Nutrient Cycles and the Carbon Cycle

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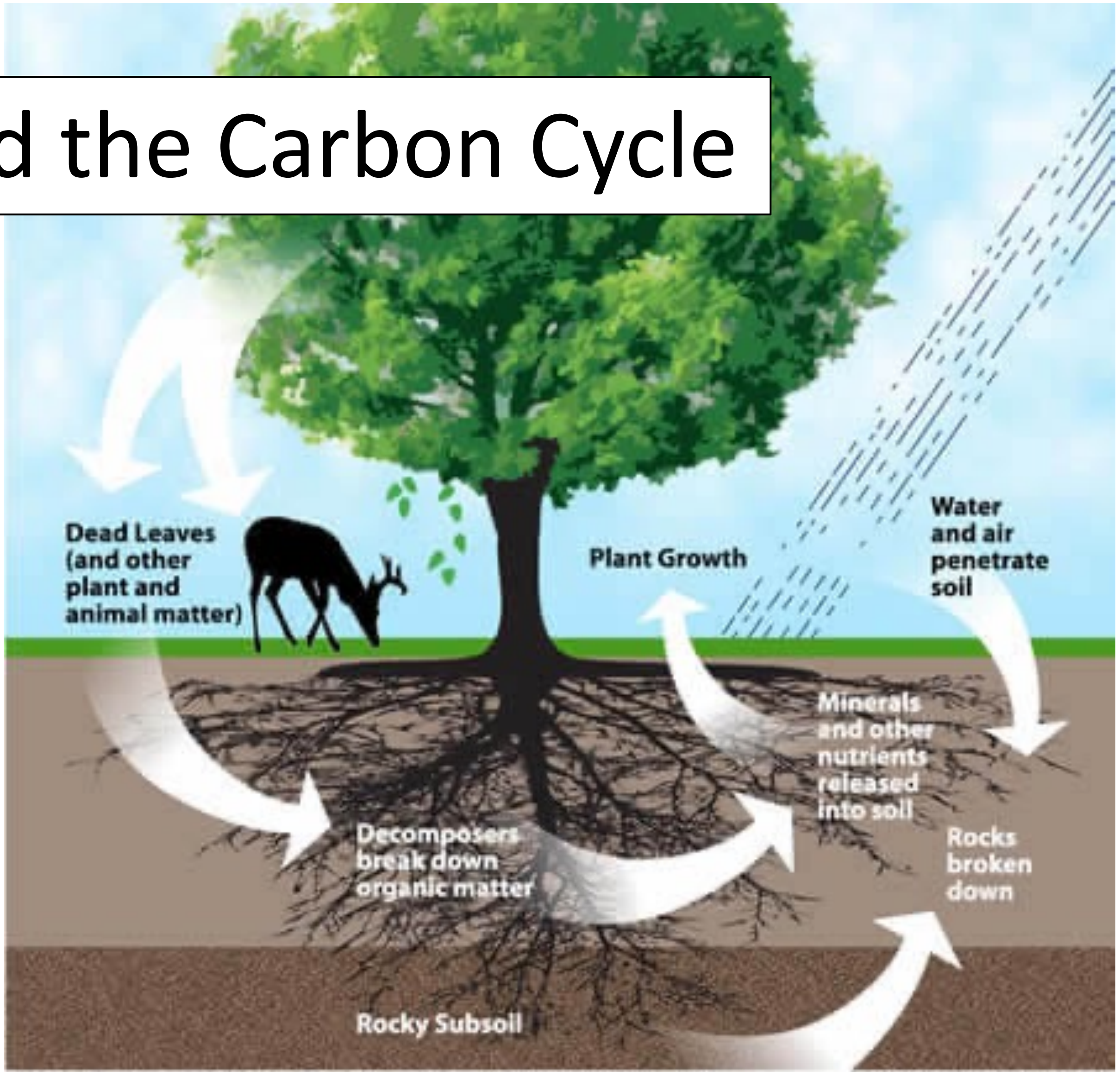
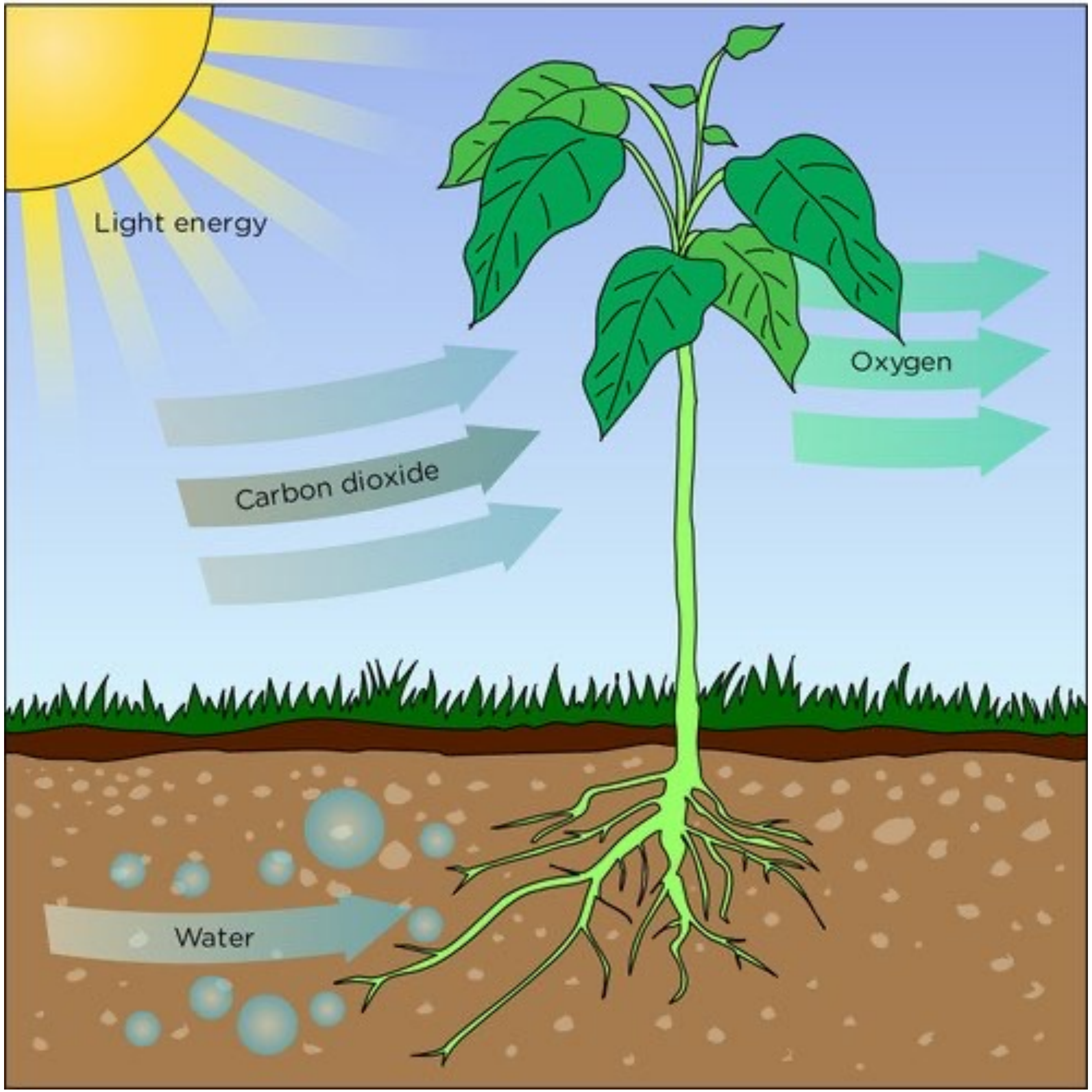


