Microbiome-mediated plant-soil feedbacks as a tool for resilient agriculture

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Introduction: Why PSF Can No Longer Be Ignored

The agricultural crisis

50% Increase in food production needed by 2060 for 10 billion people

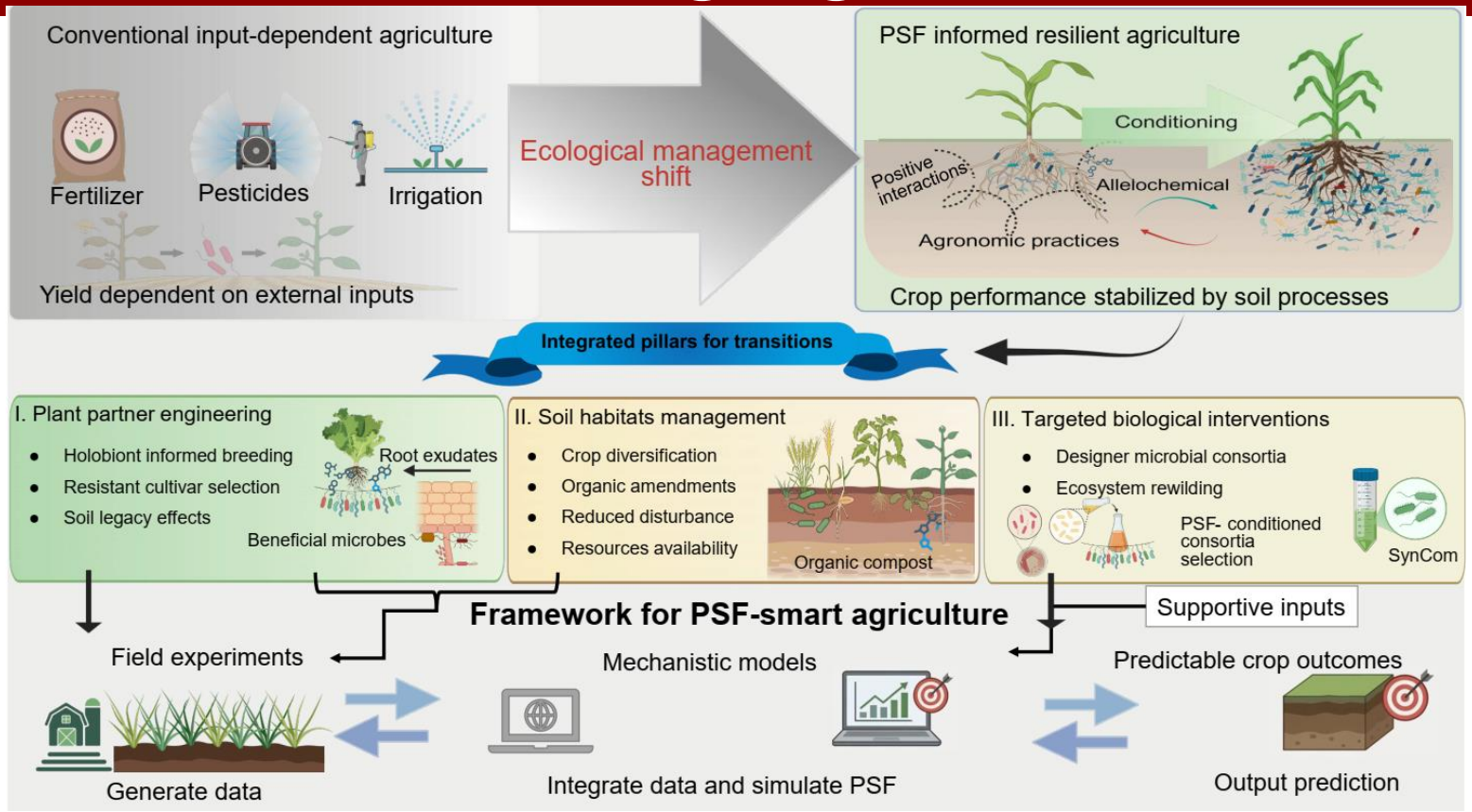
Risk Monocultures drive pathogen outbreaks, and soil degradation

Lost Beneficial microbiome alliances eroded by decades of intensive

- Fertilizers
- Pesticides
- Irregular irrigation
- Conventional agriculture
- Breeding strategies

