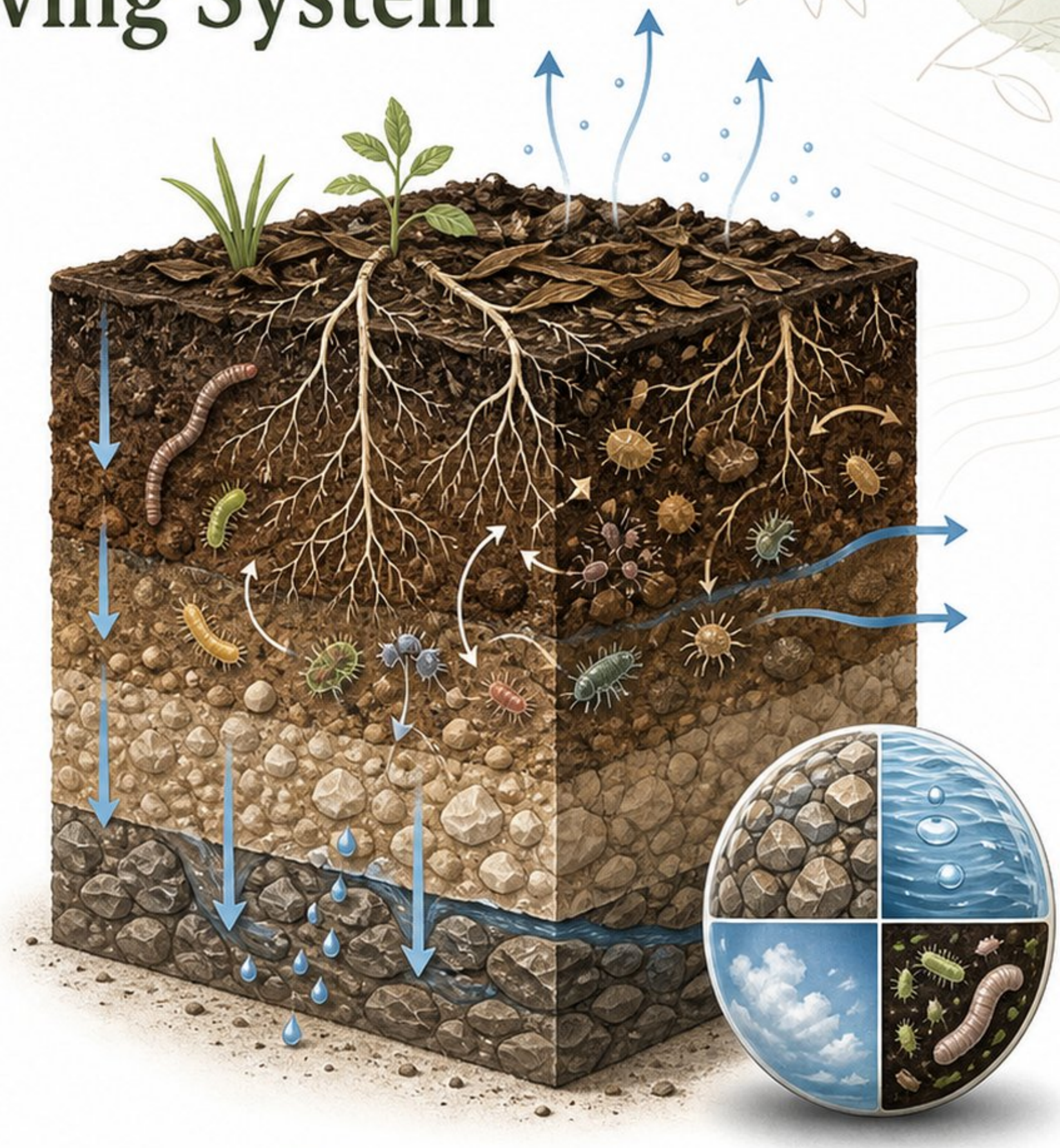
Introduction to Soil: Minerals, Water, Air, and Life

- “- Soil is a dynamic natural body of minerals, water, air, and life—not just dirt.”
- “- It underpins global food production, water filtration, carbon storage, and ecosystem health.”
- “-Healthy mineral soil is roughly 45% minerals, 25% water, 25% air, and 5% organic matter.”
- “- FAO 2025/2026 data: over 1,660 million hectares of land are degraded by human activities, threatening food security for 1.7 billion people.”
- “- This course progresses from mineral particles to soil health management. ”

Viewing Soil as a Living System

- Soil as an ecosystem where minerals, water, air, and organisms continuously interact
- Regulates water storage, purification, climate, and immense biodiversity
- Soil health: resilience, biological productivity, and ecological services
- Integration of chemical, physical, and biological indicators defines function
- Understanding whole soil begins with its mineral building blocks