What’s in a plant?

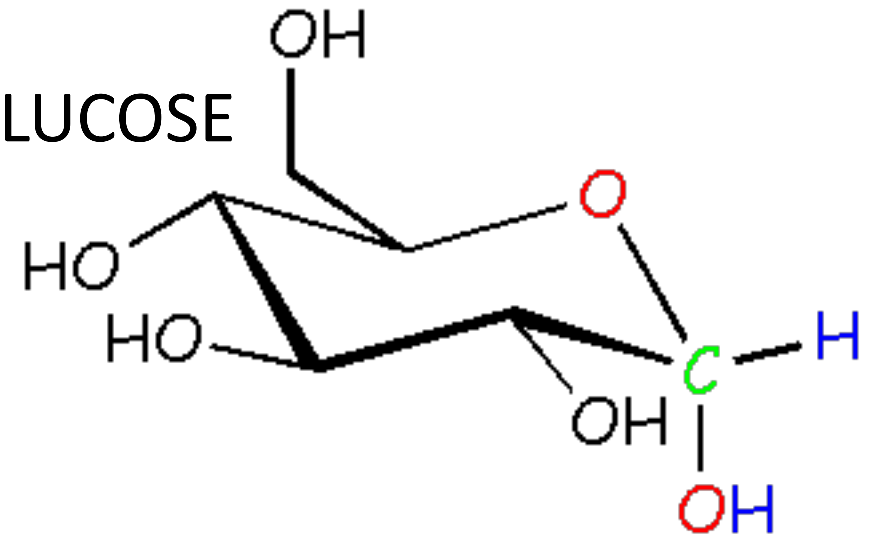


The basics of photosynthesis:
carbon dioxide (CO_2)
and water (H_2O)
in the presence of chlorophyll
and sunlight
are converted to glucose ($C_6H_{12}O_6$)
which stores solar energy