Impact Disrupted reciprocal interactions, and the soil microbiome

Highlights



- Plant-soil feedback (PSF) governs microbial interactions vital for crop yield.
- Host genetic control of root exudates govern microbiome assembly, enables engineering of positive PSF.
- Steering positive PSF enhances nutrient cycling and suppresses soil pathogens.
- Synthesizes a pathway from lab to field by advocating for microbiome-assisted breeding and diagnostic, adaptive management cycles to overcome the implementation gap.
- Meta-omics leveraged, integrated state-contingent agronomic and microbial interventions act as achievable alternative to chemical input dependence.

The concept of plant–soil feedback and nature of the effect

- The concept of PSF provides framework for understanding soil-microbiome interactions.
- PSF is not merely descriptive ecology; it is a quantifiable, steerable force.
- In natural ecosystems, PSF fundamentally structures plant community composition, maintains diversity, and drives successional trajectories.
- PSF direction varies in grassed and diverse crops.

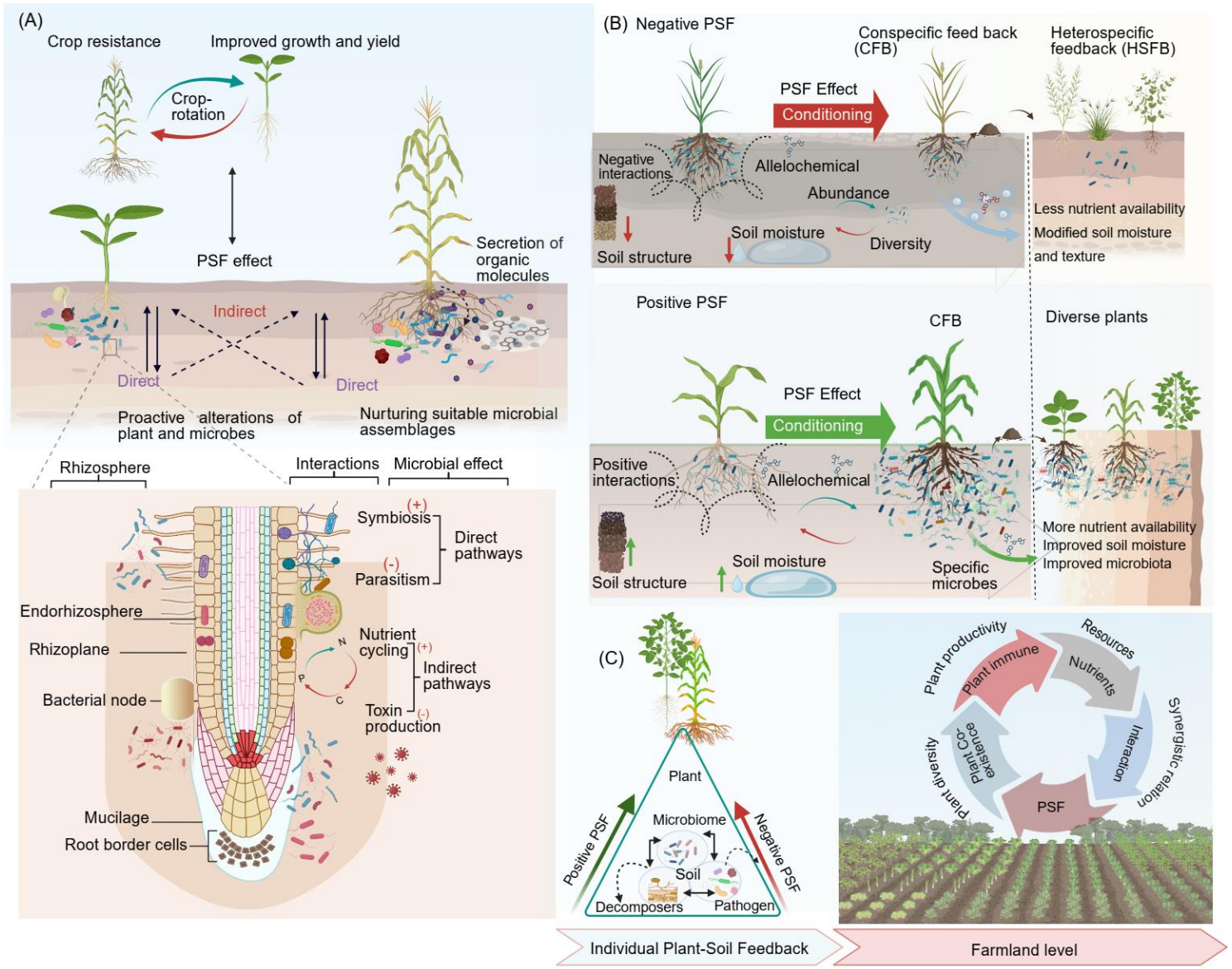


Figure 1 Multiscale depiction of plant-soil feedback (PSF) dynamics influencing crop resistance, growth, and yield at individual to farmland levels.

Microbial Mechanisms and Pathways Driving PSF

- These molecular loci — FERONIA, RIN, PHR1, FIT, NRT1.1B — are transitioning from research tools to targets for microbiome-assisted breeding.
- Root exudates constitute the primary biochemical interface through which plants engineer their rhizosphere microbiome in real time.
- Among the root exudates, Flavonoids, Strigolactones, Benzoxazinoids, Coumarins (scopoletin, fraxetin), Organic acids (citrate, malate) help reshape microbiome and regulate multiple plant regulatory processes.