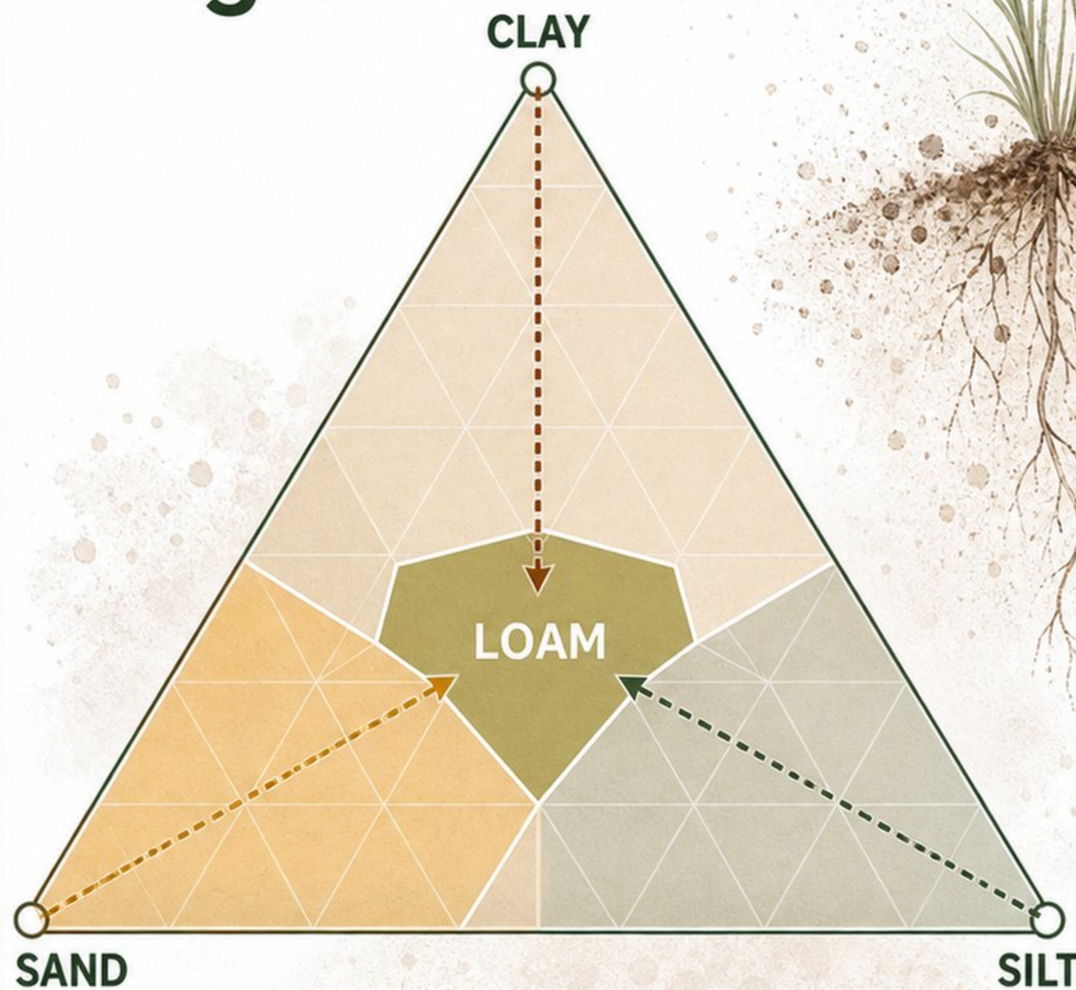
Mineral Particles: Sand, Silt, and Clay

Mineral particles vary in size. Their size and surface area influence how soils hold water and nutrients.

- **Sand (2.0–0.05 mm):** coarsest, visible grains, rapid drainage
- **Silt (0.05–0.002 mm):** intermediate, smooth feel, moderate water retention
- **Clay (<0.002 mm):** finest, sticky when wet, high nutrient storage
- Particle size controls surface area, water films, and cation exchange capacity
- Parent material weathers into primary and secondary minerals over time

