



## Module 3: Soil Science & Soil Health Lesson

### Speaker Notes

#### Lecture Content

#### How to Use Speaker Notes (For Teachers)

These speaker notes are designed to support your presentation of Module 8: Energy Use & Technology in Agriculture. They provide suggested explanations, sample dialogue, and prompts to help you guide discussion and deepen student understanding.

#### Flexible and Adaptable

- You are not expected to read the notes word-for-word. Use them as a resource to help you frame each slide and select what works best for your teaching style and time constraints.
- The level of detail you include can vary based on your class. For AP students, you may choose to explore more technical or data-rich explanations. For other groups, simplify the language or focus on key takeaways.

#### Use Your Voice

- You are encouraged to rephrase content in your own words and bring in local or current examples.
- Feel free to add metaphors, stories, or connections that make the material more relevant and memorable for your students.
- If you have relevant videos, articles, or short activities, these can be used to reinforce or replace certain parts of the notes.

#### Promote Active Engagement

- The notes often include reflection questions, discussion prompts, and interactive activity suggestions.
- All activities listed are optional. Choose those that best fit your group's time, interests, and learning level.
- A student-facing worksheet has been provided to support note-taking, reflection, or review during and after the lesson.

#### Be Selective and Strategic

- Not every slide needs to be covered in the same way. Some may require brief explanations; others may invite more time and exploration.
- Consider selecting two to three main points or questions per slide that align with your goals for the lesson.
- Focus on the overall learning objectives: helping students understand how energy is used in agriculture, how technology is changing the field, and how we can design sustainable systems.

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## Introduction

### Slides 1-2

#### Slide 1: Introduction to Module 3 – Soil Science & Soil Health

##### Introduction

- Welcome students to Module 3: *Soil Science & Soil Health*.
- Highlight that this module is about the hidden world beneath our feet—soil—and why it is critical to agriculture, food security, and the environment.

##### Provide context on:

- Soil is more than “dirt.” It is a living system that sustains crops, cycles nutrients, stores water, and helps regulate climate.
- Farmers, scientists, and policymakers are all paying attention to soil health because it directly impacts food production and environmental sustainability.

##### Emphasize that:

- Healthy soils are the foundation for resilient farms and ecosystems.
- By understanding how soils work, students can see the connection between science in the lab and real-world farming practices.
- This module blends both science and sustainability—showing how research can translate into innovation in the field.

##### This module will break down:

- The structure and function of soils.
- The role soils play in nutrient cycling and water management.
- How soil management practices affect climate and long-term farm resilience.

##### Suggested Dialogue

*“Think of soil as nature’s hidden factory—it produces the food we eat, cleans the water we drink, and even influences the air we breathe. In this module, we’ll uncover how soil works, why it matters, and how we can take care of it to support both farming and the planet.”*

##### Wrap up the introduction

- Transition: “Now that you have a sense of what this module is about, let’s break it down into the specific lessons we’ll be covering.”

#### Slide 2: Soil Science & Soil Health – Lesson Overview

##### Address the purpose of the slide:

- This slide gives students the outline of Module 3.
- It helps them see the three main lessons and how each one builds toward understanding soil health and its global importance.

##### Tell students they’ll be looking at:

- Lesson A: *Soil Basics & Functions*
- Lesson B: *Soil Carbon & Management*
- Lesson C: *Living Soils & Ecosystem Services*
- Together, these lessons connect soil science to farming, climate, and sustainability goals.

##### Explain the different lessons and each focus:

- Lesson A – Soil Basics & Functions
  - Students will learn what “soil health” means using the official USDA NRCS definition.
  - They’ll practice hands-on methods like testing soil texture by feel and measuring pH.
  - They’ll see how soil properties affect roots, drainage, and nutrient availability.
  - Each test links back to global Sustainable Development Goals (SDGs).
- Lesson B – Soil Carbon & Management

- Students will explore the soil-carbon cycle, learning how soils store and release carbon.
- They'll classify management practices into Build–Maintain–Consume categories.
- They'll analyze class test data to predict how soils are changing and how that impacts water and fertility.
- The focus is on designing solutions that improve soil carbon and connect to multiple SDGs.
- Lesson C – Living Soils & Ecosystem Services
  - Students will discover the roles of microbes, fungi, and earthworms in keeping soils alive.
  - They'll test how stable soil aggregates are and what that means for erosion and water quality.
  - They'll design practices—like adding compost or cover crops—for their school garden and connect them to ecosystem services and SDGs.
  - The capstone is writing a 1-page recommendation memo that ties everything together.

#### Suggested Dialogue

*“Here’s how Module 3 will unfold. In Lesson A, you’ll get hands-on with soil basics—what it is, how it works, and why it matters. In Lesson B, we’ll zoom in on carbon, the heart of soil management and climate solutions. Finally, in Lesson C, we’ll explore living soils—microbes, worms, and fungi—and how they provide ecosystem services that benefit farms and communities. By the end, you’ll be able to connect what we test in class to the bigger picture of global sustainability.”*

#### Transition into the module

- “Now that you know the roadmap, we’re ready to dive into Lesson A. Let’s start by asking a simple question: *What is soil, really—and why is it so important for life on Earth?*”

## Lesson A: Every Drop Tells a Story

### Slides 3-24

#### **Slide 3: How do we improve soil health so that it functions as a vital living ecosystem that sustains plants, animals, and humans?**

##### Objective:

Help students begin thinking about soil as more than just dirt by framing it as a living system that supports all life.

##### Introduction/overview:

This slide introduces the essential question of Lesson A: what makes soil healthy and how does it function as a living ecosystem? Students will see that soil is the foundation for food, water, and climate systems, and that soil health is directly tied to human and environmental well-being.

##### Key Points to Emphasize:

- Soil is alive, full of organisms, and provides critical functions for plants, animals, and people.
- Healthy soil supports agriculture, clean water, and climate regulation.
- This lesson will lay the groundwork for measuring soil properties and connecting them to real-world outcomes.

##### Facilitation Tips:

- Encourage students to share what they already think of when they hear the word “soil.”
- Use guiding questions to shift their perspective from soil as “dirt” to soil as a dynamic system.
- Connect the discussion back to their own experiences (gardens, parks, farms, or even noticing soil after rain).

##### Suggested dialogue:

*“When you hear the word ‘soil,’ what comes to mind? Many people think of soil as just dirt under our feet. But in reality, soil is alive—it’s a living system that cycles nutrients, holds water, and even influences our climate. In this lesson, we’re going to explore what makes soil healthy and why that matters for every living thing, including us.”*

##### Wrap-up Prompt:

“Think about this: if soil is alive, what do you think it needs to stay healthy? We’ll explore that as we move deeper into Lesson A.”

#### **Slide 4: What Is “Soil Health”?**

##### Objective:

Introduce students to the concept of soil health, its core definition, the five key soil functions, and why these functions matter for ecosystems and humans.

##### Introduction/overview:

This slide explains what soil health means according to the NRCS and highlights the five main functions that make soil a vital living ecosystem. Students will also begin to connect these functions to real-world outcomes and Sustainable Development Goals (SDGs).

##### Key Points to Emphasize:

- NRCS short definition: soil health is the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans.
- Five key soil functions: regulate water, cycle nutrients, filter/buffer pollutants, provide stability, and sustain life.
- Soil health is not just about farming—healthy soil impacts water quality, climate, and biodiversity.
- Each function can be linked to specific SDGs, reinforcing the global importance of soil management.

#### Facilitation Tips:

- Briefly review each of the five soil functions with examples students can relate to (e.g., water infiltration in a garden, nutrient cycling in compost).
- Ask students to suggest other ways soil affects daily life or the environment.
- Encourage tagging of soil functions to SDGs to make the global connection tangible.

#### Suggested dialogue:

*“According to the NRCS, soil health is the continued capacity of soil to function as a living ecosystem that supports plants, animals, and humans. There are five main functions that make soil so important: regulating water, cycling nutrients, filtering pollutants, providing stability, and sustaining life. Today, we’ll explore each of these and see how they connect to global goals, like clean water and food security.”*

#### Wrap-up Prompt:

“Keep these five functions in mind as we dive into measuring and evaluating soil properties—every test and activity in this lesson relates back to one or more of them.”

### Slide 5: Soil ≠ Dirt

#### Objective:

Clarify the difference between soil and dirt and help students recognize the characteristics of healthy soil.

#### Introduction/overview:

This slide emphasizes that soil is a living ecosystem with structure, pores, air, water, and organisms, while dirt is simply soil out of place. Healthy soil has physical and biological properties that support plant growth and ecosystem functions.

#### Key Points to Emphasize:

- Soil is composed of structure, pores, air, water, and life.
- Dirt is soil out of place, like on floors or shoes—it does not function as an ecosystem.
- Healthy soil has crumbly aggregates, often compared to chocolate-cake crumbs, formed by fungal threads and microbial “glues.”
- Healthy soil promotes water infiltration, oxygen availability, and strong root growth.
- Unhealthy soil leads to runoff, low oxygen, and shallow roots.

#### Facilitation Tips:

- Show a sample of healthy soil if available or use photos to illustrate the “chocolate-cake” crumb texture.
- Ask students to describe differences they notice between soil in a garden vs. soil tracked inside on shoes.
- Relate infiltration, oxygen, and root health to plant success and ecosystem services.

#### Suggested dialogue:

*“Notice the difference: soil is alive, full of structure, pores, air, water, and life. Dirt is just soil out of place. Healthy soil looks like chocolate-cake crumbs, held together by fungi and microbes. When soil is healthy, water soaks in, roots grow strong, and oxygen is plentiful. If the soil is compacted or degraded, we see runoff, low oxygen, and shallow roots.”*

#### Wrap-up Prompt:

“Remember, soil is a living system, not just dirt—everything we measure and manage in this lesson depends on this distinction.”

## Slide 6: Soil Structure & Aggregates

### Objective:

Help students understand how soil structure affects water, air, root growth, and microbial activity, and connect healthy structure to global sustainability goals.

### Introduction/overview:

This slide explains the role of aggregates in creating pore space, which allows air and water movement, supports roots, and sustains microbial life. It contrasts healthy soil with degraded soil and introduces a quick hands-on check for structure.

### Key Points to Emphasize:

- Aggregates are clusters of soil particles that create pore spaces for air and water.
- Healthy aggregates allow roots to breathe and microbes to thrive.
- Degraded soils with crusting, compaction, or dust lead to poor infiltration, runoff, erosion, and stressed roots.
- Quick field check: squeeze soil; crumbles indicate good structure, smears indicate compaction risk.
- Healthy soil structure is linked to SDG 6 (Clean Water) and SDG 15 (Life on Land).
- Reinforce: soil is a living system, not just dirt.

### Facilitation Tips:

- Encourage students to feel a soil sample to distinguish crumbling vs. compacted soil.
- Relate soil structure to water quality and erosion control to make SDG links tangible.
- Ask students to consider why microbes and roots struggle in compacted soils.

### Suggested dialogue:

*“Soil aggregates create spaces for air and water to move, helping roots breathe and microbes thrive. When soil is degraded—crusted, compacted, or dusty—infiltration suffers, runoff and erosion increase, and roots are stressed. You can check soil health quickly by squeezing a sample: if it crumbles, structure is good; if it smears into a hard slab, that’s a compaction risk. Healthy structure ties directly to clean water and life on land.”*

### Wrap-up Prompt:

“Think about the soil under your feet—how do you know if it’s healthy? This simple squeeze test gives a quick answer and links back to global impacts.”

## Slide 7: Warm-Up: What is Soil?

### Objective:

Introduce students to the importance of soil organic matter (OM) and engage them in thinking about soil’s key roles.

### Introduction/overview:

This slide focuses on why even a small percentage of organic matter in soil (around 5%) is crucial. It highlights how OM fuels microbes, holds water, builds aggregates, and stores nutrients. A quick interactive poll gets students thinking about their own associations with soil.

### Key Points to Emphasize:

- 5% organic matter may seem small, but it is critical for soil health.
- Functions of OM: fuels microbial life, retains water, forms stable aggregates, stores nutrients.
- Soil is a living system with chemical, physical, and biological components (bricks, chemistry, water, microbes).
- Quick poll encourages students to connect personal experiences or perceptions to soil science.

### Facilitation Tips:

- Ask students to write down three words that come to mind when they hear “soil.”
- Invite volunteers to share their words and discuss connections to soil functions.

- Use the emojis on the slide to illustrate that soil combines physical structure, chemical properties, water, and biological life.

Suggested dialogue:

*“Even though soil organic matter is only about 5% of the soil, it’s incredibly important. It feeds microbes, holds water, helps form aggregates, and stores nutrients. Let’s do a quick poll—take a moment to jot down three words that come to mind when you hear ‘soil.’ We’ll see how your ideas connect to what makes soil alive and healthy.”*

Wrap-up Prompt:

“Keep your three words in mind as we explore soil properties—they all tie back to why organic matter and soil health matter in the real world.”

## Slide 8: Texture + Structure: How Soil Behaves

Objective:

Help students understand soil texture as a fixed trait, learn the characteristics of sand, silt, and clay, and see how texture influences soil behavior with structure.

Introduction/overview:

This slide introduces the three main soil particle types—sand, silt, and clay—and explains how their proportions give each soil a “personality” that affects water retention, nutrient availability, and overall soil function. Students will connect texture to structure to predict how soil behaves in the field.

Key Points to Emphasize:

- Soil texture is determined by the relative amounts of sand, silt, and clay.
- Sand feels gritty, silt feels floury, clay feels sticky or plastic.
- Texture is a fixed trait—it does not change quickly, unlike structure.
- Texture sets the “personality” of the soil, influencing water-holding capacity, drainage, and nutrient availability.
- Combined with structure, texture determines how soil behaves for roots, water infiltration, and microbial activity.

Facilitation Tips:

- Encourage students to feel and compare sand, silt, and clay samples if available.
- Ask them to predict how water would move through each soil type.
- Relate soil “personality” to real-world examples, like sandy soil in deserts vs. clay soil in wetlands.

Suggested dialogue:

*“Texture is all about the mix of sand, silt, and clay. Sand is gritty, silt is soft and floury, and clay is sticky. This mix gives each soil a personality that affects how it holds water and nutrients. Texture alone doesn’t change much, but when combined with structure, it determines how soil behaves—how roots grow, how water moves, and how microbes thrive.”*

Wrap-up Prompt:

“Think about your local soil or a garden you’ve seen—can you guess its personality based on sand, silt, and clay proportions? This will help as we start testing soils in class.”

## Slide 9: Texture + Structure: How Soil Behaves

Objective:

Explain how soil structure, as a changeable trait, interacts with texture to influence water movement, root growth, and microbial activity.

Introduction/overview:

This slide emphasizes that soil structure is made of aggregates and pores, which are dynamic and can be improved through management. Students will learn how structure affects infiltration, oxygen availability, root exploration, and microbial nutrient cycling.

#### Key Points to Emphasize:

- Structure consists of clumps (aggregates) and the pore network between them.
- Unlike texture, structure is changeable and can be improved through practices like adding organic matter.
- Good structure controls water infiltration, oxygen availability, and root growth.
- Aggregates create micro-environments with varying pH and oxygen levels, supporting microbial nutrient cycling.
- Structure combined with texture determines overall soil behavior.

#### Facilitation Tips:

- Show a sample or photo of well-aggregated soil versus compacted soil.
- Ask students how roots or water might behave differently in crumbly vs. compacted soil.
- Relate structure improvements to real-world practices, such as adding compost or avoiding compaction.