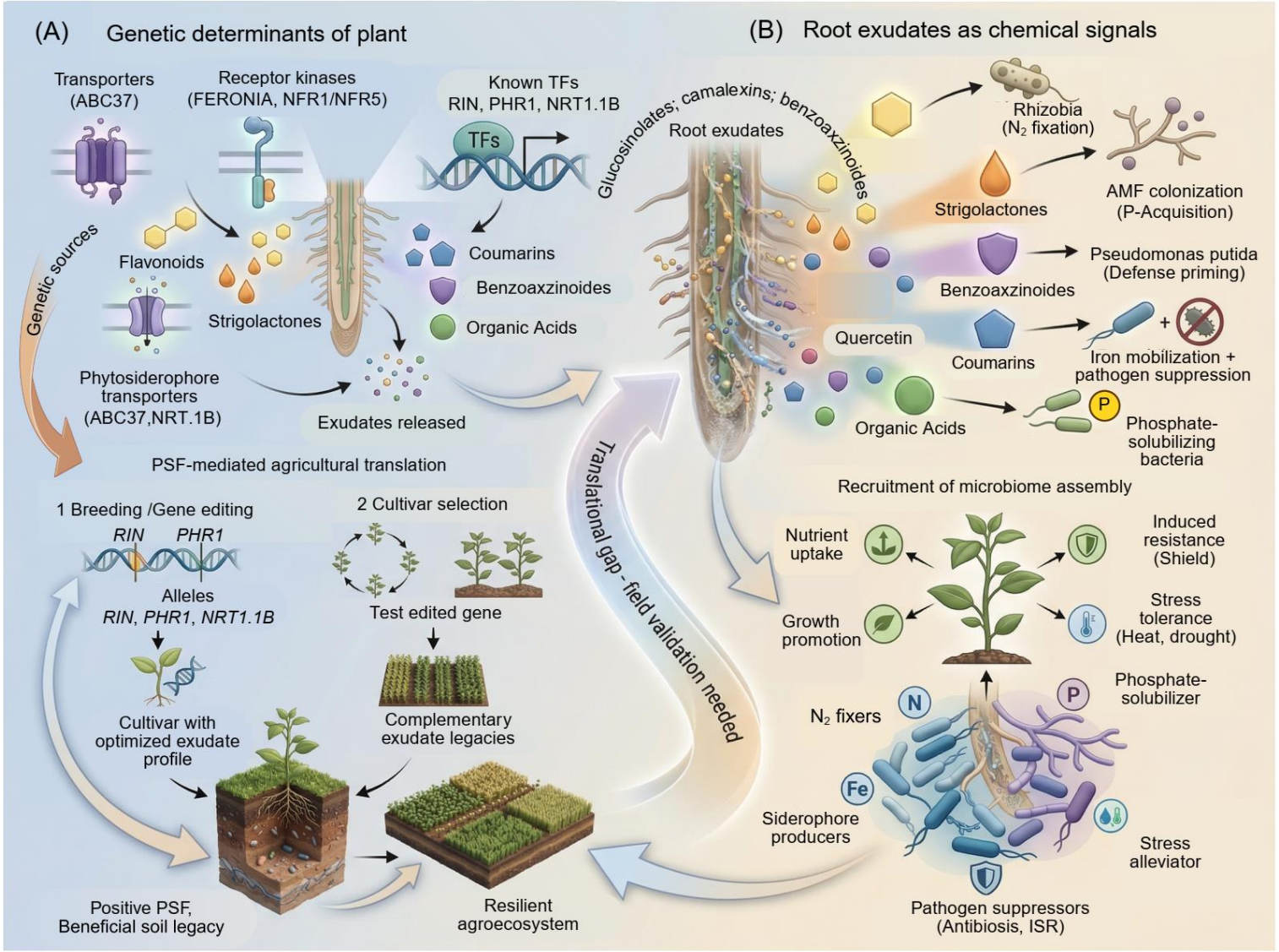


Figure 2 Genetic regulation of root exudates, microbiome recruitment, and translation into plant-soil feedback (PSF) mediated agriculture.