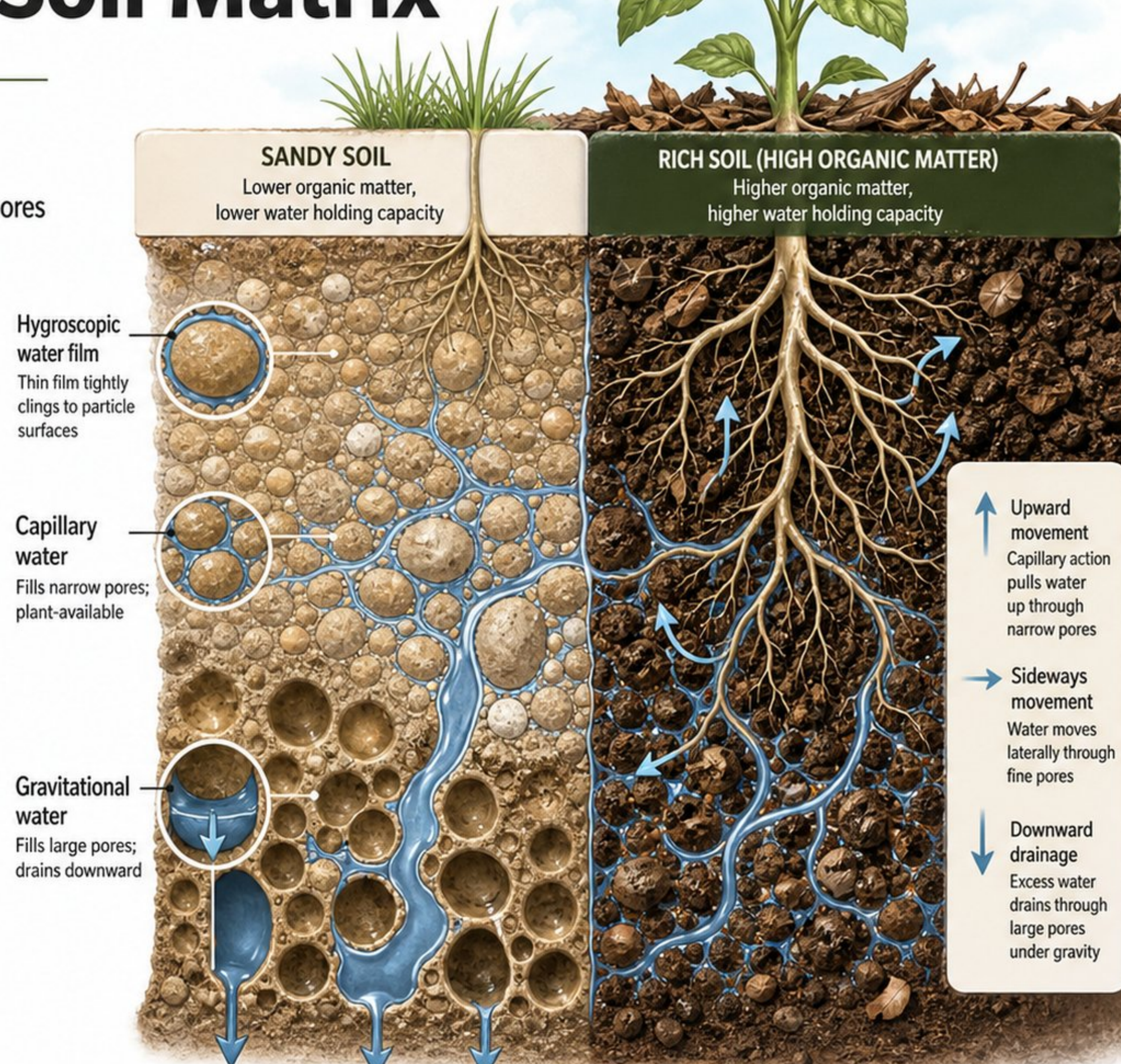
The Soil Texture Triangle

- Soil texture: proportion of sand, silt, and clay in a sample
- Use the triangle: intersect three percentages to find texture class
- Texture controls water, aeration, workability, and root growth
- Loams balance drainage and retention; avoid pure sand or heavy clay
- Field ribbon test: estimate texture by feel without a lab

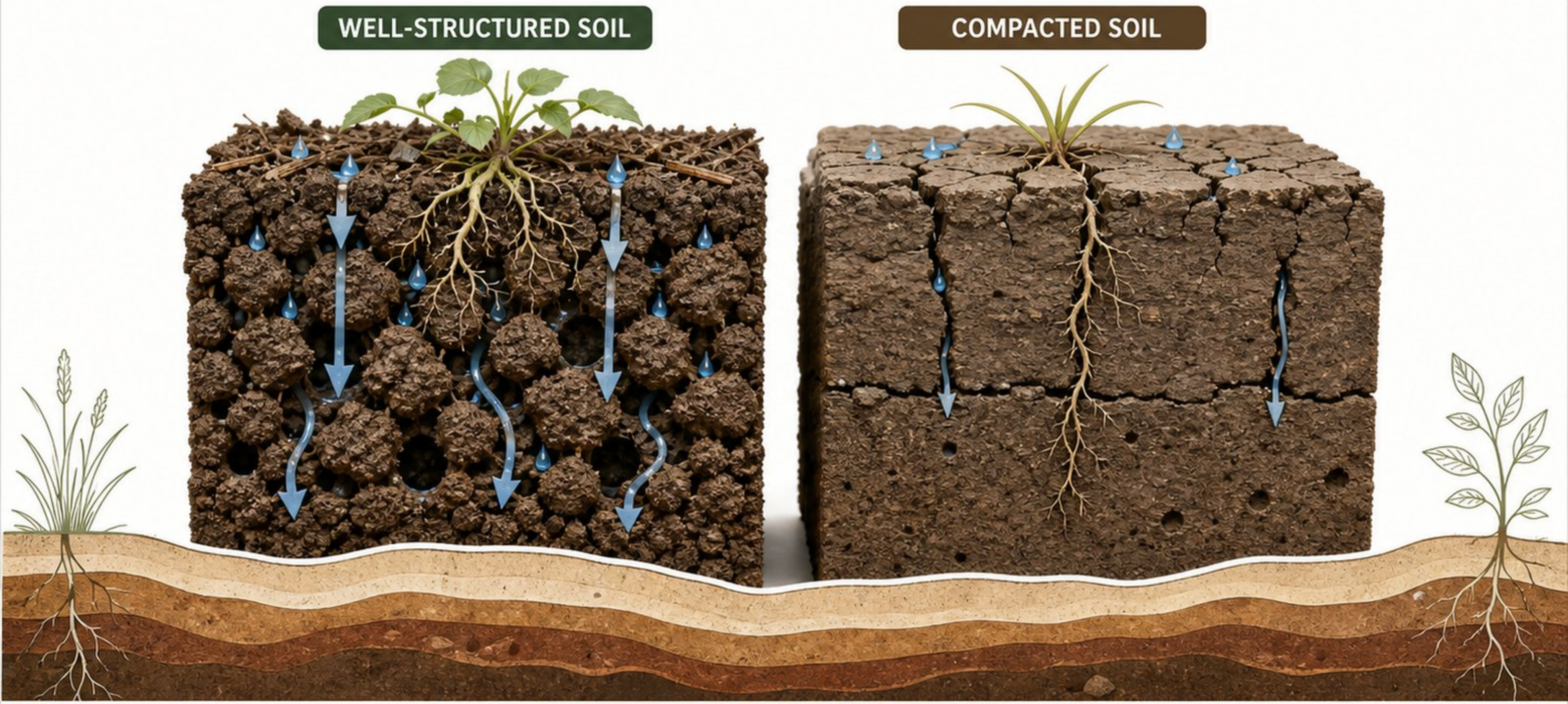


Water in the Soil Matrix

- Gravitational water drains fast; capillary water is plant-available in pores
- Hygroscopic water binds tightly to particles and cannot be used
- Field capacity: water left after drainage; wilting point: plants can't extract more
- Capillary action pulls water upward and sideways through narrow pores
- Organic matter boosts water holding capacity, especially in sandy soils



