Science Societies

Managing soilborne pathogens biologically through anaerobic soil disinfestation

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Over the last century, growers of specialty crops have relied heavily on soil fumigation to manage soilborne pests and pathogens. But since the phaseout of methyl bromide, growers have been left with less effective fumigant options. Anaerobic soil disinfestation offers a biological alternative to chemical fumigation. It harnesses soil biology to suppress pests and diseases while promoting healthier soils, making it an increasingly attractive option for vegetable, fruit, and specialty crop production.

Soilborne pests and pathogens such as fungi, bacteria, plant-parasitic nematodes, and weeds cause significant damage to crop production, leading to heavy losses in both yield and quality of produce. In severe cases, growers suffer complete crop loss and are forced *to use synthetic chemicals*, *leave the soil unfarmed*, *or switch to less profitable crops.* This is even more challenging in vegetable, fruit, and specialty crops for which soil is intensively cultivated, often with the same crop grown season after season. This offers the soil very little opportunity to recover, and soilborne pests and pathogens accumulate over time. Modern agricultural practices such as monoculture aggravate pathogen issues, while chemical control delays them.

Over the last century, and especially since the 1950s, growers of specialty crops have relied heavily on soil fumigation to manage soilborne pests and pathogens. But since the phaseout of methyl bromide (MeBr), a potent broad-spectrum, one-for-all

fumigant that killed most pathogens but also affected the environment adversely, growers are left with less effective fumigant options.

The very concept of chemical fumigation relies on killing the pathogen population while ignoring consequences for nontarget organisms such as beneficial microbes. The search for more sustainable alternatives to MeBr has also raised awareness of the importance of soil health and its functions. With renewed interest in sustainably produced food, growers are increasingly looking for more sustainable, possibly biological, ways to manage soilborne pests and pathogens.

Alternative pre-planting soil management options not requiring the use of synthetic chemicals include soil steaming, solarization, biofumigation, biosolarization, and anaerobic soil disinfestation (ASD). Among these alternatives, ASD is gaining interest due to its broad-spectrum efficacy against a range of soilborne pests and pathogens across different crop systems and environmental conditions, even at relatively low temperatures.

What is anaerobic soil disinfestation?

Anaerobic soil disinfestation, also known as biological or reductive soil disinfestation, relies on using readily labile organic amendments (as in biosolarization), combined with water to moisten the soil and a tarp to facilitate the temporary development of anaerobic conditions and activate resident soil microorganisms against soilborne pests and pathogens. Since ASD is a microbial-driven process, higher soil temperatures are helpful for the success of the treatment; however, obtaining high temperatures like those in soil solarization or soil steaming is not required, making it easier for growers to fit this treatment in their cropping system even in temperate regions.

Anaerobic soil disinfestation is a pre-planting soil management strategy aimed at creating a temporary anaerobic soil environment for the suppression of soilborne pests and pathogens, while preserving and possibly promoting soil health. It was developed independently in Japan and the Netherlands around the early 2000s as a biological alternative to soil fumigation, combining the principles of soil organic amendment, flooding, and solarization to stimulate the soil biology and suppress soilborne pests and pathogens without the use of fumigants.

Although developed primarily as an alternative to fumigants, today we have evidence that if implemented properly, ASD can provide multiple ecosystem services, including provisioning, regulating, and supporting services (Figure 1), thus turning ASD into a regenerative approach to manage soil health.

