FEATURE

Can Dirt Save the Earth?

Agriculture could pull carbon out of the air and into the soil — but it would mean a whole new way of thinking about how to tend the land.

By Moises Velasquez-Manoff

April 18, 2018

When John Wick and his wife, Peggy Rathmann, bought their ranch in Marin County, Calif., in 1998, it was mostly because they needed more space. Rathmann is an acclaimed children's book author — "Officer Buckle and Gloria" won a Caldecott Medal in 1996 — and their apartment in San Francisco had become cluttered with her illustrations. They picked out the 540-acre ranch in Nicasio mostly for its large barn, which they planned to remake into a spacious studio. Wick, a former construction foreman — they met when he oversaw a renovation of her bathroom — was eager to tackle the project. He knew the area well, having grown up one town away, in Woodacre, where he had what he describes as a "free-range" childhood: little supervision and lots of biking, rope-swinging and playing in the area's fields and glens.

The couple quickly settled into their bucolic new surroundings. Wick began fixing leaks in the barn. Rathmann loved watching the many animals, including ravens, deer and the occasional gopher, from the large porch. She even trained the resident towhees, small brown birds, to eat seed from her hand. So smitten were they with the wildlife, in fact, that they decided to return their ranch to a wilder state. For nearly a century, this had been dairy country, and the rounded, coastal hills were terraced from decades of grazing. Wick and Rathmann would often come home and find, to their annoyance, cows standing on their porch. The first step they took toward what they imagined would be a more pristine state was to revoke the access enjoyed by the rancher whose cows wandered their property.

Within months of the herd's departure, the landscape began to change. Brush encroached on meadow. Dried-out, uneaten grass hindered new growth. A mysterious disease struck their oak trees. The land seemed to be losing its vitality. "Our vision of wilderness was failing," Wick told me recently. "Our naïve idea was not working out so well."

Wick was especially bothered by the advance of a prickly, yellow-flowered invasive weed called the woolly distaff thistle. He pulled it, mowed it, doused it with herbicides. But the distaff kept moving into what had been pasture. He thought about renting goats to eat the weeds and brush, but they were too expensive. He even considered introducing wild elk, but the bureaucratic hurdles seemed too onerous.

Then Wick and Rathmann met a rangeland ecologist named Jeff Creque. Instead of fighting against what you dislike, Creque suggested, focus on cultivating what you want. Squeeze out weeds by fostering conditions that favor grasses. Creque, who spent 25 years as an organic-pear-and-apple farmer in Northern California before earning a Ph.D. in rangeland ecology, also recommended that they bring back the cows. Grasslands and grazing animals, he pointed out, had evolved together. Unlike trees, grasses don't shed their leaves at the end of the growing season; they depend on animals for defoliation and the recycling of nutrients. The manure and urine from grazing animals fuels healthy growth. If done right, Creque said, grazing could be restorative.

Peggy Rathmann and John Wick on their Marin County ranch, where an atypical approach to land conservation led to unexpected success.
Jonno Rattman for The New York Times

This view ran counter to a lot of conservationist thought, as well as a great deal of evidence. Grazing has been blamed for turning vast swaths of the world into deserts. But from Creque's perspective, how you graze makes all the difference. If the ruminants move like wild buffalo, in dense herds, never staying in one place for too long, the land benefits from the momentary disturbance. If you simply let them loose and then round them up a few months later — often called the "Columbus method" — your land is more likely to end up hard-packed and barren.

Wick was persuaded. He began preparing for the cows' return. He dug wells for water, pounded in steel posts and strung nonbarbed wire. He even bought a molasses lick to supplement the animals' diet of dry thatch. He didn't want medicated livestock excreting drugs that might harm the worms and insects living in his soil — most cows are routinely dewormed — so he tracked down a herd of untreated cows and borrowed them for the summer of 2005.

The cows beat back the encroaching brush. Within weeks of their arrival, new and different kinds of grass began sprouting. Shallow-rooted annuals, which die once they're chewed on, gave way to deep-rooted perennials, which can recover after moderate grazing. By summer's end, the cows, which had arrived shaggy and wild-eyed after a winter spent near the sea, were fat with shiny coats. When Wick returned the herd to its owner that fall, collectively it had gained about 50,000 pounds. Wick needed to take an extra trip with his trailer to cart the cows away. That struck him as remarkable. The land seemed richer than before, the grass lusher. Meadowlarks and other animals were more abundant. Where had that additional truckload of animal flesh come from?

