Promoting Biodiversity in Food Systems

Edited by

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CRC Press
Taylor & Francis Group

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SECTION I Biodiversity Loss, Planetary Boundaries, Food Systems, and Human Health

4 Our Soils in Peril

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> "The story of our relationship to the earth is written more truthfully on the land than on the page. It lasts there. The land remembers what we said and what we did."
>
> **Robin Wall Kimmerer,** *2013*

4.1 INTRODUCTION

Past civilizations from the valley of the Nile, Central and Southern America, China, North America, Soviet Russia, and Europe all share a similar story. In his book "Dirt: The Erosion of Civilizations", David R. Montgomery writes about how each civilization in its own way has known the importance of fertile soil as the key to agricultural productivity and yet has repeatedly made the mistake of mistreating and relentlessly mining precious top soil.

Early groups of hunter-gatherer humans figured out how to take care of the plants that fed them and kept them alive. Soon they discovered how to grow vegetables, tubers, and grains through the sowing of seeds in the soil. Thus began the process of farming or altering existing landscapes for human food. It wasn't long before they learned how to store surplus food and had enough to eat all year-round, providing a sense of security that led to larger families. Within just a few hundred years the small groups exploded into large and prosperous regions. A large population led to centralized systems of governance and economics. Despite becoming accustomed to their lifestyle, war and death brought an abrupt end to past civilizations.

What really happened to these societies? The question more accurately is, what has happened again and again to so many different civilizations that have existed throughout history? To understand this mystery, one needs to look a little closer at these highly evolved and well-organized societies to read the story that is hidden between the lines. This forgotten story is about the most neglected, exploited, and abused foundation of all civilizations: soil. Our repeated failure over the last 10,000 years to take care of the "living skin" of the Earth—the very basis for existence of all life on Earth—may lead us in the same direction of our predecessors (Montgomery 2007).

4.2 SOIL: THE FOUNDATION OF LIFE AND AGRICULTURE

To understand how the lack of soil conservation can destroy civilizations it is important to grasp what soil truly is and why it is so important. Only over the last few decades have scientists discovered and confirmed that soil is actually alive, extremely complex, and comprised of astounding biodiversity. Montgomery and Bilke (2016) defines fertile soils as, "the frontier between geology and biology; a mix of weathered rock fragments and organic matter". Often misunderstood as dead or inert, soil is actually bursting with soil dwellers and microbial life. We are only just beginning to understand the importance of what soil biologist Elaine Ingham calls the "soil food web" (USDA 1999). According to Ingham, the five main types of microorganisms found in the soil are bacteria, fungi, nematodes, protozoa, and microarthopods, which are abundant in both numbers and species (USDA 1999).

As mentioned in Chapter 3, a teaspoon of soil, depending on its fertility, may have between 1 billion and 7 billion organisms within which there may exist 75,000 species of bacteria, 25,000 species of fungi, 1,000 species of protozoa, and 100 species of nematodes (Ohlson 2014). Added to these microorganisms are other soil dwellers such as earthworms, beetles, voles, etc. and together they form the soil food web. There may be differences in the composition of these microbial species depending on different environments and soil types, but they perform similar functions everywhere. They play the role of decomposing organic matter, purifying water, and renewing soil fertility through nutrient cycling. Nutrient cycling refers to the ability of these microorganisms to convert decaying and dead organic matter (leaf litter, plant detritus, dead animals, etc.) into nutrients that the plants require for their growth (Ohlson 2014). In addition to decomposition, many microorganisms are capable of extracting minerals from rocks and subsoils thereby making those available to plants as well. This process of mineral mining and nutrient extraction by microorganisms had been occurring in the soil long before plants evolved on Earth. With the appearance of plants, however, the process of cooperation and symbiosis between plant and soil organisms began.

