SCIENCE

Sampling soils at DIRT plots at Allegheny College's Bousson Experimental Forest. Pictured on the right is Rich Bowden, soil scientist at Allegheny College and an SSSA member, and then student at the college, Katherine Brozell. Photo by Derek Li, Allegheny College.

FEATURES

Thirty Years in the DIRT

Tracking the Controls of Soil Organic Matter in Forest Ecosystems

| **By** Tess Joosse

Most of you reading this probably know that "dirt" is a dirty word in soil science. As one of Rich Bowden's professors once put it, "Soil is where plants grow, dirt is what you get under your fingernails."

But "DIRT" means something different to Bowden, a soil scientist at Allegheny College and an SSSA member. It's an acronym for "Detritus Input and Removal Treatments," a decades-long, multisite experiment investigating the soil organic matter that governs physical, chemical, and biological functions of soil in forest ecosystems.

"The whole DIRT study began from a desire to understand fundamental controls on soil organic matter," Bowden says. With study sites spanning black cherry deciduous forests in northwestern Pennsylvania, old-growth coniferous forests in Oregon's Cascade Range,

- DIRT (Detritus Input and Removal Treatments) is a decades-long, multisite experiment investigating the soil organic matter that governs physical, chemical, and biological functions of soil in forest ecosystems.
- Soil scientist Rich Bowden established DIRT plots at Allegheny College's Bousson Experimental Forest in 1991. In a recent article in *Soil Science Society of America Journal*, he and his team track 30 years of the experiment's impacts.
- Though long-term research like DIRT doesn't immediately provide a payout, sustaining it now is essential for answering questions about gradual ecosystem changes.

DOI: 10.1002/csan.21414

Photo by Derek Li, Allegheny College.

Photo by Derek Li, Allegheny College.

and even forests in Hungary and China, the DIRT study investigates the sources of organic matter in soils for a variety of forest ecosystems.

In the study "Litter and Root Sources of Soil Organic Matter in a Temperate Forest: Thirty Years in the DIRT," published in *Soil Science Society of America Journal* (SSSAJ) as part of a recent special section highlighting proceedings of the 14th North American Forest Soil Conference (NAFSC), Bowden and colleagues report on results from their DIRT experiment site in Pennsylvania.

First, 'SOM' Background

Soil organic matter (SOM) comes from many sources. Leaves, seeds, flowers, and woody parts constitute what are known as aboveground inputs while belowground inputs include roots and their exudates. "There's all the soil fauna that are in there, too," Bowden explains: mycorrhizae attached to roots, fungi, bacteria, and soil-dwelling animals big and small.

Fecal and decomposing animal matter also contribute to SOM, but all SOM fundamentally is derived from plants, Bowden says. "That's critical because it's a source of nutrition. Those nutrients get cycled back into the system." Soil organic matter also provides structure to the soil and helps prevent erosion. "Like a nice sponge, it's terrific for water-holding capacity… it's providing energy, nutrients, and soil stabilization."

> **"Like a nice sponge, [SOM is] terrific for water holding capacity... it's providing energy, nutrients, and soil stabilization."**

But the prospect of increasing forest SOM's contribution to soil carbon storage is still up in the air. Soils are often touted as carbon sinks, and stakeholders often suggest improving forest management strategies to enhance soil C storage as the pace of global climate change quickens. However, researchers are still trying to understand what the controls are. When the DIRT experiments first started, "no one knew how important leaves were, or how important roots were, or what would happen if you added more," Bowden says.

DIRT's Origins

The DIRT network first sprung from a bus ride conversation between Knute Nadelhoffer, at the time a Ph.D. student at the University of Wisconsin–Madison (UW), and the late Francis Hole, a soil scientist at UW and 52-year member of the Societies. In 1956, Hole started a project at the UW Arboretum adding leaf litter input treatments to experimental prairie and oak forest plots and evaluating their long-term effects on SOM. Nadelhoffer was inspired and started up his own similar project at the Harvard Forest in 1990. There, he christened the projects with the DIRT name. Despite Hole's comments that dirt is what's swept out of the house while soil is the "complex and beautiful, yet unseen, world beneath our feet," he gave the moniker his blessing. (Nadelhoffer later moved to the University of Michigan Biological Station where he established more DIRT plots.)

That's also where Bowden got involved. In his postdoctoral research at the Harvard Forest, he was initially interested in soil respiration: what controls the rates of CO_2 coming out of soils. By removing live roots and adding or removing litter sources, Bowden and his colleagues calculated the proportions of respiration coming from live roots and from organic matter derived from above- or belowground litter.

Photo by Derek Li, Allegheny College.

> "Roots are certainly important, and we've never said they're not important. But they may be important is ways that we haven't appreciated before."

When Bowden arrived at Allegheny College in northwestern Pennsylvania in 1990, he decided to start up DIRT plots at the college's Bousson Experimental Forest. "Our soils are somewhat different. And I thought, well, let's see how the system responds here," he says. At Bousson, a 100-year-old forest likely used as pasture in the past, glacial till holds roots of stately black cherry trees and sugar maples in the understory. There, "we began to come up with more questions," Bowden says, like how forest soils absorb carbon in the context of climate change.

