From: Science Magazine, July 28, 2023

Shaky ground

A company called Indigo is paying farmers to trap carbon in their soils. Some researchers say the climate benefits are dubious

By Gabriel Popkin

PHOTO: CAPELLE.R/GETTY IMAGES

Lance Unger has been doing things a little differently lately on his farm near the Wabash River in southwestern Indiana. After last fall's harvest, rather than leaving his fields fallow, he sowed some of

them with cover crops of oats and sorghum that grew until the winter cold killed them off. And before planting corn and soybeans this spring, Unger drove a machine to shove aside yellowing stalks—last season's "trash," as he calls it—rather than tilling the soil and plowing the stalks under.

For these efforts, a Boston-based company called Indigo paid Unger $26,232 in late 2021 and an even larger chunk late last year. That's how much an emerging market values the hundreds of tons of carbon that, in theory at least, Unger yanked out of the atmosphere with his cover crops or left in the soil by not tilling. Slowing climate change isn't a priority for him, he says, and it hasn't been easy to change his longstanding farming practices. But he says the money made it worthwhile. "I need to see economic benefits."

Indigo also made money in the deal. It took a 25% cut of the bundle of credits it then sold at about $40 per ton of captured carbon. Buyers were companies such as IBM, JPMorgan Chase, and Shopify, which were looking to offset greenhouse gas emissions from their operations and bolster their green bona fides.