#### Suggested dialogue:

*“Structure is all about how soil particles clump together and the spaces between them. These aggregates and pores control how water moves, how much oxygen reaches roots, and where microbes can thrive. Unlike texture, which is fixed, structure can be changed through good management practices. Combined with texture, structure determines how soil behaves in the real world.”*

#### Wrap-up Prompt:

“Keep in mind that improving soil structure can help solve many problems in your garden or farm, from drainage to plant health.”

### Slide 10: Texture + Structure: How Soil Behaves

#### Objective:

Engage students in thinking about the advantages of different soil textures and reinforce the management takeaway that structure can be improved, even though texture is fixed.

#### Introduction/overview:

This slide prompts students to consider real-world applications of sand and clay soils through a Think–Pair–Share activity. It emphasizes that while texture cannot be changed, soil structure can be improved through management practices.

#### Key Points to Emphasize:

- Sand and clay each have strengths: sand drains quickly and warms fast, clay holds nutrients and water.
- Texture is fixed, but structure is changeable.
- Management practices such as adding cover crops, retaining residues, and reducing soil disturbance can improve soil structure.
- Understanding texture + structure helps predict soil behavior and informs better management decisions.

#### Facilitation Tips:

- Give students 1 minute to think individually, 1–2 minutes to discuss with a partner, and then invite a few pairs to share with the class.
- Encourage examples from gardens, local parks, or farms they are familiar with.
- Connect their answers back to the management takeaway: improving structure enhances soil performance regardless of texture.

#### Suggested dialogue:

*“Take a minute to think: where might sand be helpful, and where might clay be helpful? Turn to a partner and discuss your ideas. Now let’s hear a few thoughts. Remember, while we can’t change texture, we can improve structure using cover crops, leaving residues, and reducing disturbance. This is how we manage soils to behave better in real-world conditions.”*

Wrap-up Prompt:

“By understanding texture and structure together, we can make smarter decisions to improve soil health and support plants, water, and microbes.”

### Slide 11: What Makes Soil Healthy?

Objective:

Introduce students to the NRCS definition of soil health and frame the discussion of the key functions that make soil a vital, living ecosystem.

Introduction/overview:

This slide explains what makes soil healthy by highlighting the NRCS definition and setting the stage for exploring soil functions. Students will begin to see soil as a system that sustains plants, animals, and humans, linking ecology and practical land management.

Key Points to Emphasize:

- NRCS defines soil health as “the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans.”
- Healthy soil supports ecosystem functions such as nutrient cycling, water regulation, pollutant filtration, stability, and life support.
- Soil health is both a scientific concept and a practical goal for farmers, gardeners, and land managers.
- This slide also includes a visual reference from the Massachusetts Healthy Soils Action Plan to illustrate soil functions in context.

Facilitation Tips:

- Point out the NRCS definition and ask students what “vital living ecosystem” makes them think of.
- Encourage students to relate soil functions to examples they know, such as gardens, parks, or local farms.
- Emphasize that healthy soil is critical for both local and global sustainability goals.

Suggested dialogue:

*“According to the NRCS, soil health is the continued capacity of soil to function as a living ecosystem that sustains plants, animals, and humans. But what exactly does that mean in practice? Healthy soil performs many important functions—cycling nutrients, regulating water, filtering pollutants, providing stability, and supporting life. We’ll explore each of these functions in more detail to see how soil supports ecosystems and human needs.”*

Wrap-up Prompt:

“Keep this definition and these functions in mind as we move through the activities—every test or observation we do in this lesson relates back to what makes soil healthy.”

### Slide 12: Soil Functions - What Makes Soil Healthy?

Objective:

Help students understand that healthy soil functions as a living ecosystem and that these functions arise from interactions among physical, chemical, and biological components.

Introduction/overview:

This slide builds on the previous definition of soil health by explaining what a living soil ecosystem provides. Students will see that soil functions—like water storage, filtration, organic matter buildup, and biodiversity—emerge from the combination of soil properties, land cover, and management practices.

Key Points to Emphasize:

- Healthy soil is a living ecosystem that provides: water storage and filtration, increased organic matter, biological diversity, and sustained productivity.
- These functions are not isolated—they result from the interaction of physical (structure, texture), chemical (pH, nutrients), and biological (microbes, fungi, earthworms) attributes.

- Land cover and landscape management practices also influence how well soil performs these functions.

Facilitation Tips:

- Use examples like compost addition, cover crops, or mulching to show how management enhances soil functions.
- Encourage students to think about how these functions impact both plants and the broader environment.
- Connect this to SDGs or real-world impacts, e.g., clean water, crop yield, or habitat for organisms.

Suggested dialogue:

*“A healthy soil ecosystem provides water storage and filtration, builds organic matter, supports biodiversity above and below ground, and maintains productivity. These benefits come from the interaction of physical, chemical, and biological components, as well as how we manage the land. Everything we do in soil management affects these functions.”*

Wrap-up Prompt:

“Remember, soil health is more than one property—it’s about how the entire system works together to support life.”

### Slide 13: What Makes Soil Healthy? (Systems View + NRCS Principles)

Objective:

Introduce students to the five NRCS soil health principles and show how they guide farming practices to maintain and improve soil as a living ecosystem.

Introduction/overview:

This slide uses an infographic to present the five principles of soil health. Students will see that healthy soils are managed according to specific practices that maximize productivity while protecting and enhancing ecosystem functions.

Key Points to Emphasize:

- The five principles of soil health help farmers sustain soil as a living ecosystem.
- Soil management focuses on maintaining organic matter, minimizing disturbance, keeping soil covered, promoting biodiversity, and integrating livestock or crops in rotations.
- Healthy soils lead to better water retention, nutrient cycling, carbon storage, and resilience to erosion.
- This slide emphasizes a systems view: all principles interact to support soil functions and overall farm sustainability.

Facilitation Tips:

- Walk students through each principle using the infographic visuals.
- Relate principles to real-life examples they might know: cover crops in gardens, crop rotation, composting, minimal tillage.
- Ask students how each principle might help solve a problem like erosion, poor water retention, or low fertility.

Suggested dialogue:

*“Healthy soil isn’t just about what’s below the surface—it’s also about how we manage it. The NRCS identifies five principles for maintaining soil health: keep it covered, minimize disturbance, maintain organic matter, promote biodiversity, and use integrated rotations. When these principles are applied together, soils function better, crops grow stronger, and ecosystems are healthier.”*

Wrap-up Prompt:

“Think about these principles as a toolbox—each one supports the others. As we move through Lesson A, notice how measuring and managing soil relates back to these principles.”

## Slide 14: What Nutrients Do Plants Need?

Objective:

Introduce students to essential plant nutrients, the difference between macronutrients and micronutrients, and why soil pH affects nutrient availability.

Introduction/overview:

This slide explains that plants require a variety of nutrients to grow, some in large amounts (macronutrients) and others in smaller amounts (micronutrients). Soil pH influences how easily plants can access these nutrients, making it a key factor in soil health and management.

Key Points to Emphasize:

- Both macro- and micronutrients are essential for plant growth.
- Macronutrients are needed in larger quantities (e.g., nitrogen, phosphorus, potassium).
- Micronutrients are needed in smaller amounts (e.g., iron, zinc, manganese).
- Soil pH affects nutrient availability: some nutrients become less available if the soil is too acidic or too alkaline.
- Managing pH and nutrient levels is critical for maintaining healthy soils and productive plants.

Facilitation Tips:

- Provide examples of macronutrients and micronutrients with their roles in plant growth.
- Ask students to brainstorm common signs of nutrient deficiencies in plants (yellow leaves, stunted growth, poor fruiting).
- Relate pH to everyday examples: acidic soil in a lemon grove vs. alkaline soil in a desert garden.

Suggested dialogue:

*“Plants need nutrients just like we need vitamins and minerals. Macronutrients, like nitrogen, phosphorus, and potassium, are needed in larger amounts. Micronutrients, such as iron or zinc, are needed in smaller amounts—but they are still essential. Soil pH matters because it affects whether these nutrients are available to plants. Too acidic or too alkaline, and plants can’t absorb what they need.”*

Wrap-up Prompt:

“Keep in mind that healthy soil not only has the right structure and organic matter, but also provides the nutrients plants need in the right balance.”

## Slide 15: Nutrients 101: Macro vs. Micro & Why pH Matters

Objective:

Explain the optimal soil pH range for nutrient availability and the consequences of soils that are too acidic or too alkaline.

Introduction/overview:

This slide focuses on how soil pH affects the availability of macro- and micronutrients for plants. Students will learn the “sweet spot” for pH and the nutrient limitations or toxicities that occur outside this range.

Key Points to Emphasize:

- Optimal soil pH is approximately 6.0–7.0, where most nutrients are available to plants.
- Soils that are too acidic (<6) can cause phosphorus tie-up and toxicity risks for iron, manganese, and aluminum.
- Soils that are too alkaline (>7.5) can cause deficiencies in iron and zinc and phosphorus tie-up as calcium phosphate.
- Maintaining the right pH is critical for maximizing nutrient uptake and overall soil health.

Facilitation Tips:

- Use a pH scale visual to show the sweet spot and the nutrient issues at both extremes.
- Relate this to everyday observations, like plant chlorosis in alkaline soils or stunted growth in acidic soils.

- Encourage students to think about how farmers or gardeners might adjust pH (lime for acidic soils, sulfur for alkaline soils).

Suggested dialogue:

*“The ideal soil pH for most plants is between 6.0 and 7.0. In this range, nutrients are readily available. If the soil is too acidic, phosphorus can become unavailable, and iron, manganese, or aluminum can become toxic. If the soil is too alkaline, iron and zinc may be deficient, and phosphorus can bind to calcium. Understanding pH helps us ensure plants can access the nutrients they need.”*

Wrap-up Prompt:

“Remember, testing and managing pH is a simple but powerful way to improve soil health and plant growth.”

## **Slide 16: How organic matter and microbial activity influence nutrient availability and soil pH**

Objective:

Explain how organic matter and microbial activity influence nutrient availability and soil pH, and connect this to a hands-on class activity measuring soil pH.

Introduction/overview:

This slide emphasizes the role of organic matter (OM) in buffering pH, releasing nutrients gradually, and supporting microbial activity. Students will see how these factors interact to make nutrients available and will apply this understanding in a class pH measurement activity.

Key Points to Emphasize:

- Organic matter buffers pH by gradually releasing nutrients, chelating metals, and reducing pH swings.
- Microbial activity converts nutrients into forms plants can absorb, especially N, P, and K.
- Measuring soil pH in class helps students interpret nutrient availability in the context of macronutrients.
- Understanding these processes links soil chemistry to practical management decisions.

Facilitation Tips:

- Remind students that OM is critical even in small amounts for nutrient cycling and pH stability.
- Relate microbial activity to real-world examples like composting or organic amendments.
- During the pH test, ask students to predict nutrient availability before taking measurements.

Suggested dialogue:

*“Organic matter doesn’t just feed microbes—it also buffers soil pH, helping nutrients become available gradually and preventing harmful swings. Microbes break down nutrients so plants can take them up. In class, you’ll measure soil pH and interpret what it means for N, P, and K availability. This hands-on test shows how chemistry and biology work together in healthy soil.”*

Wrap-up Prompt:

“Keep in mind that soil is a living system: organic matter and microbes are essential for maintaining pH and nutrient availability.”

## **Slide 17: Think Pair Share - Nutrients 101: Macro vs. Micro & Why pH Matters**

Objective:

Engage students in applying their knowledge of soil pH to identify problems and propose simple, sustainable management practices.

Introduction/overview:

This slide uses a Think–Pair–Share activity to explore the consequences of acidic soil (pH 5.2) and brainstorm ways to nudge pH toward the optimal range without excessive chemical inputs. Students will connect theory to practical solutions.

Key Points to Emphasize:

- pH 5.2 is acidic and may limit nutrient availability or cause toxicities (e.g., aluminum, manganese).

- Management practices can gradually nudge pH toward neutral: adding lime or wood ash, increasing legumes or diverse residues, improving drainage, reducing over-fertilization with acidifying fertilizers.
- Emphasize sustainable, non-dumping practices rather than quick chemical fixes.
- This activity reinforces the link between soil chemistry and management decisions.

Facilitation Tips:

- Give students 1 minute to think individually, 1–2 minutes to discuss with a partner, then share as a class.
- Encourage creative solutions that are environmentally responsible.
- Use the discussion to highlight how small changes in practice can have meaningful impacts on soil health and plant growth.

Suggested dialogue:

*“Imagine a soil with a pH of 5.2. What issues might plants face? Now, think of one practice you could use to gradually move the soil toward neutral, without just dumping chemicals. Turn to a partner and share your ideas. Some options include adding lime or wood ash carefully, increasing legumes and diverse plant residues, improving drainage, or reducing acidifying fertilizer use. Let’s hear a few ideas from the class.”*

Wrap-up Prompt:

“Notice how understanding pH helps us make smart management decisions that support soil health and plant growth sustainably.”

### Slide 18: Minimize Disturbance (Why It Pays)

Objective:

Explain why minimizing soil disturbance is critical for maintaining healthy aggregates, microbial networks, nutrient cycling, and overall soil function.

Introduction/overview:

This slide emphasizes that reducing tillage or other disruptive practices preserves soil structure and biology, leading to better water infiltration, steadier nutrient cycling, and more efficient use of labor and inputs. Students will connect management practices to soil function and sustainability.

Key Points to Emphasize:

- Minimizing disturbance protects aggregates and fungal hyphae, which are essential for soil structure.
- Reduced erosion and increased infiltration help maintain soil moisture and fertility.
- Stable soil biology leads to steadier nutrient cycling.
- Fewer tillage passes save labor and fuel.
- Smarter input use (right rate, right time) supports productivity while reducing environmental impact.
- Rotational grazing helps protect soil in pastures; over-grazing damages structure.
- Healthy soil depends on this “fragile scaffolding” of aggregates, pores, and microbial networks.

Facilitation Tips:

- Use examples of tillage vs. no-till fields or rotational grazing practices.
- Ask students why soil disturbance might be necessary sometimes, and how it can be minimized.
- Emphasize both ecological and practical benefits: productivity, water, and nutrient management.

Suggested dialogue:

*“Minimizing disturbance protects the delicate scaffolding of soil—aggregates, pores, and fungal networks. This reduces erosion, increases infiltration, keeps nutrients cycling efficiently, and saves labor and fuel. In pastures, rotational grazing prevents over-grazing and maintains structure. By managing soils carefully, we get healthier soil, smarter use of inputs, and more resilient ecosystems.”*

Wrap-up Prompt:

“Think about the soil in your garden or school yard—what disturbances could you reduce to keep it healthy and productive?”

## Slide 19: Maximize Biodiversity (Above & Below Ground)

Objective:

Explain how above- and below-ground biodiversity supports soil health, pest management, nutrient cycling, and farm resilience.

Introduction/overview:

This slide emphasizes that managing for diversity—through crop rotations, multi-species cover crops, and habitat strips—enhances both the biological community in the soil and beneficial organisms above ground. Students will learn how these practices improve ecosystem services and farm outcomes.

Key Points to Emphasize:

- Diverse rotations and multi-species cover crops increase plant variety above ground.
- Habitat strips and field edges provide shelter and resources for beneficial insects and organisms.
- Greater above-ground diversity supports below-ground microbial diversity, forming a healthier soil ecosystem.
- Outcomes include reduced pest and disease pressure, improved nutrient cycling, and more stable farm profits.
- Biodiversity is a cornerstone of sustainable soil and crop management.

