked: the pathogenic soil fungus *Verticillium* was successfully suppressed by the chitin fertilizer. ‘But more research must first be done on this approach before it can be applied in practice,’ says De Boer.

Van der Putten too talks about new methods of organic pest control. His own research, for instance, has recently shown that growing willow shoots in a field is good for the wheat crop in the following year. ‘Exactly why that is, is not entirely clear,’ he says. ‘It might have something to do with the salicylic acid willows exude. That suppresses certain pathogens, so there are more worms, good nematodes, springtails and bacteria.’

FEWER APHIDS

Unexpected relations sometimes emerge between what happens underground and above ground. Agriculture can make use of this too in future, guesses Van der Putten. For example, fewer aphids live on grasses



that are eaten by soil nematodes than on healthy grasses. This is because the damaged plants make less of a particular amino acid which is essential for aphids. Remarkably, the aphids in this smaller group are larger than those of their species living on grasses without nematodes, because they are less hampered by competition. In turn, these larger aphids are more attractive prey for ichneumon wasps, which therefore visit the affected plant more often and keep it more aphid-free. ‘In this case, then, nematodes increase the plants’ defence system against aphids on two fronts,’ says Van de Putten. ‘Firstly through the substances in the plant itself, and secondly by attracting the aphid’s natural enemies. But these defences get broken if all the nematodes are destroyed by spraying.’
Wietse de Boer mentions another surprising new finding: micro-organisms influence each other from a distance by producing certain volatile substances. ‘They use these substances in their competition with each other,’ he explains. ‘That way they suppress each other and the pathogens as well. The next step is to find out which volatile substances particular pathogens are sensitive to, and then to stimulate the micro-organisms which produce them.’
This is still far off. But other new insights about soil are already being applied in the field. In the context of the greening of European agricultural policy, for example, farmers are expected to plant nitrogen-fixing plants and plants which lure harmful nematodes away from the main crop. ‘With this in mind we are now looking for multifunctional crops,’ says Van der Putten, ‘which have beneficial effects on several fronts: nutrient availability, soil structure, plant resistance and pest control.’

REMOVING SPECIES

The soil, conclude both experts, is one big black box in which hundreds of different biological and non-biological factors combine to determine how well plants grow. How do you separate these factors? ‘You can of course isolate individual species and study them in the lab,’ says Van der Putten, ‘but the crux is really that organisms often have their effect in interrelation to one another. So what we are also doing is removing species selectively, or trying to divide them into functional groups. By doing this we try at least to isolate a few factors from this big jumble of elements.’
Jan-Willem van Groenigen opts for the same approach in his earthworm research. He studies pots of soil containing not just earthworms but also hundreds of springtails, mites and other organisms. The researchers build up their experiments systematically from a simple collection of tiny creatures to an increasingly complex ecosystem. Then they exclude species in turn so as to see what changes. ‘An enormous logistical challenge,’ says Van Groenigen. ‘We not only measure the emission of gases but also make 3D images using x-ray tomography so as to see how these worms change the soil structure. Ultimately this allows us to model how gases get diffused through the soil under different conditions.’ ■

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