Regenerative Organic Agriculture and Climate Change

A Down-to-Earth Solution to Global Warming

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Executive Summary

We are at the most critical moment in the history of our species, as manmade changes to the climate threaten humanity's security on Earth. In 2012, total annual global emissions of greenhouse gases were approximately 52 $GtCO_2e$. These emissions must soon drop to a net of 41 $GtCO_2e$ if we are to have a feasible chance of limiting warming to 1.5°C, above which point we dare not pass.

The key term in the above paragraph is "net." Gross greenhouse gas emissions come from numerous manmade sources. The resulting climate chaos has begun to modify our planet in ways that are not fully understood, leading to natural emissions that add to the complexity of the challenge. If we continue to attack the climate crisis solely from the direction of reducing gross manmade emissions, we will be forced to confront all the bewildering complexity of climate chaos. We will also be forced to battle carbon pumps everywhere – industrial, agricultural, the transportation sector – and from every direction on the globe. We will be forced to ask what countries should bear what responsibility, what industries should bear what portion of the blame and burden, and who should pay for the sacrifices we tremble to imagine? This daunting challenge is posed by trying to solve the problem by addressing only the "pump," and it has led to international bickering, incoherence, and inaction. People are left to pray for a yet undiscovered "technological messiah" to undo the damage, for our political will is paralyzed.

All this flows from the failure to look beyond the source of the problem, namely, the swarming carbon pumps that endlessly contaminate our atmosphere. The purpose of this paper is to redirect the discussion from the "swarm" to the "simple." We suggest an obvious and immediately available solution – put the carbon back to work in the terrestrial carbon "sinks" that are literally right beneath our feet. Excess carbon in the atmosphere is surely toxic to life, but we are, after all, carbon-based life forms, and returning stable carbon to the soil can support ecological abundance.

Simply put, recent data from farming systems and pasture trials around the globe show that we could sequester *more than 100% of current annual CO_2 emissions* with a switch to widely available and inexpensive organic management practices, which we term "regenerative organic agriculture." These practices work to maximize carbon fixation while minimizing the loss of that carbon once returned to the soil, reversing the greenhouse effect.

Regenerative organic agriculture for soil-carbon sequestration is tried and true: Humans have long farmed in that fashion, and there is nothing experimental about it. What is new is the scientific verification of regenerative agricultural practices. Farming trials across the world have contrasted various forms of regenerative and conventional practices and studied crop yield, drought impact, and carbon sequestration. Some of these studies are in their third decade of data, such as this Institute's Farming Systems Trial, and there are important fresh looks such as in the new Tropical Farming Systems Trial ("TFST") on the Caribbean slope of Costa Rica. The TFST is exactly the type of research needed for us to understand the full sequestration potential of regenerative agriculture, and Rodale Institute is pleased to be collaborating there with local researchers associated with Finca Luna Nueva and EARTH University. Taken together, the wealth of scientific support for regenerative organic agriculture has demonstrated that these practices can comfortably feed the growing human population while repairing our damaged ecosystem. This scientific support has also led the United Nations Commission on Trade and

Development ("UNCTAD") to issue, in September, 2013, it report "Wake Up Before It's Too Late," a powerful call for the return to these sustainable practices.

Developing a comparable set of global farming system trials designed to more specifically measure carbon sequestration is our best hope for demonstrating the power of regenerative organic agriculture to help solve the climate equation. At the same time, these trials will act as hubs of skills incubation and support networks for farmers already working in, or transitioning to, regenerative organic models.

Today there are farmers and agricultural scientists in every corner of the world committed to and excited about the results of regenerative organic agriculture's role in reversing both climate issues and food insecurity, and the specific research needs have been well documented. Now is the time to harness cutting-edge technological understanding, human ingenuity and the rich history of farmers working in tandem with the wisdom of natural ecosystems. Now is the time to arrive at a stable climate by way of healing our land and ourselves - through regenerative organic agriculture.

UNCTAD titled its report on regenerative farming "*Wake Up Before It's Too Late*."
This paper is the massive awakening.