Creque had an answer for him. The carbohydrates that fattened the cows had come from the atmosphere, by way of the grass they ate. Grasses, he liked to say, were like straws sipping carbon from the air, bringing it back to earth. Creque's quiet observation stuck with Wick and Rathmann. It clearly illustrated a concept that Creque had repeatedly tried to explain to them: Carbon, the building block of life, was constantly flowing from atmosphere to plants into animals and then back into the atmosphere. And it hinted at something that Wick and Rathmann had yet to consider: Plants could be deliberately used to pull carbon out of the sky.

Climate change often evokes images of smokestacks, and for good reason: The single largest source of carbon emissions related to human activity is heat and power generation, which accounts for about one-quarter of the carbon we put into the atmosphere. Often overlooked, though, is how we use land, which contributes almost as much. The erosion and degradation of soil caused by plowing, intense grazing and clear-cutting has played a significant role in the atmospheric accumulation of heat-trapping gases. The process is an ancient one. Ice cores from Greenland, which contain air samples trapped thousands of years ago, reveal increases in greenhouse gases that correspond with the rise of farming in Mesopotamia.

Since the start of the Industrial Revolution, agricultural practices and animal husbandry have released an estimated 135 gigatons — 135 billion metric tons — of carbon into the atmosphere, according to Rattan Lal, a soil scientist at Ohio State University. Even at current rates, that's more than a decade's worth of carbon dioxide emissions from all human sources. The world is warming not only because fossil fuels are being burned, but also because soils, forests and wetlands are being ravaged.

In recent years, some scientists have begun to ask whether we can put some of that carbon back into the soil and into living ecosystems, like grasslands and forests. This notion, known as carbon farming, has gained traction as it becomes clear that simply reducing emissions will not sufficiently limit global warming. According to the 2014 report by the Intergovernmental Panel on Climate Change, an authority on climate science that operates under the auspices of the United Nations, humankind also needs to remove some of the carbon already in the atmosphere to avoid, say, the collapse of polar glaciers and the inundation of coastal cities worldwide. "We can't just reduce emissions," Keith Paustian, a soil scientist at Colorado State University and an author of an earlier I.P.C.C. report, told me. "It's all hands on deck. Things like soil and land use — everything is important."

Some of the proposed methods to begin this drawdown include scrubbing the air with great air-conditioner-like machines; fertilizing the oceans with iron dust to prompt algal blooms that, when they die, carry captured carbon to the bottom of the sea; capturing and storing the carbon dioxide that results when energy is produced by burning trees and other plants that removed carbon from the atmosphere during their growth; and crushing and spreading certain types of rock, like basalt, that naturally absorb atmospheric carbon. None of these approaches are yet proved or affordable at the scale needed to make a difference. The most obvious hurdle is the additional energy some of them require, which, unless it comes from a free, renewable source, adds more costs.

Plants, however, remove carbon from the atmosphere already, require no additional power and grow essentially free. During photosynthesis they harness the sun's energy to make sugars by combining hydrogen atoms (acquired from water molecules) with carbon atoms (from carbon dioxide), while emitting oxygen as a byproduct. (Lest we forget, the fossil fuels that now power civilization contain carbon removed from the air during photosynthesis millions of years ago.) Every spring, as the Northern Hemisphere greens, the concentration of carbon dioxide in the atmosphere dips, before rising again the following fall and winter as foliage dies. Some scientists describe this fluctuation as the earth breathing.

Nearly all the carbon that enters the biosphere is captured during photosynthesis, and as it moves through life's web, every organism takes a cut for its own energy needs, releasing carbon dioxide as exhaust. This circular voyage is the short-term carbon cycle. Carbon farming seeks to interfere with this cycle, slowing the release of carbon back into the atmosphere. The practice is often conceptualized and discussed in terms of storing carbon, but really the idea is to change the flow of carbon so that, for a time at least, the carbon leaving a given ecosystem is less than the carbon entering it.

Dozens of land-management practices are thought to achieve this feat. Planting or restoring forests, for one: Trees lock up carbon in woody material. Another is adding biochar, a charcoal made from heated organic material, directly to soil. Or restoring certain wetlands that have an immense capacity to hold carbon. (Coal beds are the fossilized remains of ancient marshes and peatlands.)