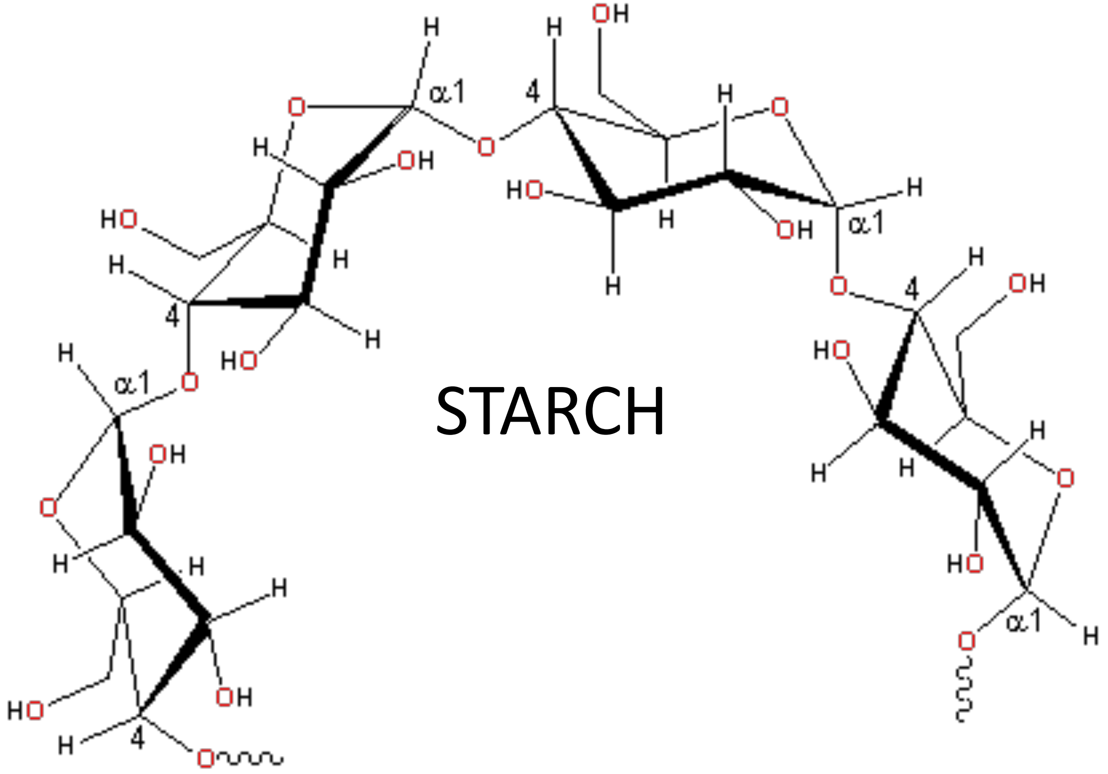
So plants are made of glucose: C, H, O

Some phytochemicals – like fiber -- are made from glucose. Plants make starch and cellulose by attaching glucose molecules to one another.