Facilitation Tips:

- Use examples like legumes in cover crops improving nitrogen, or flowering strips attracting pollinators.
- Ask students to brainstorm ways local gardens or parks could increase biodiversity.
- Connect the concept to SDGs related to life on land, food security, and sustainable agriculture.

Suggested dialogue:

*“By increasing diversity above ground—through rotations, multi-species covers, and habitat strips—we also boost below-ground biodiversity. Healthy soil microbes and beneficial insects thrive, which reduces pests, enhances nutrient cycling, and helps farms be more resilient. Biodiversity is one of the most powerful tools we have for sustainable soil management.”*

Wrap-up Prompt:

“Think about how planting a variety of crops or adding habitat strips can improve both soil and ecosystem health.”

## Slide 20: Soil Health = Ecosystem Services (Beyond Yield)

Objective:

Help students connect soil health to broader ecosystem services, showing that healthy soils provide benefits beyond crop yields.

Introduction/overview:

This slide highlights how managing soils for health impacts food production, water regulation, human health, and climate mitigation. Students will see that soil is a critical ecosystem that provides multiple services simultaneously.

Key Points to Emphasize:

- Food: healthy soils support strong roots and stress-tolerant crop yields.
- Water: improved infiltration reduces runoff and erosion, protecting water quality.
- Human health: nutrient-rich crops and fewer contaminants support better nutrition.
- Climate: increased soil organic matter stores carbon, helping mitigate climate change.
- Soil health is a systems concept—enhancing one function often benefits others.

Facilitation Tips:

- Relate ecosystem services to real-life examples, such as a community garden producing nutritious food or rainwater soaking into fields.
- Ask students to identify which soil functions benefit both the environment and humans.

- Highlight how sustainable soil management links to multiple SDGs (2, 6, 13, 15).

Suggested dialogue:

*“Healthy soils do more than grow crops—they provide ecosystem services. Strong roots and stress-tolerant yields improve food security. Better infiltration reduces runoff and erosion, protecting water. Nutrient-rich crops improve human health, and more organic matter stores carbon, helping fight climate change. Soil health truly benefits the whole ecosystem.”*

Wrap-up Prompt:

“Think beyond the garden or farm—how does healthy soil support the environment, people, and the planet?”

## Slide 21: Link Back to Modules 1–2 & the SDGs

Objective:

Help students connect soil health concepts from Module 3 to prior lessons and demonstrate how these ideas align with Sustainable Development Goals (SDGs).

Introduction/overview:

This slide reinforces the continuity of the curriculum by linking soil health to topics from Modules 1–2 (e.g., water management, energy efficiency) and illustrating how soil management contributes to multiple SDGs. Students will see the broader relevance of soil science.

Key Points to Emphasize:

- Healthy soils support water regulation, nutrient cycling, and climate resilience, tying back to Module 1 (water systems) and Module 2 (energy use and sustainability).
- Connecting soil functions to SDGs shows real-world relevance (e.g., SDG 2 – Zero Hunger; SDG 6 – Clean Water; SDG 13 – Climate Action; SDG 15 – Life on Land).
- Soil management is part of a larger system of sustainable agricultural and environmental practices.

Facilitation Tips:

- Ask students to recall lessons from Modules 1–2 and discuss how they relate to soil management.
- Use SDG icons or visuals to make the connection concrete.
- Encourage students to think about how individual soil management practices influence broader sustainability goals.

Suggested dialogue:

*“Let’s link what we’ve learned about soil health back to our previous lessons. In Module 1, we looked at water management, and in Module 2, energy efficiency and sustainability. Healthy soils improve water retention, nutrient cycling, and climate resilience—connecting directly to SDGs like Zero Hunger, Clean Water, Climate Action, and Life on Land. This shows that soil management isn’t just about farming—it’s about contributing to global sustainability.”*

Wrap-up Prompt:

“Consider how the small practices we do in managing soil connect to bigger environmental and societal goals.”

## Slide 22: Team Design Activity – Soil Infiltration

Objective:

Engage students in a hands-on activity to explore how soil structure and management practices influence water infiltration and connect these effects to soil functions and Sustainable Development Goals (SDGs).

Introduction/overview:

Explain that water movement through soil is critical for plant growth, water quality, and ecosystem health. Students will investigate factors that improve or reduce infiltration and design solutions to enhance it.

Key Points to Emphasize:

- Students will identify factors that affect water infiltration, such as soil texture, compaction, organic matter, or surface cover.

- Teams propose one practice that could increase infiltration (e.g., adding organic matter, reducing compaction, planting cover crops).
- Students link their proposed practice to a soil function (like water storage or nutrient cycling) and an SDG (e.g., clean water – SDG 6, sustainable agriculture – SDG 2).
- Optional “Soil Infiltration” corner for students to explore creative or advanced approaches.

Facilitation Tips:

- Encourage students to think critically about cause-and-effect relationships between soil structure, practices, and water movement.
- Circulate and ask guiding questions: “Why does this factor increase or reduce infiltration?” or “How does your practice support an ecosystem service?”
- Promote Think-Pair-Share discussion so students can refine ideas before presenting to the group.

Suggested dialogue:

“Now it’s your turn to be soil engineers! Identify a factor that affects water infiltration in soil, propose a practice to improve it, and connect it to a soil function and an SDG. Work with your partner to plan and share your ideas.”

Wrap-up Prompt:

Have students share one factor they identified and one practice to improve infiltration, explaining the link to soil health and sustainability.

### Slide 23: Review Questions

Objective:

Check student understanding of key concepts from Lesson A: soil health, texture & structure, and pH. Encourage discussion and synthesis of ideas.

Introduction/overview:

This slide prompts students to reflect on the main concepts from Lesson A. It’s a chance to clarify any misconceptions and reinforce the links between soil properties, plant growth, microbial activity, and ecosystem services.

Key Points to Emphasize:

- Questions:
  - What is the NRCS definition of soil health, and why is it important?
  - How do soil texture and structure influence plant growth and microbial activity?
  - Why is soil pH called the “gatekeeper” of nutrients, and what problems can arise when pH is too low or too high?
- NRCS definition: “The continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans.”
- Soil texture and structure determine water retention, root penetration, aeration, and microbial habitat.
- Soil pH controls nutrient availability: too low or too high pH can limit plant growth or cause toxicity.

Facilitation Tips:

- Use Think–Pair–Share: ask students to think individually, then discuss in pairs before sharing with the class.
- Encourage students to connect answers to real-world examples (school garden, local farm, or backyard soil).
- Ask probing questions: “How might clay soil behave differently than sandy soil in terms of microbes?” or “What would happen to crops if pH drops below 5.5?”

Suggested dialogue:

*“Let’s review some key ideas from Lesson A. First, what is the NRCS definition of soil health, and why does it matter? Next, how do texture and structure affect plant growth and microbes? Finally, why do we call pH the ‘gatekeeper’ of nutrients, and what problems arise if it’s too high or too low? Take a moment to think, then discuss your answers with a partner.”*

Wrap-up Prompt:

“By answering these questions, you’re connecting soil properties to plant and microbial health, and seeing why managing soils properly is essential for ecosystems and sustainable agriculture.”

## Slide 24: Review Answers

Objective:

Provide clear answers to the Lesson A review questions, reinforcing key concepts about soil health, texture & structure, and pH.

Introduction/overview:

This slide summarizes the main points from Lesson A and ensures students have a correct understanding of soil fundamentals.

Key Points to Emphasize:

- Answers:
  - The capacity of soil to function as a living ecosystem that sustains plants, animals, and humans.
  - Texture sets water and nutrient holding; structure (aggregates) controls air, water, and root access.
  - pH controls nutrient availability—too acidic or alkaline locks up nutrients or causes toxicity.
- Soil health (NRCS definition): “The capacity of soil to function as a living ecosystem that sustains plants, animals, and humans.”
- Texture sets the soil’s water and nutrient-holding capacity: sandy soils drain quickly but hold fewer nutrients; clay holds water and nutrients but may limit drainage.
- Structure (aggregates) creates pores that allow air, water, and roots to penetrate, supporting microbial activity and plant growth.
- Soil pH is the “gatekeeper” of nutrients: too acidic or alkaline soils can lock up nutrients or create toxic conditions for plants.

Facilitation Tips:

- Review each answer slowly, asking students to give examples from a school garden, backyard, or local farm.
- Highlight the connections between soil properties and broader ecosystem services (water regulation, nutrient cycling, plant growth).
- Encourage students to relate the answers to SDGs if possible (e.g., SDG 2 – Zero Hunger, SDG 6 – Clean Water).

Suggested dialogue:

*“Here are the answers to our review questions. Soil health is all about its capacity to sustain life. Texture determines how water and nutrients move and are stored. Structure gives roots and microbes space to thrive. And pH controls nutrient availability—too low or high, and nutrients get locked up or become toxic. Can anyone give an example from your own experience where soil texture or pH affected plant growth?”*

Wrap-up Prompt:

“Remember, these soil fundamentals—health, texture, structure, and pH—are the foundation for all soil management and ecosystem services we’ll explore in the next lessons.”

## Lesson B: Climate Knobs

### Slides 25-49

#### **Slide 25: How does carbon enter, stay in, and leave soil—and how can we tip the balance to build SOM and resilience?**

##### Objective:

Introduce students to the soil-carbon cycle and the Build–Maintain–Consume framework, showing how management practices influence soil organic matter (SOM) and ecosystem resilience.

##### Introduction/overview:

This slide transitions from Lesson A (soil fundamentals) to Lesson B, focusing on carbon in soils. Students will explore how carbon enters, is stored, and leaves the soil, and how different practices can shift the balance toward building SOM for improved soil health, water retention, and climate benefits.

##### Key Points to Emphasize:

- Carbon enters soil through plant residues, roots, and organic amendments.
- SOM stores carbon, supports microbial activity, improves structure, and retains water and nutrients.
- Carbon leaves soil via decomposition, respiration, erosion, and harvest removal.
- The Build–Maintain–Consume triad is a way to categorize soil management practices:
  - Build → add carbon to the soil (e.g., cover crops, compost)
  - Maintain → protect existing carbon (e.g., reduce tillage, maintain residues)
  - Consume → remove or use carbon for short-term benefits (e.g., intensive grazing, burning crop residues)

##### Facilitation Tips:

- Use visual examples of carbon entering soil (roots, litter, compost) and leaving (decomposition, erosion).
- Ask students to think of everyday examples where carbon is added or removed from soils.
- Connect the Build–Maintain–Consume framework to the SDGs: carbon storage links to climate action (SDG 13), food security (SDG 2), and sustainable land use (SDG 15).

##### Suggested dialogue:

*“Carbon is a critical component of healthy soils. It enters through plants and amendments, stays in soil as organic matter supporting microbes and structure, and leaves through decomposition, erosion, or harvest. Using the Build–Maintain–Consume framework, we can categorize practices that add, protect, or remove carbon. By tipping the balance toward building SOM, we improve soil resilience, water holding, and even help fight climate change.”*

##### Wrap-up Prompt:

“Think about a local garden, farm, or park. What practices would you classify as Build, Maintain, or Consume, and how do they affect soil carbon and resilience?”

#### **Slide 26: Carbon In, Carbon Out, Carbon Kept**

##### Objective:

Students will use the Build–Maintain–Consume triad to understand how carbon moves through soils and how management practices influence soil organic matter (SOM) and overall soil health.

##### Introduction/overview:

This slide focuses on the mechanisms of carbon flow in soil: inputs (Build), protection (Maintain), and losses (Consume). It emphasizes that the goal of soil management is to tip the balance toward carbon retention, supporting microbial activity, soil structure, and ecosystem services.

##### Key Points to Emphasize:

- Build: carbon enters the soil through roots, crop residues, compost, and root exudates—these are the inputs that feed microbes and form organic matter.

- Maintain: carbon is stabilized in aggregates and bound to minerals; minimizing disturbance (like tillage) protects it.
- Consume: carbon is lost through microbial respiration (normal CO<sub>2</sub> release), erosion, or harvest removal.
- The goal is balance: enough consumption to maintain nutrient cycling, but enough retention to build SOM, improve water holding, and enhance resilience.

Facilitation Tips:

- Draw a simple diagram showing arrows for carbon entering (Build), staying (Maintain), and leaving (Consume).
- Ask students to brainstorm examples of each category from gardens, farms, or even composting at home.
- Highlight connections to SDGs: SOM retention supports SDG 13 (Climate Action), SDG 2 (Zero Hunger), and SDG 15 (Life on Land).

Suggested dialogue:

*“Think of soil as a carbon bank. Build is the deposit—roots, residues, and compost add carbon. Maintain is keeping it safe—aggregates and minerals protect it. Consume is the spending—microbes break down carbon and release CO<sub>2</sub>. The goal isn’t to stop consumption—it’s to maintain a healthy balance so the soil stays productive, resilient, and capable of supporting plants, water regulation, and life.”*

Wrap-up Prompt:

“Which practices in your school garden or backyard would you classify as Build, Maintain, or Consume, and how could adjusting them help soil store more carbon?”

## Slide 27: The Soil-Carbon Cycle

Objective:

Students will understand how carbon enters, cycles through, and is stored in soils, and how these processes support soil health and ecosystem services.

Introduction/overview:

This slide shows the soil-carbon cycle, emphasizing the roles of plants and microbes in moving carbon into, through, and out of the soil. Students will connect carbon dynamics to soil management practices and ecosystem outcomes.

Key Points to Emphasize:

- Plants capture atmospheric CO<sub>2</sub> via photosynthesis and convert it into sugars.
- Carbon enters the soil through roots, litter, and root exudates—feeding microbial communities.
- Microbes transform carbon: some is respired as CO<sub>2</sub> (natural loss), while some becomes stabilized as Soil Organic Matter (SOM).
- SOM improves structure, water retention, nutrient cycling, and overall soil resilience.
- Challenges to carbon farming include erosion, excessive disturbance, and rapid decomposition.

Facilitation Tips:

- Use a simple diagram with arrows showing CO<sub>2</sub> → plant sugars → roots/litter/exudates → microbes → SOM / CO<sub>2</sub>.
- Ask students to identify which parts of the cycle they can influence with management practices.
- Connect to SDGs: carbon retention links to SDG 13 (Climate Action), SDG 2 (Zero Hunger), and SDG 15 (Life on Land).

Suggested dialogue:

*“Plants act as carbon pumps, taking CO<sub>2</sub> from the atmosphere and converting it into sugars. Some of this carbon goes into roots, litter, and exudates, feeding the soil microbes. Microbes then either respire some carbon back to the atmosphere or help stabilize it as Soil Organic Matter. Managing soils wisely can tip this balance toward more carbon storage, which benefits soil health, plant growth, and climate resilience.”*

Wrap-up Prompt:

“Think about which practices in a garden or farm add carbon, protect it, or lead to losses—and how adjusting these can improve soil health and ecosystem resilience.”

## Slide 28: The Soil-Carbon Cycle: Storage vs. Sequestration

Objective:

Students will learn the difference between soil carbon storage (stock) and sequestration (rate), and understand which practices truly build long-term soil carbon.

Introduction/overview:

This slide clarifies key terms in soil-carbon management. Students will see why adding organic matter alone (like compost) doesn't always increase long-term soil carbon, and why both inputs and loss prevention matter.