Plants help maintain the biology in the soil through exudates which are sugars, carbohydrates, and proteins that the plant releases through its roots to feed beneficial organisms (USDA 1999). These organisms, in turn, provide the plant with the nutrients through a complex web of interactions. Plants exudate one-third or 40% of their food to attract the microorganisms that will provide the plant with the specific nutrients it needs (Ohlson 2014). The zone near plant root tips is an area of intense soil organism activity called the rhizosphere. Unlike what is widely professed, plants need more than just nitrogen, phosphorus, and potassium. In healthy living soils, they receive all the fertilization they need through indirect processes in the rhizosphere. Soils that do not have organic matter cannot provide the food that soil dwellers need to survive, thus leading to degraded soils where plants are unable to thrive (Ohlson 2014). Nutrients from organic matter and plant exudates are first ingested by bacteria, which are then preyed upon by protozoa, nematodes, or microarthopods. These larger organisms, through their excretion, produce a chemical version of the nutrients that are finally available to the plant in a form it can absorb. Nutrients are distributed by mychorrhizal fungi that form symbiotic relationships with plant roots; the fungi are responsible for reducing plant competition through equitable distribution of those nutrients throughout the plant community (FAO and ITPS 2015).

Specific microorganisms are adapted to specific plant communities and environments. This specialization means that if you place a healthy plant in degraded soil, it will show signs of struggle because it is missing its special soil dynamics. Soil dwellers and microorganisms not only help plants access nutrients from the air (such as nitrogen), rocks, and organic matter—they also build soil structure by anchoring themselves to particles of sand, clay, and silt, gluing them together and building aggregates (Ohlson 2014). These aggregates allow for spaces in the soil for gases and water to move through without taking the soil apart and destroying the homes of these creatures. Earthworms and other larger organisms are well known for their process of aeration by moving up and down through the soil while eating and releasing nutrient-rich excretions. The benefits of having this healthy soil structure is that the ground becomes a large sponge capable of holding just the right amount of moisture and air that plants require. Their roots systems have the space and ease to grow in volume and length, which is the best sign of a healthy and productive plant.

Another important element of soil is carbon. Organic matter in soil contains 55%–60% of carbon by mass (FAO and ITPS 2015). Plants use carbon dioxide from the air for the process of photosynthesis. However, not all of it is used by the plant; some carbon gets stored in the soil as humus (Ohlson 2014). Plants growing on living, healthy soil can steadily remove carbon dioxide from the atmosphere, which is then sequestered in the soil (Ohlson 2014). Soils are capable of storing large quantities of carbon and are only second to oceans in being a carbon sink. Healthy soil can nourish plants leading to the maximization of carbon fixation with the added effect of reducing carbon dioxide in the atmosphere. These benefits depend on the organisms of the soil food web (Shiva 2017). Carbon stored in soil organic matter has helped determine essential soil properties and functions such as pH balance, nutrient storage and availability, and regulating soil moisture. When there is adequate soil carbon content, it has a positive impact on soil structure, particle agglomeration, and stability, as these properties influence water infiltration rates and create resistance to water and wind erosion (FAO and ITPS 2015). Healthy soils are key to sustaining soil fertility for thousands of years, making plants naturally resilient to environmental fluctuations, pests, and disease. Healthy soils can also prevent the release of carbon from soil into the atmosphere.

4.2.1 Learning from History

It was 5000 BC when agriculture first started in the fertile floodplains of the mighty Nile River valley. The floodplains were blessed with fresh silt deposits, which meant that soil nutrients were being renewed every year. For many years balance and prosperity prevailed through simple technologies, such as minimally modified seasonal irrigation overflow channels that were locally controlled (Montgomery 2007). By 3000 BC, surplus food production and storage led to the centralization of economics and governance, creating the desire to export. This led to a few key changes in the traditional agricultural practices. Irrigation changed from being seasonal to becoming more aggressive and year-round with cash crops grown for export. Over time this excessive irrigation led to the increase of salts in the soil, diminishing plant yields and degrading the fertility of the land (Montgomery 2007).