More than one-third of earth's ice-free surface is devoted to agriculture, meaning that much of it is already managed intensively. Carbon farming's fundamental conceit is that if we change how we treat this land, we could turn huge areas of the earth's surface into a carbon sponge. Instead of relying solely on technology to remove greenhouse gases from the air, we could harness an ancient and natural process, photosynthesis, to pump carbon into what's called the pedosphere, the thin skin of living soil at the earth's surface. If adopted widely enough, such practices could, in theory, begin to remove billions of tons of carbon dioxide from the atmosphere, nudging us toward a less perilous climate trajectory than our current one.

In a 2016 paper, Pete Smith, a soil scientist at the University of Aberdeen in Scotland, and the influential climate scientist James Hansen argued that land-management practices are one of the few affordable options available today for drawing down carbon. "What's surprising to me is that we've not done it sooner," says Smith, who is also a lead author on a recent U.N. report that explores carbon-dioxide-removal technologies. "This has the potential to make a huge difference." Otherwise, Hansen told me, we're leaving the problem to our grandchildren. "That assumption that somehow young people, and people later this century, are going to figure out how to suck it out of the air — that's a pretty big burden to place on them," he said.

The I.P.C.C. is preparing a special report on climate change and land use, to be finalized in 2019, that will consider in greater detail the potential of sequestering carbon in soil. But for now the biggest international effort to promote carbon farming is a French-led initiative called "four per 1,000." The proposal aims to increase the amount of carbon in the soil of crop- and rangelands by 0.4 percent per year through a variety of agricultural and forestry practices. These include agroforestry (growing trees and crops together increases carbon retention), no-till agriculture (plowing causes erosion and carbon loss) and keeping farmland covered (bare dirt bleeds carbon). Doing so, the French argue, could completely halt the buildup of atmospheric carbon dioxide.

Few experts I spoke to think the impact would be quite that grand; Pete Smith, for example, estimates that soil could, at the most, store just 13 percent of annual carbon-dioxide emissions at current levels. "I appreciate that everyone wants to save the planet," he told me, "but we shouldn't fool ourselves that this is all we need to do." Even so, the four-per-1,000 goal highlights how a relatively small annual increase in soil carbon could, on a large-enough scale, have a substantial impact. Increasing soil carbon could yield other benefits, too: Improvements in soil fertility, water retention and greater crop resilience would help agriculture adapt to a warming world. More soil carbon would also reduce the amount of fertilizer needed, decreasing emissions of the powerful greenhouse gas nitrous oxide, a byproduct of excess nitrogen fertilization. It would be profoundly appropriate if agriculture, whose modern practices have themselves contributed to climate change, could become part of its solution. Farming, responsible for the birth of civilization, could now help save it.

In 2007, at Jeff Creque's behest, John Wick got in touch with Whendee Silver, an ecologist at the University of California, Berkeley. Letting cows graze on his property had certainly made the land look healthier, he told Silver. But he and Creque wanted to know: Had it put carbon in the ground? And if so, was it possible to measure how much?

Silver was skeptical that she could measure what was likely to amount to very small changes in his land's soil carbon. The endeavor seemed akin to looking for cups of water added to a swimming pool. But she did sketch out a way to arrive at a definitive answer. When Wick offered to underwrite such a study, she warned him that he might not like the results. She wasn't just going to tell him what he wanted to hear. "That's when I knew I had to work with her," Wick recalls.

Silver agreed to the project, which she began that year. Seeking baseline values for the carbon concentrations in the soil, she and her students collected samples from different rangelands in Marin and Sonoma Counties. The samples with the most carbon, it turned out, came from current and former dairy farms. What distinguished these operations, she learned, was that they often sprayed manure onto their pastures; this was done both to fertilize the land and dispose of waste. Apparently, how soil was treated could very much affect its carbon content — a surprise. The larger implication was that people could potentially "grow" soil carbon deliberately.

But how quickly could they do so? Silver found an answer, in part, by looking for nuclear fallout. In the mid-20th century, radioactive carbon isotopes were spewed into the atmosphere as a result of aboveground nuclear tests. Plants around the world absorbed those isotopes during photosynthesis, effectively turning them into a time stamp. Wherever that carbon shows up, it must have arrived there relatively recently. On dairy farms, Silver found the isotopes a full three feet below the surface. This was another surprise. Conventional wisdom holds that it takes perhaps hundreds of years for carbon-rich topsoil to accumulate. On these dairy farms, however, atmospheric carbon had pushed deep into the earth in a matter of decades.

Wick wanted to know if he could deliberately replicate this process on his ranch — but without manure, which, as it decomposes, can release potent greenhouse gases like methane and nitrous oxide. The former traps about 30 times as much heat as carbon dioxide, the latter 300 times as much. As a carbon-farming tool, manure might be self-defeating.