Key Points to Emphasize:

- Storage (stock) = the total amount of carbon currently in the soil.
- Sequestration (rate) = the net increase in soil carbon per year (e.g., CO<sub>2</sub>e/ha/yr).
- Compost adds carbon, but it may just relocate carbon unless it contributes to stable SOM.
- True gains in soil carbon come from increasing on-site plant inputs and reducing carbon losses over time.
- Practices that reduce erosion, minimize disturbance, and build aggregates help retain carbon.

Facilitation Tips:

- Use examples: a farm adding compost vs. planting cover crops; discuss which leads to real sequestration.
- Encourage students to connect this to the Build–Maintain–Consume triad: Build = inputs, Maintain = protect, Consume = losses.
- Relate to SDGs: sequestration contributes to SDG 13 (Climate Action), SDG 15 (Life on Land), and SDG 2 (Zero Hunger).

Suggested dialogue:

*“Carbon storage tells us how much is in the soil now, while sequestration tells us how fast we’re adding it. Adding compost is helpful, but it doesn’t always mean long-term storage—sometimes the carbon is just moved around. True gains happen when we add on-site plant inputs and prevent losses through careful soil management.”*

Wrap-up Prompt:

“Think about the soils you know—school garden, farm, or backyard. Which practices would increase carbon stock, and which would increase sequestration? How could you maximize both?”

## Slide 29: The Soil-Carbon Cycle: Why It Matters for Climate

Objective:

Students will understand why soils are a critical carbon pool and how small increases in soil carbon across large areas contribute to climate action.

Introduction/overview:

This slide emphasizes the global significance of soil carbon. It connects the Build–Maintain–Consume framework to climate mitigation and shows how soil management can support SDG 13: Climate Action.

Key Points to Emphasize:

- Soils hold more carbon than plants and the atmosphere combined—making them the largest land-based carbon pool.
- Even small percentage increases in soil carbon, when applied across large areas, have a substantial impact on climate mitigation.
- Net carbon gains occur when:
  - Build (inputs) > Consume (losses), and
  - Maintain practices protect existing carbon.

- Proper soil management supports multiple ecosystem services, from water retention to nutrient cycling.

#### Facilitation Tips:

- Ask students to imagine a farm or school garden: if every square meter gained a small amount of carbon each year, what might that add up to across a region?
- Highlight the link between soil health practices and SDG 13 (Climate Action). Encourage discussion about realistic ways students or communities could “tip the balance” toward carbon storage in soils.

#### Suggested dialogue:

*“Think of soil as a giant carbon bank. Soils hold more carbon than all the plants and the atmosphere combined. That means even tiny percentage gains in carbon, applied across farms, gardens, and landscapes, can make a huge difference for climate. By using Build–Maintain–Consume wisely, we can protect and grow soil carbon, supporting climate action.”*

#### Wrap-up Prompt:

“Consider one soil management practice that could help tip the balance toward carbon storage on your campus or in your local area. How does that connect to climate action and SDG 13?”

### Slide 30: From “Magic Humus” to a Continuum: What Stays, What Goes

#### Objective:

Students will understand that soil carbon is a continuum of compounds with different decomposition rates, and that management determines what carbon is stabilized versus respired.

#### Introduction/overview:

This slide challenges the misconception that soil carbon is a single “magic humus.” Students will learn that carbon exists in multiple forms, some of which are short-lived while others contribute to long-term soil organic matter (SOM).

#### Key Points to Emphasize:

- Soil carbon is a spectrum: fresh plant residues → microbial products → small molecules.
- Fast-decomposing carbon is respired as CO<sub>2</sub>; slow-decomposing carbon can be stabilized in aggregates or bound to minerals.
- Long-term carbon storage relies on practices that protect SOM in aggregates and mineral associations.
- Not all added organic matter automatically increases soil carbon; protection and stabilization matter.

#### Facilitation Tips:

- Use a visual continuum diagram: fresh residue → microbial breakdown → stabilized SOM.
- Ask students to identify examples of fast vs. slow carbon from a garden, farm, or compost pile.
- Connect to the Build–Maintain–Consume framework: Build = add carbon, Maintain = protect stabilized carbon, Consume = natural microbial respiration.
- Relate to SDGs, especially SDG 13 (Climate Action) and SDG 15 (Life on Land).

#### Suggested dialogue:

*“Many people think of soil carbon as one magic substance called humus. In reality, it’s a continuum: plant bits break down, microbes process them, some carbon is respired as CO<sub>2</sub>, and some gets locked into aggregates or minerals for the long term. Our management choices determine which carbon stays in the soil and which leaves.”*

#### Wrap-up Prompt:

“Think about your school garden or backyard: which carbon inputs are likely to be respired quickly, and which are more likely to be stabilized for long-term soil health?”

## Slide 31: The Build–Maintain–Consume Triad (How We Steer It)

Objective:

Students will explore how soil management practices influence the Build–Maintain–Consume balance, and understand which practices tip the soil-carbon cycle toward long-term storage.

Introduction/overview:

This slide connects the soil-carbon cycle to practical management. Students will see how farmers and gardeners can “steer” carbon flows using the triad: Build (inputs), Maintain (protection), and Consume (losses).

Key Points to Emphasize:

- Build: adding carbon to soil via roots, residues, compost, or other organic amendments.
- Maintain: protecting soil carbon by preserving aggregates, reducing tillage, and minimizing erosion.
- Consume: carbon lost through microbial respiration, harvest, or erosion; some consumption is necessary for nutrient cycling.
- Management decisions can increase the proportion of carbon retained as SOM, improving soil health, water retention, and climate mitigation.

Facilitation Tips:

- Show a simple diagram with arrows for Build, Maintain, and Consume, highlighting which practices influence each.
- Ask students to brainstorm examples from gardens, farms, or school yards that fit each category.
- Connect to carbon markets or incentives: farmers can earn rewards for practices that increase soil carbon storage (linking to real-world applications).
- Relate to SDGs: Build–Maintain–Consume practices support SDG 13 (Climate Action), SDG 2 (Zero Hunger), and SDG 15 (Life on Land).

Suggested dialogue:

*“Think of the Build–Maintain–Consume triad as steering soil carbon. Build adds carbon, Maintain protects what’s already there, and Consume is the natural loss through respiration or erosion. Farmers and gardeners use these principles to manage soils so that more carbon stays in the ground, improving fertility, water holding, and even contributing to climate action.”*

Wrap-up Prompt:

“Identify one practice in your own school garden or backyard for each part of the triad. How does it help tip the soil-carbon balance toward storage?”

## Slide 32: Review: Data → Decision (Apply the Triad)

Objective:

Students will practice applying the Build–Maintain–Consume framework to real soil data, make management recommendations, and connect decisions to SDGs.

Introduction/overview:

This slide provides a mini-dataset for students to analyze. They will identify constraints, propose practices to improve soil carbon and health, and link their recommendations to sustainable development goals.

Key Points to Emphasize:

- Use soil indicators (pH, texture, infiltration, slake, SOM proxy, respiration) to assess limitations.
- Build = add carbon inputs (roots, residues, compost).
- Maintain = protect soil structure and existing carbon (reduce disturbance, maintain residues).
- Consume = natural carbon loss; some consumption is normal, but balance is key.
- SDGs (e.g., SDG 2, 6, 13, 15) can be linked to management practices.

Facilitation Tips:

- Encourage students to discuss constraints in pairs before proposing solutions.
- Guide them to choose realistic two-practice bundles that combine Build + Maintain approaches.

- Ask students to justify predicted changes in indicators and explain why their practices support specific SDGs.
- Encourage connections back to the soil-carbon cycle and prior lessons.

Suggested dialogue:

*“Here’s a small dataset: pH 5.5, sandy loam, fast infiltration, weak slake, low SOM proxy, moderate respiration. First, what constraints can you infer from this data? Next, in pairs, propose a two-practice bundle using the Build–Maintain–Consume framework. Predict how each practice will affect soil indicators and tag at least one SDG that your plan advances. Remember, we’re aiming to tip the balance toward soil carbon storage and health.”*

Wrap-up Prompt:

“After sharing your recommendations, reflect on how applying the triad helps make evidence-based decisions that improve soil health and support sustainable development.”

### Slide 33: Bottom Line: When Do We Sequester?

Objective:

Students will understand the conditions necessary for soil carbon sequestration and the role of management practices in achieving long-term gains.

Introduction/overview:

This slide summarizes the main takeaway from Lesson B: soil carbon sequestration occurs when inputs exceed losses and protection practices preserve those gains. It reinforces the link between biology, structure, and carbon storage.

Key Points to Emphasize:

- Sequestration happens when Build (carbon inputs) > Consume (losses) over time.
- Maintain practices protect gains by stabilizing carbon in aggregates and minerals.
- Active soil biology and stable structure are crucial for an upward trend in soil carbon.
- Long-term management matters: temporary gains can be lost without protection.

Facilitation Tips:

- Use a simple diagram: arrows showing Build vs. Consume, with Maintain shielding the stored carbon.
- Ask students to brainstorm real-life examples of practices that tip the balance toward sequestration (cover crops, reduced tillage, residue retention).
- Connect to SDG 13 (Climate Action) and highlight co-benefits for SDG 2 (Zero Hunger) and SDG 15 (Life on Land).

Suggested dialogue:

*“Sequestration isn’t just about adding organic matter—it’s about ensuring that Build exceeds Consume over time, and that Maintain practices protect the gains. When soil biology is active and structure is stable, the soil’s carbon stock trends upward, benefiting plant growth, water retention, and climate mitigation.”*

Wrap-up Prompt:

“Think about your school garden or local farm: which practices would help ensure that Build > Consume and gains are maintained over years?”

### Slide 34: Practices That Work (Field-Proven & School-Friendly)

Objective:

Students will explore field-tested, school-friendly soil management practices that improve soil health and learn how each connects to building structure, supporting biology, and enhancing ecosystem services.

Introduction/overview:

This slide shows four key principles of soil health management: maximize living roots, minimize disturbance, maximize biodiversity, and maximize soil cover. Students will connect these principles to practical examples in gardens, farms, or school projects.

### Key Points to Emphasize:

- Maximize Continuous Living Roots: Plant rotations, cover crops, forage, or perennials to feed soil microbes and build organic matter.
- Minimize Disturbance: Reduce tillage, avoid working wet soils, and control traffic to protect aggregates and prevent erosion.
- Maximize Biodiversity: Use crop rotations, integrate legumes or pollinator plantings, practice rotational grazing, and include agroforestry or mixed crop-livestock systems to support soil food webs.
- Maximize Soil Cover: Mulching, residue retention, cover crops, and green manures reduce erosion, retain moisture, and protect microbial habitats.
- These practices support the NRCS principles and improve nutrient and water management, as well as long-term soil health.

### Facilitation Tips:

- Ask students to identify which of these practices they have seen or could implement in a school garden.
- Relate each quadrant to ecosystem services: water retention, nutrient cycling, erosion prevention, and carbon storage.
- Encourage discussion on why multiple principles combined are more effective than one alone.

### Suggested dialogue:

*“Healthy soils rely on multiple practices working together. Continuous roots feed microbes, reducing disturbance protects the soil’s structure, biodiversity supports a resilient ecosystem, and soil cover keeps moisture and nutrients in place. Even in a school garden, small-scale versions of these practices can make a big difference.”*

### Wrap-up Prompt:

“Which of these four principles could you apply in your school garden or backyard? How might combining two or more practices amplify soil health benefits?”

## Slide 35: Co-Benefits and Trade-Offs of Soil Design

### Objective:

Help students understand how thoughtful soil management provides multiple co-benefits while considering trade-offs, emphasizing that building soil organic matter (SOM) strengthens overall system resilience.

### Introduction/overview:

Explain that when we design agricultural systems with soil health in mind, we are not just building carbon; we are creating a cascade of benefits that improve water retention, nutrient cycling, crop stability, and reduce disease pressure. Highlight that these benefits often stack, meaning one improvement reinforces another.

### Key Points to Emphasize:

- Increasing SOM improves water holding capacity and infiltration, which reduces runoff and erosion.
- Healthy soil acts as a buffer against drought and heat, stabilizing crop yields.
- Nutrient cycling becomes steadier, often allowing farmers to reduce external inputs over time.
- Diverse and active soil life reduces disease pressure, supporting plant health.
- Overall message: More SOM leads to more resilient farming systems.

### Facilitation Tips:

- Encourage students to think of soil as a living ecosystem rather than just “dirt.”
- Use examples from local agriculture or gardens to illustrate stacked benefits.
- Ask students to brainstorm what happens if soil is poorly managed—contrast with healthy soil outcomes.

### Suggested dialogue:

*“Notice how each of these benefits builds on the others. When water infiltration improves, runoff decreases, which also reduces erosion. That means nutrients stay in the soil longer, feeding plants more efficiently. At the*

*same time, a diverse soil ecosystem helps keep disease pressures low. So, by focusing on building organic matter, we're stacking wins—each benefit reinforces another, making the farm more resilient.”*

Wrap-up Prompt:

“So the takeaway here is simple: investing in soil health by increasing organic matter doesn't just help the soil itself—it makes the entire system stronger and more resilient.”

### **Slide 36: Co-Benefits and Trade-Offs: Design Considerations**

Objective:

Teach students that while building soil health has many benefits, careful design is essential to avoid unintended negative outcomes.

Introduction/overview:

Explain that soil management is a balancing act. While adding organic matter and improving structure generally helps, poor practices or conditions can create trade-offs, such as emissions, compaction, or pest problems. Highlight that adaptive management—testing, observing, and adjusting—is key.

Key Points to Emphasize:

- Over-wet soils can increase N<sub>2</sub>O emissions, a potent greenhouse gas.
- Heavy machinery or repeated foot traffic can compact soil, reducing infiltration and root growth.
- Some plant residues, if left unmanaged, can become pest habitats.
- There is no one-size-fits-all approach; soils and climates differ, so adaptive management is necessary.

Facilitation Tips:

- Use local or school garden examples to show compaction or over-watering issues.
- Encourage students to think critically about how good intentions can have trade-offs.
- Ask students how they might test and adjust practices to avoid these problems.

Suggested dialogue:

*“Even though building soil organic matter has many benefits, the design of the system really matters. For example, if soil is too wet, it can release more N<sub>2</sub>O, a greenhouse gas. Heavy equipment or repeated foot traffic can compact soil, making it harder for roots and water to move through. And if plant residues aren't managed, they can attract pests. This is why adaptive management—testing, observing, and adjusting—is so important. Every farm, garden, or soil is different, so there's no single solution that works everywhere.”*

Wrap-up Prompt:

“The key idea is that soil health practices are powerful, but they need careful design and monitoring to avoid trade-offs and keep the system resilient.”

### **Slide 37: Co-Benefits and Trade-Offs: Thinking About Carbon**

Objective:

Engage students in thinking critically about carbon in soils and how management practices affect sequestration versus mere storage.

Introduction/overview:

Introduce the idea that not all organic amendments automatically lead to carbon sequestration. Explain the difference between adding carbon to a system versus increasing the system's net carbon stock over time.

Key Points to Emphasize:

- Sequestration means increasing carbon stock beyond the baseline due to your management practices.
- Purchased compost may temporarily store carbon but doesn't always result in net sequestration unless the soil's overall carbon stock increases.
- Encourage students to think about how management choices affect long-term soil carbon.

Facilitation Tips:

- Use a real-world analogy: moving a book from one shelf to another doesn't increase the total number of books—it just relocates them.
- Give students 30–60 seconds to discuss in pairs before sharing with the class.
- Prompt them to provide reasoning, not just yes/no answers.