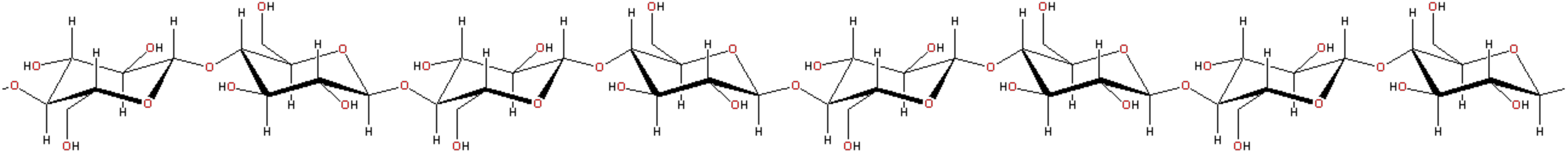
GLUCOSE



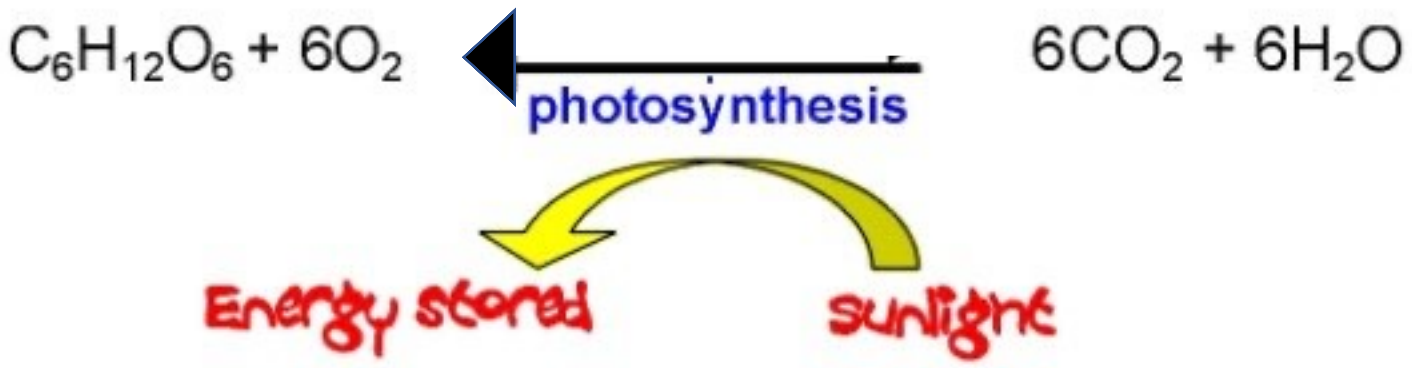
STARCH



CELLULOSE

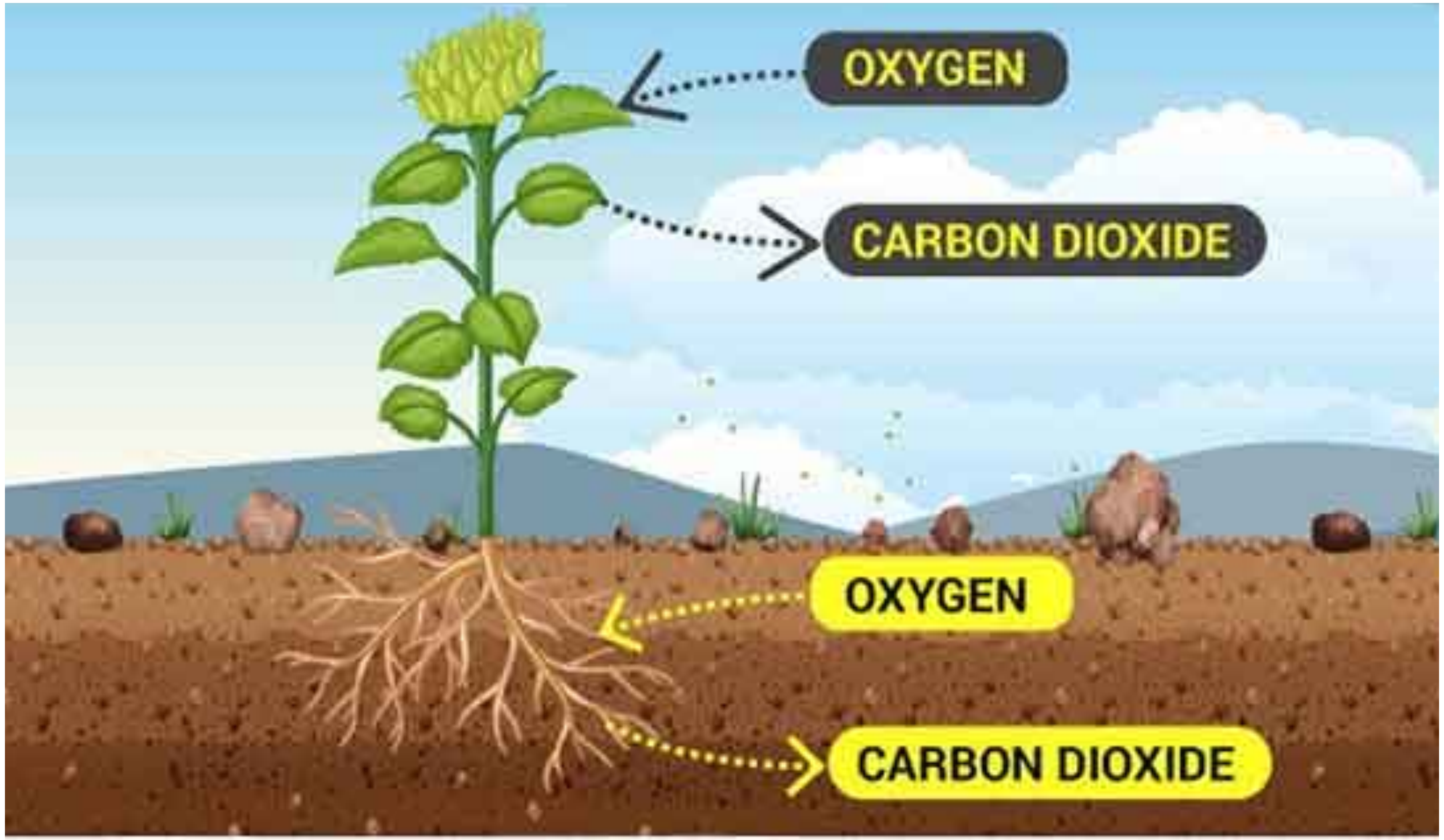


Stitching glucose molecules together (and all other chemical transformations) requires energy.



Plants obtain this energy by combining glucose molecules with oxygen (“plant respiration”). So while plants don’t breathe, they need oxygen just as much as we do.

Both leaves and roots need to take in oxygen (respire) to fuel chemical transformations.



But a plant is not a pile of glucose

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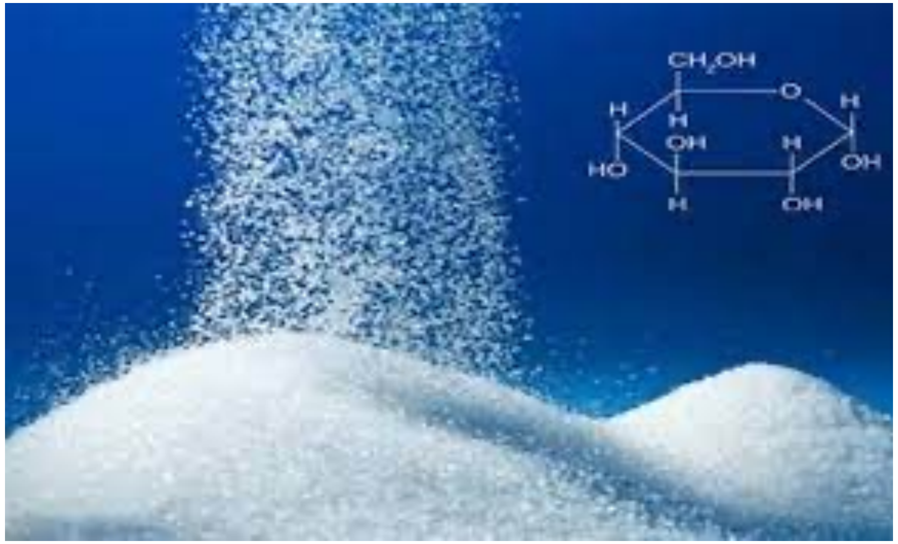


In addition to fiber (cellulose, wood), plants contain starches, fats, proteins, enzymes, pigments, genetic material (DNA, RNA), defensive chemicals, hormones, fragrances, resins, tannins, waxes, and much more. These molecules contain other elements besides C, H, and O.

About 89% of a plant’s dry weight is made up of carbon, oxygen, and hydrogen.

What about the other 11%?