Jeff Creque, a onetime organic farmer, had a suggestion: Why not use compost? Compost can contain manure, but whereas manure alone can release nitrogen as nitrous oxide, the nitrogen in compost becomes locked up in complex molecules. At least in theory, that limits the escape of a powerful greenhouse gas. In 2008, Wick, Silver and Creque spread several semi trucks full of the stuff, purchased from a composting plant near Sacramento, onto Wick's ranch and on another ranch in the foothills of the Sierra Nevada. In total, it amounted to about half an inch spread over three acres.

After three years, Wick was disappointed to discover that grazing on its own wasn't leading to carbon sequestration. In fact, the soil lost carbon in untreated control plots. No one knows precisely why, but grasslands throughout California are bleeding carbon. European settlers introduced shallow-rooted annual grasses to the state, which partly displaced deeper-rooted perennial grasses. So carbon put into the ground long ago by deep-rooted grasses may now be seeping out. That's what made the treated plots so remarkable. They had the same history and were exposed to the same conditions, but instead of losing carbon, they absorbed it — at a rate equivalent to nearly 1.5 tons of carbon dioxide per acre per year. That's roughly equal to your car's emissions if you drove from Miami to Seattle.

Silver had thought that the compost would simply break down, releasing its carbon back into the atmosphere or, worse, produce nitrous oxide. But those emissions never occurred; moreover, judging by its chemical signature, most of the carbon moving into the soil came from the air, not the compost. The compost appeared to help the plants draw more carbon from the atmosphere than they otherwise would have.

When it comes to mitigating climate change, soil scientists are most interested in what Silver calls occluded carbon — organic material, often in the form of dead microbes, trapped in clods of dirt. This type of carbon can potentially stay locked away for centuries. (Another carbon type, called labile carbon, continuously cycles among the atmosphere, plants and organisms in the soil.) It was precisely this more durable carbon, Silver discovered, that increased in the treated plots.

Her findings corresponded with a shift in recent decades in scientists' understanding of how soil carbon forms. Previously they emphasized how dead organic material had to physically work its way into the soil. But the newer model stressed the importance of living plants. Their rootlets are constantly dying, depositing carbon underground, where it's less likely to go airborne. And perhaps more important, as plants pull carbon from the air, their roots inject some of it into the soil, feeding microorganisms and fungi called mycorrhiza. An estimated 12,000 miles of hyphae, or fungal filaments, are found beneath every square meter of healthy soil. Some researchers refer to this tangled, living matrix as the "world wood web." Living plants increase soil carbon by directly nourishing soil ecosystems.

In the years that followed, Silver's analyses of soil cores indicated that the treated land kept taking in carbon. Computer simulations suggest that it will continue to do so for decades. It also retained more moisture and grew about 50 percent more grass. One dose of compost ignited what Silver calls a state change: The plants and the soil — and everything that inhabited it — moved toward a new equilibrium in which the soil ecosystem pulled in and retained greater amounts of carbon.

Silver began publishing her findings in scientific journals in 2010. Her second paper, written with her postdoc Marcia DeLonge and the graduate student Rebecca Ryals, offered a remarkable bit of extrapolation. California has about 56 million acres of rangeland, the single largest type of land use in the state. If compost made with manure was applied to just 5 percent of that area, they calculated, it would offset emissions from about 80 percent of the state's agricultural sector — all the cows raised, crops grown, fertilizer applied and tractors driven in California. Much of that offset came from diverting manure from festering lagoons — where it releases methane and nitrous oxide into the atmosphere — into compost, a one-time benefit. But the ongoing drawdown of carbon dioxide from enhanced grass growth could be important, too. If you treated 41 percent of the state's rangeland, Silver told me, carbon pumped into the earth by photosynthesis might render the entire agricultural sector of the world's sixth-largest economy carbon-neutral for years to come.

The soil-improving practices that Wick, Silver and Creque stumbled into have much in common with another movement known as regenerative agriculture. Its guiding principle is not just to farm sustainably — that implies mere maintenance of what might, after all, be a degraded status quo — but to farm in such a way as to *improve* the land. The movement emphasizes soil health and, specifically, the buildup of soil carbon. This happy coincidence is one reason that carbon-farming advocates repeatedly describe their project as a "win-win." Society could theoretically remove carbon from the atmosphere and store it in the earth, and at the same time enhance the fortunes of farmers and the overall stability of the nation's food supply.