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A Down-to-Earth Solution to Global Warming

Solving the long-term climate equation means getting to a zero carbon economy devoid of fossil fuels. It is widely acknowledged that we are not going to arrive at a new low-carbon economy any time soon; the technologies, markets, political and social structures needed to shift the world's economies are not materializing quickly enough.[1] In the decades it will take to decarbonize the economy, an unacceptable level of warming will become locked in.[2] With each passing year of inaction, hope for our planet's future becomes harder and harder to rally. We are on a trajectory of too little too late. If we wait, our only hope for the future lies in yet-to-be-discovered technological fixes coupled with the loss of whole cultures and species. The numbers are so sobering that untested technologies for carbon capture and storage have in short order gone from unsafe, outlandish whims to pressing societal needs: bioengineering the human body has even entered the climate conversation.

And yet, there is hope right beneath our feet. There is a technology for massive planetary geo-engineering that is tried and tested and available for widespread dissemination right now. It costs little and is adaptable to local contexts the world over. It can be rolled out tomorrow providing multiple benefits beyond climate stabilization. The solution is farming. Not just business-as-usual industrial farming, but farming like the Earth matters. Farming like water and soil and land matter. Farming like clean air matters. Farming like human health, animal health and ecosystem health matters. Farming in a way that restores and even improves on soil's natural ability to hold carbon. This kind of farming is called regenerative organic agriculture and it is *the* short-term solution to climate change we need to implement today.

We don't have to wait for technological wizardry: regenerative organic agriculture can substantially mitigate climate change, now.

On-farm soil carbon sequestration can potentially sequester *all* of our current annual global greenhouse gas emissions of roughly 52 gigatonnes of carbon dioxide equivalent (~52 $GtCO_2e$). Indeed, if sequestration rates attained by exemplar cases were achieved on crop and pastureland across the globe, regenerative agriculture could sequester *more* than our current annual carbon dioxide (CO_2) emissions. Even if modest assumptions about soil's carbon sequestration potential are made, regenerative agriculture can easily keep annual emissions to within the desirable lower end of the 41-47 $GtCO_2e$ range by 2020, which is identified as necessary if we are to have a good chance of limiting warming to 1.5°C.[2]

But agriculture as it is practiced today across most of the world is not part of the solution; it is, instead, part of the problem. Rather than mitigating climate change, it is a net producer of greenhouse gas emissions both directly through conventional farming practices that deplete soil carbon stocks while emitting nitrous oxide (N_2O), and indirectly through land-use change.[3] In addition, the intensification of livestock production and rice paddy agriculture has exacerbated release of the greenhouse gas methane (CH_4). Since the dawn of farming, most agricultural soils have lost from 30% to 75% of their original soil organic carbon.[4] With the widespread modernization of farming in the mid-20th century, contemporary agricultural practices, such as synthetic nitrogen fertilization, tillage, monocropping, and yield-based management systems,

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have accelerated the depletion of soil carbon stocks adding to the human-induced, or anthropogenic, atmospheric load of N_2O and CO_2.[3,5] Over the past decade, these direct agricultural emissions have increased about one percent a year, reaching 4.6 Gt CO_2 yr^{-1} in 2010, or about 10% of total annual emissions.[6] Direct emissions are not the whole picture. The food system at large, including feed, fertilizer and pesticide manufacture, processing, transportation, refrigeration and waste disposal, accounts for 30% or more of total annual global greenhouse gas emissions.[7]

Improved management of agricultural land with known, low-cost practices has the potential to both reduce net greenhouse gas emissions and to act as a direct CO_2 sink.[3,8] Moving agriculture from a source of carbon pollution to a potential carbon sink is in everyone's best interest. Agriculture that sequesters carbon is also agriculture that addresses our planetary water crisis, extreme poverty, and food insecurity while protecting and enhancing the environment now and for future generations.[9] Regenerative organic agriculture is the key to this shift. It is *the* climate solution ready for widespread adoption now.