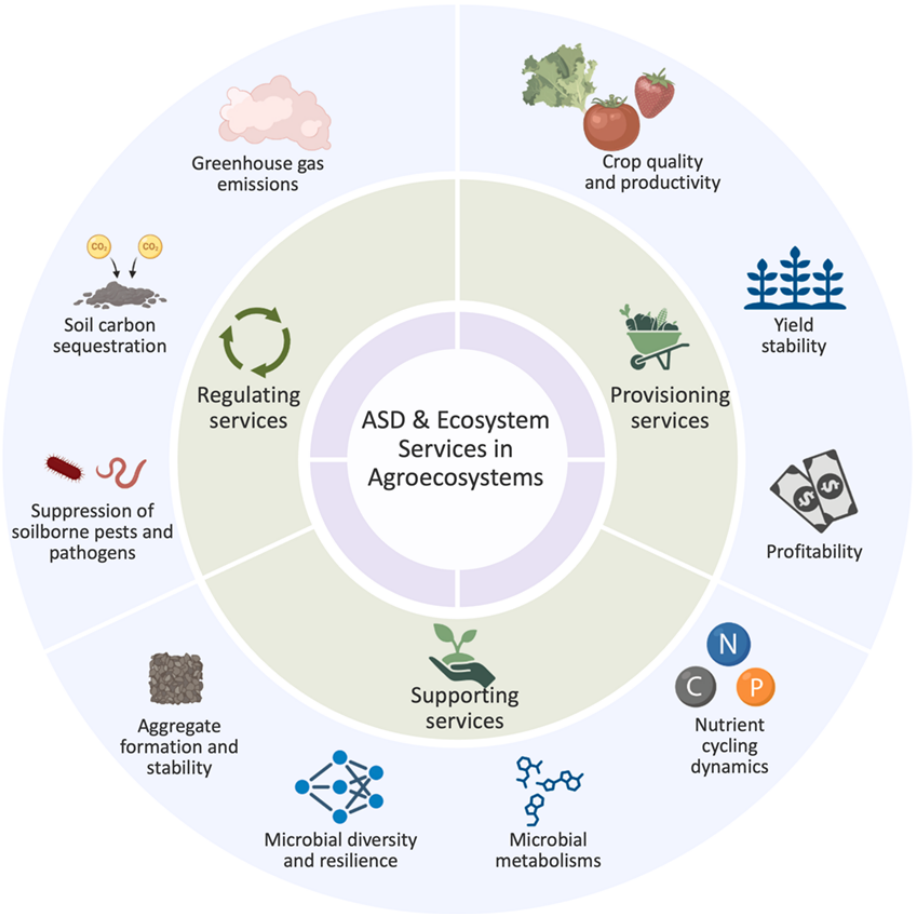

Figure 1. *Anaerobic soil disinfestation (ASD) as a regenerative tool to improve ecosystem services and soil functions in agroecosystems (from Ono-Raphel et al., 2026).*

How does ASD work?

By incorporating a readily decomposable carbon source (e.g., organic amendments such as wheat middling, rice bran, molasses, mustard meal, etc.), followed by irrigation (2 inches or 5 cm) and soil tarping with an impermeable plastic film, a temporary (three to four weeks) oxygen-limited environment is created. Under these conditions, anaerobic microbes become active and start fermenting the organic amendment. This process produces organic acids, volatile organic compounds, and reduced metal ions (like Fe^{2+} and Mn^{2+}) that together make the soil temporarily inhospitable to many soilborne pathogens and pests (Figure 2).

Through this anaerobic process and after soil re-aeration, there are microbial shifts whereby the community transitions toward beneficial anaerobes that outcompete or inhibit disease-causing organisms, and the gap left by soilborne pathogens is quickly filled by beneficial microbial communities that continue to feed on the organic residues even post-ASD.

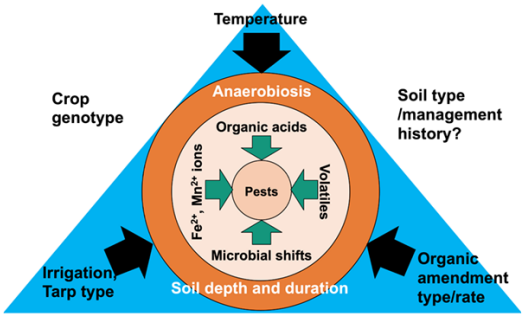

Figure 2. *Anaerobic soil disinfestation disease management triangle (from Muramoto et al., 2025).*

How is ASD implemented?

Anaerobic soil disinfestation is implemented in three simple steps (Figure 3):

1. **Amending** the soil with fresh organic material, which can provide carbon (and nitrogen) to feed microbes in the soil.

2. **Tarping/mulching** the soil with an impermeable film to prevent air exchanges (the tarp should be sealed). Cover raised beds or the entire soil surface with totally impermeable film, silage tarp, or a standard polyethylene mulch, and bury the edges.

3. **Irrigating** the soil to field capacity (2 inches of water is generally sufficient). Keep the tarp on for three to four weeks and then open or punch the film and wait a couple of days, so volatile compounds dissipate and the soil is oxygenated before planting.