Farmers' obsession with soil health isn't new, of course. It has been a preoccupation for ages. But modern, conventional agriculture has largely relied on synthetic fertilizer to compensate for losses in natural fertility. And while fertilizers help plants grow, some evidence suggests that they can, in excess, accelerate the loss of carbon from the soil. An influx of nutrients may feed precisely those microbes that release carbon back into the atmosphere. Plants may also excrete less carbon into the earth when bathed in synthetic fertilizers, causing the ancient relationship among plant roots, soil fungi and microbes — the symbiosis that increases soil carbon — to fray.

In recent years, the United States Department of Agriculture's Natural Resources Conservation Service, which was founded in response to the Dust Bowl crisis of the 1930s, has promoted the fostering of soil carbon as an important farming practice. But one of the more remarkable aspects of the regenerative-agriculture movement is that it has been driven largely by farmers themselves. Its proponents fret over soil carbon not necessarily because the N.R.C.S. tells them to, or because they worry about the planet's fate. They have discovered that doing so can help their bottom line.

Darin Williams is one such farmer. He lives near Waverly, Kan., with his wife, Nancy, in a tidy, gray-painted house with a stone chimney. A life-size plastic deer sits on his front lawn, run through with arrows; he uses it for target practice to sharpen his hunting skills. He's a big man with a baby face and a mischievous squint. When he drove me around his farm last October in his red "one-tonner" pickup truck, he talked incessantly about soil.

For nearly 20 years, Williams worked as a contractor, building houses in Kansas City. But work dried up after the financial crisis hit in 2007. Williams decided to return to the family farm near Waverly, an area of gently rolling plains, and give farming a try. His family had farmed some when he was a teenager before leasing the land to tenants for years, and he knew it was difficult to make ends meet. But he was inspired by an article about a North Dakota rancher and farmer named Gabe Brown, who claimed to have developed, through trial and error, a more efficient and cost-effective way to farm.

The gist of Brown's argument was that if you focus on the health of the soil and not on yield, eventually you come out ahead, not necessarily because you grow more corn or wheat per acre but because the reduction in spending on fertilizer and other inputs lets you produce each bushel of grain more cheaply. Williams decided to follow Brown's prescription. "If after three years, I'm bankrupt, I'll admit it was a bad joke," Williams remembers thinking.

Seven years later, his gamble seems to have paid off. He started with 60 acres, now farms about 2,000 and, when I visited last fall, had just purchased an additional 200. In one of his fields, we walked down a lane he had mowed through his warm-weather cover crops — plants grown not to be harvested, but to enrich the soil — which towered over us, reaching perhaps eight feet. They included sorghum, a canelike grass with red-tinted tassels spilling from the tops, mung beans and green-topped daikon radishes low to the ground. Each plant was meant to benefit the earth in a different way. The long radishes broke it up and drew nutrients toward the surface; tall grasses like sorghum produced numerous fine rootlets, adding organic material to the land; legumes harbored bacteria that put nitrogen into the soil. His 120-strong herd of British white cattle — he introduced livestock in 2013 — would eventually eat through the field, turning the plants into cow patties and enriching the soil further. Then he would plant his cash crops. "Had I not found this way to farm," he told me, "we would not be farming."

A mat of dead vegetation — from cover crops, cash-crop residue and dung — covered Williams's fields. The mulch, along with his cover crops, inhibited weeds from becoming established, a major concern for conventional farmers, because so many weeds have evolved resistance to herbicides. "I don't lie awake at night wondering how I'm going to kill weeds," Williams said.

Williams doesn't till his fields. By minimizing soil disturbance, no-till farming prevents erosion, helps retain moisture and leaves the soil ecosystem — worms, fungi, roots and more — mostly intact. At one of his soybean fields, Williams showed me how this translated to soil with "structure." "See how that crumbles into a cottage-cheese look?" he said, massaging a fistful of earth. Small clods fell through his fingers. "That's what you want." Worm holes riddled the dirt, giving it a spongelike quality that was critical, he said, for absorbing rain and preventing runoff. Weather patterns seemed to be changing, he noted. Rain used to arrive in numerous light storms. Now fewer storms came, but they were more intense. "We have to be able to capture rain and store it," he said.