The Dual Role of Soil Decomposers in PSF

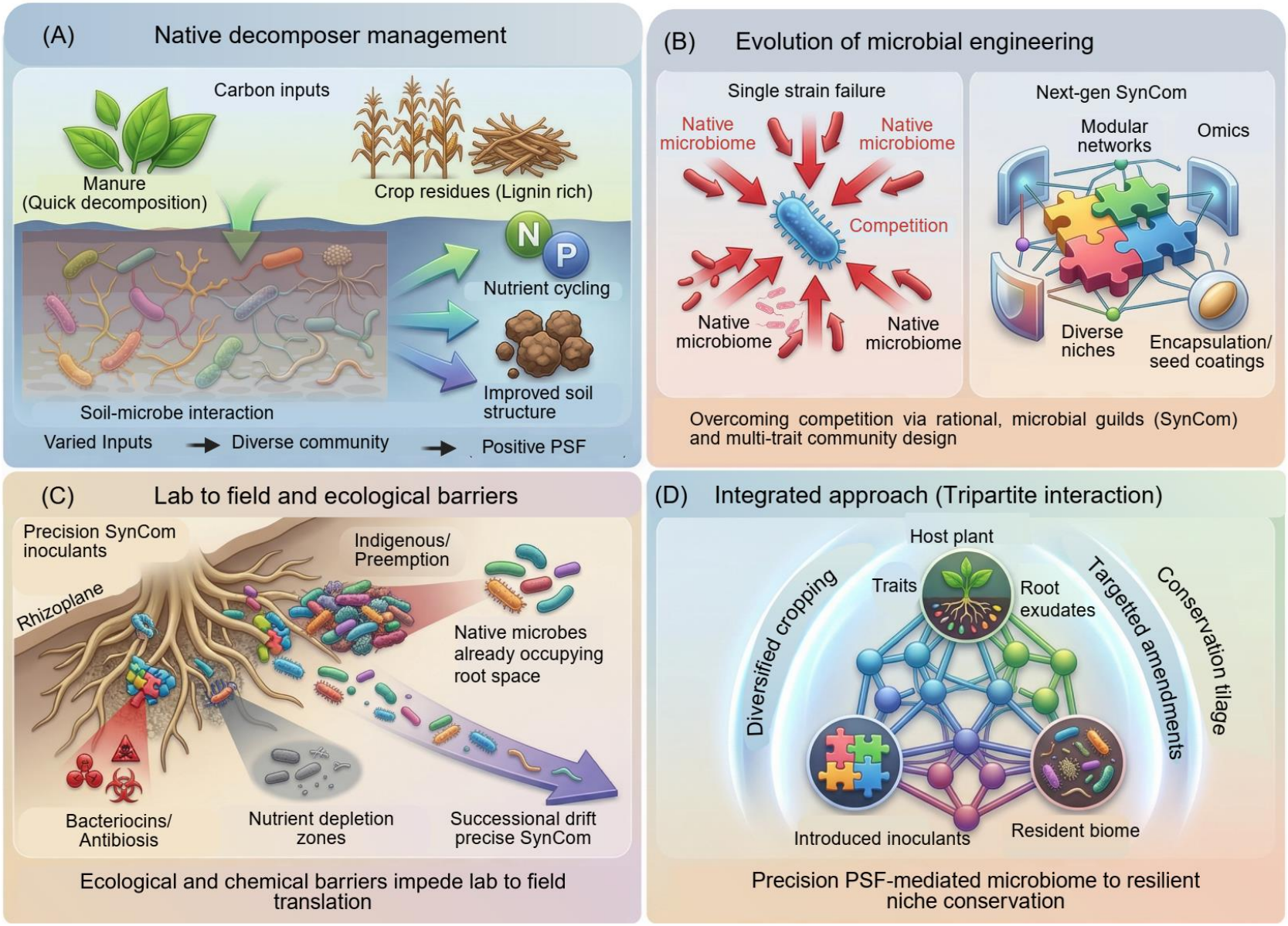


Figure 3 Strategies, challenges, and integrated approaches in microbial engineering for positive plant-soil feedback (PSF).

Agronomic Practices as PSF Management Tools

- Agronomic practices, and resources management comes under diagnostic strategy of the PSF
- Agronomic practices serve as the structural foundation, utilizing conservation tillage to improve aggregate stability
- Strategic crop rotation, and intercropping improve soil structure, SOC return to spatial heterogeneity and dilute host-specific pathogens.
- Positive PSF state is recovered by special microbial guilds by introducing via cover cropping
- Timely management of resources results in improved PSF
- Reading the soil is a diagnostic interface that integrates quantitative biological and physicochemical indicators
- Resilient crop-soil system and PSF state ensure
  Reducing pathogen load
  Improving health and yield of crop