Texture, Structure, and Water Movement



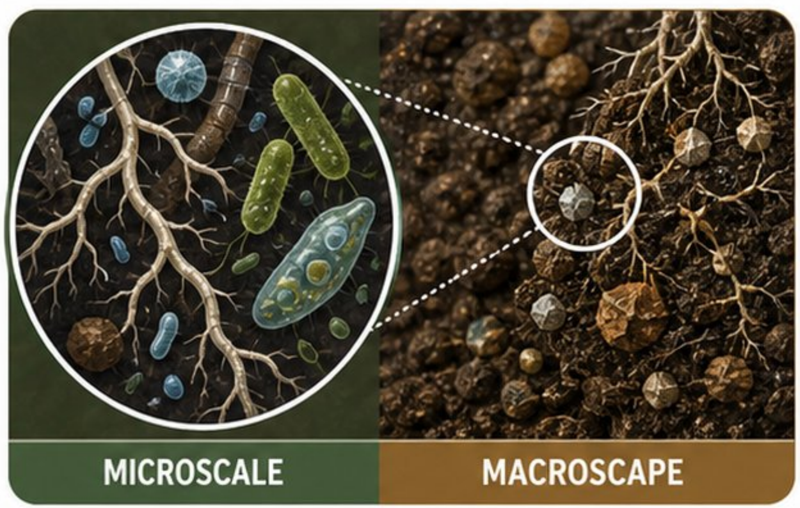
- Soil structure: how particles clump into aggregates (peds)
- Pores within and between peds control water flow and storage
- Sandy soils: fast drainage, low retention; clay soils: slow flow, high storage
- Compaction crushes large pores, choking air, water, and roots
- Common structures: granular, blocky, platy, massive—each hints at function

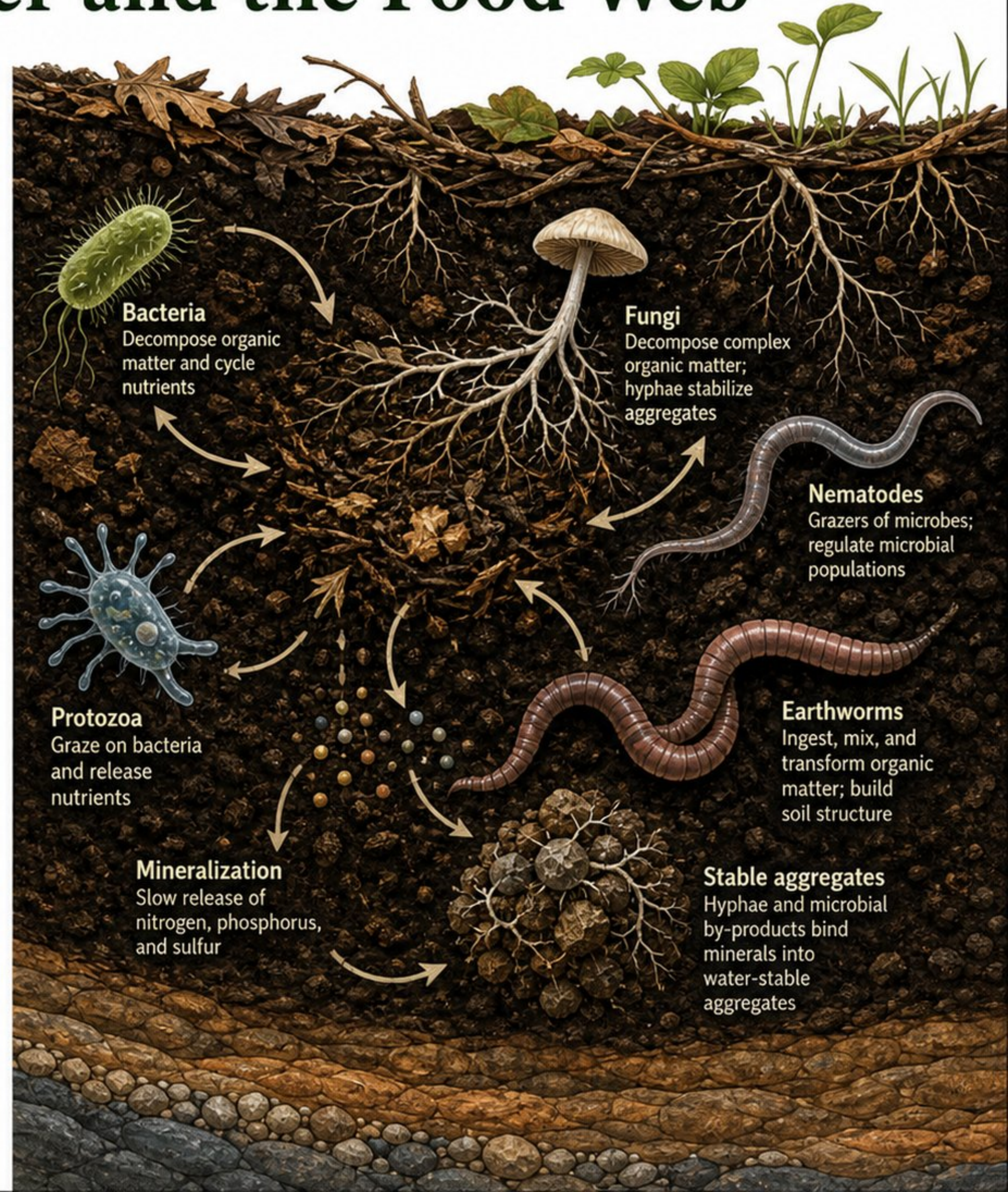
Air and Gas Exchange in Soil

- Soil air has less O_2 (10-15%) and more CO_2 (up to 10%) than atmosphere
- Roots and microbes consume O_2; respiration releases CO_2
- Diffusion and mass flow drive soil-atmosphere gas exchange
- Waterlogging and compaction deplete O_2, causing root asphyxiation
- Good aeration supports root respiration and healthy microbial communities