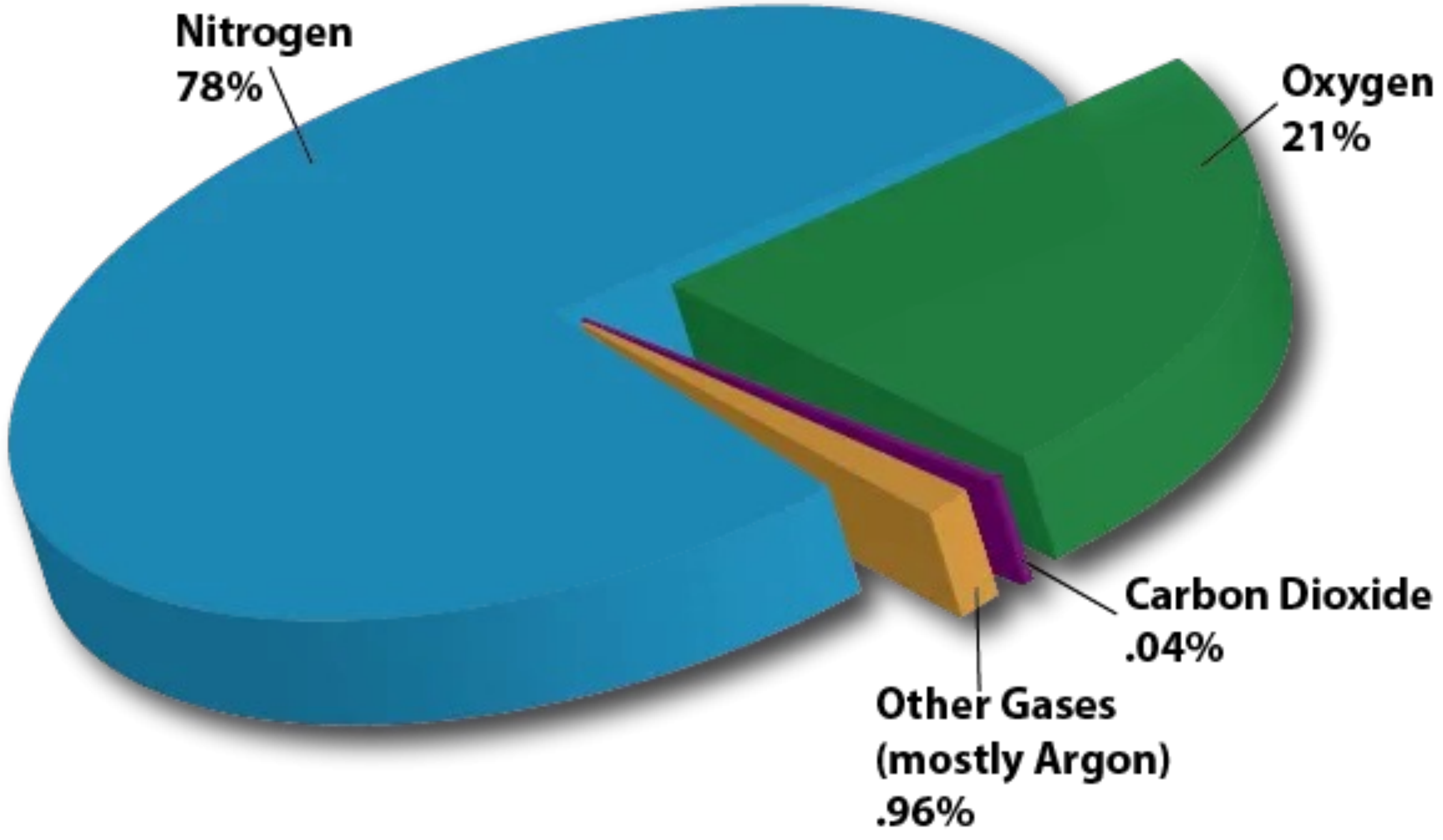
Chlorophyll contains nitrogen (N) and magnesium (Mg)
DNA contains nitrogen (N) and phosphorus (P)
Proteins contain nitrogen (N) and sulfur (S)
ATP, which stores energy, contains phosphorus (P)
Plants use potassium (K) to maintain water in their cells
Plant cell walls and membranes contain calcium (Ca)

These elements – C, H, O, N, P, S, K, Mg, Ca -- are called **macronutrients**.

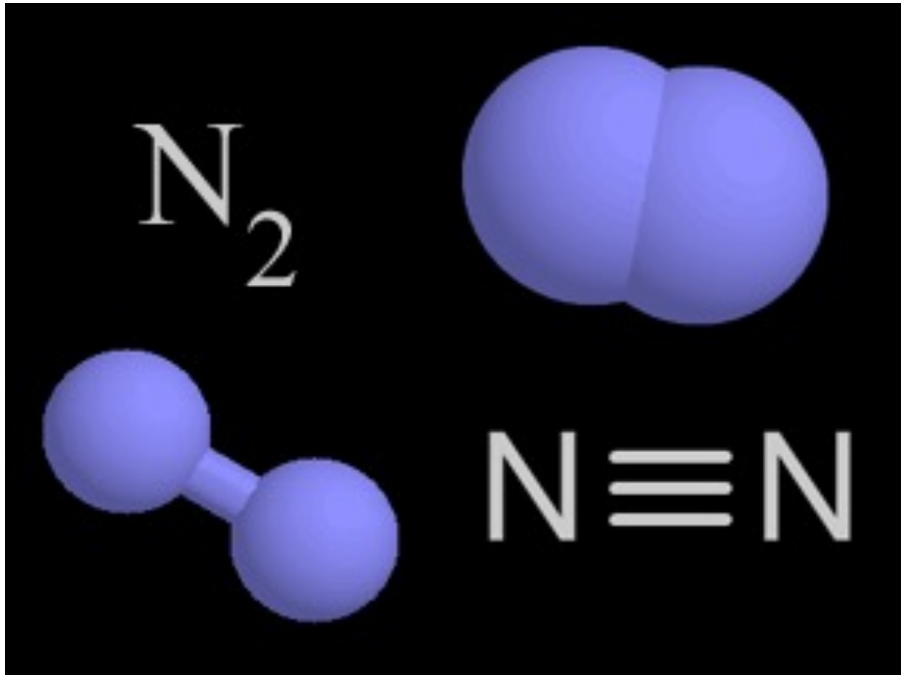
Countless other essential chemical reactions require smaller amounts of boron (B), zinc (Zn), copper (Cu), manganese (Mn), silicon (Si), iron (Fe), molybdenum (Mo), nickel (Ni), and chlorine (Cl). These are called **micronutrients**.

