# Soil Health — Recovery from Degradation

Once our soil becomes depleted or polluted — what can be done to bring it back to good health?

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Weare relatively familiar with the idea of air or water pollution. In contrast, we are less aware of soil pollution. For the purposes of this article, soil pollution refers to presence in the soil biosphere of toxic chemical compounds. Common examples include heavy metals, hydrocarbons (chlorinated or polycyclic), and pesticides. These materials can arrive due to irrigation or flooding, dust deposition, rain water (acid rain is one example), spills/leaks, or solid material deposition.

Some places are at greater risk than others due to rivers, wind patterns, local geology, and industrial activity, but everywhere is exposed to airborne pollutants to some extent. A global review of soil pollution is provided in this FAO report. Accumulations of pollutants can be detrimental to plant and microbial life directly. Clearly, from the food we eat to the air we breathe, this can be detrimental to our life too. So, what can be done to bring damaged soil back to life?

Plants are capable of a degree of concentration. That is the concentration of a compound in plant tissue can be higher than the concentration in the soil due to (passive or active) absorption combined with sequestration. In fact, plants and microbes may “cooperate” to “inactivate” pollutants. This is the basis of bioremediation.

All the organisms in the soil are also in it for themselves. It is AS IF they are working together; they are not cooperating the way that you or I might discuss and then divide up work.

Most organisms have multiple enzymes devoted to detoxification. Many are generic in the sense that they can react with many toxins. These enzymes (technically, their genes) are subject to mutation induced by radiation, chemicals in the environment, and biological “error”. While some mutations are “fatal,” many have non-obvious effects. These mutations can basically hang around until something in the environment creates selection pressure to reveal the consequence.

The key point is that the soil contains a huge variety of organisms with a huge variety of genes for detoxifying enzymes and these are often “idle” or “latent.” When selection pressure is applied, those organisms that have genes for enzymes to effectively cope with the pressure survive and/or multiply faster than less fit organisms. In the case of a toxic pollutant, those organisms lacking the ability to detoxify either die out or go dormant (many soil microbes form spores that are really tough) waiting for conditions to change. Similar selection of latent (or novel) mutants can be observed in the seasonal flu or wheat rusts in response to emergence of resistance.

The presence of a pollutant can be to change the population size or change the prevalence of organisms within the microbiome.

Perhaps 60,000 species of bacteria and hundreds of species of fungi are present in one gram of soil. In addition to species diversity, individuals within a species may vary. Cell numbers range from 10e6–10e8, and depending on how you categorize and count microbes the diversity could be even greater. As the concentration of pollutants increases in a soil, some of these organisms will be damaged and shrink in population, while others will be unaffected. In fact, some organisms may be able to utilize the pollutants in a positive way (metabolizing them for energy). These processes are going on all the time with no human intervention. But if we want to restore a soil to a condition where it is safe to grow food for human consumption, we need to remediate more actively.

https://www.westernsydney.edu.au/hie/topics/how_plants_benefit_from_partnerships_with_soil_fungi

**Remediation**

The approach of physical remediation is often used on industrially polluted sites. It can involve steps like removing the soil, washing it with solvents, then treating the soil to remove the solvents (if needed). This process might be used to cope with leaky tanks, railroad derailment or the like. Obviously expensive and targeted, it is a poor choice for use at large scale or multi-pollutant situations.

A better choice is bioremediation. Plants are surprisingly good at transformation of pollutants, so use of mixed cover crops is a good step. But given the potential of microbes to bioremediate, a stronger move is to promote microbial growth and diversity in the soil. The best way to do this is to increase fertility and organic matter in the soil. This combined approach is sometimes called phytoremediation.

Rapid remediation requires high metabolic activity. The best way to get that is to combine lots of food (soil organic matter) with plenty of other nutrients (like fertilizer, manure, compost, or plant matter) and oxygen. In many ways, these are not conditions we would encourage for an unpolluted soil. While we would encourage a modest amount of soil organic matter (2–5%), we probably would prefer a just-enough fertility and barely enough plowing. Our goal is to remove the pollutant and then return to a lower disturbance, lower feeding regime — so modest over-fertilization, frequent plowing, copious organic material.

Some soils might be fully remediated in a season, but some compounds might be highly resistant and be present for decades. The half-life of DDT for example is more than 15 years (and we can still detect DDT in US soils even though DTT was banned in 1974).

Can this be accelerated? An experiment was described to me 20 years ago in which a site seriously polluted by hydrocarbons from an industrial facility was to be bioremediated. It was impractical to remove and treat the soil, but the agency charged with remediation wanted to accelerate things. Their approach was to heavily fertilize the site with nitrogen and phosphorus, plow the site at least twice a year, and to add a large amount of molasses.

Their thinking was this: there were lots of bacteria in the soil, and some are capable to detoxify the pollutant. They had no idea what organisms matter or how to stimulate them specifically (except by adding even more of the pollutant). So, they decided on an extreme strategy. They would supply so much food that all the microbes would go into a feeding frenzy and multiply like crazy. Even the slow growing organisms (where the detoxifying power may exist) would increase. Then the food would run out and the microbes would do what they do best — chemical war. It is beyond the scope of this article to describe the range of chemicals that microbes use against each other, but suffice to say it's a lot. Lots of organisms will starve to death (adding to soil organic matter), some will kill each other (another organic matter addition), but the organisms that can utilize the pollutants as food may stay around longer and switch from easy-to-digest sugars to hard-to-digest methyl-ethyl-chloro-ohmygod.