Suggested dialogue:

*“Here’s a question to think about: is purchased compost considered carbon sequestration, or is it just storage? Remember, sequestration is about increasing the system’s carbon stock beyond its baseline. Purchased compost often just relocates carbon unless your soil system’s net stock increases over time. Turn to a partner, discuss for a minute, and be ready to explain your reasoning.”*

Wrap-up Prompt:

“After sharing, highlight that true carbon sequestration requires management that builds lasting soil carbon, not just moving it from one place to another.”

### Slide 38: Quick Round: Place the Practice

Objective:

Engage students in actively connecting specific soil management practices to their effects on carbon, water, and soil health.

Introduction/overview:

Explain that this is a fast-paced interactive activity to help students recall and apply what they’ve learned about soil practices and their benefits or trade-offs.

Key Points to Emphasize:

- Each practice has different impacts on soil carbon, structure, water holding, and nutrient cycling.
- Encourage students to think about where each practice fits: does it build carbon, improve water retention, or reduce disease risk?
- Reinforce that some practices have multiple co-benefits.

Facilitation Tips:

- Call out a practice and ask students to quickly decide where it “fits” in the system.
- Encourage students to explain their reasoning in one sentence.
- Keep the pace lively—1–2 minutes per practice.
- Examples:
  - Compost → adds organic matter, can build carbon if net stock rises.
  - No-till → protects soil structure, improves water infiltration, reduces erosion.
  - Cover crops → adds organic matter, supports nutrients, protects against erosion.
  - Turning compost pile → accelerates decomposition, may temporarily release some carbon.

Suggested dialogue:

*“Let’s do a quick round! I’ll call out a practice, and you tell me where it fits in terms of soil health and carbon management. Remember, some practices have multiple benefits. Ready? Compost... No-till... Cover crops... Turning a compost pile... Think fast and explain your reasoning in one sentence!”*

Wrap-up Prompt:

“Notice how different practices contribute in unique ways, and how thoughtful combinations can stack multiple benefits for the soil ecosystem.”

### Slide 39: Quick Round: Place the Practice – Answers and Nuance

Objective:

Clarify the effects of common soil management practices and highlight how they interact to build and maintain soil health.

### Introduction/overview:

After the interactive round, summarize the outcomes and emphasize that each practice “pulls different levers” in the soil system. Explain how combining practices thoughtfully leads to stronger, more resilient soil.

### Key Points to Emphasize:

- Practices differ in how they contribute: some add carbon, others protect structure, some moderate moisture or temperature.
- Smart systems stack actions: Build (increase carbon/organic matter), Maintain (protect existing soil health), and Manage Consume (reduce losses, use nutrients efficiently).
- Examples:
  - Compost → adds carbon
  - Cover crops → add new biomass and root exudates
  - Biochar → adds stable carbon (context-specific)
  - Turning compost → speeds decomposition
  - No-till/reduced till → protects aggregates and fungal networks
  - Residue mulch → provides surface protection and moderates temperature/moisture

### Facilitation Tips:

- Reinforce that no single practice does it all; effective soil systems use multiple, complementary strategies.
- Encourage students to think about how practices might be combined in a real farm or garden setting.
- Use visuals or diagrams from the slide to show “Build + Maintain + Manage Consume” stacking.

### Suggested dialogue:

*“Here’s what we see when we break down these practices: each one influences the soil in a different way. Compost adds carbon, cover crops add new biomass, biochar adds stable carbon in certain contexts. Turning compost accelerates decomposition, while no-till protects soil structure and residue mulch moderates temperature and moisture. Smart systems combine these approaches to build, maintain, and manage the soil over time.”*

### Wrap-up Prompt:

“The key takeaway is that soil health requires multiple strategies working together. Each practice pulls different levers, and when we stack them smartly, we maximize benefits and resilience.”

## Slide 40: Optional Extended Learning – Carbon Accounting in Action

### Objective:

Students will understand the role of soil carbon in the global carbon cycle and recognize how small changes in soil management can have large climate impacts.

### Introduction/overview:

Introduce the concept that soil is not just dirt—it is a major carbon reservoir. Explain that soils store more carbon than both the atmosphere and all plant life combined. Highlight that improving soil health can have multiple benefits beyond carbon storage, including water retention, nutrient cycling, and overall ecosystem resilience.

### Key Points to Emphasize:

- Soil is a critical carbon sink.
- Even small increases in soil carbon can significantly affect climate outcomes.
- Healthy soils provide multiple ecosystem services: water infiltration, nutrient cycling, and resilience to stress.
- Soil management practices can either add to or reduce carbon storage.

### Facilitation Tips:

- Ask students to imagine digging a hole in their backyard and thinking about all the carbon stored below.
- Connect soil carbon to real-life practices, like composting, cover cropping, or reduced tillage.

- Use visuals showing carbon in soil versus the atmosphere and vegetation to make the numbers tangible.

Suggested dialogue:

*“You might be surprised to learn that soil stores more carbon than the air around us and all the plants combined. That means the way we manage soils—like adding compost, planting cover crops, or avoiding over-tilling—can actually make a measurable difference in the climate. And healthy soils don’t just help the climate—they help water soak in, keep nutrients cycling, and make ecosystems more resilient to droughts and floods.”*

Wrap-up Prompt:

“Think about one small soil practice you might do at home or in a garden that could help store carbon and improve soil health. How could that scale up if applied on farms everywhere?”

## Slide 41: Optional Extended Learning – Carbon Accounting in Action: Storage vs. Sequestration

Objective:

Students will learn the difference between soil carbon storage and sequestration and understand practical ways to increase soil carbon using the Build–Maintain–Consume framework.

Introduction/overview:

Explain that soil carbon can be thought of in two ways: the amount already stored in the soil (stock) and the rate at which soil carbon increases over time (sequestration). Introduce the Build–Maintain–Consume framework as a way to manage soils to increase carbon storage.

Key Points to Emphasize:

- Storage refers to the carbon currently held in the soil, measured in tons per hectare.
- Sequestration is the net annual increase in soil carbon.
- The Build–Maintain–Consume framework outlines practical strategies:
  - Build: add organic matter through roots, residues, compost, and cover crops
  - Maintain: protect soil carbon with reduced tillage and mulching
  - Consume: carbon losses through erosion, respiration, and harvest removal
- Even a small increase in soil organic matter, like 0.1%, across cropland can sequester gigatons of CO<sub>2</sub>, showing the large climate impact of small changes.

Facilitation Tips:

- Use a visual or diagram to show the difference between stock (storage) and flow (sequestration).
- Ask students to give examples of Build, Maintain, and Consume practices they might have seen in gardens, farms, or landscapes.
- Relate small changes in soil organic matter to large-scale climate benefits to make it tangible.

Suggested dialogue:

*“Think of soil carbon like money in a bank. Storage is the balance you currently have, and sequestration is the interest you earn each year. By building soil organic matter with compost or cover crops, maintaining it with mulching and reduced tillage, and minimizing losses through erosion or overharvesting, we can increase the soil ‘balance’ and capture carbon from the atmosphere. Even a tiny increase across all cropland adds up to huge amounts of CO<sub>2</sub> removed from the air.”*

Wrap-up Prompt:

“Consider one Build or Maintain practice you could apply in a garden or farm. How might even a small improvement add up if scaled to thousands of hectares?”

## Slide 42: Optional Extended Learning – Carbon Accounting in Action: Soil Carbon Flows & Feedbacks

**Objective:**

Students will understand how carbon moves through the soil system and how management practices create feedbacks that either increase or decrease soil carbon over time.

**Introduction/overview:**

Explain that soil carbon is dynamic, flowing through plants, microbes, and soil organic matter. Introduce the concepts of positive and negative feedbacks in soil carbon cycling to show how certain practices accelerate losses or enhance storage.

**Key Points to Emphasize:**

- Carbon flows from photosynthesis into plant roots and exudates.
- Microbes process this carbon, converting some into stable soil organic matter and releasing some as CO<sub>2</sub>.
- Positive feedback: repeated tillage accelerates decomposition, lowers SOM, and speeds up carbon loss.
- Negative feedback: cover crops add biomass, stabilize soil aggregates, and slow decomposition.
- Recognizing these feedbacks helps predict long-term outcomes for soil carbon and climate impact.

**Facilitation Tips:**

- Use a simple flow diagram to show carbon moving from plants → roots → microbes → SOM or CO<sub>2</sub>.
- Ask students to think about which common farming practices might create positive or negative feedbacks.
- Relate feedbacks to real-world consequences, like soil degradation vs. soil improvement.

**Suggested dialogue:**

*“Carbon in the soil isn’t static. It flows from plants to microbes and either becomes stable soil organic matter or is released back into the air as CO<sub>2</sub>. Certain practices, like repeated tillage, create a positive feedback that accelerates carbon loss. Other practices, like planting cover crops, create a negative feedback that slows decomposition and builds carbon over time. By understanding these feedbacks, we can predict and manage soil carbon for long-term climate and ecosystem benefits.”*

**Wrap-up Prompt:**

“Think of one practice that could create a positive feedback in soil carbon loss, and one that could create a negative feedback to build carbon. How could farmers use this knowledge to improve soil health?”

**Slide 43: Optional Extended Learning – Carbon Accounting in Action: Real-World Applications & Trade-Offs****Objective:**

Students will explore how soil carbon science translates into real-world practices, including carbon markets, and understand the trade-offs involved in different management strategies.

**Introduction/overview:**

Introduce the idea that soil carbon management is not just theoretical—it has practical applications. Farmers can generate income through carbon markets by verifying carbon sequestration. Discuss that not all practices sequester carbon equally and some may simply relocate it.

**Key Points to Emphasize:**

- Carbon markets allow farmers to sell verified carbon credits.
- Example: Australia’s Carbon Farming Initiative demonstrates large-scale soil carbon projects.
- Trade-offs exist:
  - Compost may move carbon temporarily but not result in long-term sequestration.
  - Practices like cover cropping and reduced tillage provide genuine net increases in soil carbon.
- Understanding these trade-offs helps connect scientific principles to real-world decision-making.

**Facilitation Tips:**

- Present a simple diagram showing carbon credits and how sequestration is verified.

- Invite students to brainstorm benefits and limitations of different practices.
- Relate to local farming or gardening examples when possible.

Suggested dialogue:

*“Farmers can actually earn money by increasing soil carbon through verified sequestration, participating in carbon markets. However, not all actions are equally effective—some, like composting, may move carbon around without long-term storage. Practices like cover cropping and reduced tillage, on the other hand, can create genuine, lasting carbon gains. This shows how understanding soil carbon science helps make informed decisions in agriculture and climate action.”*

Wrap-up Prompt:

“Think about a soil management practice you’ve learned about today. Would it likely result in long-term carbon sequestration or just move carbon around? Why does this distinction matter in real-world applications?”

## Slide 44: Optional Extended Learning – Carbon Accounting in Action: Deeper Scientific Insights

Objective:

Students will gain a deeper understanding of the scientific principles and measurements behind soil carbon accounting, including microbial roles and system interactions.

Introduction/overview:

Explain that soil carbon is studied using specific metrics and measurements, and that microbes are key players in determining whether carbon becomes stable soil organic matter or returns to the atmosphere. Highlight that management practices influence these processes, and data collection informs practical decisions.

Key Points to Emphasize:

- Carbon accounting metrics:
  - t C/ha measures carbon stock.
  - $\Delta$  t C/ha/yr measures sequestration rate.
  - Emission factors quantify greenhouse gas losses.
- Microbes are central to carbon cycling: root exudates feed microbes, which either stabilize carbon in soil or release it as CO<sub>2</sub>.
- System interactions: management practices affect decomposition rates, soil structure, erosion, and feedback loops.
- Data-driven science: measuring SOM, respiration, and infiltration helps make informed decisions for soil and climate management.

Facilitation Tips:

- Use a simple diagram linking plants → microbes → soil organic matter → CO<sub>2</sub>.
- Discuss with students how different practices can influence these processes.
- Show a table or visual of metrics and explain how scientists interpret them.

Suggested dialogue:

*“Scientists measure soil carbon in terms of stock and the rate at which it’s increasing, and they also consider emission factors for greenhouse gases. Microbes play a huge role: the carbon in root exudates can either become stable soil organic matter or be released as CO<sub>2</sub>. Management practices influence these pathways and the feedback loops in the system. By measuring things like soil organic matter, respiration, and infiltration, we can make data-driven decisions that improve soil health and climate outcomes.”*

Wrap-up Prompt:

“Consider how measuring soil properties like organic matter and respiration can guide farmers or land managers. Why is it important to rely on data rather than guesswork?”

## Slide 45: Optional Extended Learning – Carbon Accounting in Action: Group Design Activity – Carbon Detective Lab

### Objective:

Students will apply carbon accounting concepts to real-world scenarios, analyze soil datasets, and design management strategies that increase soil carbon while connecting practices to sustainability goals.

### Introduction/overview:

Introduce the Carbon Detective Lab as a hands-on, problem-solving activity where students act as “soil detectives.” They will interpret mini-datasets of soil organic matter (SOM), respiration, and infiltration to determine which soils are gaining or losing carbon and propose practices to improve soil health.

### Key Points to Emphasize:

- Students will work with SOM %, respiration rates, and infiltration measurements.
- The goal is to identify soils that are gaining or losing carbon.
- Students will select a 2-practice bundle (Build + Maintain) to improve soil carbon.
- Predict how soil indicators will shift with management (e.g., infiltration ↑, respiration ↓).
- Map practices to relevant Sustainable Development Goals (SDGs 2, 6, 12, 13, 15).
- Example: SOM 1.8% with high respiration → apply cover crops + no-till → expect SOM to increase.

### Facilitation Tips:

- Encourage teamwork and discussion when interpreting datasets.
- Remind students to connect scientific reasoning with practical management strategies.
- Provide guidance on linking practices to SDGs without giving direct answers.
- Consider having students present their findings briefly to reinforce learning.

### Suggested dialogue:

*“In this lab, you are soil detectives. You’ll look at data like SOM, respiration, and infiltration to figure out which soils are gaining or losing carbon. Then, you’ll propose a 2-practice bundle—one Build practice and one Maintain practice—to help improve carbon storage. Think about how these practices will change soil indicators, like higher infiltration or lower respiration. Finally, connect your practices to the Sustainable Development Goals to see the broader impact of soil management.”*

### Wrap-up Prompt:

“After completing your design, ask: Which soils showed the biggest potential for improvement, and which practices had the most impact? How does this activity help you understand the real-world importance of soil carbon management?”

## Slide 46: Optional Extended Learning – Carbon Accounting in Action: Discussion Questions

### Objective:

Students will reflect on soil carbon practices, distinguish between storage and sequestration, and connect local actions to global climate outcomes.

### Introduction/overview:

This slide prompts students to think critically about their learning from the extended activity and consider real-world applications. Encourage open discussion and reasoning rather than memorized answers.

### Key Points to Emphasize:

- Questions:
  - Which practice would you adopt first if you were managing a farm — compost, cover crops, or no-till — and why?
  - How do you know whether compost addition is “storage” or true “sequestration”?
  - What’s one way soil carbon practices at a school garden could connect to climate action at global scale?
- Reflect on practical choices: which soil practice to adopt first and why.
- Understand the difference between temporary carbon storage (stock) and long-term sequestration (net increase).
- Connect local soil carbon practices to broader climate action and sustainability goals.