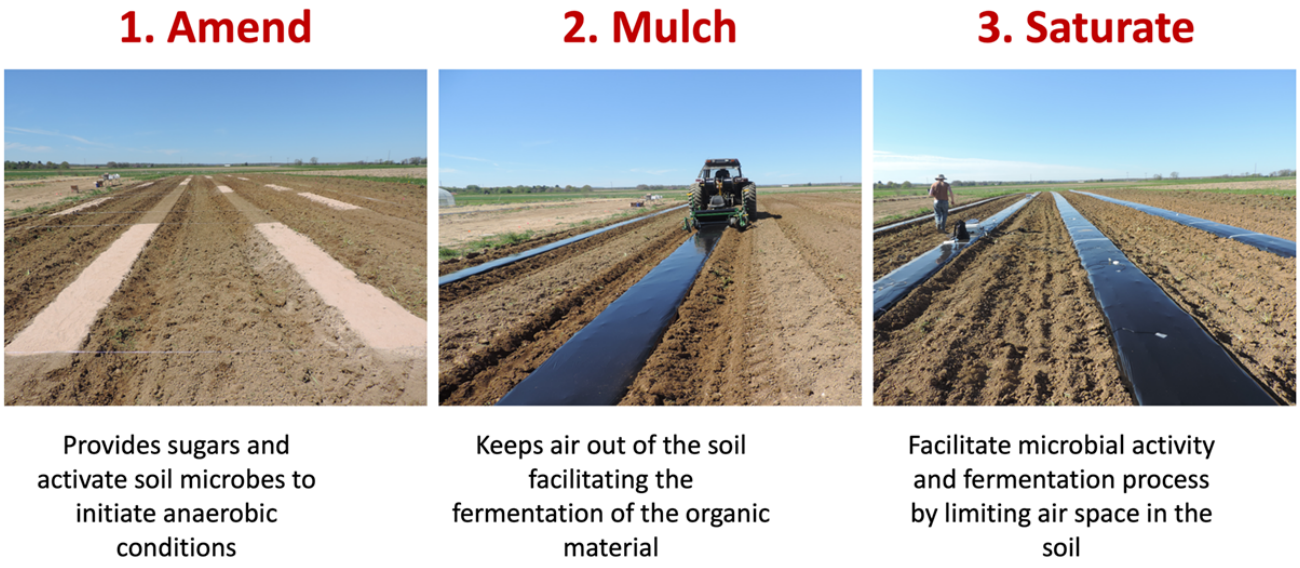

Figure 3. *Steps to implement anaerobic soil disinfestation.*

Note that the diagram depicts raised bed ASD application commonly employed for some specialty crops; however, a broadcast application is also feasible and often recommended as it allows for suppressing pathogens in the entire field. Controlling pests and pathogens harboring in the soil at different depths can be challenging and usually requires treating the soil at a good depth before planting the crop. Soil temperature above 60°F is recommended for ASD efficacy. A new crop can be

established three to four weeks later, after punching planting holes or removing the plastic tarp and aerating the soil. Allowing a few days for the soil to re-aerate is recommended before establishing a new crop.

What amendments and application rates should be used?

Readily decomposable organic materials suitable as ASD carbon sources include rice husk, wheat middlings, feed-grade sugarcane molasses, spent brewery grain, fresh crops or cover crop residues, and supplementary N sources such as chicken manure or poultry litter. Besides suppressing soilborne pests and pathogens, these organic amendments can provide nutrients for the following crop.

While optimal application rates depend on soil type and the level of pathogen infestation, a general recommendation is to apply carbon sources at a rate equivalent to 6,000 kg C ha^{-1}. For instance, in the case of wheat middlings (~C:40%, N:2%), it takes 15,000 kg of middlings per hectare to apply the equivalent of 6000 kg ha^{-1} of total C. One can scale this up or down to calculate the amount of C needed for the piece of land to treat, either in an open field, a high tunnel, or a home garden.