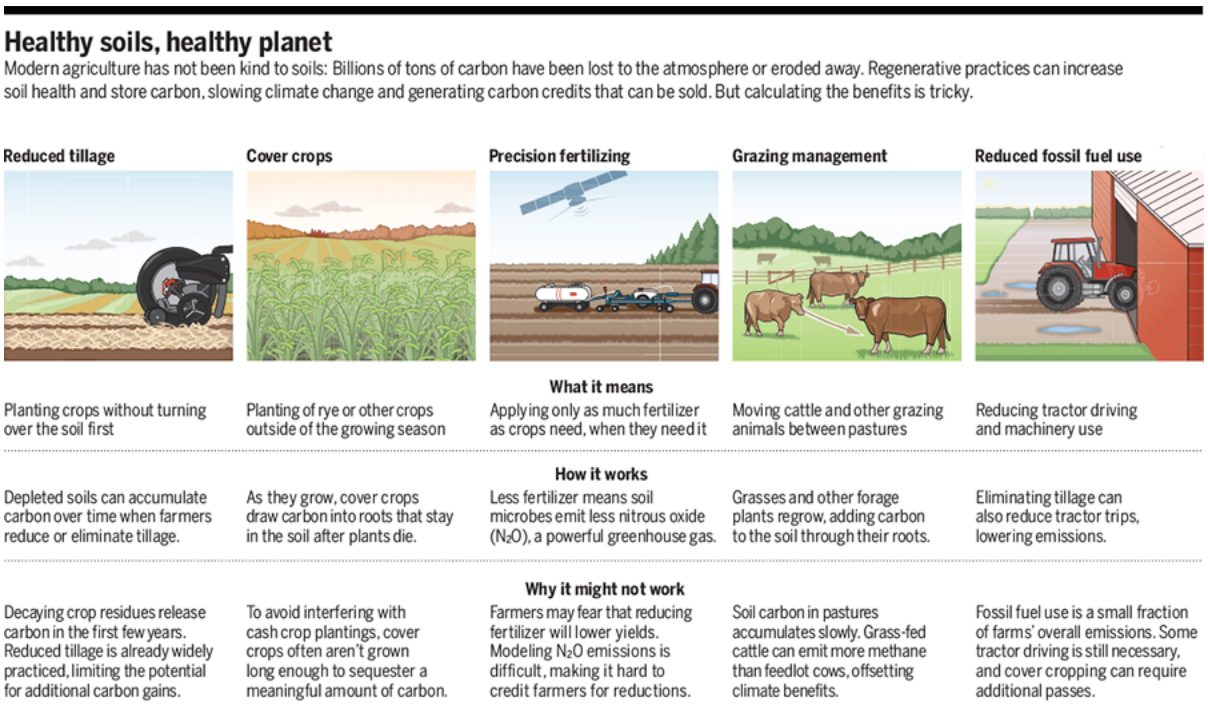

Illustration by A. Fisher

For advocates, the exchange represents a beautiful marriage of idealism and capitalism in the service of an urgently needed climate solution. If applied across the globe's farmland, soil-based carbon capture could offset between 5% and 15% of greenhouse gas emissions every year, according to an influential 2004 study by Ohio State University soil scientist Rattan Lal. "I and many other scientists have a lot of confidence that we can build carbon in soil," says Deborah Bossio, lead soil scientist for the Nature Conservancy.

Millions of dollars of soil credits have already been sold, and companies like Indigo are ramping up aggressively to claim a piece of an industry that could overall be worth $50 billion by 2030, according the consulting firm McKinsey & Company. With other carbon markets based on planting or preserving

trees facing accusations of peddling questionable or outright fraudulent credits, some buyers may see soil as a safer option.

But as the industry heats up, so does the skepticism. Some researchers say the science of how soils store and release carbon is too uncertain to support an industry claiming to be cooling the planet. They accuse companies like Indigo of exaggerating the benefits of their programs.

” I think the eagerness has sort of distorted the vision of what is really possible,” says Ernie Marx, a soil scientist who retired from Colorado State University (CSU) in 2021 and worked for more than a decade on the computer model Indigo and other companies use to calculate the credits. Emily Oldfield, a soil scientist with the Environmental Defense Fund who has examined soil-based carbon markets, also has her doubts. “It’s really hard to evaluate the actual greenhouse gas benefit of these programs.”

ONE THING is not in dispute: Modern agriculture has not been kind to soils—or the climate. Over millennia, microbes converted some of the carbon in dead trees and plants into long-lasting forms, building rich soils around the world. But since humans started plowing and disturbing soils some 12,000 years ago, about 116 billion tons of carbon have been lost, either eroded away by wind and water or digested by microbes and respired to the atmosphere as carbon dioxide (CO2), scientists estimated in a 2017 study.

So-called regenerative practices are supposed to build and protect soil carbon rather than release it. Some of the world’s biggest food giants, including General Mills, Land O’Lakes, and Cargill, have embraced the movement and claim to be reducing the climate impact of their supply chains by paying farmers to adopt regenerative tactics. The U.S. government is also pumping billions of dollars into what it calls “climatesmart agriculture.”

A Maryland farmer plants a cover crop after a corn harvest, a practice that can pull carbon from the air and store it in soils.
PHOTOS: EDWIN REMSBERG/VWPICS/UNIVERSAL IMAGES GROUP VIA GETTY IMAGES

Cylindrical cores pulled from fields are the gold standard for measuring carbon in soil. INDIGO AG

A meta-analysis of data from experimental plots published in May offered encouragement. It found that no-till and cover cropping each increased topsoil carbon by an average of more than 11%, although the practices had to be applied for at least 6 years to generate significant gains.

Other recent findings have tempered some of the enthusiasm. Many studies show that when tillage is reduced, carbon accumulates in the topmost soil layers. But scientists who dug deeper often found offsetting losses, in part because crop residues that tilling would have driven into deeper soils instead decompose on the surface and release carbon into the atmosphere. And farmers usually till every few years anyway, to counter weeds and break up compacted soil, releasing much of the stored carbon in upper soil layers. When it comes to carbon, “I’ve never seen too much of a benefit in notill alone,” says Jon Sanderman, a soil scientist at the Woodwell Climate Research Center.