By focusing on soil health, Williams says he has reduced his use of herbicides by 75 percent and fertilizers by 45 percent. He doesn't use pesticides — he relies instead on beneficial insects for pest control — and he saves money by not buying expensive genetically modified, herbicide-resistant seed. He estimates that he produces a bushel of soybeans for about 20 percent less than his conventionally farming neighbors. Last fall, he claims, his yields ranked among the highest in the county. While doing all this, he has so far raised the amount of soil organic matter, a rough predictor of soil carbon concentrations, from around 2 percent to 3.5 percent in some fields. Gabe Brown, for his part, says he has more than tripled his soil carbon since the 1990s. And an official with the U.S.D.A.'s Agricultural Research Service confirmed to me that the amount of carbon in Brown's soil — what his farming has pulled from the atmosphere — was between two and three times as high as it was in his neighbors' land.

The successes of Brown and Williams suggest that farmers can increase carbon in the soil while actually reducing their overall expenses. This could be vital, because in order for carbon farming to have an impact on the climate, as much land as possible, including both crop- and rangeland, will have to be included in the effort.

Critics of regenerative agriculture say that it can't be adopted broadly and intensively enough to matter — or that if it can, the prices of commodities might be affected unfavorably. Mark Bradford, a professor of soils and ecosystem ecology at Yale, questions what he sees as a quasi-religious belief in the benefits of soil carbon. The recommendation makes sense intuitively, he told me. But the extent to which carbon increases crop yield hasn't been quantified, making it somewhat "faith-based."

William Schlesinger, an emeritus soil scientist at Duke, points out that "regenerative" practices might inadvertently cause emissions to rise elsewhere. If you stop tilling to increase soil carbon, for example, but use more herbicides because you have more weeds, then you probably haven't changed your overall emissions profile, he says. He thinks the climate-mitigation potential of carbon farming has been greatly oversold.

Williams has reduced his herbicide use, not increased it, but Schlesinger's broader point — about the need for a careful overall accounting of greenhouse gases — is important. Williams, Brown and others like them aren't focused on climate change; no one really knows if the carbon they put in the ground more than offsets the methane produced by their cows, for example. What they do demonstrate is that augmenting soil carbon while farming is not only possible, but also beneficial, even in a business sense. And that makes the prospect of rolling out these practices on a larger scale much easier to imagine.

The carbon-farming idea is gathering momentum at a time when national climate policy is backsliding. The Trump administration has reversed various Obama-era regulations meant to combat or adapt to climate change, including the Clean Power Plan, which required power plants to reduce their carbon emissions, and a rule instructing the federal government to consider sea-level rise and other effects of a changing climate when building new roads, bridges and other infrastructure.

In the absence of federal leadership on climate — and as emissions continue to rise globally, shrinking the time available to forestall worst-case outcomes — state and local governments (as well as nonprofits) have begun to look into carbon farming. Last year, Hawaii passed legislation meant to keep it aligned with the Paris agreement, which President Trump has said he will abandon; the state has also created a task force to research carbon farming. The New York state assemblywoman Didi Barrett introduced legislation that would make tax credits available to farmers who increase soil carbon, presumably through methods like those employed by Darin Williams and Gabe Brown. A bill to educate farmers about soil has been proposed in Massachusetts. And in Maryland, legislation focused on soil health passed in 2017. Other carbon-farming projects are in the works in Colorado, Arizona and Montana.

But it is California, already in the vanguard on climate-mitigation efforts, that has led the way on carbon farming. By 2050, the state aims to reduce greenhouse-gas emissions to 20 percent of what they were in 1990. Nearly half its 58 counties have farmers and ranchers at various stages of developing and implementing carbon-farming plans. San Francisco, which already has the largest urban composting program in the country, hopes to become a model carbon-farming metropolis. Cities don't have much room to plant trees or undertake other practices that remove carbon from the atmosphere, says Deborah Raphael, the director of San Francisco's Department of the Environment. But they can certainly produce plenty of compost. "If we can show other cities how doable it is to get green waste out of landfills, we can prove the concept," Raphael told me. "We like to say that San Francisco rehearses the future."

Many of California's carbon-farming efforts owe a debt to Wick, Creque and Silver. In 2008, they founded the Marin Carbon Project, a consortium of ranchers, scientists and land managers. The goal is to develop science-based carbon-farming practices and to help establish the incentives needed to encourage California farmers to adopt them. Silver continues to publish her findings in respected journals. Creque also started a nonprofit, the Carbon Cycle Institute, that assists farmers and ranchers in making carbon-farming plans.