#### Facilitation Tips:

- Allow students to discuss in pairs or small groups before sharing with the whole class.
- Encourage students to justify their answers using concepts from the previous slides (Build–Maintain–Consume, feedbacks, metrics).
- Prompt students to think about both environmental and social benefits of soil practices.

#### Suggested dialogue:

*“Let’s reflect on what we’ve learned. If you were managing a farm, which practice would you try first—compost, cover crops, or no-till—and why? Remember to consider how each practice affects carbon storage and sequestration. Also, how can we tell whether adding compost is just moving carbon around or actually creating long-term sequestration? Finally, think about a small-scale example, like a school garden—how could practices there connect to climate action on a global scale?”*

#### Wrap-up Prompt:

“After sharing your ideas, consider how these discussions show that soil carbon management is not just a scientific concept but a tool for real-world climate solutions.”

### **Slide 47: Optional Activity Corner: Make a Compost Cake**

#### Objective:

Engage students in a hands-on activity to visualize how decomposition drives soil carbon and nutrient cycling.

#### Introduction/overview:

Explain that this activity models the decomposition process in a “compost cake,” helping students see how different layers and management choices influence carbon storage and nutrient availability.

#### Key Points to Emphasize:

- Compost layers include browns (carbon-rich), greens (nitrogen-rich), soil, and water.
- Decomposition moves carbon and nutrients through the system, affecting soil health.
- Students can experiment by redesigning their cake for different goals: maximizing carbon storage or accelerating nutrient release.
- This activity reinforces the concept that management choices influence the cycling and fate of soil organic matter.

#### Facilitation Tips:

- Group students into pairs or small teams to encourage collaboration.
- Provide materials for drawing/coloring layers and arrows to show flows.
- Encourage students to discuss why they chose each layer and flow direction.
- Remind students that there’s no single “right” answer—different designs illustrate different management goals.

#### Suggested dialogue:

*“For this activity, you’ll create a compost cake to model decomposition and nutrient cycling. Start by coloring and labeling the layers—browns, greens, soil, and water. Then add arrows to show how carbon and nutrients move through the system. Finally, try redesigning your cake: do you want to focus on storing more carbon, or releasing nutrients faster? Discuss with your partner why you chose that design.”*

#### Wrap-up Prompt:

“Reflect on how small design choices—like layer order or moisture—can change how carbon and nutrients move through soil, helping us see the impact of real-world soil management.”

### **Slide 48: Review Questions: Soil Carbon and Management**

#### Objective:

Check students’ understanding of soil carbon concepts, management strategies, and the trade-offs/co-benefits of soil organic matter practices.

### Introduction/overview:

Explain that this slide is a quick review to reinforce key ideas from the lesson, including the difference between carbon storage and sequestration, practical examples of soil management, and co-benefits/trade-offs.

### Key Points to Emphasize:

- Questions:
  - What is the difference between soil carbon storage and sequestration?
  - In the Build–Maintain–Consume triad, give one example practice for each lever.
  - What is one co-benefit and one trade-off of building soil organic carbon?
- Carbon storage: holding carbon in the soil temporarily; may not increase net soil carbon over time.
- Carbon sequestration: increasing the soil's net carbon stock beyond the baseline due to management practices.
- Build–Maintain–Consume triad: management strategies target building carbon, maintaining soil health, or managing losses.
- Co-benefits of building SOM: improved water retention, nutrient cycling, disease suppression, yield stability.
- Trade-offs: over-wet soils can emit N<sub>2</sub>O, compaction from traffic, pests from unmanaged residues.

### Facilitation Tips:

- Encourage students to answer aloud or in pairs before discussing as a class.
- Use examples from prior slides to guide reasoning.
- Reinforce that multiple answers may be correct, especially for co-benefits and trade-offs.

### Suggested dialogue:

*“Let’s review what we’ve learned. First, what’s the difference between soil carbon storage and sequestration? Next, in the Build–Maintain–Consume framework, can you give one practice for each lever? Finally, think about building soil organic carbon: what is one co-benefit you notice, and what is one trade-off? Discuss with a partner, then we’ll share with the class.”*

### Wrap-up Prompt:

“Reviewing these questions helps us connect the theory of soil carbon with real-world management practices, and reminds us to balance benefits and trade-offs in designing resilient systems.”

## Slide 49: Review Answers: Soil Carbon and Management

### Objective:

Provide clear answers to the review questions, reinforcing students’ understanding of soil carbon concepts, management practices, and associated co-benefits and trade-offs.

### Introduction/overview:

Explain that this slide summarizes the answers from the previous review questions, helping students connect concepts with practical examples.

### Key Points to Emphasize:

- Answers:
  - Storage is the amount of carbon currently in the soil; sequestration is the increase in that stock over time due to management that adds more carbon inputs than losses.
  - Build = adding cover crops or compost; Maintain = reduced tillage to protect aggregates; Consume = microbial respiration (normal) but managed by avoiding bare, over-tilled soils.
  - Co-benefit: improved water holding and yield stability. Trade-off: poorly designed systems (e.g., over-wet soils) may increase nitrous oxide (N<sub>2</sub>O) emissions or compaction.
- Storage vs. sequestration:
  - Storage = amount of carbon currently in the soil.
  - Sequestration = increase in soil carbon stock over time due to management that adds more carbon than is lost.
- Build–Maintain–Consume examples:
  - Build → adding cover crops or compost.

- Maintain → reduced tillage to protect soil structure and aggregates.
- Consume → microbial respiration, but managed by avoiding bare or over-tilled soils.
- Co-benefit of building SOM: improved water holding capacity and yield stability.
- Trade-off: poorly designed systems (over-wet soils, heavy traffic) can increase N<sub>2</sub>O emissions or cause compaction.

Facilitation Tips:

- Review each point slowly and encourage students to relate answers to the earlier slides and activities.
- Highlight that co-benefits and trade-offs depend on how practices are designed and managed.
- Ask students to give their own examples of each lever (Build, Maintain, Consume) to reinforce learning.

Suggested dialogue:

*“Here are the answers: storage is the current carbon in the soil, while sequestration is the increase over time due to management. For the Build–Maintain–Consume triad, Build could be adding cover crops or compost, Maintain is reduced tillage, and Consume is microbial respiration—but we can manage it by avoiding bare, over-tilled soils. A key co-benefit is improved water holding and yield stability, but a trade-off is that poorly designed systems—like over-wet soils—can increase N<sub>2</sub>O emissions or cause compaction.”*

Wrap-up Prompt:

“Understanding these concepts helps us design soil systems that maximize benefits while minimizing trade-offs, making our soils more resilient and productive.”

## Lesson C: Water Smart Urban Farming

### Slides 50-68

#### **Slide 50: How do living soil organisms build structure, cycle nutrients, and suppress disease—and how can we manage them to deliver clean water, climate resilience, and healthy crops?**

Objective:

Introduce students to the role of living soil organisms in building soil structure, cycling nutrients, suppressing disease, and supporting ecosystem services like clean water, climate resilience, and healthy crops.

Introduction/overview:

Explain that soils are living ecosystems, with organisms—from microbes to earthworms—playing key roles in maintaining soil health. Their activity influences water retention, nutrient availability, plant health, and resilience to climate extremes.

Key Points to Emphasize:

- Soil organisms physically build and stabilize soil structure (e.g., aggregates, pores).
- Microbes and fungi drive nutrient cycling, transforming organic matter into forms plants can use.
- Soil life suppresses diseases naturally by outcompeting pathogens and supporting plant immunity.
- Managing soils to support these organisms enhances ecosystem services:
  - Clean water through better infiltration and reduced runoff.
  - Climate resilience by storing carbon and buffering against drought or heat.
  - Healthy crops through improved nutrition and reduced disease pressure.

Facilitation Tips:

- Use analogies (soil as a living city with many workers performing essential tasks).
- Ask students to name soil organisms they know and discuss their functions.
- Emphasize that human management—like adding organic matter, reducing tillage, and maintaining cover—can support these organisms.

Suggested dialogue:

*“Living soil organisms are the engineers, recyclers, and protectors of the soil ecosystem. Earthworms and microbes build structure, fungi cycle nutrients, and diverse soil life helps suppress disease. By managing soils carefully—adding organic matter, reducing tillage, keeping the soil covered—we can support these organisms to deliver clean water, resilient crops, and even climate benefits.”*

Wrap-up Prompt:

“The big idea is that healthy soils are alive, and the organisms in them are central to ecosystem services that sustain agriculture and the environment.”

#### **Slide 51: The Rhizosphere: Where the Action Is**

Objective:

Explain how roots and soil organisms interact in the rhizosphere to build soil structure, cycle nutrients, and support plant health.

Introduction/overview:

Introduce the rhizosphere as the zone of soil immediately surrounding plant roots where intense biological activity occurs. Emphasize that this is where plants, microbes, fungi, and soil fauna interact to create healthy soils.

Key Points to Emphasize:

- Root exudates act as “root lattes,” feeding microbes and stimulating microbial activity.
- Bacteria and fungi break down organic matter and release nutrients in plant-available forms.
- Fungal glues like glomalin help bind soil particles into stable aggregates, improving structure.
- Mycorrhizal fungi extend root reach and trade nutrients (like phosphorus) for plant carbon.

- Earthworms create biopores for air and water movement and leave nutrient-rich castings.

Facilitation Tips:

- Show diagrams or images of the rhizosphere to visualize interactions.
- Ask students why each organism's activity benefits plants and soil health.
- Highlight the connection between this micro-scale activity and larger ecosystem services.

Suggested dialogue:

*"In the rhizosphere, roots and soil organisms are constantly interacting. Plants feed microbes with exudates—think of it as a 'root latte.' In return, bacteria and fungi release nutrients, fungi help bind soil particles, mycorrhizae extend roots and trade nutrients, and earthworms create channels and nutrient-rich castings. All of these interactions build healthy, productive soil."*

Wrap-up Prompt:

"The rhizosphere is where soil life meets plant life, and managing it well means healthier plants and more resilient soils."

## Slide 52: Carbon to Nitrogen Balance in Soils

Objective:

Teach students how the carbon-to-nitrogen (C:N) ratio affects microbial activity, nutrient cycling, and soil health.

Introduction/overview:

Explain that microbes need both carbon and nitrogen to grow. The balance of these elements in organic matter determines how quickly nutrients are released and how much carbon is stored in the soil.

Key Points to Emphasize:

- Optimal microbial activity occurs around a 24:1 C:N ratio (approximately 16 parts carbon for energy, 8 parts for building biomass).
- Too much nitrogen leads to rapid decomposition and carbon loss.
- Too little nitrogen slows nutrient release, which can temporarily create nitrogen deficits for plants.
- High-carbon residues (like straw or wood chips) may temporarily tie up nitrogen as microbes decompose them.

Facilitation Tips:

- Use a visual spectrum or diagram of the C:N ratio to show low, balanced, and high C:N materials.
- Give examples of materials: straw = high C:N, compost = balanced, manure = low C:N.
- Encourage students to think about how farmers or gardeners might manage residues to maintain nutrient balance.

Suggested dialogue:

*"Microbes need a balance of carbon and nitrogen to grow efficiently. Around a 24:1 C:N ratio, microbes have enough carbon for energy and enough nitrogen to build their biomass. If there's too much nitrogen, decomposition is fast but carbon is lost. If there's too little nitrogen, nutrient release slows and plants may experience temporary nitrogen deficits. This explains why high-carbon residues, like straw, can sometimes tie up nitrogen in the short term."*

Wrap-up Prompt:

"Understanding the C:N ratio helps us manage organic matter in ways that support soil microbes, maintain nutrients, and build healthy soils over time."

## Slide 53: Balancing C:N: Practices and Microbes

Objective:

Explain how different types of organic inputs influence nutrient release, microbial activity, and soil structure, and how blending inputs can optimize benefits.

### Introduction/overview:

Introduce the idea that not all organic matter behaves the same way in soil. Some residues decompose quickly and release nutrients fast, while others decompose slowly, building long-term soil structure and supporting fungi. Combining inputs can give the best of both worlds.

### Key Points to Emphasize:

- Low-carbon, high-nitrogen inputs (e.g., legumes like clover) decompose quickly and provide a fast nutrient boost for crops.
- High-carbon, low-nitrogen inputs (e.g., grasses like rye or straw) break down slowly, feed fungi, and help build stable soil structure.
- Using a mix of cover crops balances short-term nutrient availability with long-term soil building, supporting a diverse microbial community.
- Thoughtful blending maximizes both immediate crop growth and long-term soil health.

### Facilitation Tips:

- Give examples of common cover crops and their C:N tendencies.
- Ask students how they might combine fast and slow-decomposing residues to meet crop and soil goals.
- Relate to previous slides on the rhizosphere and microbial needs.

### Suggested dialogue:

“Legumes like clover have low carbon and high nitrogen, so they break down quickly and give crops a fast nutrient boost. Grasses and residues like rye or straw have high carbon, break down slowly, and feed fungi while building soil structure. By mixing these types in cover crop blends, we can balance immediate nutrient needs with long-term soil health, supporting a diverse microbial community.”

### Wrap-up Prompt:

“The key idea is that managing the type and mix of organic inputs helps us feed microbes, maintain nutrients, and build resilient soils over time.”

## Slide 54: Balancing C:N: Quick Check

### Objective:

Engage students in identifying which crops produce higher C:N residues and reinforce understanding of how residue type affects decomposition and microbial activity.

### Introduction/overview:

Explain that students will use a quick think-pair-share activity to apply their knowledge of carbon-to-nitrogen ratios in different crops and how it influences nutrient release and soil microbes.

### Key Points to Emphasize:

- Legumes like clover have low C:N and release nitrogen quickly.
- Grasses like rye have higher C:N as they mature, break down slowly, and provide long-term carbon for fungi.
- Understanding C:N helps in designing cover crop mixes for both immediate nutrients and soil structure.

### Facilitation Tips:

- Give students 30–60 seconds to discuss in pairs before sharing with the class.
- Encourage them to explain why their choice makes sense based on the C:N concept.
- Highlight that higher C:N residues decay more slowly and feed fungi, while lower C:N residues release nitrogen quickly.

### Suggested dialogue:

“Here’s a quick check: which crop leaves behind higher C:N residues when you cut it down? Option A: Oats + clover, or Option B: Rye alone? Turn to a partner, discuss for a minute, and be ready to share your reasoning. Remember, high C:N residues decay more slowly and feed fungi, while low C:N residues release nitrogen fast.”

Wrap-up Prompt:

“The correct answer is B, rye alone. This reinforces how the type of crop residue influences decomposition speed and nutrient cycling in the soil.”

### Slide 55: Balancing C:N: Ballpark Ratios

Objective:

Help students understand approximate carbon-to-nitrogen (C:N) ratios for common cover crops at or near flowering and how maturity affects residue decomposition.

Introduction/overview:

Explain that C:N ratios vary by crop type and maturity, influencing how quickly residues decompose and how they feed soil microbes. Students will use this information in a quick think-pair-share exercise.

Key Points to Emphasize:

- Clover (legume): ~10–20:1 → low C:N, decomposes quickly, fast N release.
- Oats (grass): ~25–40:1 → moderate C:N, moderate decomposition speed.
- Rye (grass): ~40–80+:1 → high C:N, slow decomposition, supports fungi and long-term structure.
- Residue maturity increases C:N; older plant material decomposes more slowly.

Facilitation Tips:

- Give students 30 seconds to think individually, 60 seconds to discuss with a partner, and 30 seconds to share with the class.
- Ask students to justify their choice based on residue type and maturity.
- Reinforce that understanding C:N helps in planning cover crop mixes for both nutrient release and soil building.