The Yao dynasty in China started around 2357 BC. As favorable agricultural conditions led to population growth, the demand for agricultural land increased. This led to deforestation on the surrounding hills for farming. Very quickly, intensive farming and grazing on the hills led to severe soil erosion on sloped hillsides. Less than 100 years after its establishment, the Yao dynasty collapsed (Montgomery 2007).

The story of ancient Rome, though much more complex, has a very similar story. The main impact in this case was through the introduction of the metal plow. Early Roman farms were multilayered, diverse, and farmers tended them by hand. When the metal plow was introduced, it allowed for deep subsoil digging and plowing of the hillsides. As productivity skyrocketed, severe soil erosion began within a few seasons of farming on fragile sloping lands. Philosophers Plato and Aristotle both posited the degradation of the land was due to the land-use practices of the Bronze Age (Montgomery 2007). Despite these warnings, the health of the soil was ignored. Farmers were encouraged to continue plowing and in less than a thousand years, the Roman heartland had lost all its precious topsoil (Montgomery 2007).

Loss of soil organic matter is what defines the story of the Mayan civilization. In 2000 BC the Mayans traditionally used the slash and burn method that involved deforesting a small area, farming the land for a couple of years, and then leaving the land fallow for 10 to 20 years, allowing the soil and ecosystem to regenerate during their absence (Montgomery 2007). This was a stable system that worked when there was access to large sections of land and a rather small population. But as the population started increasing from 200,000 in 600 BC to 1 million in 300 AD, the Mayans stopped moving from one piece of land to another and instead settled down, farming in the same spots (Montgomery 2007). This new intensive and extractive farming practice did not return any organic matter back to the soil and led to stripping the soil down to the bedrock. The Mayan civilization collapsed in 900 AD (Montgomery 2007).

The Egyptian, Yao, Roman, and Mayan civilizations degraded their topsoil and did not attempt to conserve the soil until it was impossible to reverse the damage in their lifetimes. Low-impact farming techniques supported smaller populations and healthy soils. High-impact methods introduced major changes that caused deforestation including new technologies like the plow, over-irrigation, and monocropping (cultivating just a single crop on a piece of farmland), which in turn caused increases in food productivity for short periods leading to population growth. However, the living topsoil steadily disappearing. Even if some efforts were made to save the soil in the end, it was too late for fertility to return quick enough to ensure their civilization's survival. Without anthropogenc involvement, soil rebuilding occurred at a rate that was too slow to sustain humans for thousands of years. Moving forward, erosion had degraded half of Australia's soils by the mid-1980s (Montgomery 2007). West Africa also experienced its own dust bowl in the 1970s (Montgomery 2007). This is the history of the human impact on soil in almost every part of the world.

4.3 MODERN AGRICULTURE AND SOIL

> "Death of soil is like a disease that remains undetected until the last stages when it has already become a crisis"
>
> **David Montgomery, 2007**

Presently, 38% of land on Earth is agricultural (FAO and ITPS 2015). The global population is expected to grow to 9.6 billion by 2050 (FAO and ITPS 2015). In the 21st century, our relationship with soil is greatly determined by our population densities and available cultivable land. Cultivated area per capita is expected to decrease by 50% by 2050 in less developed countries (FAO and ITPS 2015). It has been reported that food production will have to increase by 70%–100% to meet the population demands (FAO and ITPS 2015). However, approximately 20% of the Earth's vegetated surface shows persistent declining trends in productivity (UNCCD 2017). One-third of Earth's soils are severely degraded and fertile soil is being lost at an extremely high rate (UNCCD 2017). Only 28% of land still remains forested (FAO and ITPS 2015). These facts and figures convey that our population is growing—cultivable land is shrinking—and food productivity is reaching its limit. We are currently experiencing a silent global ecological crisis: the death of soil.