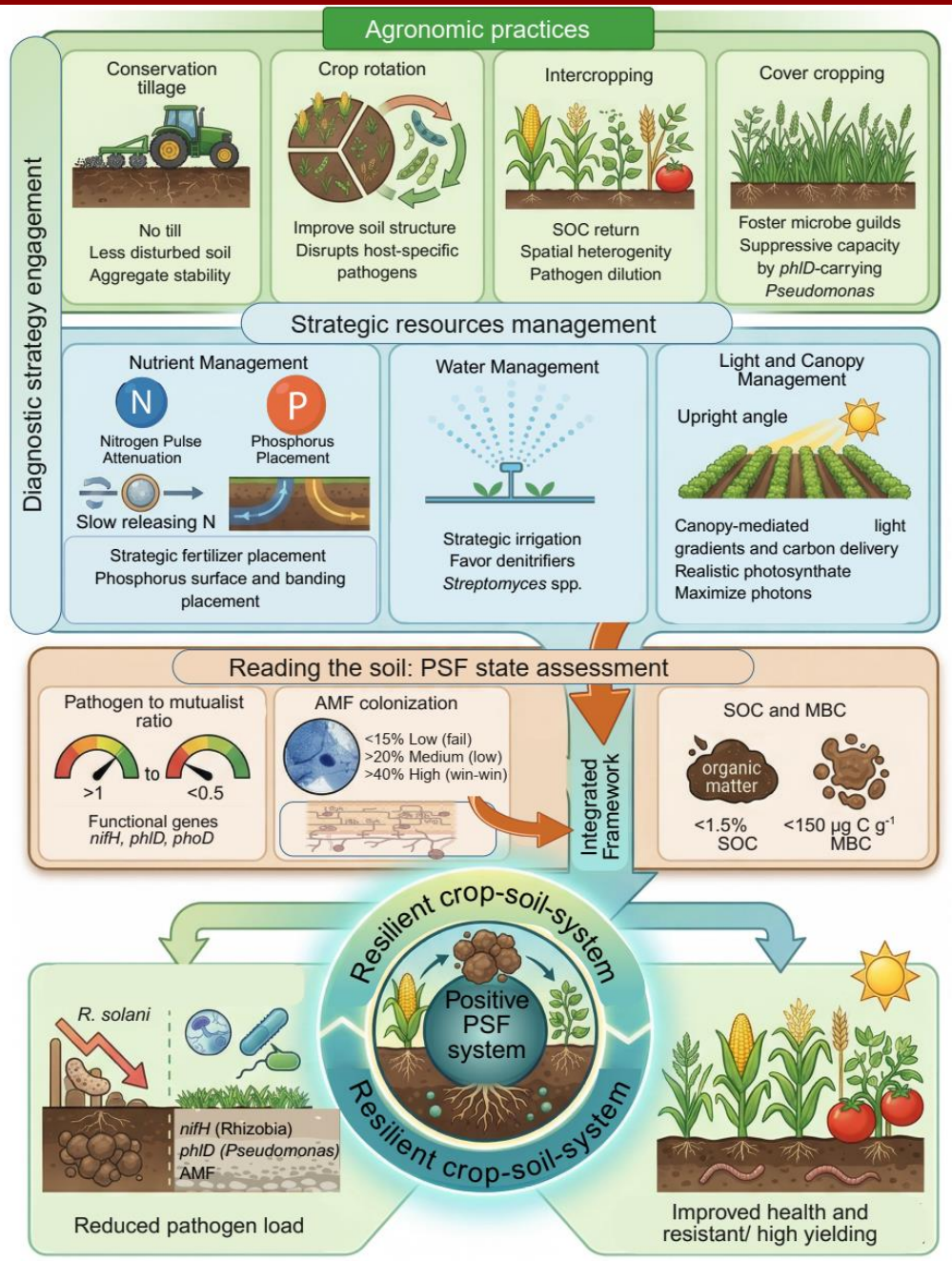


Figure 4 An integrative management framework for operationalizing plant-soil feedback (PSF) steerage in resilient agroecosystems.

Integrating the PSF Toolbox: Holobiont Breeding, Rewilding, and Vertical Transmission

- Wild plants suffer domestication syndrome leading to less responsive microbiome for active functional profile.
- Solution lies in elite crop/plant with domestication discount where it respond against active pathogen to reduce disease.
- To achieve this PSF toolbox emphasize on holobiont breeding.
- Host QTLs and genome is subject to breed for extended phenotype which shape microbiome via root exudate.
- Three strategies are essential: microbiome assisted selection; microbiome rewilding and vertical transmission.
- Thus, PSF rely on three diagnostic cyles, biotic assessment, abiotic, and genotypic calibration.