Suggested dialogue:

*“Here’s a quick guide to ballpark C:N ratios near flowering: Clover around 10–20:1, oats 25–40:1, and rye 40–80+:1. Take 30 seconds to pick a crop (A or B) that you think has higher C:N, then 60 seconds to discuss with your partner why, considering residue type and maturity. Finally, we’ll hear from a couple of pairs. Remember, higher C:N decomposes more slowly and supports fungi, while lower C:N releases nitrogen quickly.”*

Wrap-up Prompt:

“This exercise reinforces how crop choice and growth stage influence residue decomposition, nutrient cycling, and soil microbial activity.”

### Slide 56: Soil Microbes: Many Jobs, One Ecosystem

Objective:

Introduce students to the diverse roles of soil microbes and how they contribute to healthy, functioning soils and resilient agricultural systems.

Introduction/overview:

Explain that soil microbes are incredibly versatile, performing multiple functions simultaneously that sustain plant growth, soil structure, and ecosystem services. Highlight that microbes are the “workers” of the soil, each with specialized roles.

Key Points to Emphasize:

- Decomposition: Microbes break down organic matter, recycling nutrients for plant use.
- Nutrient cycling: Transform nutrients like nitrogen into forms plants can uptake (e.g., ammonium to nitrate via nitrification).
- Soil structure and aggregation: Microbes, especially fungi and bacteria, help bind soil particles into aggregates, improving water infiltration and aeration.
- Disease suppression: Certain microbes and biological control agents reduce pathogen activity, protecting plants.

- Phytohormone production: Microbes produce hormones (IAA, CK, ABA, SA, GB) that influence plant growth and stress responses.
- Symbiotic relationships: Mycorrhizal fungi extend roots and exchange nutrients for carbon, enhancing plant nutrition.
- Salinity regulation: Microbes in association with plants help regulate soil salinity by influencing ion movement and uptake.

Facilitation Tips:

- Use the diagram to point out each microbial function and its impact on the plant-soil system.
- Ask students to connect these functions to real-world benefits like crop yield, water retention, and soil resilience.
- Highlight that supporting microbial diversity through management practices (organic matter addition, cover crops, reduced tillage) amplifies all these functions.

Suggested dialogue:

*“Soil microbes perform many jobs in a single ecosystem. They decompose organic matter, cycle nutrients, help build soil structure, suppress diseases, produce plant hormones, form symbiotic relationships with roots, and even help manage salinity. Each group of microbes contributes in unique ways, and together they keep soils productive and resilient. Our management choices can support these microbes to maximize these benefits.”*

Wrap-up Prompt:

“The big takeaway: healthy soils are living soils, and the diversity of microbial functions drives nutrient availability, plant health, and ecosystem resilience.”

## Slide 57: Microbe Functions: Decomposition & Nutrient Cycling

Objective:

Explain the role of soil microbes, particularly bacteria and fungi, in decomposition and nutrient cycling, and how they support plant growth.

Introduction/overview:

Introduce students to the concept that soil is a living ecosystem. Highlight that microbes, though invisible to the naked eye, are essential for breaking down organic matter and recycling nutrients that plants need to grow.

Key Points to Emphasize:

- Breakdown crew: bacteria and fungi decompose crop residues and manure.
- Release nutrients: microbes mineralize nitrogen (N), phosphorus (P), and sulfur (S), and make “bound” nutrients available to plants.
- Steady supply: microbial activity prevents nutrient losses (like leaching) and ensures roots have a continuous supply of nutrients.
- Microbes are essential partners in soil health and plant productivity.

Facilitation Tips:

- Use analogies like “microbes are the soil’s chefs” breaking down organic matter to feed plants.
- Show visuals of decomposing leaves, manure, or compost to connect with real-world examples.
- Ask students to think of microbes as unseen workers supporting a garden or farm.

Suggested dialogue:

*“Think of soil like a busy kitchen. The bacteria and fungi are our chefs—they break down leftover plant material and manure. In doing so, they release nutrients like nitrogen, phosphorus, and sulfur. These nutrients aren’t just floating around randomly—they become available to plant roots in a steady supply, helping plants grow strong. Without these tiny workers, nutrients would be lost, and plants would struggle to get what they need.”*

Wrap-up Prompt:

“Now that we know what microbes do in the soil, how do you think their work affects the crops or gardens we see every day?”

## Slide 58: Microbe Functions: Structure & Aggregation

Objective:

Students will learn how soil microbes help form soil structure through aggregation and why this is important for water and air movement in soil.

Introduction/overview:

Explain that microbes don't just recycle nutrients—they also physically change the soil. Certain microbes release sticky substances that help soil particles clump together, forming aggregates.

Key Points to Emphasize:

- Some microbes produce sticky compounds that bind soil particles into small “crumbs” called aggregates.
- Aggregates create pore spaces in soil, improving air and water movement.
- Well-aggregated soil supports healthy root growth and nutrient uptake.
- This process connects directly to the slake test students will perform, which shows how well soil holds together in water.

Facilitation Tips:

- Relate the sticky compounds to something familiar, like glue or honey holding crumbs together.
- Ask students to visualize or gently squeeze a handful of healthy soil to feel the crumb structure.
- Emphasize that good structure reduces erosion and water runoff.

Suggested dialogue:

*“Microbes are like tiny architects in the soil. Some of them exude sticky substances that help soil particles stick together into aggregates. These aggregates create small spaces for air and water to move, which is critical for plant roots. When you do the slake test, you’ll see the difference between soil that holds together well and soil that falls apart—this is directly influenced by microbial activity.”*

Wrap-up Prompt:

Ask students: “How might the spaces created by soil aggregates help plants survive drought or heavy rain?”

## Slide 59: Microbe Functions: Disease Suppression

Objective:

Students will understand how certain soil microbes protect plants from diseases and reduce the need for chemical pesticides.

Introduction/overview:

Introduce the concept that some microbes are “bodyguards” in the soil. They help plants stay healthy by suppressing harmful pathogens.

Key Points to Emphasize:

- Beneficial microbes can produce antimicrobial compounds that kill or inhibit pathogens.
- They can prey on harmful microbes or outcompete them for resources.
- This activity creates disease-suppressive soils, meaning plants experience fewer outbreaks.
- Example: Trichoderma is a beneficial fungus that combats pathogenic fungi.
- Disease suppression reduces the need for pesticides and supports sustainable agriculture.

Facilitation Tips:

- Use an analogy of microbes as defenders protecting a castle (the plant roots).
- Ask students to think about why reducing pesticide use is beneficial for the environment.
- Highlight that disease suppression is a natural, ongoing process in healthy soils.

Suggested dialogue:

*“Some microbes act like tiny bodyguards in the soil. They can produce compounds that kill harmful pathogens, eat them, or compete for the nutrients pathogens need. This helps create disease-suppressive soils, meaning*

*plants stay healthier and we don't need to rely as much on chemical pesticides. One example is Trichoderma, which fights pathogenic fungi naturally."*

Wrap-up Prompt:

Ask students: "Why do you think having disease-suppressive soils is better than using pesticides all the time?"

## Slide 60: Microbe Functions: Phytohormones & Symbioses

Objective:

Students will learn how soil microbes support plant growth and stress resilience through hormone production and symbiotic partnerships.

Introduction/overview:

Explain that some microbes do more than recycle nutrients—they directly influence plant growth and health by producing hormones and forming partnerships with plants.

Key Points to Emphasize:

- Certain microbes produce phytohormones like auxin, cytokinin, and gibberellin, which:
  - Promote root growth
  - Slow plant aging
  - Increase stress tolerance (e.g., drought or disease)
- Symbiotic relationships include:
  - Mycorrhizae: fungi that extend the root system and trade nutrients and water for plant sugars
  - Endophytes: microbes living inside plant tissues that can fix nitrogen
- Farming practices like planting cover crops and minimizing soil disturbance support these beneficial partnerships.

Facilitation Tips:

- Compare microbes to helpful teammates working directly with plants.
- Ask students to visualize roots growing longer and stronger with microbial help.
- Highlight that good soil management enhances these natural partnerships.

Suggested dialogue:

*"Some microbes act like growth coaches for plants. They produce hormones that help roots grow, slow aging, and increase tolerance to stress. Others, like mycorrhizal fungi, form partnerships with roots, extending their reach to gather more nutrients and water. Endophytes live inside plants and can even fix nitrogen. By planting cover crops and disturbing soil less, we can support these amazing microbial relationships."*

Wrap-up Prompt:

Ask students: "How might promoting these microbial partnerships reduce the need for fertilizers or improve plant survival during stress?"

## Slide 61: Microbe Functions: Salinity Regulation

Objective:

Students will understand how certain soil microbes help plants manage salt stress and enable farming in challenging environments.

Introduction/overview:

Introduce the idea that high soil salinity can harm plants, but microbes can help plants survive in salty soils by managing or transforming salts.

Key Points to Emphasize:

- Some microbes can exclude excess salt from plant roots or convert harmful salts into less toxic forms.
- These microbial activities improve plant growth and survival in saline soils.
- Salinity-regulating microbes make it possible to farm in coastal or otherwise salty regions where plants would normally struggle.

#### Facilitation Tips:

- Use an analogy: microbes act like filters or detoxifiers, protecting plants from salt stress.
- Ask students to consider where salty soils might naturally occur and why managing salinity is important.
- Highlight that these microbes are a natural solution for expanding farming into marginal lands.

#### Suggested dialogue:

*“Excess salt in soil can stunt or even kill plants. Luckily, some microbes act like tiny bodyguards, either keeping salt away from roots or transforming it into forms that are less harmful. This allows plants to survive and grow in salty soils, opening up opportunities for farming in coastal or high-salinity areas.”*

#### Wrap-up Prompt:

Ask students: “Why would it be important for farmers to use microbes to manage soil salinity instead of only relying on irrigation or chemical treatments?”

### Slide 62: How Healthy Soils Protect People

#### Objective:

Students will understand the connection between soil health, microbes, and human health, and how sustainable farming practices can reduce disease risk.

#### Introduction/overview:

Explain that soil is not only important for growing food but also plays a key role in protecting people from pathogens. Healthy soils contain beneficial microbes that help control harmful organisms.

#### Key Points to Emphasize:

- Soil can harbor both harmful human pathogens and beneficial microbes.
- Beneficial microbes help suppress pathogens in the soil, reducing the risk of contamination in crops, animals, and ultimately humans.
- Pathogens can move through the food chain (soil → plants/animals → humans) if soils are unhealthy.
- Sustainable practices, such as adding organic matter, rotating crops, and supporting microbial diversity, enhance soil’s protective role.
- This slide illustrates the cycle of how soil health connects to food safety and human well-being.

#### Facilitation Tips:

- Point out the arrows in the diagram showing pathogen movement versus beneficial microbe protection.
- Use real-life examples like composted manure improving soil health or crop rotation reducing disease outbreaks.
- Emphasize the “One Health” concept—healthy soil contributes to healthy plants, animals, and humans.

#### Suggested dialogue:

*“Notice how the diagram shows both harmful and beneficial microbes. Healthy soils with plenty of beneficial microbes can suppress pathogens, keeping crops and livestock safer. This protection travels through the food chain, which is why managing soil well is not just good for plants—it’s good for people too. Sustainable practices help maintain these natural protections.”*

#### Wrap-up Prompt:

Ask students: “How might improving soil health reduce the chance of foodborne illness in humans?”

### Slide 63: One Health: Soil ↔ People ↔ Planet

#### Objective:

Explain the critical connections between soil, human health, and the environment, emphasizing how healthy soils support food production, water quality, climate stability, and overall ecosystem health.

#### Introduction/overview:

Begin by framing soil as more than “dirt.” Highlight that soil is a living system that underpins almost every aspect of human life—from the food we eat to the water we drink and the climate we experience. Introduce the concept of One Health, which connects the health of people, animals, and the planet.

### Key Points to Emphasize:

- Soils grow about 95% of the world's food, making them foundational for human nutrition.
- Soil microbes produce antibiotics and other medicines, showing the direct link between soil and human health.
- Soils act as natural filters and storage systems for water, preventing contamination and supporting clean water supplies.
- Soils are the largest land carbon pool, storing more carbon than plants and the atmosphere combined, highlighting their role in climate regulation.
- Healthy soils contribute to safe food, clean water, and climate resilience.
- Sustainable agricultural practices support these soil functions and are essential for a One Health approach.

### Facilitation Tips:

- Ask students to think about where their food comes from and what role soil plays in its production.
- Use real-world examples, like antibiotics derived from soil microbes or wetlands filtering water, to make abstract concepts tangible.
- Relate the carbon storage role of soil to climate change in simple terms: soil as a “carbon bank.”

### Suggested dialogue:

*“Did you know that almost all of our food comes from soil? And it’s not just about growing plants—microbes in the soil give us important medicines like antibiotics. Healthy soils also filter water and even help regulate our climate by storing carbon. When we take care of soil through sustainable farming, we’re taking care of people and the planet—this is the idea behind One Health.”*

### Wrap-up Prompt:

Ask students to summarize how healthy soil connects to food, water, and climate, and why it matters for the health of people and the planet.

## Slide 64: One Health: Soil ↔ People ↔ Planet - Risks

### Objective:

Help students understand how certain agricultural practices degrade soil, how to diagnose soil health, and how these issues connect to One Health.

### Introduction/overview:

Start by explaining that not all farming practices are beneficial for soil. Some actions can harm its structure, fertility, and biological activity, which in turn affects food, water, and climate. Introduce the concept of diagnosing soil health as a way to identify problems and guide solutions.

### Key Points to Emphasize:

- Common degrading practices include:
  - Excess tillage that disrupts soil structure.
  - Erosion that removes fertile topsoil.
  - Compaction that reduces water infiltration and root growth.
  - Salinization from improper irrigation.
  - Nutrient imbalance that limits plant growth and microbial health.
- Soil health diagnosis can include:
  - Texture assessment.
  - Aggregation test (slake test) to see how soil holds together.
  - Measuring soil organic carbon (SOC).
  - pH testing.
  - Observing microbial activity.
- Understanding these risks allows farmers and scientists to take targeted actions to maintain healthy soils.
- Healthy soil supports One Health—benefiting people, ecosystems, and the planet.

#### Facilitation Tips:

- Show a simple demonstration or images of compacted vs. healthy soil to make the impact tangible.
- Connect soil tests to things students can see, like soil crumbling in their hands (aggregation) or changes in color/texture.
- Reinforce that diagnosing soil problems is the first step toward solutions.

#### Suggested dialogue:

*“Some farming practices, like too much plowing or poor irrigation, can harm the soil, making it harder to grow crops and store water. Scientists and farmers can diagnose soil health using simple tests, like checking texture, aggregation, pH, and microbial activity. By addressing these risks, we protect not just the soil, but people, food, and the planet—this is the One Health perspective.”*

#### Wrap-up Prompt:

Ask students to list one soil-degrading practice and one way to diagnose or fix it, emphasizing the link between soil health and broader ecosystem health.

### Slide 65: One Health: Soil ↔ People ↔ Planet - Responses

#### Objective:

Teach students practical strategies to maintain or restore healthy soils and emphasize how these practices benefit food, water, and the environment.

#### Introduction/overview:

Explain that just as humans need care to stay healthy, soils need thoughtful management to stay productive and resilient. Highlight that treating soils properly reduces risks and supports the One Health connection between soil, people, and the planet.