"I can't honestly say I knew I was about to embark on this now 34-year journey," he says of the study's initiation. But once they were up and running, it became clear that the plots had value for answering long-term questions—which, perhaps, most questions about soils and forests broadly are. "Soil processes are inherently slow," Bowden says.

Roots and Results

Bowden established the DIRT plots at Bousson in 1991 and has sampled them several times since. In his recent SSSAJ article, Bowden and his team sampled the plots in 2021 to track 30 years of the experiment's impacts and compare Year 30 to past sampling milestones.

The DIRT experiment includes a control, which receives typical above- and belowground inputs, a treatment receiving twice the typical amount of inputs (double litter), and a treatment with aboveground leaf litter removed. It also includes a no-root treatment, where the researchers severed the plot's roots and blocked their ingress in 1991 and then again in 2006, and a no-input treatment, which has both litter and roots removed.

The no-root treatments provided the biggest surprise of the study, Bowden says. "Of course, nature has other designs and doesn't always listen to our rules," he says. When the team sampled the plots in Year 20, roots had infiltrated despite the removal and blockage. "They're persistent," he says. "They just found a way to get in."

At Year 20, they found that no litter resulted in a big drop in soil carbon. "Our initial interpretation there is, 'Oh, leaves really matter,'" Bowden says. "But then we come back 30 years later, and especially in the no-roots plots that now have roots, the carbon has come back," he continues. "We don't fully … understand it yet, but the results suggested these roots have moved back in and they're bringing organic matter levels back up pretty quickly, faster than we thought," he continues. "Roots are certainly important, and we've never said they're not important. But they may be important is ways that we haven't appreciated before."

The double-litter plots also led to some unexpected insights. At Year 20, these plots paradoxically saw a decrease in carbon. What Bowden and colleagues gleaned from other work was that this was due to something called soil priming: with the additional material for soil microbes to "eat," they then had energy to go after and decompose other, harder-to-break-down sources of energy.

But now, at Year 30, organic matter in these double-litter plots has gone back up a tiny bit. However, throwing double litter on forests is not a fix-all management solution to boost SOM, Bowden says. "If you look at our double-litter plots … what we have is an incredibly extreme experiment. It's not meant to mimic differences in forest productivity. We're doubling it, that's a 100% increase in aboveground production, which is virtually impossible in an intact forest," he says. The researchers are still analyzing the full slate of Year 30 carbon, microbial, and molecular results.

Sustaining a Long-Term Soil Study

Thirty-plus years is a long time to keep up any scientific study, and Bowden notes that keeping the DIRT plots going can be a difficult task. "It's sometimes challenging because my plots are 3-by-3 m, so we're very careful with them," he says. The researchers have to be very deliberate


Photo by Derek Li, Allegheny College.

with their sampling. “Every time you take a sample out of there, you disturb the system,” he says. “We can’t turn it into Swiss cheese.”

Another important component of sustaining such a long-running study? “Developing a really cool set of highly talented colleagues.” The DIRT network includes study sites in Arizona, Idaho, Oregon, Hungary, and China in addition to the sites at the UW Arboretum, Harvard Forest, University of Michigan (UM) Biological Station, and Allegheny College. “We all work together and help each other and can contribute different kinds of analyses to the system; it makes it exciting and worthwhile to keep the experiments going even though you don’t necessarily see an immediate result coming out,” Bowden says.

Across all the participating sites, what does the future of the DIRT project look like? There are some options. “One is we can never retire,” Bowden laughs. Another more realistic path forward is for colleagues early in their career to take up the mantle. The plots at the Harvard Forest, UM Biological Station, and H.J Andrews Experimental Forest in Oregon all have assurances by site leadership that they’ll be maintained or have new principal investigators who have agreed to continue the experiments there.

Though long-term research like DIRT doesn’t immediately provide a payout, sustaining it now is essential for answering questions about gradual ecosystem changes, Bowden says. “We have to have the courage to invest in projects like this where the question is out there, two decades, three decades later, and you might not even know which direction the answer is going to go. But you’re not going to know until you put in the time to get the answer,” he says.

And though soil is at times dismissed by some as just “dirt,” its value can’t be overstated, Bowden adds. “Protecting soil really protects the productivity of the things that we as humans tend to think about most, whether it’s forage, crops, or forest.”

“Every time you take a sample out of there, you disturb the system. We can’t turn it into Swiss cheese.”

DIG DEEPER

View the original research in the *Soil Science Society of America Journal*:

Bowden, R.D., Simpson, M.J., Saucedo, N.P., Brozell, K., DiGiacomo, J., & Litter, K.L. (2024). Root sources of soil organic matter in a temperate forest: thirty years in the DIRT. *Soil Science Society of America Journal*, *88*, 593–601. https://doi.org/10.1002/saj2.20634

This article is part of the special section, “Proceedings of the 14th North American Forest Soils Conference,” which can be viewed here: https://bit.ly/3ZADNy3.