Many researchers have higher hopes for off-season cover crops such as rye or radishes, whose carbon-rich roots sequester carbon in the soil. But cover crops also have drawbacks. They can delay or complicate planting of the cash crop, so farmers often kill them early, sacrificing some of their benefits. And in colder regions, including much of the U.S. Corn Belt, the window between the fall harvest and winter is often too short and cold for cover crops to germinate and grow.

But perhaps the biggest impediment to the widespread adoption of climate-friendly farming is the lack of a practical way to quantify the soil carbon gained through a regenerative tactic. Even harder to measure are emissions of nitrous oxide (N2O), a potent greenhouse gas released by soil microbes digesting nitrogen fertilizer that accounts for about 6% of total climate warming. Precise measurements would require expensive instruments and soil coring campaigns. “We don’t have a soil carbon thermometer to stick in the ground,” says Keith Paustian, a CSU soil scientist and consultant for Indigo. “A farmer can’t just check his N2O meter once a day.”

These issues have bedeviled companies trying to commercialize soil carbon. In 2019, Seattle-based startup Nori announced it had sold the first ever soil carbon credits, generated by a grower in Maryland. But its methods faced criticism. Not only did Nori collect no soil samples, it also did not have its credits validated by a registry—a third-party entity intended to add transparency and rigor to carbon markets. Scientists at Indigo thought they could do better.

The privately held company, which has raised more than $1 billion, had a different agenda when it launched in 2013. At that time, its focus was beneficial microbes that, when applied to crop seeds, were supposed to help plants grow faster and more resiliently. The company later set up a commodities marketplace to try to help farmers earn premiums for sustainably grown grain—a venture that didn't go as planned. In 2019, the company announced it was getting into the soil carbon credit business.

Unlike Nori, Indigo chose to work with a third-party registry called the Climate Action Reserve, known for its work in California's regulatory carbon market. And it would require 30-centimeter-deep soil cores, taken every 5 years, from 10% to 30% of participating farm fields—enough, the company's scientists calculated, to assess the total sequestered carbon with reasonable accuracy. The company would also rely heavily on an academic computer model, developed at CSU and funded by the U.S. Department of Agriculture (USDA), to estimate the climate benefits of farming practices.

THE MODEL, launched in the 1980s, was originally called Century because it simulated soil carbon dynamics on timescales of a century or longer. As concerns about climate change grew, the CSU team looked to expand the model to capture how the three major greenhouse gases—CO2, methane, and N2O—pass between air and land during a growing season. But Century modeled changes in monthly time steps, far too coarse to capture real-world greenhouse gas fluxes.

Young corn pushes through previous years' stubble. Planting without tilling is thought to improve soil health and store carbon. PHOTO: RON NICHOLS/USDA NRCS

By the late 1990s, researchers had upgraded to a daily time step, and DayCent was born. It has since become one of the world's most prominent soil models. Many of world's top climate change–forecasting models include DayCent code, and the U.S. Environmental Protection Agency relies on its results for annual emissions reports to the United Nations.

Despite its prominence, DayCent has plenty of shortcomings. It doesn't explicitly represent how soils actually work, with billions of microbes feasting on plant carbon and respiring much of it back to the atmosphere—while converting some of it to mineralized forms that can stick around for centuries.

Instead, the model estimates soil carbon gains and losses based on parameters tuned using published experimental results.

Another challenge is accounting for N2O, which soil microbes can belch out suddenly in big pulses. Without explicitly representing microbial activity, DayCent has struggled to predict when soils will vent the gas, and how much. “N2O is even more uncertain than [soil organic carbon],” says Ram Gurung, a CSU statistician who works on the model.

A third weakness: To tune and ground-truth DayCent, researchers rely on data from a modest number of university and government field trials that do not always mimic real farm conditions accurately. It’s far too puny a data set to represent the vast, varied landscapes and farming systems in the United States, much less the world, says Stephen Ogle, a CSU soil scientist and one of DayCent’s primary developers. “I would say we’re data hungry.”