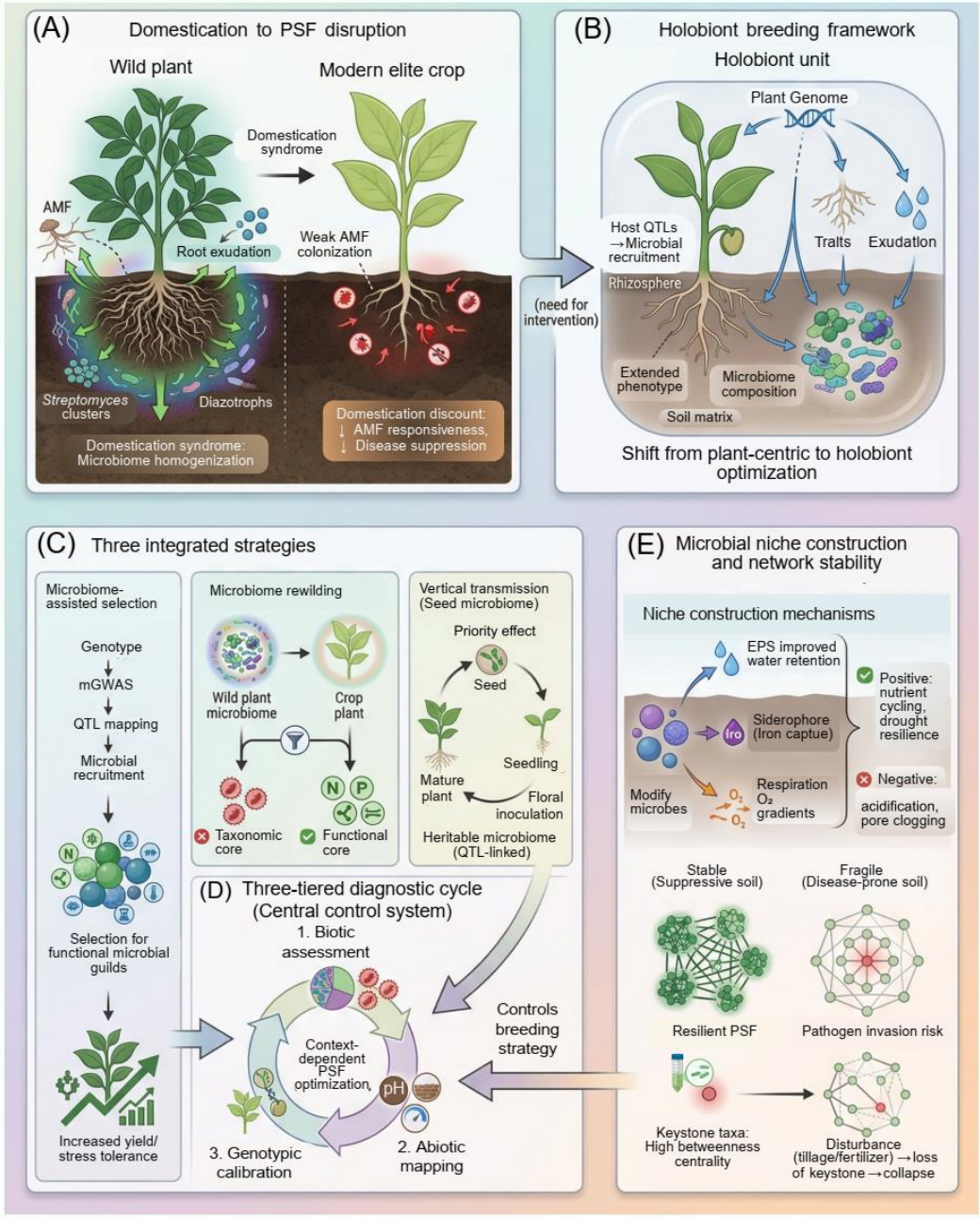


Figure 5 Engineering positive plant-soil feedback (PSF) through holobiont breeding, microbiome rewilding, and microbial niche construction

