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The Paradox of the Plough

Paritosh Thakur and Sunil Jaswal

Department of Environmental Science, HPU Summerhill Shimla, India

ABSTRACT

Modern agriculture has transformed landscapes, increased food production, and enabled the growth of human civilization, yet it has also become one of the largest contributors to climate change, biodiversity decline, freshwater depletion, and soil degradation. This article examines the paradoxical role of agriculture as both an environmental challenge and a potential solution. It reviews the ecological consequences of intensive farming, including carbon losses from soils, methane and nitrous oxide emissions, and ecosystem degradation, while discussing the scientific principles underlying regenerative agriculture. Practices such as reduced tillage, cover cropping, crop diversification, agroforestry, and integrated livestock management are evaluated for their capacity to restore soil health, improve water resilience, enhance biodiversity, and sequester carbon. The article also considers the ongoing scientific debate regarding the magnitude and permanence of soil carbon storage, emphasizing that the broader environmental and agronomic benefits of regenerative agriculture extend beyond climate mitigation alone. Ultimately, sustainable agricultural transformation requires viewing soil as a living ecosystem whose restoration can simultaneously strengthen food security, environmental resilience, and long-term ecosystem sustainability.

***Keywords*:** Regenerative agriculture; Soil health; Carbon sequestration; Climate change; Sustainable agriculture; Biodiversity; Soil conservation; Ecosystem restoration.

1. Introduction

Agriculture has long been celebrated as the foundation of human civilization, providing food security and supporting economic development. Yet the same agricultural systems that sustain humanity have also become major drivers of environmental degradation through greenhouse gas emissions, deforestation, biodiversity loss, freshwater depletion, and soil degradation. This dual role presents one of the defining paradoxes of the Anthropocene: farming is simultaneously a contributor to global ecological crises and a potential solution to them. Recent advances in soil science and ecological research suggest that regenerative agricultural practices can restore degraded soils, enhance biodiversity, improve water retention, and sequester atmospheric carbon while maintaining productive farming systems. This article explores this paradox by examining how conventional agricultural practices have altered Earth's ecosystems and how regenerative approaches offer a scientifically grounded pathway toward more resilient and sustainable food systems. Rather than portraying agriculture as either villain or saviour, it argues that the future depends on transforming how we cultivate the land (Khangura et al., 2023a; Li et al., 2025; Yang et al., 2024). There is a violence, silent to us all, in a ploughed field. A freshly turned acre is dark, uniform. We see the ploughed ground as order, as cultivation of nature, as the dawn of the agricultural civilization that is the cornerstone of the modern world. The trillions of soil inhabitants, the bacterial organisms, the fungal hyphae, the tiny mites and springtails and microscopic predators that populate each handful of dirt, the plough is a tsunami. Each row passes is the plough uproots the microbial networks of a lifetime, releases the sequestered carbon of the soils they've protected, to oxygen and then to the atmosphere where it is released as carbon dioxide. When multiplied across the roughly five billion acres of land that humans farm or use for grazing, we see the dual life of agriculture: the activity that supports 8 billion humans and yet is one of the primary forces driving the climate crisis, along with the water crisis and the extinction crisis. The irony is striking: the cause of so much harm is also one of the tools by which that harm can be undone (Moroi & Sato, 1975; Sun et al., 2018).

2. A footprint the size of a planet

Agriculture is the single biggest driver of deforestation, is the number one cause of freshwater depletion, and a number one cause of species loss in the most rapid rate of decline in history, as the world moves into its sixth mass extinction event. It's one of the main causes of eutrophication, which leads to dead zones in the oceans. The industrial agriculture model, in which we replace biodiversity with monoculture crops, is the number one cause for species loss. The story of agriculture is one of the biggest experiments that humans are conducting on the planet's habitable zones and ecosystems. And we are conducting this without a lot of data about what we're actually changing (Ingrao et al., 2023; Pendrill et al., 2022).

So, let's start with the climate change story and the number that we know best. Agriculture is estimated to be the cause of roughly 20 to 30 percent of anthropogenic greenhouse gas emissions, which is about 16 gigatons of carbon dioxide equivalents annually. If agriculture were a country, it would be the number one emitter of greenhouse gases. And unlike any other source of greenhouse gases, its main greenhouse gases are not CO_2. Its main greenhouse gases are methane and nitrous oxide. Those are potent gases. And most of the emissions come from a relatively small group of foods: dairy, beef, and rice. Those are big methane emitters. Beef cattle produce methane in the same way that a human does in the stomach or colon. And rice paddies are flooded with water, where they lack oxygen and so, as the rice grows, they grow anaerobically, which means they produce methane. It's just biology. It's not that farmers are doing something wrong. It's not a choice that they're choosing to do this to the world. We have just multiplied biology by a million. So we have beef, dairy, and rice. And then, of course, there is nitrous oxide emissions from soils with too much fertilizer. That is the climate piece. But there are many, many others (Tubiello et al., 2021, 2022).