How do plants acquire macro- and micro-nutrients?

The air would seem to be a great source of nitrogen, the macronutrient needed by plants in the greatest quantity.



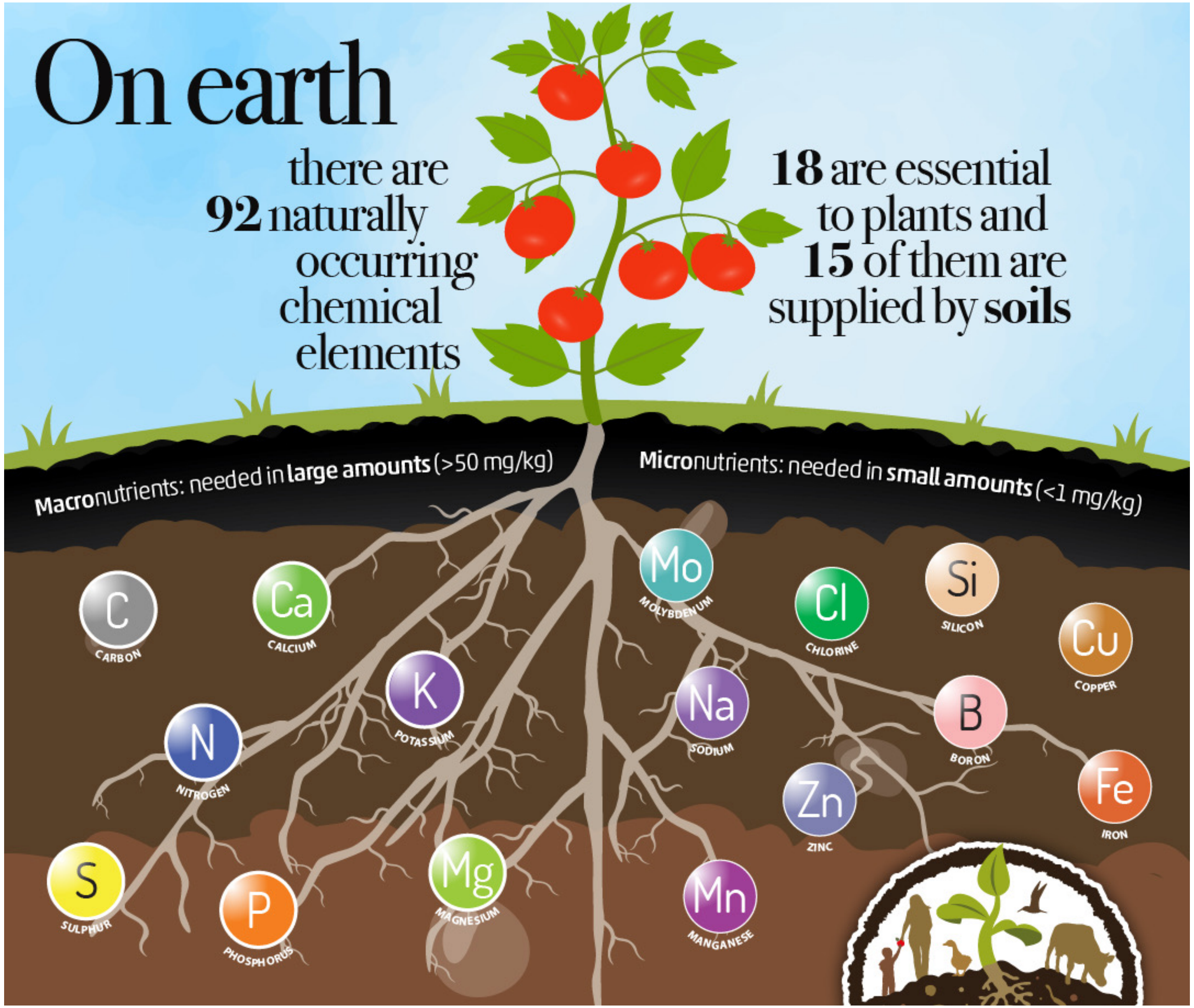
…but the triple bond of nitrogen gas requires huge amounts of energy to break….



