

WHITE PAPER

Longitudinal Soil Microbiome Testing for Sustainable Remediation of Pathogen-Infested Soils

Executive Summary

Soilborne diseases and pests cause extensive yield losses worldwide, threatening crop security in both intensive and organic systems. Anaerobic soil disinfestation (ASD) has emerged as a biologically based alternative to chemical fumigation¹. However, treatment variability across sites highlights the need for microbiome-informed strategies. Longitudinal soil microbiome testing—monitoring the biological succession of soil microbial communities over time—provides a data-driven framework to tailor ASD amendments for persistent, pathogen-infested soils, supporting both disease suppression and long-term soil recovery².

1. Background: Anaerobic Soil Disinfestation (ASD)

ASD eliminates or suppresses soil-borne pathogens by inducing controlled anaerobic conditions. The process involves the incorporation of a carbon source, soil saturation, and covering with polyethylene mulch to promote the activity of fermentative anaerobes (Fig. 1). These microbes generate pathogen-suppressive metabolites such as short-chain organic acids, volatile sulfur compounds, and alcohols. ASD has been successfully deployed against *Fusarium oxysporum*, *Verticillium dahliae*, *Ralstonia solanacearum*, and root-knot nematodes^{3,4}.



Fig 1. Raised soil beds saturated with carbon source and covered with plastic mulch for ASD

However, efficiency varies widely across soils and environments because each soil harbors a distinct microbiome that influences redox response, metabolite production, and pathogen recovery. This variability underscores the need for microbiome-guided customization.

2. Role of Microbiome Testing in ASD Optimization

Soil microbiome analysis like **Evolve Humus™**, through targeted sequencing of microbial metabarcodes like 16S rRNA, ITS or shotgun metagenomics (Fig. 2), reveals the structure and functional potential of microbial populations before, during, and after ASD treatment.

- Pre-ASD profiling: identifies pathogenic load and beneficial guilds (e.g., *Clostridium*, *Bacillus*, *Paenibacillus*) that drive fermentation and disinfestation^{5,6}.

- During ASD: longitudinal sampling detects microbial succession, signaling whether treatment conditions effectively sustain anaerobic metabolism.
- Post-ASD: data indicate soil recovery, enabling reintroduction of beneficial aerobic inoculants like *Trichoderma* or *Bacillus* to stabilize soil health^{7,8}.

These diagnostics allow iterative refinement of amendments and incubation parameters for pathogen-specific outcomes.

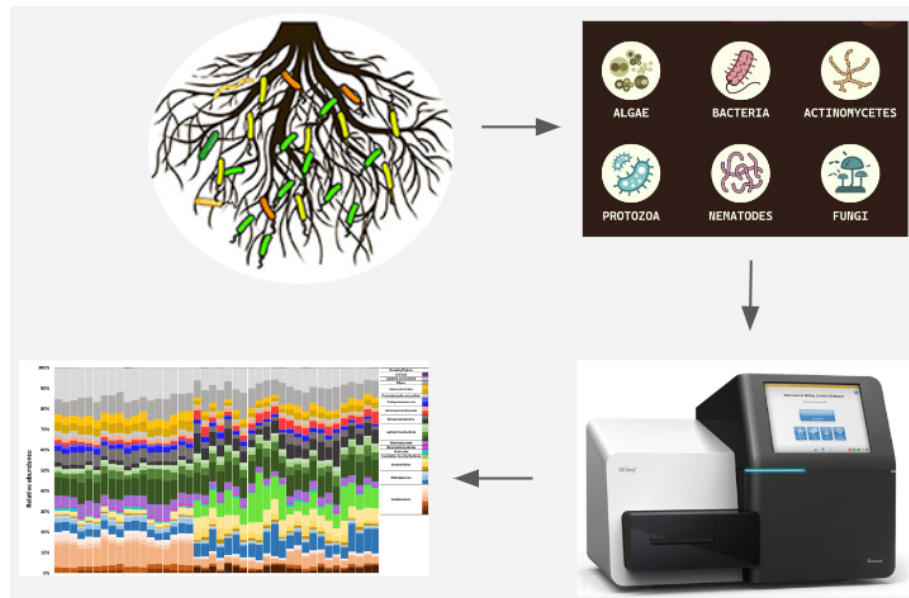


Fig 2. Typical soil rhizosphere microbiome testing workflow

3. Longitudinal Microbiome Testing Methodology

Longitudinal sampling strengthens the biological feedback loop between field management and microbiome response.

- Frequency and timeline: typically baseline (pre-ASD), midpoint (week 2–3), and post-treatment (after aeration).
- Techniques: Targeted or shotgun metagenomics for community composition, qPCR based quantification of pan-microbial abundance, paired with quantification of soil redox, pH, and metabolite profiles.
- Data analysis: modern multi-way modeling tools such as PARAFAC (Parallel Factor Analysis) detect temporal microbial structure dynamics⁹, even with missing data, allowing detection of key microbial shifts underlying soil recovery.
- Integration with farm variables: Soil fertility, amendment type, and irrigation water are incorporated into structural models (e.g., SEM) that quantify interactions between management and pathogen prevalence.

4. Integration into ASD Amendment Selection

Microbiome results directly guide amendment selection and dosing such as

- Dominance of Firmicutes (Clostridiales, Bacillales): favors rapid organic acid generation → use rice bran or molasses (C:N 25–30:1).
- Presence of Bacteroidetes and Geobacter spp.: improve sulfate reduction → incorporate green waste compost or silage.
- Low fermenter population or incomplete redox response: increase easily degradable C sources or extend incubation time.
- Post-treatment restoration: inoculate beneficial consortia (PGPRs, mycorrhizae) to rebuild aerobic balance.

These insights allow ASD to transition from a one-size-fits-all practice toward precision soil microbiome engineering.

5. Long-Term Remediation Benefits

Longitudinal microbiome monitoring confirms lasting shifts in microbial community structure, promoting soil suppressiveness beyond immediate pathogen knockdown:

- Reduced recurrence of *Fusarium* and *Ralstonia* across successive seasons.
- Improved soil aggregate stability and nutrient cycling as anaerobic taxa decompose recalcitrant organic matter.
- Enhanced resilience against re-infection by maintaining balanced functional guilds.

In multi-season trials, soils managed under microbiome-guided ASD retained higher alpha diversity and faster re-establishment of beneficial aerobic taxa—key indicators of durable soil health^{10,11}.

6. Economic and Practical Considerations

While microbiome-guided ASD customization is not a mandatory step, it is a strategic investment for precision soil management. It is most valuable where – pathogen pressure is complex or variable, organic amendment options are diverse or site-specific and long-term disease suppression and soil fertility are critical profitability factors.

The cost of microbiome sequencing has dropped significantly, making it feasible for high-value horticultural systems.

- High-value crops (e.g., strawberries, peppers): microbiome-informed ASD prevents yield loss from partial pathogen control and justifies the cost.
- Commodity crops: simplified biological proxies (soil respiration, carbon turnover rates) can substitute sequencing between ASD cycles.

Ultimately, microbiome testing reduces excessive amendment use, lowers nitrous oxide emissions, and enables sustainable remediation programs.

7. Conclusion

Longitudinal soil microbiome testing transforms ASD into a precision bioremediation tool. By tracking microbial dynamics before, during, and after disinfestation, growers can select targeted amendments, maintain pathogen suppression, and rebuild a resilient soil ecosystem. This integration bridges microbial ecology and practical soil management—establishing a regenerative cycle that enhances soil productivity while phasing out chemical fumigants.

References

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