The major anthropogenic reasons for the loss of soil biodiversity according to *The Status of the World Soil Resources* report are: Intensive human exploitation, reduced soil organic matter and carbon, soil erosion, soil pollution, soil salinization, soil compaction, land-use change, and climate change (FAO and ITPS 2015). Purported solutions include intensification and expansion. Intensification would mean increasing the use of chemical fertilization, irrigation, tillage, and increased livestock density. Increasing these practices however will further diminish soil productivity due to the extractive nature of these practices. Expansion of agricultural land from an environmental and ethical perspective is no longer possible because it results in unfair land-grabs, rapid and irreversible deforestation of the last remaining forests, and worsening climate change (FAO and ITPS 2015). Many of the technologies that modern and industrial agriculture employs are directly or indirectly responsible for poor soil health and biodiversity loss.

Soil erosion is a global ecological crisis faced by almost every country in the world. The rate of soil erosion is naturally quite slow. The current rate of soil erosion on intensely farmed agricultural and pasture land is between 100 and 1,000 times faster than in natural landscapes such as forests and grasslands. Globally, 20–200 gigatons of soil erode every year through water and wind due to agricultural practices that expose soil (FAO and ITPS 2015). For agricultural productivity to sustain itself, soil erosion must be eliminated altogether. In other words, for farming to be sustainable the rate of soil erosion needs to be the same as the rate of soil creation. Soil erosion directly impacts soil organic matter content. If it runs off or blows away, it reduces water infiltration capacity of the remaining soil due to diminished microbial activity, and leaves behind an inhospitable environment for plants to survive in.

Soil salinization indicates elevated salt content in soil. Salinization increases osmotic pressure, diminishing the soil moisture and deteriorating the soil structure, allowing very little permeability of air and water. When soil structure collapses and moisture content is reduced, plants are inhibited due to lack of water and root growth, apart from being unable to process the high salt content. Soil salinization affects more than 100 countries and 1 billion hectares of soil all over the world (FAO and ITPS 2015). Salinization occurs due to poor management of salts and sodium in soils through the use of irrigated water with high salt and sodium content—and through bringing up deep groundwater to the soil surface. The impact of these practices is exacerbated by the replacement of deep-rooted plants with others that have shallow root systems (UNCCD 2017).

Soil acidification refers to the pollution of the soil due to the excessive use of ammonium-based fertilizers and removal of biomass through constant harvesting (FAO and ITPS 2015). It results in reduced microbial activity in soil. Thirty percent of all topsoil and 75% of all subsoil is affected by soil acidification.

Soil contamination is yet another result of excessive use of fossil fuels, pesticides, and other pollutants. Even though the extent of soil contamination is difficult to assess or quantify, the extensive use of pesticides and nutrients in soil are a problem in many parts of the world (UNCCD 2017). Genetically modified (GM) seeds are also a source of soil pollution through seeds that are left behind in the soil after a harvest. They also have unknown effects on soil microorganisms, such as bacteria that are capable of capturing and using genetic material from other plant matter. This may lead to genetic contamination (Damato 2009).

Loss of soil organic matter and carbon from soil occurs due to deforestation, land-use changes, and tilling of the soil. Carbon loss from soil is highest where land-use changes from native perennial or forest cover to agricultural land (FAO and ITPS 2015). Conversion of land from native forest to cropland can result in a 42% loss of carbon while the conversion from pasture to cropland can result in a 59% loss of carbon from the soil (FAO and ITPS 2015). On lands where agriculture has been performed for millennia, the loss of soil carbon can be as high as 80% (Ohlson 2014). Globally the world's soils have lost up to 80 billion tons of carbon (Ohlson 2014). Lost soil carbon transforms into carbon dioxide and is released into the atmosphere and exacerbates the effects of climate change.

Soil erosion, salinization, acidification, and the loss of soil organic matter and carbon are linked to modern agricultural practices. Some of the most harmful and widespread agricultural technologies that impact soil biodiversity and fertility are mechanized tiling, use of chemicals fertilizers and pesticides, and large-scale monocropping.