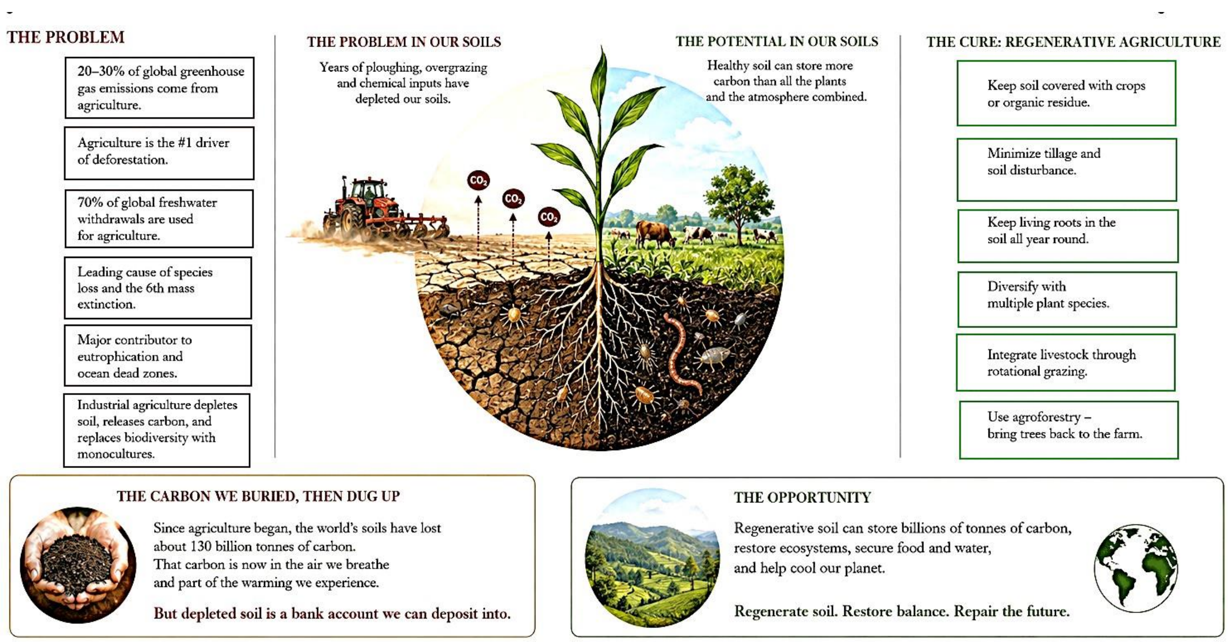

Figure 1. The Paradox of the Plough: From Soil Degradation to Regenerative Agriculture

3. The carbon we buried, then dug up

On the repair part of this equation, let's go back to the earth. The soil is not simply dirt; in fact, it is the largest store of carbon on land, more than all the trees and grasses on Earth combined and more than the entire atmosphere. Plants draw carbon dioxide from the air, and a surprising amount of that carbon goes back down into roots and is exchanged, through fungi, to the microbial economy that lives underground, where some of it ends up stored in stable pools that can sit there for decades, even centuries (Tao & Houlton, 2024; Tian et al., 2015).

For the most part of the last ten thousand years of farming, we have been withdrawing that account. According to one estimate, the world's soils have lost about 130 billion tons of carbon since agriculture began much of it since the 19th century, lost to the plow, to overgrazing, to wetland drainage, and to the unfailing practice of leaving fields bare between harvests. Today, that carbon lost from soil is in the air we breathe and part of the warming we experience (Lal, 2004; Sanderman et al., 2017).

A positive way to put this is straightforward: an empty field that was once depleted of carbon can, in theory, be filled. The soil is a depleted bank account; and depleted accounts are something we can deposit into. This is the assumption that underlies the cluster of practices that we now know as regenerative agriculture and both the enormous potential of the idea and the intense scientific debate surrounding it (Prairie et al., 2023).

4. What "regenerative" actually means

If you ignore the marketing, regenerative agriculture is mostly an old set of ideas rediscovered. Leave the soil always covered, with a growing crop or leftover organic debris, so it is never exposed to wind and rain. Minimize the disturbance of soil reduce or eliminate the use of the plow. Maintain living roots at all times, often using "cover crops" that never produce yield but are grown strictly to feed the soil. Cultivate many plant species together, rather than just one. Where it fits, move livestock back onto the fields as part of rotating grazing systems. Integrate trees into farming, a strategy known as agroforestry (Khangura et al., 2023b).

Nothing here is outlandish. Several of these methods would be familiar to a farmer from three centuries ago, or to today's subsistence cultivators that still terrace the mountain ranges of the Himalayas. The difference today is that researchers are finally focusing on a shared advantage of these practices: as they rebuild the soils, they also sequester carbon.