To avoid a shortage of nitrogen for microbes and the crop established post-ASD, it is important to maintain a good balance between carbon and nitrogen. A C:N ratio of 25:1 (mineralization threshold) is required, while a lower ratio (<20:1) is recommended for a good ASD implementation. Residue with a high C:N ratio (>30:1), like compost or grass cover crops, break down slowly and can tie up soil nitrogen; residue with a low C:N ratio (<15:1), like manure or high-N amendments, can drive nitrogen losses into the environment (Figure 4). Mixing different organic amendments is a good strategy to achieve an optimal C:N ratio (20:1), match N supply with crop demand, and minimize environmental loss risks.

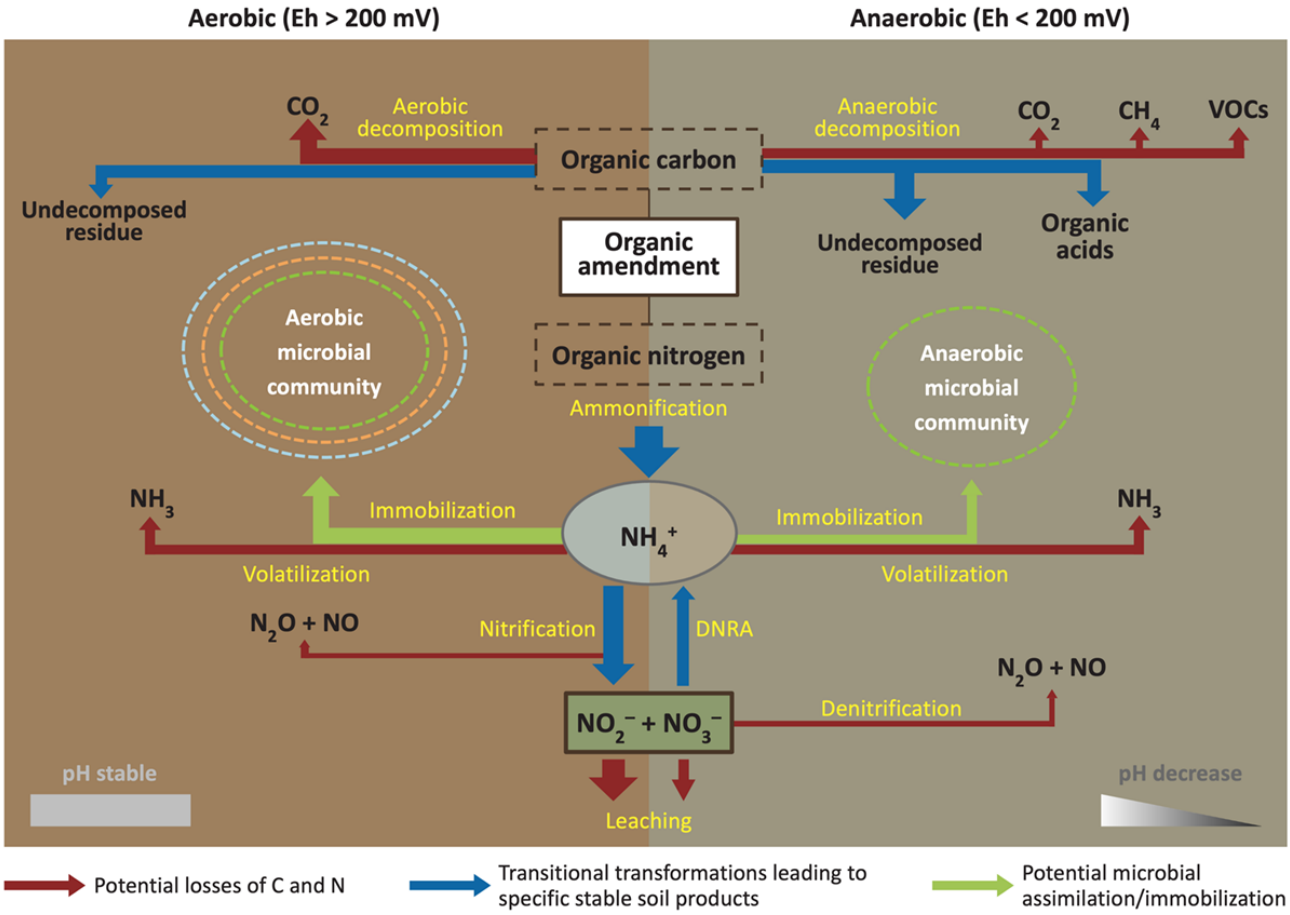

Figure 4. *Simplified organic amendment decomposition processes with carbon (C) and nitrogen (N) end-products in aerobic and anaerobic soil (from Rosskopf et al. 2020).*

How to enhance ASD and build soil health?