From Ecological Insight to Predictive Management

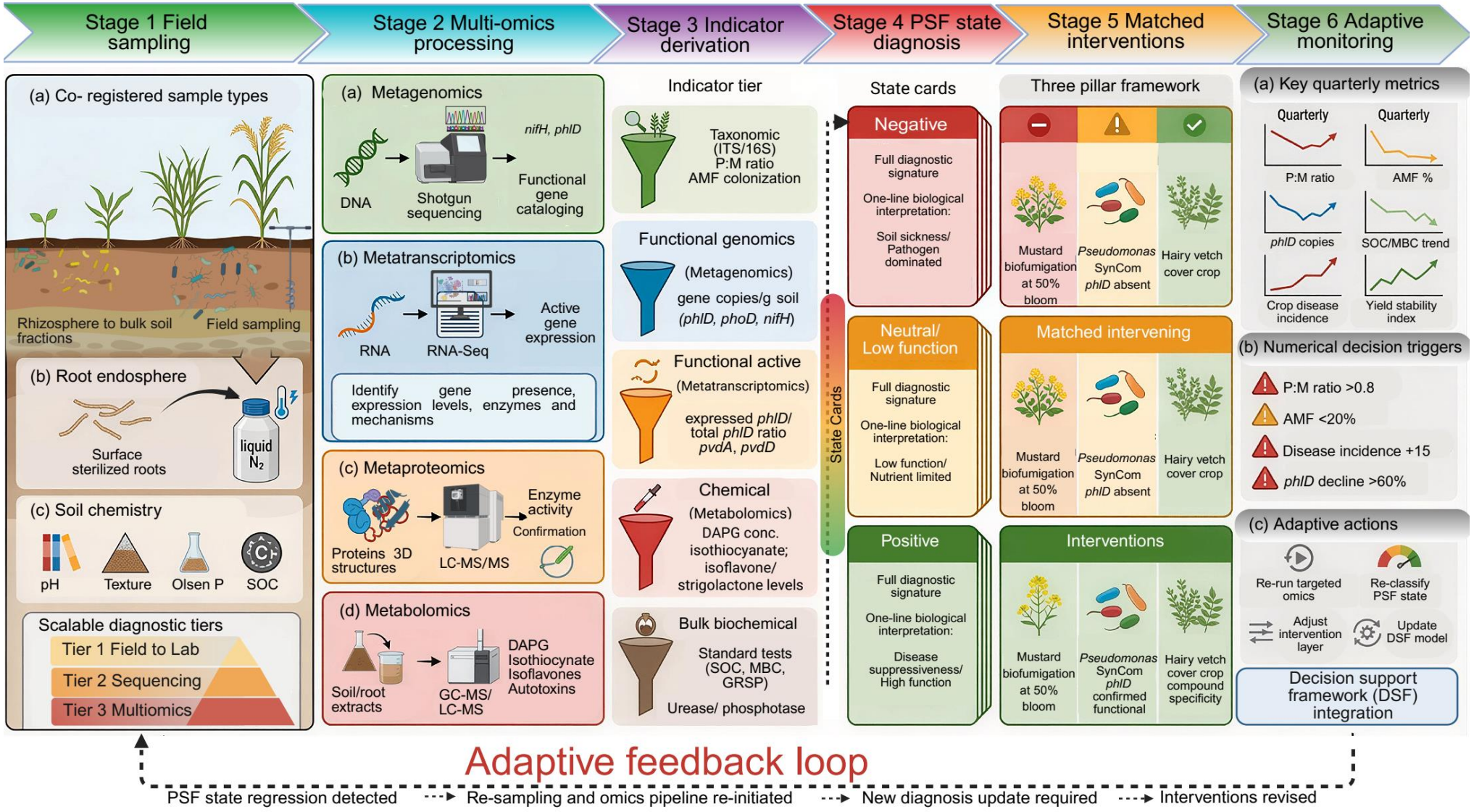


Figure 6 A meta-omics-to-management pipeline for PSF-informed agricultural decision-making.

Summary

- PSF is predictable and quantifiable. Species-specific soil legacies are real, measurable, and manageable; null models that ignore PSF systematically fail to predict plant community outcomes.
- Meta-omics is the enabling technology. All four omics layers are non-interchangeable and together render PSF tractable for precision management.