What is Regenerative Organic Agriculture?

Regenerative organic agriculture improves the resources it uses, rather than destroying or depleting them. It is a holistic systems approach to agriculture that encourages continual on-farm innovation for environmental, social, economic and spiritual wellbeing.[10]

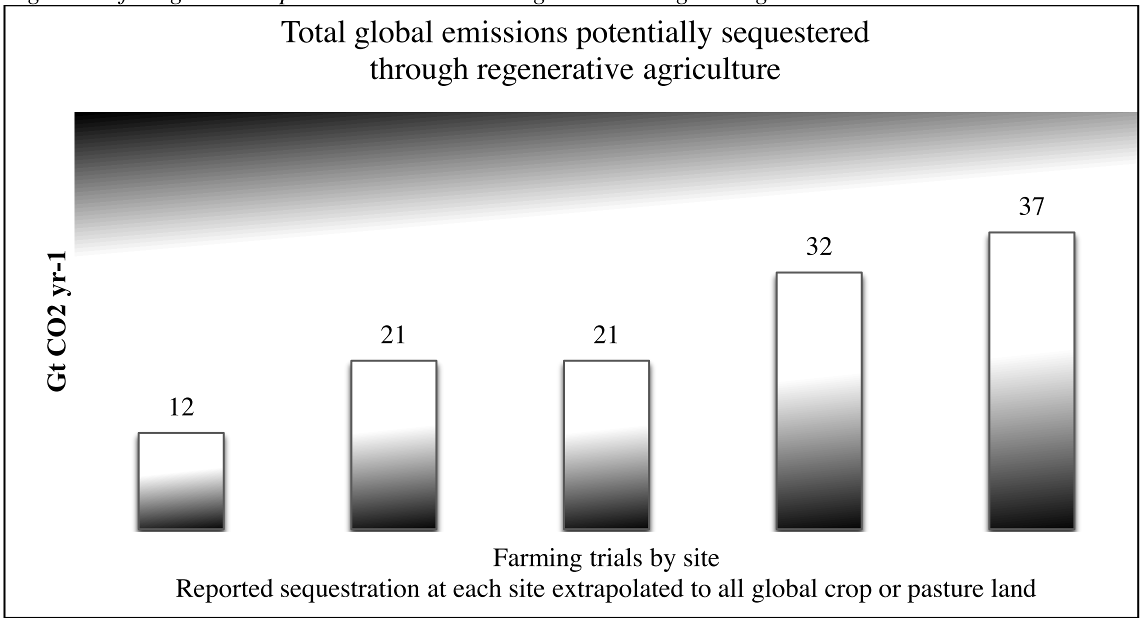
Robert Rodale, son of American organic pioneer J.I. Rodale, coined the term 'regenerative organic agriculture' to distinguish a kind of farming that goes beyond simply 'sustainable.' Regenerative organic agriculture "takes advantage of the natural tendencies of ecosystems to regenerate when disturbed. In that primary sense it is distinguished from other types of agriculture that either oppose or ignore the value of those natural tendencies." [11] Regenerative organic agriculture is marked by tendencies towards closed nutrient loops, greater diversity in the biological community, fewer annuals and more perennials, and greater reliance on internal rather than external resources.[11] Regenerative organic agriculture is aligned with forms of agroecology practiced by farmers concerned with food sovereignty the world over.[12,13]

Changing farming practices to organic, regenerative and agroecological systems can increase soil organic carbon stocks, decrease greenhouse gas emissions,[14] maintain yields,[15,16] improve water retention and plant uptake,[17]improve farm profitability,[16] and revitalize traditional farming communities[18] while ensuring biodiversity and resilience of ecosystem services.[17,19] Regenerative organic agriculture is also integral to the climate solution.

The Reversal Capability of Regenerative Organic Agriculture

Total global emissions of greenhouse gases in 2012 were about 52 $GtCO_2e$.[2] Annual emissions must drop to ~41 $GtCO_2e$ by 2020 if we are to have a feasible chance of limiting warming to 1.5°C.[2] Regenerative organic agriculture can get us there. Simply put, recent data from farming systems and pasture trials show that we could sequester more than 100% of current annual CO_2 emissions with a switch to widely available and inexpensive management practices.