The limitations saddle the model output with uncertainties that can be especially large for small areas. A 2010 study led by Ogle found these uncertainties could exceed 100% for a particular farm or even a statesize region, meaning the model could not say whether soil carbon had accumulated or decreased over time.

Nevertheless, some CSU researchers, along with their USDA sponsors, wanted to make DayCent modeling more publicly accessible. In the early 2010s, they released COMET-Farm, a web tool based largely on DayCent. Farmers could input information about their fields and proposed practice changes, such as reducing tillage or introducing cover crops, and obtain an estimate of the carbon they would sequester.

Companies began to show interest in using DayCent and COMET-Farm for carbon markets. Marx says concerns about the giant uncertainties were increasingly brushed under the rug, giving way to what he calls a “gold rush mentality.” In 2019, Paustian, leader of the CSU modeling team, founded a company called Soil Metrics to provide commercial access to DayCent. Both Nori and Indigo became clients, and in 2021, Indigo acquired Soil Metrics outright, with Paustian becoming a consultant. “I never wanted to work in business,” Paustian says, but his research group couldn’t keep up with the requests they were getting for help.

AROUND THIS TIME, Paustian and other CSU researchers launched a new project to better quantify the model’s uncertainties. Marx says the research team found that the uncertainties were still too large to tell whether a particular change in farming practice was having a positive or negative impact on the climate. The results were never published, and the public-facing COMET-Farm interface continues to state that methods to estimate uncertainty are “currently under development.”

Adam Chambers, a USDA program officer who funds and oversees the development of DayCent and COMET-Farm, says the uncertainty analysis proved harder than anticipated. “We’ve kind of bumped up against the limits of science,” he says. “We’re stumped.”

Chambers also shared with Science a Word document marked “Confidential Draft” describing part of the unpublished CSU-led project. It shows that DayCent’s results are not only uncertain, but also biased in ways that exaggerate carbon storage estimates for soils containing above a certain amount of carbon. Chambers says it could take years to understand and correct the bias.

In the meantime, Ogle says, the bias means the climate benefits of regenerative practices, though likely greater than zero, “may not be as large as we’re estimating.” He acknowledges that the team has fallen short in its reporting of uncertainties to farmers, policymakers, and other stakeholders. “We need to do better.”

Marx eventually concluded that the CSU team was deliberately obscuring the model’s shortcomings. “It doesn’t take that long to calculate uncertainty,” he says. In early 2021, he filed a complaint alleging that the uncertainty results had been suppressed, violating the university’s and USDA’s research integrity policies. He and Paustian were interviewed by an investigation committee. In his testimony, Paustian called Marx’s accusations “utterly false,” according to a copy of the committee’s report obtained by Science. He maintained that the project proved more challenging than expected and argued that because carbon storage projects created by companies such as Indigo are typically spread across many farms, quantifying uncertainties for a single field is not that relevant. “The uncertainty at Farmer Jones’s back 40 acres, to me that’s actually not really very meaningful,” he says.

Chambers also defends the team.

“There’s no other model that has done this much transparent disclosure of its strengths and weaknesses,” he says. Uncertainty estimates will be included in an updated version of COMET-Farm set to be released later this year, Paustian says.

In October 2021, the university dismissed Marx’s complaint. However, in its report, the investigation committee chastised the modeling team for claiming in the COMETFarm interface that results were “accurate”—a word that has since been removed from the website.

PEOPLE WORKING in soil carbon credit markets are aware of the limitations of DayCent and COMET-Farm. Radhika Moolgavkar, head of supply and methodology at Nori, which relies heavily on DayCent, calls the lack of uncertainty estimates “concerning.” Cristine Morgan, chief scientific officer at the Soil Health Institute, which is developing methods to sample and measure carbon in farm fields, says she has not seen a model good enough to support a soil carbon offset program. “In a transactional world, you want certainty, and the models are currently very uncertain.”