….so plants look elsewhere for nitrogen

And none of the other macro- or micro-nutrients are found in the air…


Plants obtain all other nutrients from SOIL



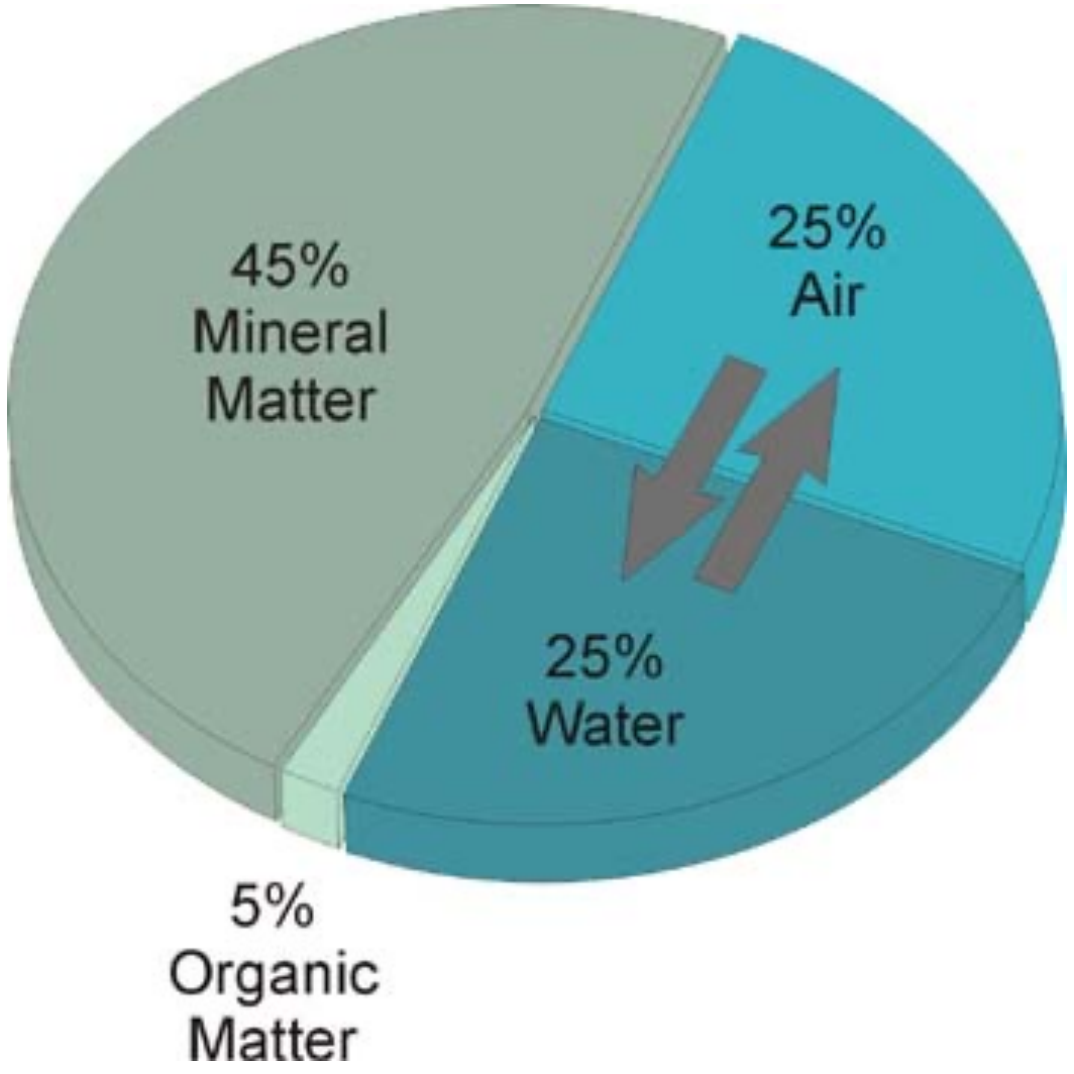
Most plant nutrients are positively charged ions:

- potassium (K^+)
- calcium (Ca^{2+})
- magnesium (Mg^{2+})
- ammonium (NH_4^+)
- sodium (Na^+)
- iron (Fe^{2+} or Fe^{3+})
- manganese (Mn^{2+})
- copper (Cu^{2+})
- zinc (Zn^{2+})