To be clear, the presence of the pollutant probably already increased the selection pressure on the system, but taking the community through a boom-bust would intensify things and thus speed them up. This approach has been put into practice and is one accepted standard approach. As mentioned in previous articles in this series, soil can become polluted directly by application of pesticides, contaminated irrigation water, and manure application, in addition to the mechanisms described above. Consequently, many agricultural soils are lightly polluted. Most of the things that would promote general soil health will have a positive effect on pollution mitigation.

**Plant power**

The emphasis so far has been on the role of microbes, but plants themselves can detoxify upper layers of soils. Some plants are hyper-concentrators and especially effective in taking up pollutants and sequestering them in their foliage. Other plants can take up and detoxify compounds or are effective at secreting compounds that stimulate microbial action. In some cases, the over effect is to demobilize toxins so that they are unable to cause damage. Thus, many of the practices that would be applied to maintain a healthy soil generally apply to soil remediation. Grow a cover crop with deep-rooted species (maybe including species recognized as suitable for your pollutant, maintain adequate moisture, soil oxygen and fertility, and (if suitable for the pollutant) ensure that the biomass remains on/in the soil to foster future microbial activity.

Not all damage to soil is from toxic additions; physically damaged soils can also be remediated. Many soils are damaged by some combination of climate and over-use. The Sahel region that crosses the African continent from the Atlantic to the Red Sea represents a damaged soil (at least from an agricultural perspective). The Sahel forms a transition zone between the Sahara and humid coastal forests. This is an arid region with about 100–200mm of precipitation on the northern edge to about 4-times that at the southern edge. However, rainfall is concentrated in a 3-month period and more than 80% of the rain falls in storms resulting in frequent floods followed by extended drought.

https://en.wikipedia.org/wiki/Great_Green_Wall_%28Africa%29

The green band in the map above is the zone where an initiative called the Great Green Wall has been underway to create a green belt to defend land to the south from increased desertification. The explicit goal is not to convert this strip to farmland, but creating the barrier requires soil improvement.

These Sahel soils are initially low in SOM, highly compacted, and dry. These are not conditions that support biogenic nutrient cycling. One element of the effort has been to use a traditional method of water harvesting to retain water in combination with planting of dry-tolerant trees and grasses. The process starts with digging a 3–4m catchment shaped like a half-moon. Grass seed, and often a tree, is planted (video 1 & video 2 provide a broader overview). During the rainy season, water is kept on the land, nurtures the tree and grass and over time SOM increases, the grass spreads, and, the soil gets stabilized. This is a process of decades and is fragile to a wide variety of problems (see here, here, and here).

https://news-decoder.com/growing-food-on-arid-land/

It is hard to express the scale of the effort involved in rebuilding these soils. The goal for the initiative is to improve 100 million ha, with perhaps 20 million ha treated so far over 16 years. The following set of images show how intense effort on the scale of about 1 km sits in a bigger landscape of about 100km. Most of the land remains in the “before” condition. Since arid conditions (or megadroughts) have been observed for 1000s of years, the soil has had ample time to degrade — we should not expect to reverse such wide-scale, persistent stress on the soil quickly. This is an extreme case of course, but also illustrates that preventing soil degradation at scale might be much easier than restoring that soil subsequently. We need to make protection of marginal lands more practical and desirable for land owners.

Adapted from 13°30'16.8"N 8°05'42.9"E on Google Earth

Remediation of damaged soils often occurs without our awareness. Why aren't there big drifts of tire dust along our roads? Partly because the tire particles are metabolized by soil bacteria and partly because they are washed or blown away. Many chemicals in the soil are degraded by soil organisms without human intervention of any type. While I can't say that our treatment of these soils is optimal, it is apparently satisfactory.

Some soils will need more care to return to a healthy condition. The best way to ensure that this restoration continues is to do what we would do to support any soil. Add organic matter, increase fertility, mix the soil — but not too much, and keep the soil moist (but not wet). Even badly damaged soils can be repaired by use of cover crops and return of organic matter to the soil. In some places, the required effort will be trivial and barely distinguishable from best practices already in place. In some areas, it will be a massive effort.

**Postscript**

After finishing the draft of this story, I saw a video about plastic eating wax worms. These (and perhaps other worms) seem to be capable of oxidizing and then subsequently digesting polyethylene which is commonly used in films and bottles. The real work is being done by insect and gut bacteria enzymes. This is an example of exploitation of a biological capability arising for some different purpose. Polyethylene is not a traditional food source for insects/bacteria and was not common in the environment until recently. The arthropods and microbes already present in the soil probably have considerable remediation capability that we are unaware of. Given the increasing present of these and other synthetic compounds in the environment, we can expect capable organisms to become more prevalent (This is NOT a reason to keep producing/discarding plastics. It is an example of selection for "useful" traits by environmental conditions.)

Photo by Josh Carter on Unsplash

There is an interesting evolutionary example. Lignin is a phenolic polymer that provides the strength to wood. Lignin is why a redwood tree can grow to 100 meters. It first appeared 400–500 million years ago but the full effects of lignin emerged over the next 50 million years as plants began to colonize the land and set the foundation of nutrient cycling.

Trees and other big plants lived, died, and then just lay there. No microorganisms had the enzymes required to break down lignin. The accumulation of partially digested biomass on the surface was the key event in the Carboniferous period. From about 360–300 million years ago, carbon was transferred from the atmosphere to the soil and eventually buried, eventually turning into coal. About 300 million years ago, fungal enzymes capable of degrading lignin emerged and spread — ending the age of coal formation. And also initiating a functional soil carbon cycle and a new dimension of soil health. In an indirect way, we can trace some of our current climate situation to a failure of soil remediation capability more than 350 million years ago. Happily, today's biosphere may have much more capability that can help us return our soils to high functioning states. Bugs have learned a lot this past 300 million years.