Regenerative practices such as cover cropping and no-till keep soil covered year-round. PHOTO: LANCE CHEUNG/USDA

Model uncertainty isn't the only problem researchers are finding with the soil carbon business. Indigo promises its credited carbon will stay locked in the soil for 100 years, offsetting fossil fuel emissions that will remain in the atmosphere for centuries. That means the company assumes farmers will maintain regenerative practices for that duration, long after annual payments end. Jane Zelikova, director of the Soil Carbon Solutions Center at CSU, is not persuaded. "The 100-year permanence isn't real."

Indigo says it is doing its best to reduce uncertainties in the model. It is attacking the problem using a new "Bayesian" method, whereby researchers identify the most important model parameters and tune them based on comparisons of the model's results and experimental data. "What Indigo is doing is far more sophisticated than what the USDA's own product is doing right now," says Michael Dietze, a Boston University ecologist who has reviewed Indigo's protocols. Although the overall approach is "not perfect," Dietze says, Indigo's strategy for merging measurements and modeling to provide reasonably accurate estimates "makes a lot of sense."

The company also accounts for uncertainties by putting 14.5% of the credits farmers create into a "buffer pool" rather than selling them, in case natural disasters wipe out carbon gains, says A. J. Kumar, Indigo's vice president of sustainability. "If we've done everything right," Kumar says, "the impact we've had is much more than we're actually creating credits for."

And the company is also doing the research scientists say is needed to put such schemes on a firmer footing. A couple of hours north of Unger's place on a farm near Arcadia, Indiana, a cover-cropped field sat alongside a bare one in April. Shortly thereafter, an Indigo-funded crew would descend on the site to pull out a slew of both 30-centimeter and meter-long soil cores that the company hopes will reveal how much faster carbon is building up in the covercropped field. Meanwhile, a solar-powered flux tower measures CO2 wafting into and out of soil every 100 milliseconds. It's all part of an ambitious soil carbon experiment that Indigo launched in 2019, alongside its offset program. And it will soon have a new ally: In July, USDA announced it would invest $300 million in a network of soil-monitoring sites across U.S. farmland—something researchers such as Ogle and Paustian have long pleaded for.

Indigo's leaders say these studies will add confidence, but waiting years for results to come in before launching their marketplace would have meant a disastrous delay. "Are we going to wait for the planet to catch on fire?" asks Chris Harbourt, Indigo's chief strategy officer. "We need solutions right now to reverse climate change." In December 2022, Indigo said it had paid more than 400 U.S. farmers $3.7 million for regenerative practices implemented on more than 170,000 hectares. Next year, it hopes to ramp up to 2.2 million hectares under contract. The chemical and seed giant Corteva has enrolled more than 400,000 hectares farmed by its customers in Indigo's program.

IN ORDER TO ultimately succeed, Indigo and other soil carbon capture programs will need more than the blessing of researchers. They will also need thousands of farmers willing to rethink practices that in many cases go back generations. Early adopters like Unger provide notes of both optimism and caution.

Although submitting years of farm data to Indigo was a pain, Unger says he has been happy working with the company so far. The payments have helped him stop tilling and plant cover crops on some of his lower quality fields—changes he wanted to make anyway. But Indigo doesn't pay enough to induce him to mess with his best fields. "If it aligns with what I'm trying to already do and they want to pay me for it, more power to them," Unger says. "But I'm not going to risk my future and my kids' future."

And like some researchers, he cautions against hyping regenerative agriculture too much. Ideas that work well on paper can be upended by the vagaries of weather, markets, and other unpredictable factors that farmers face.

“Telling people what to do on a farm when you sit in an office 1000 miles away from them is pretty easy. But if you’re the one out here making decisions every day … that’s not the world we live in,” Unger says.

“To say that every year a guy plants cover crops, that it’s going to be profitable for you, it’s going to work out—that’s a pipe dream right there.”