Figure 1: If all global cropland transitioned to regenerative organic agriculture…



If management of all current cropland shifted to reflect the regenerative model as practiced at the Iranian or Egyptian sites (see figure 1 and table 1), we could potentially sequester more than 40% of annual emissions (an estimated 21 $GtCO_2$ each year). If, at the same time, all global pasture was managed to a regenerative model, an additional 71% (~37 $GtCO_2$) might be sequestered,[1] bringing us into an annual negative emissions scenario rapidly.

Table 1: Reported carbon sequestration from trials around the world

Place	Crop and practices	reported carbon sequestration	Extrapolation to all global cropland
U.S.[21]	Corn-Vegetable-Wheat | Organic, tillage, composted manure, legume cover crop	2.36 Mg C ha^{-1} yr^{-1}	12 Gt CO_2 yr^{-1}
Egypt[22]	Peanuts | Biodynamic, compost, irrigation	4.10 Mg C ha^{-1} yr^{-1}	21 Gt CO_2 yr^{-1}
Iran[23]	Corn | No-till, manure, hand-weeding	4.10 Mg C ha^{-1} yr^{-1}	21 Gt CO_2 yr^{-1}
Thailand[24]	Unreported Crop | Organic	6.38 Mg C ha^{-1} yr^{-1}	32 Gt CO_2 yr^{-1}
Global[25]	Pasture | Improved grass species	3.04 Mg C ha^{-1} yr^{-1}	37 Gt CO_2 yr^{-1}

[1] The pasture system figure is based on the maximum annual potential of 3.04 Mg C ha^{-1} yr^{-1} for pasture with improved grass species as reviewed by Conant et al., 2001. Globally, there is much more grassland and pasture than cropland.[20]

If we extrapolate to half rather than all of global pasture and cropland, transition to regenerative modes of production may sequester 55% (29 $GtCO_2$) of 2012 annual emissions. Even if only half of all available cropland shifted to regenerative agriculture and no changes are made in pasture management, we would meet the 2020 threshold of 41 $GtCO_2e$ that makes many scenarios for limiting warming to 1.5°C feasible.

These scenarios present technical sequestration potential as a heuristic that allows us to grasp the latent power of regenerative agriculture. Investing in human capacity, knowledge infrastructure and safe, known agricultural techniques can produce the change we need while providing myriad co-benefits to farmers and eaters everywhere.

Regenerative Organic Agricultural Practices that Sequester Carbon

Sequestration means maximizing the carbon dioxide pulled from the atmosphere by plant growth and minimizing the loss of that carbon once it is stored in soil. In technical terms it is the net difference between atmospheric carbon fixed through photosynthesis and carbon respired from all ecosystem constituents. Achieving on-farm carbon sequestration must be made an explicit management goal.[26] but there are longstanding regenerative management practices that are already proven soil carbon builders.

In practical terms, regenerative organic agriculture is foremost an organic system refraining from the use of synthetic pesticides and inputs, which disrupt soil life, and fossil-fuel dependent nitrogen fertilizer, which is responsible for the majority of anthropogenic N_2O emissions. It is a system designed to build soil health. Regenerative organic agriculture is comprised of organic practices including (at a minimum): cover crops, residue mulching, composting and crop rotation. Conservation tillage, while not yet widely used in organic systems, is a regenerative organic practice integral to soil- carbon sequestration.

Although many of these practices are most associated with organic farming, they are recommended management practices for all farms because they build soil organic matter, which has far reaching benefits for plant health and farm sustainability.[15] These practices minimize biota disturbance and erosion losses while incorporating carbon rich amendments and retaining the biomass of roots and shoots, all of which contribute to carbon sequestration by photosynthetic removal and retention of atmospheric CO_2 in soil organic matter.[3,27] These practices result from management decisions regarding cropping, amendments and tillage within the wider scope of a systems approach to farming that rejects synthetic inputs.