Soil Organic Matter and the Food Web

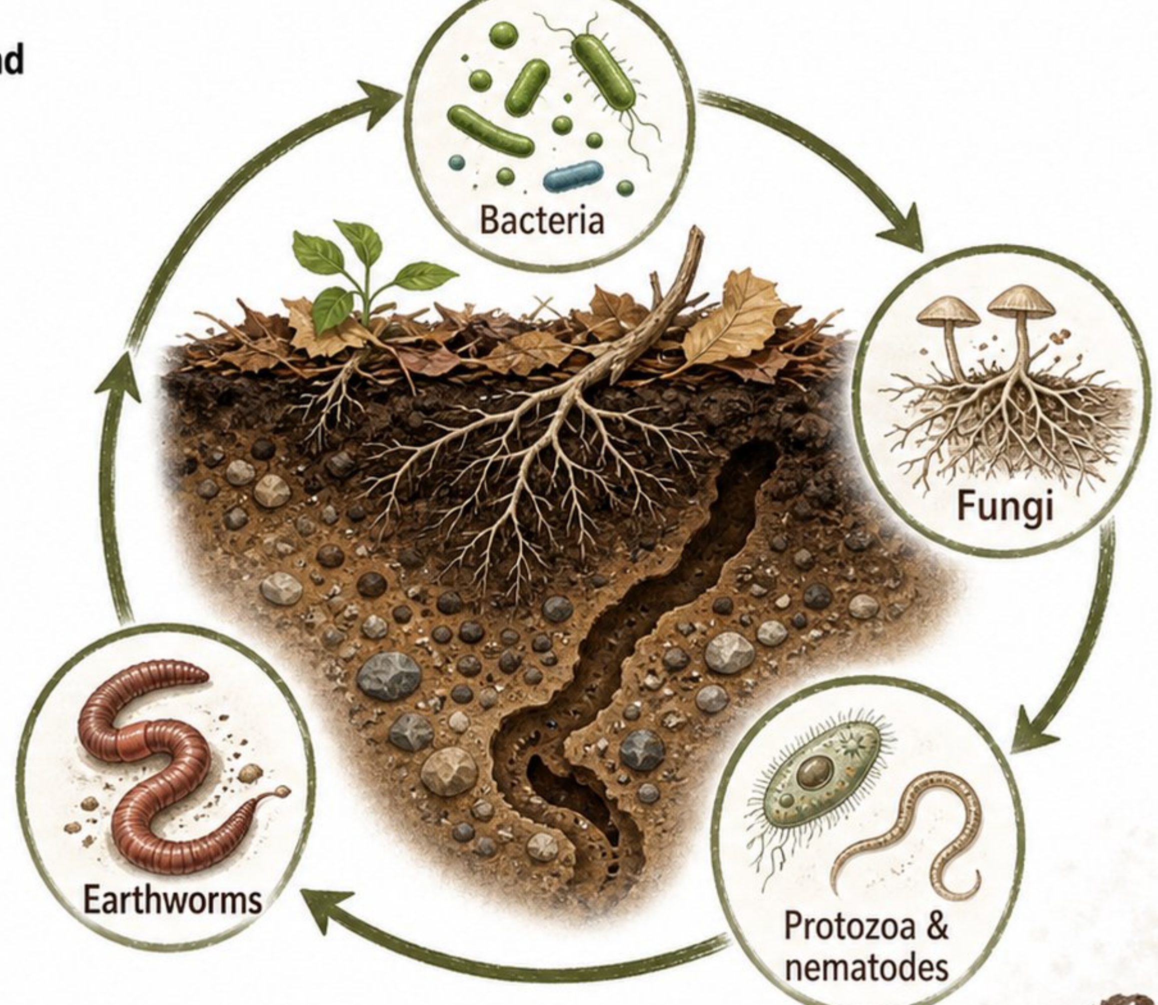
- Bacteria, fungi, protozoa, nematodes, and earthworms form a complex food web
- Fresh residues vs. humus: stable, nutrient-rich organic matter resisting decay
- Bacteria and fungi dominate biomass; earthworms act as ecosystem engineers
- Organic matter slowly releases nitrogen, phosphorus, and sulfur via mineralization
- Microbial by-products and fungal hyphae bind minerals into water-stable aggregates