Wick has thrown himself into the policy realm, hiring a lobbyist in Sacramento to push a carbon-farming agenda. (In 2014, he even testified before Congress, outlining the project's discoveries and explaining how compost could increase soil carbon on public lands. He deliberately mentioned "climate" only once.) Educating policymakers matters because, as Torri Estrada, executive director of the Carbon Cycle Institute, points out, carbon-mitigation efforts that focus on agriculture can be much cheaper per ton of carbon avoided than the flashier energy-efficiency and renewable-energy projects that usually get most of the attention. The major obstacle to their implementation, he says, is that government officials don't understand or know about them.

California's Healthy Soils Initiative, which Wick helped shape, explicitly enlists agriculture in the fight against climate change. In principle, that means carbon farmers can receive money from the state's climate-mitigation funds not just for compost but also for 34 other soil-improving practices already approved by the Natural Resources Conservation Service. That's important because the compost needed to cover just a few acres can cost thousands of dollars. Wick has also tried to tap federal funding. Once N.R.C.S. scientists vet Silver's work, a compost amendment could become the service's 35th recommendation. As a result, farm bill money, which farmers receive to subsidize food production, could help finance carbon farming done according to Wick's protocol — not to fight climate change explicitly (which is now seen as politicized), but to bolster the health of soil (which isn't).

As a carbon-farming tool, compost bears some notable advantages — namely, it works both preventively and correctively. Composting prevents emissions from the starter material — manure, food scraps — that, if allowed to decompose, might emit potent greenhouse gases. (About one-fifth of United States methane emissions comes from food and other organic material decomposing in dumps.) By enhancing plant growth, it also aids in removing carbon from the atmosphere, a corrective process. And because the carbon in nearly all organic material was originally pulled from the atmosphere during photosynthesis, compost that enters the soil represents the storage of carbon removed from the air earlier — the grass eaten by cows that became manure, or the trees that became wood chips — and at a different location. That, too, is corrective.

Calla Rose Ostrander, Wick's right-hand person at the Marin Carbon Project, told me that the project's greater goal is to completely reframe how we think about waste, to see it as more than a nuisance — to recognize it as a resource, a tool that can help us garden our way out of the climate problem. Before the modern era, farmers had no choice but to return human and animal waste to the fields. (Wick is looking into the possibility of composting human waste as well; the end product is called humanure.) In a sense, Wick and Ostrander seek to resurrect these ancient practices and, with the aid of modern science, to close the loop among livestock, plants, air and soil — and between cities and the agricultural land that feeds them.

What seems to most impress experts about the Marin Carbon Project is the quality of Silver's research. Eric Toensmeier, the author of "The Carbon Farming Solution" and a lecturer at Yale, says that the project figured out a new way to increase carbon storage on the semiarid grasslands that cover so much of the world. Jason Weller, the former head of the Natural Resources Conservation Service, told me that "the level of science investment is out of the ordinary, or extraordinary, for a group that is really self-started." Weller added that the agency's scientists still needed to vet the research, which they are in the midst of doing. In late 2016 the agency oversaw the application of compost to different California regions — inland, Southern, Northern — to see if land in various conditions would, like Wick's ranch, suck up atmospheric carbon.

But the group also has critics. "I'm very skeptical of their results and their claims," William Horwath, a soil scientist at the University of California, Davis, told me. He wants to see Silver's experiments replicated. This is the project's major weakness: Its big idea is based almost entirely on extrapolation from a few acres in California. At this point, it's impossible to say whether compost can cause land to become a carbon sponge in all climates and conditions, and for how long treated grassland will continue to take in and retain its carbon.

Cows, a flash point in any discussion about climate change, may also present problems. Ruminants burp methane, and while carbon farming does not require their presence, some argue that merely accepting them on the land undermines the goal of reaching a carbon-neutral or -negative future. Livestock emissions account for almost half the heat-trapping gases associated with agriculture, so an obvious way to reduce emissions is to decrease the number of cows on the planet. Instead of dumping compost on rangeland, says Ian Monroe, a lecturer on energy and climate at Stanford University, why not allow forests cleared for pasture to regrow, and change people's eating habits so they include less meat?

Criticism is directed at compost too. The stuff requires energy to produce; huge machines are required to shred the material and keep it aerated. And it's unclear if compost, like synthetic fertilizer, can cause nitrogen pollution when put on the land, or how much greenhouse gas composting itself generates. (As long as compost mounds are regularly aerated to prevent low-oxygen conditions, composting is thought to produce few emissions.)

Organic material from municipal sources can contain bits of plastic and glass, which no one wants on their fields. Manure might carry seeds of invasive plants. (Silver has seen no evidence of this.) Spreading compost on public rangeland could disrupt plant communities, squeezing out species adapted to conditions of scarcity. And in any carbon-farming scheme, who will monitor and verify that far-flung stretches of land are really absorbing and storing the carbon as they're supposed to?