When coupled with the management goal of carbon sequestration, these practices powerfully combine with the spirit of organic agriculture to produce healthy soil, healthy food, clean water and clean air using inexpensive inputs local to the farm. This long-term integrated approach builds soil health, providing nutrients, pest and disease resistance. Farming becomes, once again, a knowledge intensive enterprise, rather than a chemical and capital-intensive one.

While the ensuing discussion of practices is helpful for understanding how regenerative organic agriculture can sequester atmospheric CO_2, these practices are not intended to be judged or implemented in isolation. Regenerative agriculture is, above all else, a holistic systems approach to appropriate farming in context. However, since the agricultural sciences most often hinge on reductionism,[28] data for specific practices and discrete suites of practices are mobilized here to help us understand the mechanisms at work in soil carbon sequestration.

The Problem of Bare Soil
Bare soil is detrimental to carbon sequestration and to soil health in general. Bare soil is an indicator of practices that are not maximizing atmospheric CO_2 removal nor minimizing soil carbon losses. Agricultural soils that are left fallow or are heavily tilled are exposed to wind and water leading to erosion of the carbon-rich topsoil. Fallow land also fails to accumulate biomass carbon that it would otherwise by continuously growing plants. Tilled, exposed, eroded soils lead to the breakdown of soil aggregates, allowing formerly stable soil carbon to be released as a greenhouse gas (CO_2).[29,30] Tillage further undermines soil carbon sequestration by debilitating the growth of mycorrhizal fungi, which are important for long-term sequestration through their role in aggregate formation. Reducing or eliminating tillage, using cover crops and enhancing crop rotations ensure that land will not be left bare and that soil carbon will be fixed, rather than lost.

Conservation Tillage
A recent research review found that almost all studies to-date show that switching to conservation tillage not only improves soil structure, but also reduces carbon dioxide emissions and contributes to increases in soil organic carbon.[31] But, reduced or no-till is only a boon to greenhouse gas emissions reduction when it is practiced within organic systems: the soil carbon gains achieved under conventional no-till agriculture are countervailed by the greater area-scaled N_2O emissions from nitrogen fertilization.[34,35] In addition, synthetic nitrogen fertilization increases microbial respiration of CO_2 while phosphorus fertilization suppresses the growth of root symbiotic fungi, which are important for long-term soil carbon storage.[5,75]

While no-till organic remains a marginal practice, its dependence on heavy cover cropping for weed suppression,[32] coupled with the benefits of organic management in general, have been shown to increase soil organic carbon by nine percent after two years and 21 percent six years after conversion to organic no-till.[32,33] No-till systems can best reverse the trend of soil organic carbon loses in agriculture when they are complemented by cover-cropping and enhanced crop rotations.[36,37]

Cover Crops
At least half of the cropland carbon is fixed aboveground in plant biomass,[38] making cover cropping and residue retention clear necessities for carbon sequestration. Cover crops can be temporary crops planted between main cash crops (often promoted for overwintering in temperate climates), nutrient catch-crops, or perennial mulches. Cover crops increase soil carbon, reduce nitrogen leaching and discourage wind and water erosion.[8] A wide range of additional benefits accrue with the use of cover crops: reduced weed pressure, decreased water runoff, improved soil structure and water infiltration, reduced evaporation and, in legume systems, atmospheric nitrogen fixation, which is often advantageous to the subsequent main crop.[39] Due to their longer leaf stage and more complex root systems, perennial cover crops, or living mulches, are an additional boon to soil carbon sequestration.[40]

Enhanced Crop Rotations
Moving crop rotations away from monoculture with fallow and towards polyculture with no fallow increases soil biodiversity and sequesters carbon.[37] For instance switching a wheat-fallow rotation to a wheat-sunflower or wheat-legume rotation was found to increase soil organic carbon stocks significantly,[37] and a continuous barley system more than doubled soil carbon stocks compared to a barley-fallow system.[41] Integrating seeded grass species as cover crops, living mulches, or in rotation is a powerful means of increasing soil carbon due to the deep, bushy root systems of many of these perennials.[25,37] Both cover cropping and enhanced rotations result in

continuous cover, which also increases soil microbial biomass carbon by ensuring available energy and root hosts for bacteria and fungi.[42]