- The three-pillar framework is integrative, not additive. Plant partner engineering, soil habitat management, and precision inoculant deployment must be layered synergistically.
- The ultimate goal is ecology-driven agriculture, with their own rhizosphere microbial legacies, represent the operational vision for sustainable intensification.

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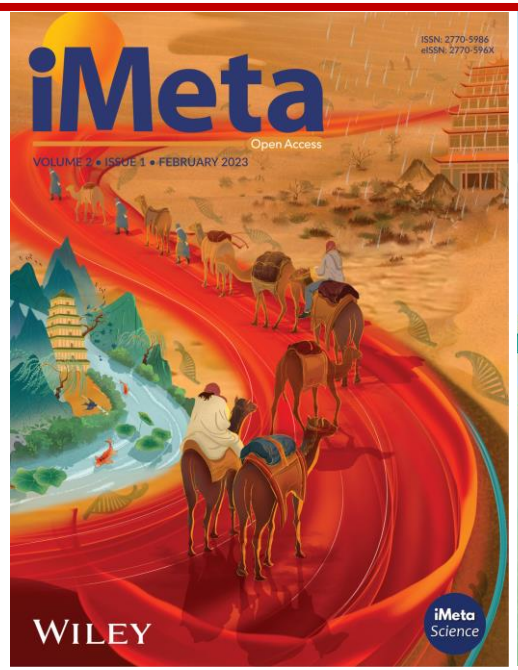

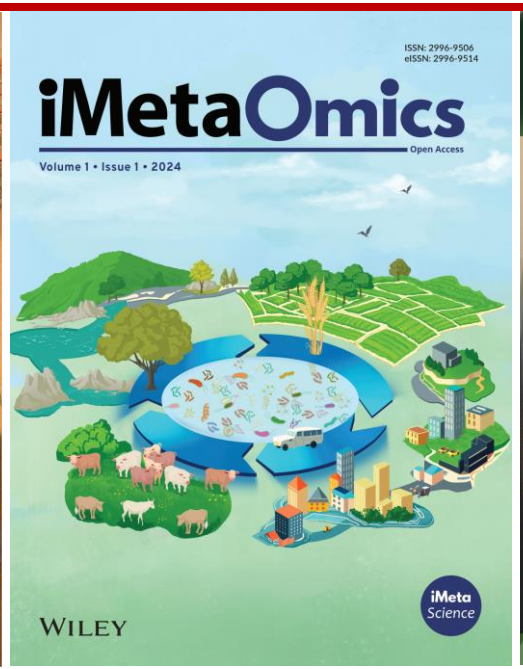

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