Tilling or plowing has been practiced through the different ages of agriculture, from Neolithic to post-Industrial Revolution. Hence, it is not a new technology but ends up destroying soil structure and hastening soil erosion. While breaking up the soil creates more aeration, tilling or plowing causes more soil compaction by the weight of the plow, making it much harder for plant roots to penetrate. In soils that are plowed over and over again, this compaction makes it almost impenetrable for plant roots (Montgomery 2007). Roots may travel deep into the subsoil to access nutrients through the help of soil dwellers who can make minerals available from the bedrock and subsoil. Compaction due to the plow cuts this access for plants and the shallow root system leads to weak plants with lowered productivity. Breaking up the soil structure contributes to decreased organic matter due to exposed soil that releases carbon into the atmosphere and reduced microbial activity. Less organic matter means less food for soil biodiversity and fewer nutrients for plants. Tilling can lower yields by up to 60% (FAO and ITPS 2015). Dr. Rattan Lal says, "Nothing in nature repeatedly turns over the soil to the specified plow depth of fifteen to twenty centimeters. Therefore, neither plants nor soil organisms have evolved or adapted to this drastic perturbation" (Ohlson 2014).

The impacts of tilling can be large-scale and devastating as witnessed in the U.S. during the dustbowls of 1933–1935. The mechanized steel plow was introduced by John Deere in 1838 (Montgomery 2007). The difference between the non-mechanized and mechanized plow was that it allowed one farmer to till very large pieces of land, turning them into industrial-sized farms. The 20th-century farmer could work 15 times more land that a 19th-century farmer. With mechanized plows, agricultural land multiplied rapidly and many fields were plowed and left open without any crops or weeds to hold the soil down. Severe droughts hit the Southern Plains of the U.S. where the highest concentration of farms existed. Without water and vegetation, strong winds created the famous dust bowls, taking away almost all the topsoil from several farms in a single day. More than 3 million people left the plains in the 1930s (Montgomery 2007). Despite the negative impacts of plowing, most farmers all over the world routinely plow their land, leaving the soil completely bare and exposed to the elements, killing the soil life that survives in the darkness of soil rich in organic matter.

How are high yields obtained from soil that has become degraded? This brings us to the other widespread technologies: synthetic fertilizers and pesticides. If the soil is unable to naturally provide the nutrients a plant needs, then the plant will be weak, susceptible to pests, and will probably produce very little food. Instead of taking care of the soil, industrial agriculture focuses on feeding the plant. This creates short-term yields while ignoring the needs of the soil. The use of synthetic fertilizers is so intensive that 30% of topsoil and 75% of subsoil globally has become too acidic to allow for sustainable plant growth (FAO and ITPS 2015). The agrichemical industry has isolated three macronutrients that plants need: nitrogen (N), phosphorus (P), and potassium (K) (referred to as NPK). However, the use and application of them is problematic. First, plants need a diversity of nutrients and minerals in addition to NPK. Isolating these nutrients chemically and then applying them over and over in large quantities deteriorates the soil quality and diminishes the availability of other key minerals that plants need (Montgomery and Biklé 2016). Another critical issue is that providing plants these nutrients in large quantities destroys the nutrient cycling that typically takes place underground between the plant roots, soil organisms, fungi, and other creatures (Montgomery and Biklé 2016). Chemicals destroy soil biodiversity and do not create biodiversity. Thus, soil is no longer living and cannot offer nourishment to the plant apart from what was artificially added by the farmer. Agrichemicals not only disrupt symbiotic relationships and nutrient transfers, but they also disable the plants internal defense system making it vulnerable to pests and pathogens, thereby increasing the need of chemical pesticides (FAO and ITPS 2015). The heavy use of pesticides can cause populations of beneficial soil microorganisms to decline (Aktar 2009).

While the literature on the impact of pesticides on soil microorganisms is growing, there is enough evidence to show that changes in soil biodiversity impacts the entire food chain. Once soil has lost all its nutrients and the plants are dependent on chemical fertilizers, more and more application is required to obtain the same yield. Chemicals often require more irrigation, causing soil salinization in addition to acidification. Chemical fertilizers and pesticides reduce soil organic matter and soil life, which causes compaction and soil erosion that, in turn, reduces water infiltration and moisture availability for plants.