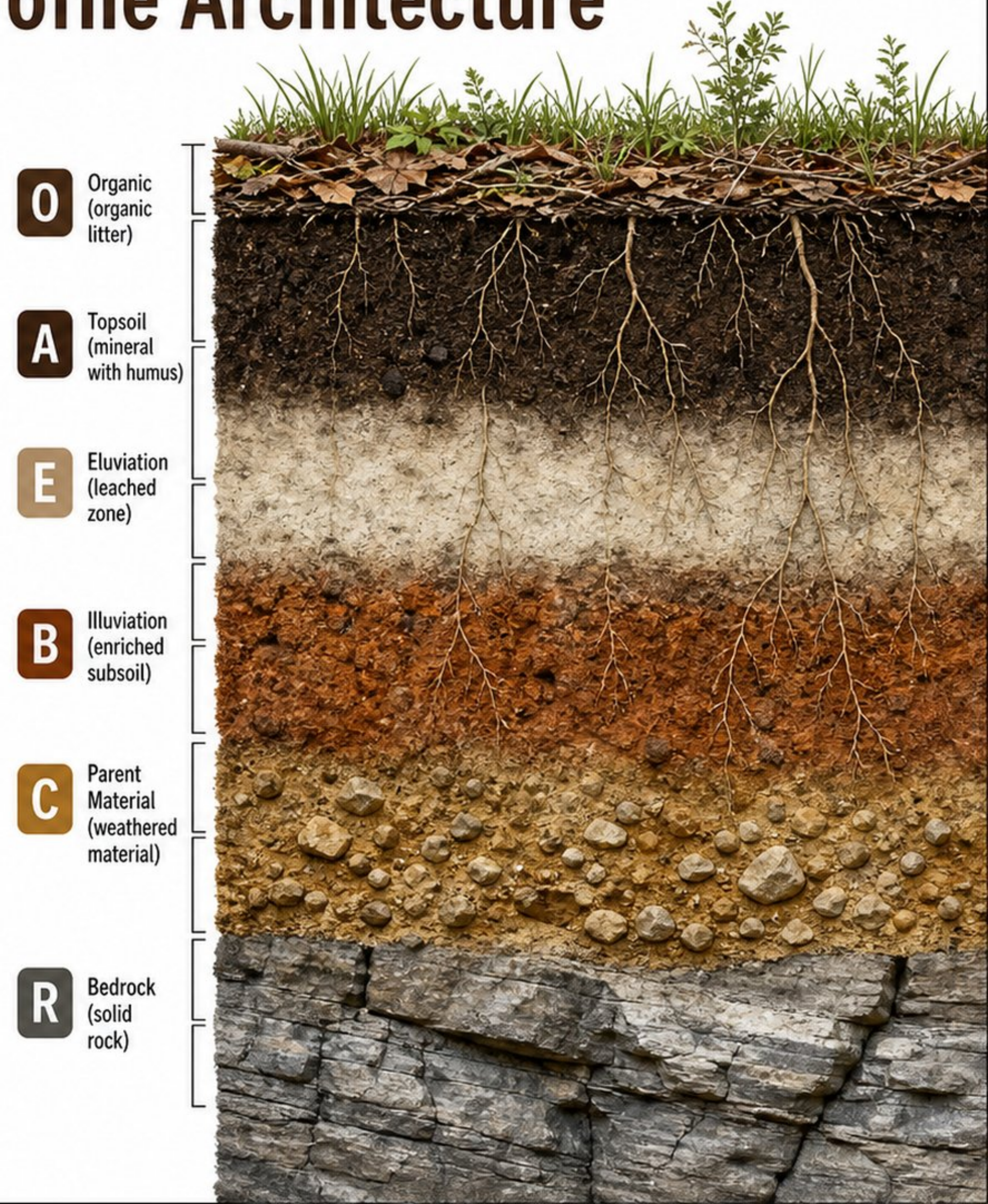
The Living Engine: Soil Organisms at Work

- **Decomposers, mutualists, predators, and pathogens** drive soil function
- **Bacteria:** decompose organic matter and drive nitrogen transformations
- **Fungi:** break down tough fibers and form nutrient-extending mycorrhizae
- **Protozoa & nematodes:** graze on microbes, releasing plant-available nutrients
- **Earthworms:** engineer macropores and mix organic matter into mineral soil