Residue Retention

Cover crops also play a significant role in soil sequestration when their plant and root residues are retained rather than removed or burned.[43] These residues are the forerunners to soil organic matter.[8] Residue removal, whether of the main crop or a cover crop, has become common for the production of bio-energy. This practice depletes soil organic matter.[44] Conversely, retention of crop residue, which is common in no-till systems, is a significant driver of soil carbon accumulation.[36]

Compost

Plants, or a portion of plant residue, from cover crops or main crops can also be composted to boost soil health and soil carbon sequestration. Composting is the controlled aerobic decomposition of organic materials such as plants, animals or manure. The resultant compost is a desirable soil amendment; it increases soil biodiversity and microbial biomass with a concomitant rise in biological services, such as nutrient cycling, disease suppression and soil structure enhancement.[45] These soil benefits translate into greater soil health and productivity while reducing water or fertilizer needs.[46] The benefits are significant and accrue quickly: after only one application season of amending with compost, soil organic carbon and aggregate stability increase significantly compared with non-amended soils.[47] Amending with composted manure in particular shows great promise for soil carbon sequestration. In a 10-year trial, fields with a crop rotation utilizing composted dairy manure sequestered more than two metric tons of carbon (Mg C) per hectare per year, while the paired conventional farming system lost carbon.[21] In addition, when compost replaces synthetic nitrogen fertilizer, plants grow more roots, fixing more atmospheric carbon in the process.[23]

Complexity

The holistic interaction of management practices, soil conditions and climatic circumstances is more important than any one practice's potential contribution to soil carbon sequestration. For instance, while it is clear that conventional-chemical, tilled monocrop systems actually contribute to greenhouse gas emissions, similar monocrop systems that do not use tillage have very low rates of carbon sequestration.[36] Tilled organic systems fair better on soil quality indicators relating to carbon sequestration, including soil organic carbon, than similarly tilled non-organic systems.[26] The interaction of the suite of management practices with the specific soil and climate plays a significant role in organic matter stability. For example, soils with greater clay content tend to stabilize carbon more readily than sandy soils.[48,49] An illustrative case found that while only half of the carbon from composted poultry manure remained in the soil at five months, with the addition of clay to the manure, half of the carbon remained in the soil after two years.[48] This inherent complexity leads to a great deal of uncertainty in extrapolating results from one farm to another farm or in garnering consistent results attributable to a specific practice. It also highlights the need for research on comparable suites of practices in different soils and climates.

Timeframe for Sequestration

The goal of regenerative organic farming for carbon sequestration is not only to increase soil organic matter content through the practices highlighted here, but also to ensure the longevity of that carbon in the soil. Since the carbon cycle is dynamic and the study of soil in-situ is difficult, the factors influencing retention time of carbon in soil are inherently complex and not yet fully understood.[50] However, rapid, stable carbon sequestration under the conditions encouraged by regenerative agriculture is possible. Fungi, depth in the soil profile and recent understandings regarding the humic fraction of soil all play a role. An Iranian trial of no-till, low-input corn production showed that regenerative methods using composted manure were able to raise soil carbon by 4.1 metric tons per hectare per year in just two years compared to .01 metric tons for the paired tilled system using synthetic fertilizer.[23]

Mycorrhizal Fungi
While the understanding of soil carbon stabilization mechanisms is evolving, it is clear that soil biota play an important role here. In general, there is a positive relationship between abundance of fungal biomass and soil carbon.[53] Recent research on carbon sequestration in boreal forests suggests that root-associated, or mycorrhizal, fungi are predominantly responsible for fixing soil carbon, and for fixing it over long time periods to such an extent that it is consequential to the global carbon cycle.[54]