Both mechanized tilling and applications of large amounts of chemicals are used on large-scale farms that grow only a single crop variety year after year on the same land. This practice of monocropping is used to align mechanization and market-focused efficiencies. However, monocropping has a negative impact on soil and plant health and facilitates erosion. Monocropping involves growing seasonal cash crops such as grains soy, fodder, and biofuels that replace the existing perennial native vegetation. The damage that monocropping has on soil, on both the macro and micro level, is immense. In most parts of the world, agricultural land replaces whatever natural ecosystem existed on that land previously, including forests. Forests, whether temperate or tropical, consist of perennial vegetation, which means that soil is never exposed at any time and nutrient cycling occurs continuously in the soil. In this situation there is almost no loss of soil and plenty of organic matter constantly replenishing the soil through falling leaves, dying plants, animals, and organisms of all kinds. When temperate forests are converted into agricultural lands, the soil loses more than half of its organic matter (FAO and ITPS 2015). The rate of soil organic matter loss is highest in monocropped industrial farms that regularly practice tilling and chemical application (FAO and ITPS 2015). "Changes in soil diversity modify vegetation dynamics directly through associations of symbionts and pathogens with plant roots and indirectly, by modifying nutrient availability to plants" (FAO and ITPS 2015). The symbiotic connections between plant roots and fungal networks either becomes severely diminished or non-existent in monocropped farms due to the lack of both plant and soil biodiversity. In a perennially vegetated world every plant has evolved to have its own set of adapted underground relationships. But in a field with row after row of the same type of seasonal plant which in a few months is completely removed, the soil is bereft of life and nutrients. Planting the same type of vegetable or crop also enhances pest problems causing further use of agrichemicals on crops and vegetables.

Agribusinesses have also produced GM seeds. In India over the last 20 years, nearly 300,000 farmers have ended their lives by ingesting pesticides or by hanging themselves (Umar 2015). These suicides have been linked to the failure of the crop they have purchased (Bt Cotton, a GM cotton seed) on credit or through the accumulation of life time savings. Unable to withstand the drought as well as native seed crops could, the monocropped Bt Cotton crops failed in these areas. Biodiverse vegetation can adapt to stresses better than GM crops.

The fundamental issue with the agricultural practices of tilling, chemical use, monocropping, and genetic modification is that they are counterproductive to soil health. These practices may boost plant productivity in the short-term, but leave behind degraded land and tragic consequences for some farmers. Other large-scale impacts include: other desertification, which is the loss of cultivable land; diminishing groundwater tables due to intensive irrigation; land sinking in areas where the aquifers have been depleted, and dust bowls.

4.4 THE FUTURE OF SOIL

When we look back at the history of our predecessors, one glaring truth is that agriculture can be purely extractive by destroying the soil. The subsequent loss of soil organic matter deprives food for soil life, which leads to the collapse of soil structure. The plants surviving in this hard, dry land without their underground allies struggle to establish deep and strong root systems. They are plagued by pests and disease, as well as unprecedented climate conditions of droughts and floods. Without organisms to hold the soil together, cultivable lands are being rapidly lost due to intensive human exploitation. No technology in modern industrial agriculture is capable of reversing soil erosion or maintaining a balance between soil erosion and soil creation. Soil is being mined as an infinite resource when it should be recognized as finite and vulnerable.

Although some farmers know that their soils have been degraded, there may be no incentive to conserve and amend their soil.

4.5 CONCLUSION

Soils are a major reservoir of global biodiversity that are essential to preserve and restore. The importance of soil biodiversity is becoming increasingly clear and the repercussions of human activities on soil health are vast. Research has demonstrated that exposing and disturbing the soil takes away organic matter and destroys a diversity of life in the soil. As long as soil erosion continues to exceed soil formation, we continue with practices that are unfavorable and potentially devastating to all of humanity. We live in a time where climate change, extreme weather events, and the overexploitation of natural resources including living soil impedes the health and well-being of both humans and the living systems of the planet.

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