A standard ASD treatment using only readily labile organic amendments is a very effective tool for managing soilborne pests and pathogens. However, when paired with other ecological solutions like cover crops, ASD can be more than a reactive disease-management tool. Cover crops, in fact, can provide multiple ecosystem services through their biomass, including both shoot and exudate-enriched root biomass (Figure 5). Together with organic amendments, they can become an integrated strategy to rebuild soil health in intensively tilled crop systems.

Cover crops enrich the soil with organic matter that promotes soil aggregation, helps in nutrient cycling, and activates soil biology, which collectively enhances soil health. Aggregate stability can lag when tillage is intensive, or nutrient mineralization may be slow when residues have a high C:N ratio. However, over the long term, cover crops provide multiple ecosystem benefits while building system resilience against soilborne pests and pathogens.



Figure 5. *Overwintering cover crops (triticale, crimson clover, and their mixture) to build soil health with anaerobic soil disinfestation.*

How to integrate cover crops and organic amendments to enhance ASD?

The first step is to select a cover crop or cover crop mix that fits your rotation system and ensure it is capable of producing sufficient biomass of adequate quality for the ASD treatment. A cover crop mix with a combination of grasses, legumes, brassicas, etc., can be a good option as long as the C:N ratio is below the net mineralization threshold of 25:1. At the time of the ASD application, cover crops can be terminated with a flail mower and incorporated into the soil with or without supplementary amendments. Combining cover crop residues with a N-rich amendment, such as wheat middlings or chicken manure, can help bring the C:N ratio closer to 20:1, which is the “sweet spot” for ASD.

Accounting for the amount of N (and other nutrients) applied with the organic amendments in your fertilization program is critical to avoid nutrient shortages or excesses. If growing a cover crop is not feasible, amending the soil with a stable C source like biochar may offer another option for improving soil health, especially in

low-pH soils, where biochar can also provide a liming effect (Figure 6).



Figure 6. *Biochar, a carbon-stable amendment that may be paired with anaerobic soil disinfestation to build soil carbon and health.*

How much does it cost to apply ASD?

Organic amendments and the impermeable tarp represent the main expenses for implementing ASD. Additional costs include labor, irrigation supplies, and equipment operation. Research at Penn State University estimates that ASD costs roughly $1,000–$1,400 for a 32- by 200-ft high tunnel devoted to the production of high-value specialty crops, or about $0.15–$0.20 ft^{-2}. Since tarp and irrigation system can be reused, and organic amendments provide nutrients for the crop following ASD, these costs are easily recovered when ASD is applied in high-value crops, especially in presence of soilborne pests and pathogens. If implemented properly, ASD benefits can last multiple seasons.

Despite its demonstrated efficacy in suppressing a range of soilborne pests and pathogens, and its adaptability to different crop systems and environmental conditions, ASD is a microbial-driven biological solution, and its efficacy is subject to the influence of many factors. As such, ASD should be optimized for specific crop systems and target pests and should be integrated with other soil health management solutions such as crop rotation, cover cropping, the use of resistant varieties and rootstocks, and sanitation practices.

Dig Deeper

Muramoto, J., Henry, P.M., Rosskopf, E., Momma, N., Broome, J.C., Di Gioia, F., … & Shennan, C. (2025). Anaerobic soil disinfestation: a biological tool for soilborne pest management. *Advances in Agronomy*,*193*, 1–78. https://doi.org/10.1016/bs.agron.2025.05.001

Ono-Raphel, J.G., Di Gioia, F., & Dini-Andreote, F. (2026). Reframing anaerobic soil disinfestation through ecosystem services in agroecosystems. *Agriculture, Ecosystems & Environment*, *410*, 110552. https://doi.org/10.1016/j.agee.2026.110552

Rosskopf, E., Di Gioia, F., Hong, J.C., Pisani, C., & Kokalis-Burelle, N. (2020) Organic amendments for pathogen and nematode control. *Annual Review of Phytopathology*, *58*(1), 277–311. https://doi.org/10.1146/annurev-phyto-080516-035608

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