Arbuscular mycorrhizal fungi are root-symbiotic fungi that secrete a protein called glomalin; this particular fungi-root partnership and its glomalin are largely responsible for creating persistent, stable soil aggregates that protect soil carbon from being lost as CO_2.[55,56] The fungal hyphae actually increase in abundance under elevated atmospheric CO_2 conditions.[57,58] When the hyphae deteriorate, glomalin remains as a stable form of organic carbon that is held in the soil for decades.[56] This initial shorter-term stabilization provides the time for organic matter to create bonds with metals and minerals, the resultant organo-mineral or organo-metal complexes can remain in the soil for millennia.[27]

Since mycorrhizal fungi need root-partners to survive, farming strategies that include perennial plantings, conservation tillage, and plants with long, bushy root systems, encourage the long-term stabilization of carbon in soils.[5960] Likewise, promising effects have been shown for inoculation of soils with fungi, especially in cases where heavy tillage has destroyed the native population of mycorrhizal fungi. Arbuscular mycorrhizal fungi can be introduced to seedlings through inoculations that are easily prepared on-farm.[61,62]

Depth
It is likely that current data sets underestimate soil organic carbon stocks in organically managed systems because soil carbon is often measured at plow depth when recent findings suggest that more than half of the soil organic carbon stocks are likely in the 20-80cm depth.[14] Beyond 30cm in the soil profile, the age of carbon increases continuously, much of it persisting for thousands of years.[63] How carbon acts in this subsoil range is poorly understood, but increasing rooting depth,[55] application of irrigated compost[63] (compost tea), choosing deep rooted grass-legume cover crops[64] and encouraging earthworm abundance[65] are all promising pathways for introducing carbon to depths where it is likely to remain stable over very long periods.

Timescales
All soil carbon is in flux and the degree to which it is protected in undisturbed soil aggregates or separated from soil life largely determines how long it is held in soil.[27] But additions of fresh organic matter can, under the right circumstances, be effectively sequestered quickly. For instance, in tropical soils, results suggest that two years of organic management may significantly and consistently enhance microbial biomass carbon.[66] Even more promising, after only one cropping season, soil that had received 67Mg per hectare of compost and beef cattle manure had statistically significantly higher organic carbon levels.[47]

A long-term biodynamic desert trial in Egypt confirmed that soil carbon sequestration is greatest in the earlier years of transition to organic practices. In a first year plot 4.1 metric tons of carbon per hectare were sequestered, whereas the average over 30 years was 0.9 metric tons per hectare.[22] These results suggest that soil carbon can be built quickly enough to result in a rapid drawdown of atmospheric CO_2 upon transition to regenerative agricultural systems. However, it is probable that soils have unique carbon saturation points,[27,67] suggesting that soil carbon sequestration is a remedy that will allow time for implementation of additional long-term solutions to the climate predicament.

The Question of Yields

No discussion promoting the widespread transition to regenerative organic agricultural systems would be complete without mentioning yields. Yields are often touted as the reason why we cannot scale up organic and regenerative systems, but evidence suggests otherwise.

Metanalyses of refereed publications show that, on average, organic yields are often lower than conventional.[15] But the yield gap is prevalent when practices used in organic mimic conventional,[68] that is, when the letter of organic standards is followed using an input mentality akin to conventional chemical-intensive agriculture. Actual yields of organic systems, rather than agglomerated averages, have been shown to outcompete conventional yields for almost all food crops studied including corn, wheat, rice, soybean and sunflower.[15]

Importantly, yields under organic systems are likely to be more resilient to the extreme weather accompanying climate change. As found in the long-running Rodale Institute *Farming System Trial*, in drought years, yields were consistently higher in the organic systems. For instance, organic corn yields were 28% to 34% higher than conventional.[16]

What's more, the continued use of the trope that 'we will soon need to feed nine billion people' as justification for seeking ever greater yields is duplicitous. Hunger and food access are not yield issues. They are economic and social issues which, in large part, are the result of inappropriate agricultural and development policies that have created, and continue to reinforce, rural hunger.[69] We currently overproduce calories. In fact, we already produce enough calories to feed nine billion people. Hunger and food access are inequality issues that can be ameliorated, in part, by robust support for small-scale regenerative agriculture.[9]