There is some compelling evidence to suggest this will be a huge help. Based on climate research, one study projects that increasing soil carbon via regenerative techniques globally could soak up about 23 billion tonnes of carbon dioxide per year by the middle of the century -- a substantial percentage of the emissions reductions needed to stabilize the climate. The most enthusiastic proponents take the case even further, claiming that farmland, if restored, could absorb a significant proportion of annual human greenhouse gas production (Paustian et al., 2019).

5. A promise worth interrogating

Here a responsible article has to slow down, because this is precisely the kind of number that deserves skepticism rather than applause.

A substantial group of researchers, including some who work at large environmental institutes, contend that the soil-carbon mitigation narrative, true as it may be, is exaggerated. Their argument goes something like this: Many soil-carbon-maximizing practices involve taking fields out of at least part of food production, meaning that carbon stored in a particular field can result in food (and forest) production being moved elsewhere. Soil carbon accumulation is also a saturable process: as a field refills its carbon bank, it asymptotes toward an eventual equilibrium, where it stops accumulating more. And, of course, carbon can be reversed. One plowing season, one drought, one owner change, and all those patient years of sequestration may be released to the atmosphere. Carbon stored in soil is a loan rather than an investment, with the potential to be called in at any time. Both propositions, in other words, are simultaneously correct, and the field's maturity is visible in its embrace of this contradictory truth. Regenerative agriculture practices are almost certainly not going to be a panacea that frees the rest of the economy from action, but neither are they some sort of con. Disagreements here tend to concern magnitude and durability rather than direction. Perhaps most importantly, the carbon discussion distracts from the much less controversial point that follows (Khangura et al., 2023c; Rehberger et al., 2023).

6. The case that doesn't depend on carbon

Assume, for the sake of argument, that the soil-carbon naysayers are entirely correct and the potential climate contribution from the regenerative movement is small. The case for healthier farmland would barely diminish, because the majority of the movement's benefits have very little to do with soil carbon. A soil high in organic matter is, effectively, a sponge. It absorbs heavy rainfall rather than channeling it into muddy streams, and it retains that water in the dry season, which is why, in practice, regeneratively managed fields tend to shrug off floods and droughts that devastate nearby conventional operations. In a warming world of increased rainfall intensity and longer dry seasons, this resiliency is no luxury but a matter of harvest versus failure. The soil biota that sequesters carbon also cycles nutrients, controls some pests and pathogens, and gradually reduces a farm's reliance on costly synthetic fertilizers whose production and excessive use cause so much downstream damage. Cover crops and complex rotations bring pollinators, predatory birds, and soil organisms back to a farm. Improved water quality means less dead zones in coastal waters. The essence of this unassuming but fundamental fact is that, although these practices are sold as climate solutions, they are really, first and foremost, agronomic solutions — practices that make farming more resilient, more autonomous, and, as we have already seen, more vibrant. Should carbon credits materialize, they will simply be an added advantage to something that already pays for itself while in the field (Fontaine et al., 2024; Khangura et al., 2023a).

7. Closer to home

The best examples can be the most unglamorous. The rice lands of South Asia demonstrate, through a technique called System of Rice Intensification, that rice paddies do not have to be constantly flooded – that, in fact, by draining them off and on, one can reduce methane emissions significantly while often increasing yields as well – an overly sweet deal that is moving from farmer to farmer. In the rain shadow parts of India, millets are being restored to a dominant position among food crops – tough, resilient grains that don't need heavy inputs of water or fertilizer, and that sustained populations before rice and wheat came along. In some Himalayan villages, the steep slopes and shallow soils never invited industrialization, so the traditional, mixed-cropping regimes have quietly kept most of what we think is new in regenerative agriculture alive all along. None of this can solve everything. Each example carries its own drawbacks, needs some education, and can't be pushed in from the top. But they also point, I think, to the main conclusion: farms of the future that are most promising for the environment might not resemble factories very closely (Materu, 2025; Pande et al., 2024).

8. Living with the paradox

It is a nice idea to want one simple result: farming is either the villain or it is the savior. But the truth is it is both. And that, I think, is not something we resolve, but a relationship we manage. We cannot take farming off the stage, nearly half the world's available land is now devoted to growing crops and raising animals, and we are not getting that land back. We can only ask: how do we farm? If we treat that land like a mine – extract, exhaust, run it into the ground, and it stays one of the heaviest weights on our overburdened planet. If instead we treat it as the living thing it is - cover it, keep it alive, keep it diverse those same fields can, gradually, imperfectly, give some of that back. In the end the plow is not the enemy of soil health. The thinking behind it is. For more than 10,000 years we have treated the soil as an inert stage on which the real play of life is enacted. New science asks for something humbler and stranger: that the soil is alive, that it has been keeping the books all along, that the most important harvests a farmer can take are the things we don't get to see, the carbon and the water, the life we have not known.

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