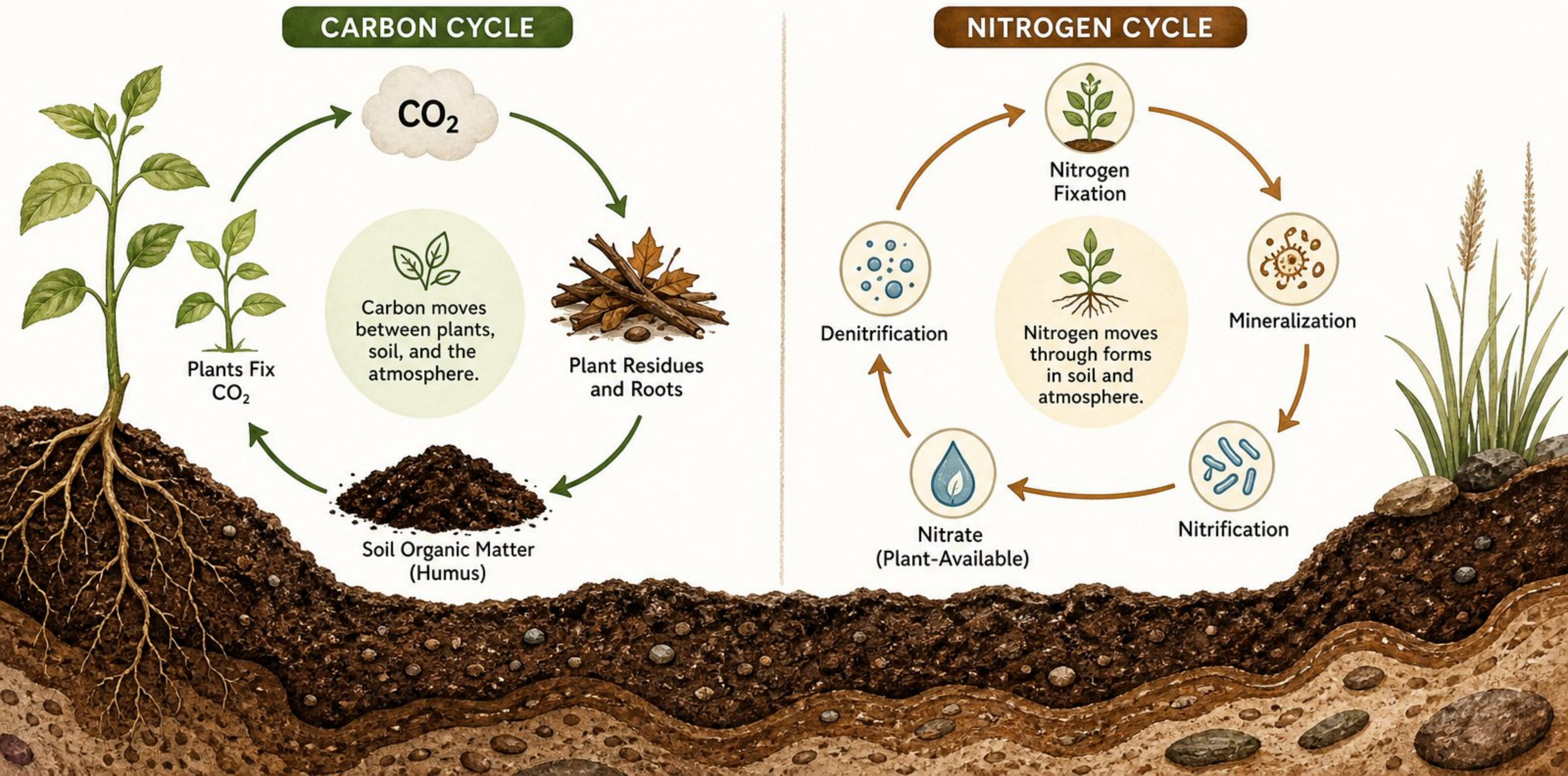
Soil Horizons and Profile Architecture

- Master horizons: O (organic), A (topsoil), E (eluviation), B (illuviation), C (parent material), R (bedrock)
- Eluviation washes clay, iron, and organics from E into B horizons
- Horizon thickness, color, and transitions signal drainage and fertility history
- Grassland profiles: thick, dark A; forest profiles: prominent O and E horizons
- Mineral, water, air, and life content shift dramatically with depth



Nutrient Cycling: The Carbon and Nitrogen Stories

- - Plants fix CO_2; residues and roots add carbon to soil
- - Decomposition releases CO_2 or stores carbon as stable humus
- - Nitrogen cycle: fixation → mineralization → nitrification → denitrification
- - Nitrate is plant-available but leaches easily; timing supply is key
- - Active organic matter fuels turnover; humus builds long-term fertility



Phosphorus, Sulfur, and Mycorrhizal Networks

- Phosphorus from rock weathering gets tightly bound to clay and organic matter
- Bacteria and fungi release organic acids that solubilize locked phosphorus
- Sulfur mineralizes to plant-available sulfate, mirroring nitrogen cycling
- Ectomycorrhizae form root sheaths on trees; endomycorrhizae penetrate crop roots
- Mycorrhizal networks act as extended root systems, boosting water and phosphorus uptake

Factors That Control Soil Formation

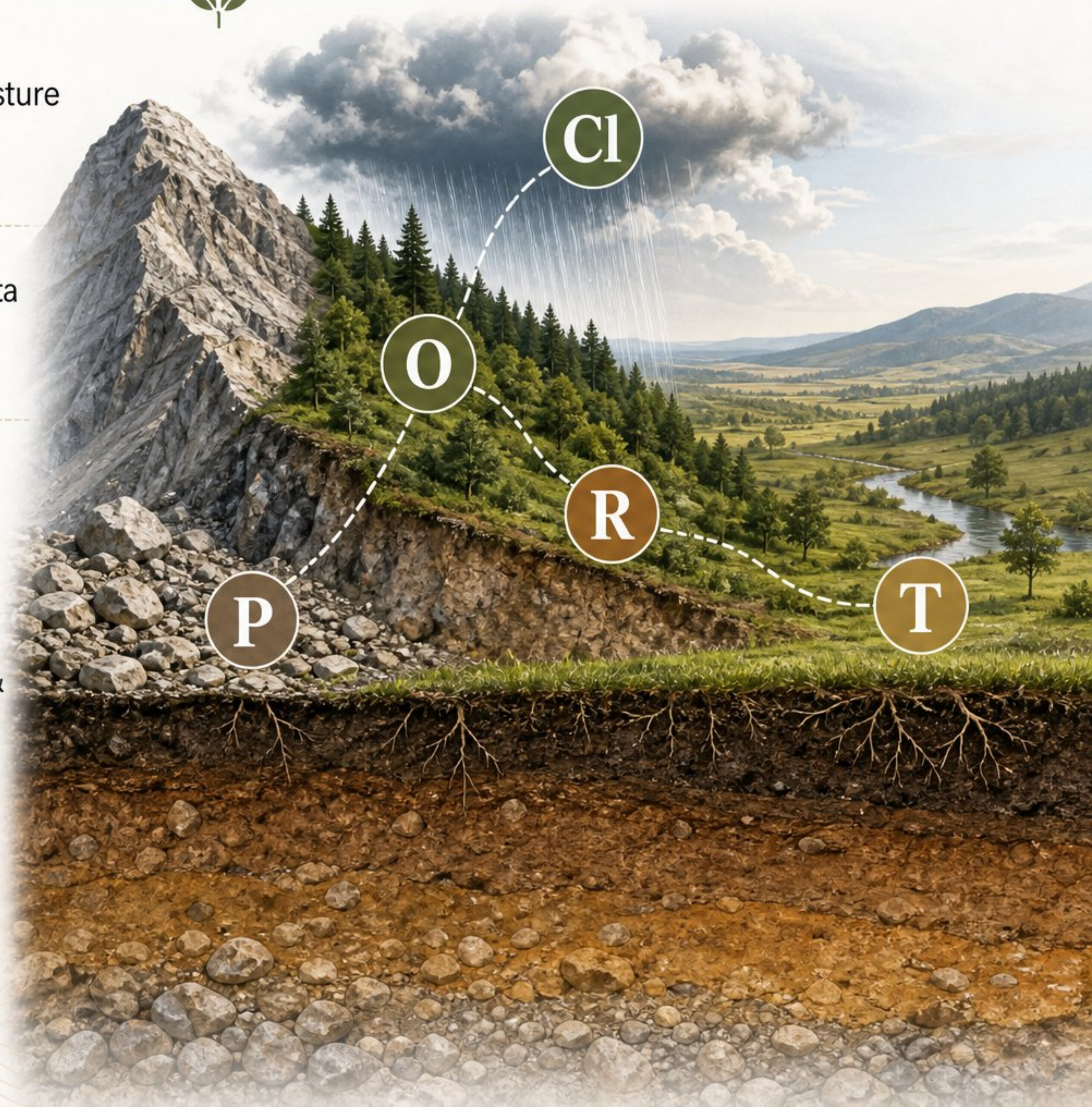
Climate: temperature & moisture drive weathering and decomposition rates