#### Key Points to Emphasize:

- Core soil treatment practices include:
  - Keep soil covered with plants or mulch to prevent erosion and moisture loss.
  - Minimize soil disturbance (reduce tillage) to preserve structure and microbial life.
  - Maintain living roots year-round to feed microbes and stabilize soil.
  - Diversify plant species to improve soil biology and resilience.
  - Return organic matter, like compost or crop residues, to replenish nutrients.
- Healthy soils lead to safer water, more reliable food production, and ecosystem resilience.
- These practices demonstrate how soil management contributes to One Health.

#### Facilitation Tips:

- Use images or short videos showing mulching, cover crops, or composting.
- Ask students if they've seen these practices in gardens or farms.
- Connect soil care to everyday impacts, like clean water and nutritious food.

#### Suggested dialogue:

*“Just like we take care of our bodies, soils need care too. Keeping soil covered, reducing disturbance, maintaining roots, planting diverse species, and returning organic matter all help soil stay healthy. When soils are healthy, our water stays cleaner, our food is more reliable, and the environment benefits—showing the connection between soil, people, and the planet.”*

#### Wrap-up Prompt:

Have students summarize one soil treatment practice and explain how it supports food, water, or climate health.

### Slide 66: Team Design Activity – Boosting Soil Health

#### Objective:

Engage students in a hands-on activity to explore how different soil management practices affect soil health, microbes, ecosystem services, and sustainability goals.

### Introduction/overview:

Explain that students will work in teams to design a small model showing how a chosen soil practice impacts soil health. This activity reinforces concepts from previous slides about risks, treatments, and One Health connections.

### Key Points to Emphasize:

- Students will choose one soil management practice: cover crops, compost, mulch, reduced tillage, vermicomposting, or biochar.
- Teams predict how their practice affects a soil indicator (e.g., microbial activity, organic matter, pH, aggregation).
- Students connect their practice to an ecosystem service (like water filtration, nutrient cycling, or food production) and a Sustainable Development Goal (SDG).
- Teams sketch their design and prepare to defend it, explaining the logic behind their choices.
- Optional: “Design Minute – Microbe Boosters” encourages quick creative thinking about ways to enhance microbial health.

### Facilitation Tips:

- Encourage students to think creatively and make connections to real-world farming or gardening practices.
- Circulate and ask probing questions: “Why does this practice boost microbes?” or “Which ecosystem service benefits the most?”
- Promote discussion during Think-Pair-Share: have pairs explain their design to each other before sharing with the whole group.

### Suggested dialogue:

*“Now it’s your turn to be soil scientists! Pick a practice like cover crops or compost, and predict how it will affect soil health. Then, link it to an ecosystem service—like clean water or nutrient cycling—and a global goal for sustainability. Sketch your ideas and be ready to defend them. Remember, your microbes are counting on you!”*

### Wrap-up Prompt:

Ask teams to share one insight from their design and explain how their chosen practice supports soil health and the wider ecosystem.

## Slide 67: Review Questions – Soil Health and Microbes

### Objective:

Reinforce key concepts about soil health, microbial activity, and their roles in ecosystems through guided review questions.

### Introduction/overview:

Explain that reviewing these questions helps students check their understanding of important soil science concepts, including the rhizosphere, nutrient cycling, and ecosystem services. Encourage students to think critically and make connections to real-world examples.

### Key Points to Emphasize:

- Questions:
  - What is the rhizosphere, and why is it important for soil health?
  - Why does the carbon-to-nitrogen (C:N) ratio matter in decomposition?
  - How do soil microbes contribute to ecosystem services beyond farming yields?
- The rhizosphere is the soil zone around plant roots where microbes are most active. It is critical for nutrient exchange, plant growth, and soil structure.
- Carbon-to-nitrogen (C:N) ratio influences decomposition rates. Balanced C:N ratios support efficient microbial breakdown of organic matter, returning nutrients to soil.
- Soil microbes contribute beyond crop yields by supporting water filtration, nutrient cycling, disease suppression, and carbon storage, all of which benefit the environment and human health.

#### Facilitation Tips:

- Ask students to answer individually, then discuss in pairs or small groups to compare ideas.
- Encourage real-life examples: e.g., composting kitchen scraps, root vegetables interacting with soil microbes.
- Reinforce connections to One Health: how microbes in soil affect food safety, water quality, and climate resilience.

#### Suggested dialogue:

*“Let’s review some key ideas. First, the rhizosphere—this is where plant roots and microbes interact closely. Why is that important? Next, think about the carbon-to-nitrogen ratio. Why does it matter for decomposition? Finally, consider how soil microbes do more than just help plants grow. Can anyone give examples of services they provide that benefit humans or the environment?”*

#### Wrap-up Prompt:

Have students share one answer for each question and discuss how it relates to the health of soil, people, and the planet.

### Slide 68: Review Answers – Soil Health and Microbes

#### Objective:

Provide clear explanations for key review questions about the rhizosphere, C:N ratio, and ecosystem services of soil microbes.

#### Introduction/overview:

This slide gives students the correct answers and reasoning for the review questions. Emphasize how each concept connects to soil health, ecosystem function, and One Health.

#### Key Points to Emphasize:

- Answers:
  - The rhizosphere is the zone around roots where plants release exudates that feed microbes; in return microbes provide nutrients, form aggregates, and protect plants.
  - Around 24:1 balances microbial energy and growth; too high (lots of carbon) ties up nitrogen, too low (lots of nitrogen) speeds decomposition and carbon loss.
  - They filter water, store carbon, suppress disease, detoxify pollutants, and even provide compounds for medicines—linking soil health to human and planetary health.
- The rhizosphere is the soil zone around plant roots where plants release exudates (sugars, amino acids, and other compounds) that feed microbes. Microbes, in turn, provide nutrients, improve soil structure by forming aggregates, and protect plants from pathogens.
- A carbon-to-nitrogen (C:N) ratio of roughly 24:1 balances microbial energy and growth.
  - Too high (excess carbon) slows decomposition because microbes tie up nitrogen.
  - Too low (excess nitrogen) accelerates decomposition and can lead to carbon loss from the soil.
- Soil microbes provide ecosystem services beyond farming yields:
  - Filter water and prevent contamination
  - Store carbon, helping mitigate climate change
  - Suppress diseases
  - Detoxify pollutants
  - Produce compounds used for medicines (linking soil to human health)

#### Facilitation Tips:

- Encourage students to connect each answer to real-world examples, like composting (C:N balance) or wetlands filtering water.
- Highlight the One Health connection: how microbes impact not just plants but also human and planetary health.
- Ask students to think of one service that surprised them or that they hadn’t considered before.

#### Suggested dialogue:

*“The rhizosphere is where roots and microbes meet. Plants feed microbes, and microbes give back nutrients*

*and protection. A balanced carbon-to-nitrogen ratio is key for decomposition: too much carbon slows it down, too much nitrogen speeds it up. And microbes do more than help plants—they filter water, store carbon, fight diseases, detoxify pollutants, and even help produce medicines. Healthy soil really supports the health of people and the planet.”*

Wrap-up Prompt:

Ask students to summarize one way microbes support ecosystem services and explain why it matters for human or planetary health.

## Wrapping It Up!

### Slides 69-72

#### Slide 69: Module 3 Key Takeaways

##### Objective:

Summarize the essential concepts from the module on soil health, emphasizing the living nature of soil, measurable indicators, microbial roles, and impactful management practices.

##### Introduction/overview:

Explain that this slide wraps up the key lessons about how soils function, how we can measure their health, and what practices promote productivity and sustainability. Reinforce connections to broader ecosystem services and Sustainable Development Goals (SDGs).

##### Key Points to Emphasize:

- Soil is a living system: its physical, chemical, and biological components work together to power five core functions (e.g., nutrient cycling, water filtration, carbon storage).
- Measuring what matters: soil texture, pH, soil organic matter (SOM), and respiration provide evidence of soil health.
- Carbon and microbes: microbial activity drives carbon storage, improves soil structure, and cycles nutrients essential for plant growth.
- Practices with impact:
  - Keep living roots in the soil
  - Add cover crops or compost
  - Reduce tillage
  - Apply biocharThese practices create soils that support both crop yields and ecosystem services.
- Linkages to SDGs: these soil practices contribute to zero hunger (2), clean water (6), responsible consumption (12), climate action (13), life on land (15), and good health (3).

##### Facilitation Tips:

- Highlight that soils are not just dirt—they are living ecosystems critical for human and planetary health.
- Encourage students to recall examples from earlier slides, like microbial benefits, water filtration, and carbon storage.
- Ask students to connect one practice to a specific SDG to reinforce real-world relevance.

##### Suggested dialogue:

*“Remember, soil is living—its physical, chemical, and biological components work together to perform key functions. We can measure soil health using texture, pH, organic matter, and respiration. Microbes drive carbon storage and nutrient cycling, which supports plants and the environment. Practices like keeping roots, adding compost, reducing tillage, and using biochar help soils deliver food and ecosystem services—and contribute to multiple Sustainable Development Goals.”*

##### Wrap-up Prompt:

Ask students to share one key takeaway from the module and explain how it connects to soil's role in food, water, or climate.

#### Slide 70: What You'll Learn: Mindmap

##### Objective:

The objective of this mindmap is to provide a comprehensive overview of soil science and soil health, focusing on the carbon cycle and its relationship to living soils and ecosystem services. By the end of this lesson, students should be able to understand the fundamentals of soil, the importance of soil carbon, and the benefits of healthy soil.

##### Introduction/Overview:

This mindmap visually breaks down the key concepts we'll be discussing today. We'll start with the fundamentals of soil, move into the critical role of carbon, and then connect these ideas to the broader benefits of healthy, living soils and the services they provide.

Key Points to Emphasize:

- The distinction between soil as just "dirt" and "soil as a living system" is crucial. Emphasize the structure, texture, and living organisms that make soil healthy.
- Highlight the soil carbon cycle. Explain how carbon is built, consumed, maintained, and sequestered in the soil. Use the analogy of a "bank account" for carbon to make it relatable.
- Connect the presence of carbon in soil to specific ecosystem services, such as nutrient cycling, disease suppression, and salinity regulation. This helps students see the practical benefits of soil health.
- Stress that soil health is determined by several factors, including minimizing soil disturbance, maximizing living roots, and maximizing crop diversity.

Facilitation Tips:

- Start by asking students what they think the difference between "dirt" and "soil" is. This can be a great way to gauge their prior knowledge and engage them.
- As you go through the mindmap, you can ask students to give examples of different ecosystem services. For example, "What does it mean for soil to suppress disease?"
- Use the mindmap's visual structure to help students see the connections between different concepts. You can trace the pathways with your finger or a pointer.
- The "Trade-Offs" section provides a great opportunity for a class discussion on the pros and cons of certain agricultural practices.

Suggested Dialogue:

*"Good morning, everyone. Today, we're going to dive into the world of soil science. I want you to look at this mindmap as a roadmap for our lesson. We'll start on the left, with the basics of what soil is, and then we'll move to the center to talk about carbon. Finally, we'll see how all of this connects to the amazing things healthy soil can do for us."*

*"Let's look at the top-middle section: Carbon in Soils. Think of soil as a carbon bank. When we have healthy soil, we're making deposits. When we have unhealthy soil, we're making withdrawals. The goal is to always have more deposits than withdrawals."*

*"Now, let's connect this to the right side of the mindmap. All of that carbon we're building up helps us with what are called 'Living Soil & Ecosystem Services.' These are the benefits that healthy soil provides. Things like making sure plants get the nutrients they need and even protecting them from disease."*

Wrap-up Prompt:

"To wrap up this slide, I want you all to take a moment to look at the 'What is Soil Health?' and 'Why Soil Health Matters' sections. What is one thing you learned today that makes you think about soil differently? What is one way that healthy soil can help our environment?"

## Slide 71: Career Pathways in Soil Health

Objective:

Introduce students to potential careers related to soil health, water, climate, and sustainable agriculture, highlighting opportunities in fieldwork, labs, technology, and education.

Introduction/overview:

Explain that soil health knowledge can lead to diverse career paths, from scientific research to hands-on stewardship and innovative technology applications. Encourage students to think about how their interests in science, environment, or sustainability could translate into a future career.

Key Points to Emphasize:

- Field and lab careers:
  - Soil Scientist: conducts research in labs and in the field.
  - Soil Conservationist: works with government or resource districts to protect soils.
  - Agronomist / Soil Health Specialist: advises on crop and soil management.

- Soil Lab Tech / Microbiology Tech: analyzes soil samples and microbial activity.
- Water, climate, and land stewardship:
  - Watershed/Water-Quality Specialist: monitors and protects water resources.
  - Restoration Ecologist / Rangeland Manager: restores ecosystems and manages land sustainably.
  - Soil Carbon Project Developer / MRV Analyst: works on carbon accounting and soil-based climate solutions.
  - Conservation Planner: designs and implements sustainable practices through NGOs or districts.
- Technology, circular economy, and education:
  - Precision Agriculture / Remote Sensing Analyst: applies tech to optimize soil and crop management.
  - Compost & Vermicompost Operations: manages organic waste and soil amendment production.
  - Soil Health Product Representative / Start-up: develops or markets innovative soil solutions.
  - Extension Educator / K–12 Garden Coordinator: teaches soil health and sustainable practices to the community.

#### Facilitation Tips:

- Encourage students to match their interests to one or more career paths.
- Highlight the diversity of roles: some are field-based, some lab-based, some tech-focused, and some education-focused.
- Use real-world examples or local professionals if possible to make careers tangible.

#### Suggested dialogue:

*“Healthy soils create not just food and ecosystem benefits, but also career opportunities. Whether you’re interested in hands-on fieldwork, lab research, managing ecosystems, using technology, or teaching others, there’s a role in soil health for you. Look at these careers—from soil scientists to compost operators to educators—each contributes to sustaining our planet.”*

#### Wrap-up Prompt:

Ask students to pick one career that interests them and explain why it appeals to them and how it relates to soil health or sustainability.

## Slide 72: Sneak Peek of Hands-On Soil Activities

#### Objective:

Introduce students to upcoming hands-on experiments that demonstrate key soil properties and their importance for plant growth, water management, and ecosystem health.

#### Introduction/overview:

Explain that students will get to explore soils directly through simple tests and observations, linking what they’ve learned about soil health, microbes, and ecosystem services to tangible experiences.

#### Key Points to Emphasize:

- Soil pH activity: Students test soils from different locations using pH strips to measure acidity or alkalinity. Discuss how pH influences nutrient availability and plant growth.
- Soil Organic Matter (SOM) activity: Students observe soil color as an indicator of organic matter. Highlight how SOM supports water retention, nutrient cycling, and carbon storage.
- Soil Glue and Respiration activity: Students observe soil stability in water (aggregation) and fizzing with CO<sub>2</sub> (microbial respiration). This shows soil structure and microbial activity in action.

#### Facilitation Tips:

- Emphasize safety and careful handling of materials.
- Encourage students to make predictions before testing soils.
- Connect observations to broader concepts: plant growth, water filtration, and carbon cycling.
- Ask students to record results and reflect on how these properties relate to healthy soils and ecosystem services.

Suggested dialogue:

*“You’ll get to see soil in action! You’ll test soil pH, match soil color to organic matter levels, and observe how soil holds together and produces CO<sub>2</sub>. These hands-on activities will help you understand how soil properties affect plant growth, water, nutrients, and even the carbon cycle.”*

Wrap-up Prompt:

Ask students to predict what they expect to observe in each activity and how it might demonstrate the role of soil in supporting plants and ecosystems.