



Module 4: Plant Growth, Management & Pest Control - Extended Learning

Differentiated Content Lecture & Speaker Notes: Metabolic Modeling for Root Microbiomes

Differentiated content

Option 1, broader. This content supports biology, plant science, and sustainability learning. It aligns with NGSS concepts such as microbial interactions, ecosystem stability, and system design in agriculture. It also reinforces themes of biodiversity and energy flow through ecological communities.

Option 2, more specific. Relevant NGSS science topics:

- Interdependent relationships in ecosystems (MS-LS2-2)
- Natural selection and adaptation (HS-LS4-4)
- Using mathematics and computational thinking (Science and Engineering Practice)
- Human impacts on Earth systems (ESS3.C)
- Engineering design and optimization (ETS1.A/B)

Option 1: Introduction of Metabolic Modeling in Microbial Communities

Overview of Metabolic Modeling

Today, we explore how scientists use computational simulations to design root-associated microbial communities that help plants fight off disease. In this extended lesson, we ask: How can we design communities of microbes that help plants fight off disease?

Key Concepts:

- **Root Zone Partnerships**
 - Plants do not grow alone—their roots host communities of bacteria and fungi.
 - Inputs: Microbes consume sugars, carbon, and other compounds released by roots.
 - Outputs: Microbes provide nutrients (N, P), vitamins, and protective compounds.
 - Big Idea: Root microbes act as partners that boost growth and defense.
- **Microbial Interactions**
 - Microbes influence on another in three key ways:
 - Cooperation: One microbe produces compounds (e.g., vitamins, amino acids) that another can use.
 - Competition: Two or more microbes compete for the same limited nutrient (e.g., carbon, phosphorus).
 - Defense Alliances: Certain microbes produce antimicrobials that block pathogens from attaching to roots.
- **Challenges with Field Testing**
 - Trial-and-error in real soil has limitations:
 - Slow: Crop growth takes weeks to months.
 - Unpredictable: Weather and soil conditions vary.
 - Expensive: Requires repeated trials, land, and labor.
- **Microbial Consortia**
 - Scientists design microbial communities with complementary traits.
 - Example:
 - Microbe A consumes sugar and produces nitrogen.
 - Microbe B consumes nitrogen and produces vitamins.
 - Pathogen blocker defends the plant from invaders.
 - Big Idea: Microbial teams can be engineered to both nourish and protect crops.
- **From Paper Models to Digital Models**
 - Instead of only drawing arrows on paper, scientists use computers to model microbes.
 - Metabolic Modeling: Simulates nutrient flows, cooperation, competition, and defense.
 - Advantages: Faster, cheaper, and more reliable than field-only testing.

- What-if Scenarios: Predicts outcomes under stress (e.g., drought, pathogens, nutrient limits).
 - **The KBase Platform**
 - KBase (U.S. Department of Energy) is a professional tool for microbiome design.
 - Shows microbial genome data.
 - Metabolic maps of what each microbe can metabolize / produce.
 - Interactions with other microbes in simulated environments.
 - Prediction of growth, inhibition, and resource sharing.

Real-World Applications

Students will explore how these simulations help design microbial "probiotic" blends to suppress pathogens in crops like lettuce, tomato, and strawberries, reducing the need for chemical inputs.

Screenshot Reference

Show a screenshot of the KBase interface. Explain how it visualizes microbial metabolic pathways, predicts interactions (e.g., competition for carbon sources), and allows testing of community designs before trials in soil.

Ask Students: How might building a synthetic microbial community help reduce pesticide use? What kinds of traits would you want your root microbes to have?

Option 2: Technical Lecture on Root Microbiome Engineering via Metabolic Modeling

Introduction

In this session, we examine metabolic modeling as a systems-engineering tool to simulate interactions between root-associated microbes. The goal is to reduce pathogen pressure and optimize plant performance through microbiome design.

System Inputs and Outputs

Component	Input	Output
KBase Simulation	Microbial genomes, metabolic models	Predicted nutrient flows, competitive outcomes
Rhizosphere Field Data	Soil conditions, pathogen levels	Microbiome trait selection, suppression metrics

Modeling Interactions

- Mutualism modeling: Simulate cooperation (e.g., cross-feeding of amino acids or vitamins)
- Competition modeling: Identify resource overlap with pathogens
- Metabolite mapping: Predict which microbes produce defense-related compounds (e.g., siderophores, antibiotics)

Circular Design Benefits

- Reduce synthetic pesticide use
- Engineer resilient microbiomes with built-in disease resistance
- Improve nutrient uptake and soil health simultaneously

Challenges Addressed

- Pathogen resurgence from disrupted microbiomes
- Overuse of fertilizers and antimicrobials
- Limited predictability of live microbial products

Ask Students: If you could design a "dream team" of root microbes, what would their functions be? How would you know if they're working together or competing?

NGSS Integration and Student Reflection

Relevant NGSS Science Topics:

- Interdependent relationships in ecosystems (MS-LS2-2)
- Human impacts on Earth systems (ESS3.C)
- Using mathematics and computational thinking (SEP-5)
- Engineering design and optimization (ETS1.A/B)

Encourage teams to sketch a theoretical microbial consortium using icons (e.g., nitrogen-fixer, pathogen blocker, cross-feeder) and annotate predicted interactions.