Organisms: vegetation & biota shape horizon sequence and nutrient cycling

Relief/topography: slope, aspect, and position control drainage & erosion

Parent material: the mineral & chemical starting point of soil development

Time: horizon development occurs over decades to millennia

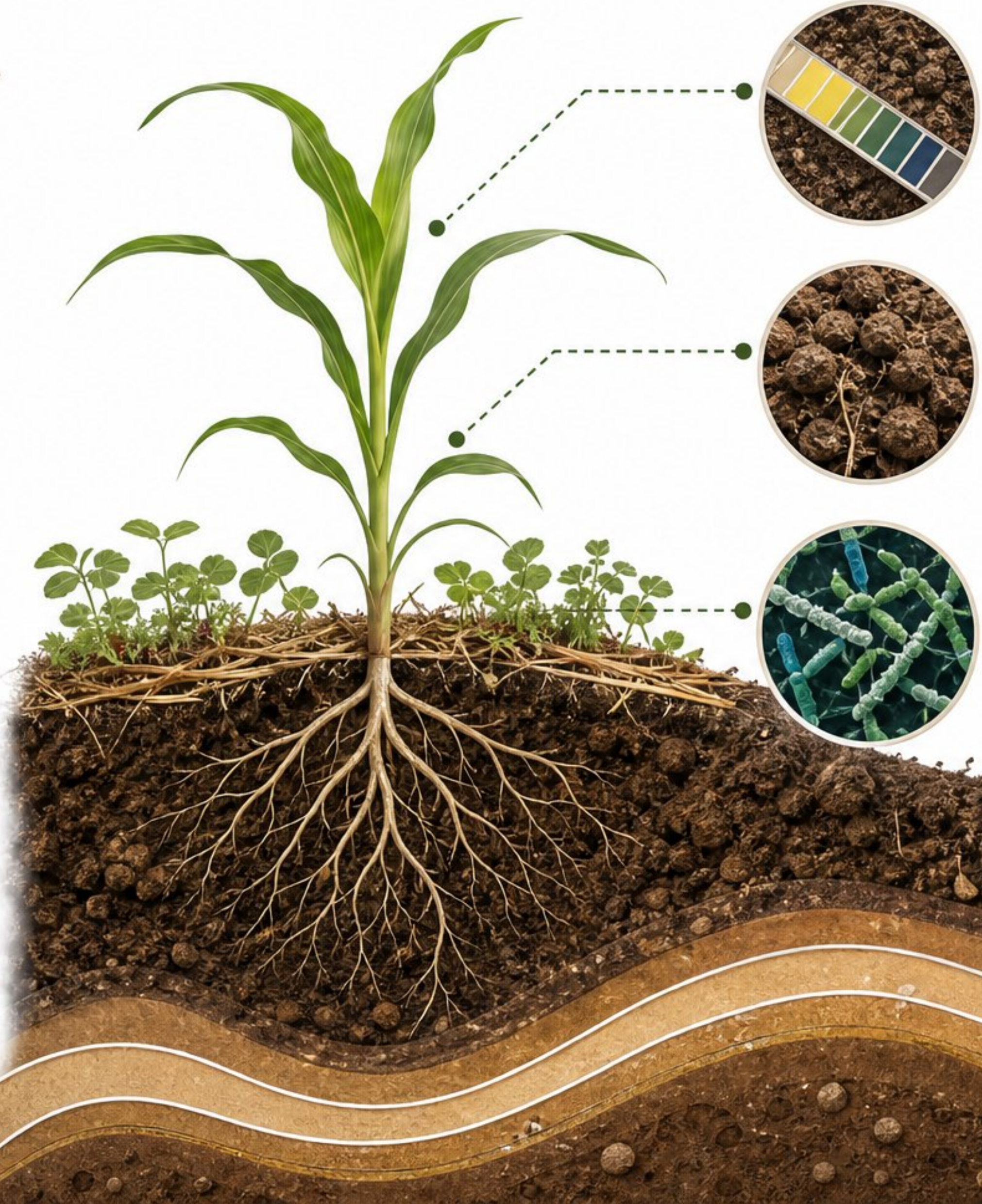


Human Impacts as a Soil-Forming Factor

- Human activity is now a dominant, global soil-forming factor
- Deforestation, tillage, and urbanization accelerate erosion and carbon loss
- Over 60% of human-induced land degradation occurs on agricultural lands
- Conservation agriculture, terracing, and reforestation actively rebuild soil
- Management choices matter enormously for food security and ecosystem health

Soil Health, Resilience, and Conservation

- Integrating chemical, physical, and biological indicators defines soil health.
- Common threats in 2026: erosion, compaction, salinization, organic matter decline.
- Conservation agriculture: minimum tillage, permanent soil cover, crop rotation.
- Balancing minerals, water, air, and life builds resilient soil.
- Reversing just 10% of cropland degradation could feed 154 million more people.



Balanced pH
Soil pH in a balanced range supports nutrient availability and plant growth.

High Aggregate Stability
Well-formed aggregates improve structure, water infiltration, and erosion resistance.

Active Microbial Biomass
Diverse and active microbes drive nutrient cycling and soil vitality.

From Theory to Practice: Summary and Next Steps

- Recap core components: minerals, water, air, and life form living, layered soil.
- Try two field tests: ribbon test for texture and slake test for aggregate stability.
- Apply knowledge in gardening, farming, land restoration, and urban planning.
- Explore FAO Global Soil Partnership, soil maps, and citizen science programs.
- Dig a small hole—identify horizons, texture, structure, and signs of life.