Horwath considers the amount of compost used in Silver's research — about 10 times the usual application, he estimates — to be unrealistically high for practical use. "It seems an inordinately large amount to apply to any system," he told me. And given what he sees as the many unknowns in Silver's research, that compost would be put to better use on cropland where, he says, scientists know with greater certainty that it could improve water retention and the efficiency of fertilizer.

Then there's the problem of supply. Demand for San Francisco's compost, which mostly goes to vineyards in California's wine country, already outstrips what's available. But Wick thinks more starter material shouldn't be hard to find: Americans throw out between 30 and 40 percent of all the food they buy, sending it to landfills where it rots and generates greenhouse gases. Silver has calculated that there's enough organic waste material in California to treat one-quarter of its rangeland every few decades.

Still, given the energy requirements, the logistical headaches and the cost, skeptics question whether spreading compost across extensive portions of the world's surface — including conflict zones in the Sahel or Central Asia — is really feasible. Even if it is, soils probably can't soak up carbon indefinitely. If they have a saturation point, increases in carbon will eventually stop when that moment is reached. And because soil degradation can cause the release of whatever carbon it holds, treated lands would have to be well cared for in perpetuity.

On a cool autumn day at Wick and Rathmann's ranch house, Wick fielded phone calls while I wandered around the cluttered, semicircular room that served as his office and meeting space. A whiteboard displayed scribbles from a presentation on the carbon cycle. Coils of warmly hued yarn hung from the doorways. They came via a local nonprofit dedicated to climate-friendly ranching practices called Fibershed. And draped over a chair was a T-shirt bearing what might as well have been Wick's battle cry: "seq-C," it read, punny shorthand for "sequester carbon." Under that it read, "Doing it in the dirt."

Down the road, he showed me a composting facility that Creque dreamed up initially. He and Wick hoped it would serve as a self-sustaining prototype. "Anything that has ever been alive can be composted," he told me, surveying the 10-foot-tall piles of chicken droppings and feathers, horse bedding (manure and straw) and shredded trees. A tractor mixed woody refuse with animal waste — to get the composting process started requires the right mix of carbon- and nitrogen-rich materials. (That's why some backyard composters recommend urinating on the pile to kick things off: Urine is rich in nitrogen.)

Across the lot, a hulking machine straddled rows of steaming black compost, turning them with a metal spinner. Compost has to be regularly "fluffed," or aerated, Wick explained, to prevent anaerobic microbes from producing methane and nitrous oxide. The manure piles were acrid, but the compost itself had a rich and pleasant odor, like cigars.

Wick hopes that facilities like this will someday dot the American agricultural landscape. The idea is to manufacture compost close to both its source material and the place where it will be used, obviating the emissions from carting heavy materials over long distances. The plant also embodied Wick's contention that composting can help farm carbon and manage waste at the same time. The challenge of affordably creating millions of tons of compost and applying it to great expanses of land is formidable. But there is a pleasing symmetry to the idea that we could use waste to bring the excess carbon in the atmosphere back to Earth, all while making the world lusher and more bountiful.

When I first got in touch with Wick, in late 2016, he greeted me with a question: "Do you know how the earth's atmosphere was oxygenated?" He was referring to a period 2.3 billion years ago when oxygen, produced by photosynthetic organisms, began building up in the atmosphere, prompting a mass extinction and clearing the way for multicellular life (and, eventually, humans).

"Cyanobacteria?" I guessed.

"Very good," he said. "This might work." Evidently I had passed some sort of scientific literacy test. But his bigger point was that living things — and particularly photosynthetic life — had always been the great engineers of the planet's climate. Now, he believed, we could use that fact to our advantage.

That sort of cosmic thinking about the planet and its history is ultimately what makes Wick's vision so compelling and potentially powerful. The essential insight is one often overlooked when we talk about climate change: The element that threatens to smother civilization is also, in different forms, the fundamental building block of life. To prevent carbon from causing misery and destruction, perhaps we just need to change its location. Perhaps we can find a way to pull it from the air and restore it to the earth.

Moises Velasquez-Manoff is a contributing Op-Ed writer for The Times and author of "An Epidemic of Absence: A New Way of Understanding Allergies and Autoimmune Diseases." He last wrote for the magazine about self-medicating animals.

A version of this article appears in print on April 22, 2018, Page 28 of the Sunday Magazine with the headline: Can Dirt Save the Earth?