Proving Grounds: Multiple, Global, Farming System Trials

As we have well learned from the charged climate debates, science evolves, contradicts itself and is certainly not definitive. The science of soil carbon sequestration is no different than climate science in this regard and it suffers doubly from a relative dearth of serious inquiry into organic, regenerative and agroecological systems due to the formidable economic and political constraints at work in contemporary agriculture and agricultural sciences research.[69–71] Questions abound over the technical and feasible potential of soil carbon sequestration when metanalyses are modeled regionally or globally.[14,67,72,73] Additionally, any claims of soil carbon sequestration must be balanced with a whole farm lifecycle analysis that considers, for instance, the origin and alternative fates of compost substrates and the role of livestock in organic systems.[65]

The range of potential and level of debate is a clear call for a new model of farming systems research: trials designed explicitly to study the carbon sequestration potential of regenerative agriculture as compared to conventional agriculture. Regenerative suites of practices can be studied alongside business-as-usual practices in different climates, soils and within different farming-culture contexts. The need for these data is pressing: scant peer-reviewed literature on soil carbon sequestration is available for most of the world's continents, including Africa, Central and South America and large swaths of Asia.[65]

The first of these global farming trials was initiated in 2013 on the Caribbean slope of Costa Rica, conducted by local researchers associated with Finca Luna Nueva and EARTH University. This *Tropical Farming Systems Trial* is partnered with and supported by Rodale Institute's long-standing U.S. based *Farming Systems Trial*. The *Tropical Farming Systems Trial* is designed to rigorously test and compare the carbon sequestration potential, total carbon footprint, yields and economics of conventional, organic and biodynamic farming systems.

Developing a set of global farming systems trials designed specifically to measure carbon sequestration is our best hope for quantitatively and definitively demonstrating the power of regenerative agriculture to begin reversal of_the climate equation. These trials will be designed with international comparison in mind while remaining grounded in local knowledge and farming cultures. At the same time these trials will act as hubs of skills incubation and support networks for farmers already working in, or transitioning to, regenerative models. There are committed, enthusiastic farmers and agricultural scientists in every corner of the world and the specific research needs have been well documented.[65,67,74] Now is the time to mobilize resources and seize this opportunity to change course, before it is too late.

Beyond Sustainable

We are at a critical moment in the history of our species. Climate change is a monumental opportunity to change course and move into a future that embraces life, a future bent on encouraging health, a future where clean air and clean water is available to all. In so many ways, a fundamental restructuring of how we cultivate our food is at the heart of this shift. Widespread regenerative organic agriculture will be built on supports that necessarily also support rural livelihoods, strengthen communities and restore health the world over. Regenerative organic agriculture is our best hope for creating a future we all want to live in, and a future our children will be happy to inherit.

Soil carbon sequestration through regenerative agriculture is a known, proven, technical, remedy to global warming: it gives humanity the necessary time to decarbonize. By investing in multiple, global farming system trials we can both provide the needed data to support widespread transition directly work towards that transition through incubating skills and providing a global support network, on the ground, for farmers to lead the evolution to regenerative systems.

This positive, hopeful vision for our future addresses many of our most pressing societal issues. It is a vision of agriculture that Robert Rodale urged us toward almost three decades ago:[10]

> My hope is that the period of sustainability will not be sustained for more than 10 or 15 years but that we will move beyond that to the idea of regeneration, where what we are really doing with the American Land is not only producing our food but regenerating, improving, reforming to a higher level the American landscape and the American Spirit.

Nearly 30 years later, the specter of climate change has provided an unparalleled opportunity to harness cutting-edge technological understanding, human ingenuity and the rich history of farmers working in tandem with the wisdom of natural ecosystems to arrive at a stable climate by way of healing our land and ourselves. Let's get going.

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