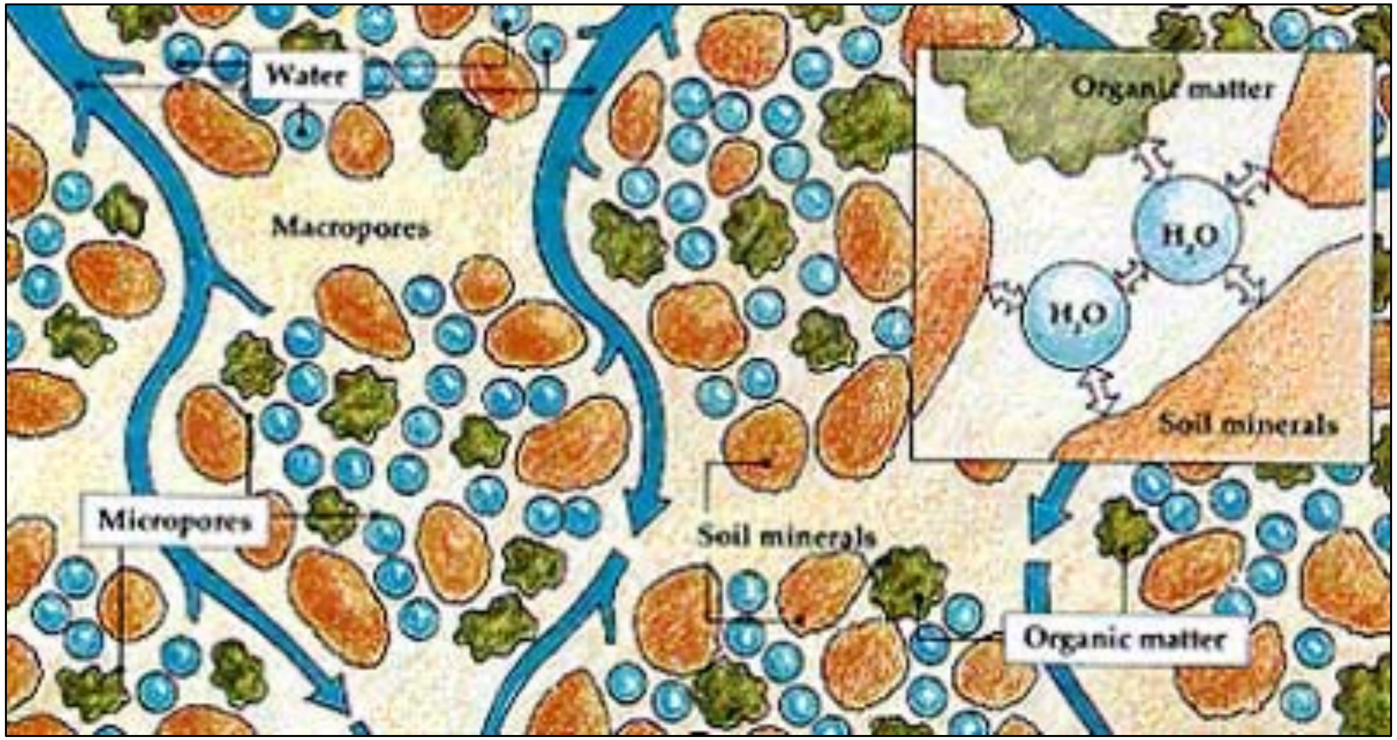
This is important because…

Remember the 4 components of soil:

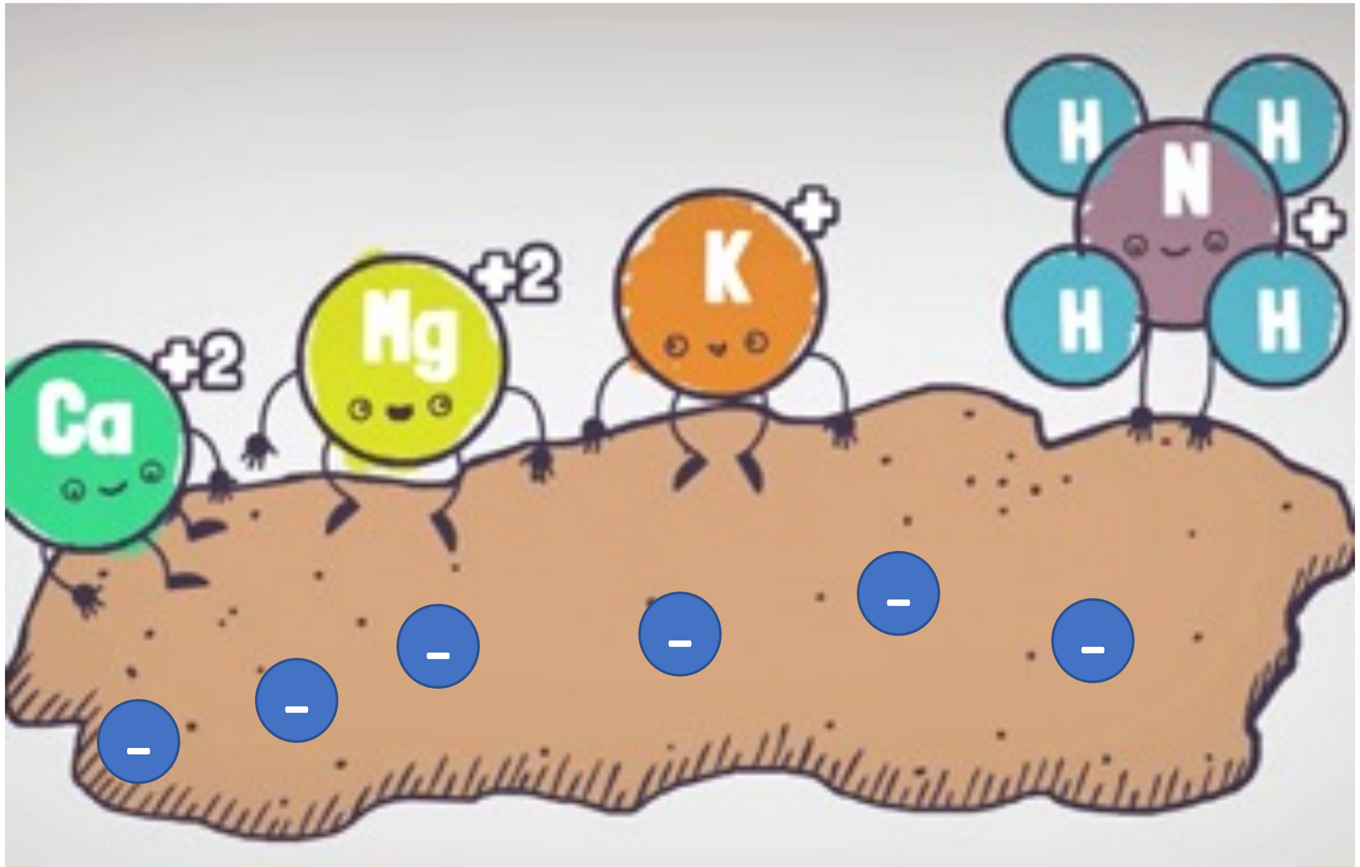
- mineral particles (pieces of rock)
- water
- air pockets
- organic matter (living, decomposed and decomposing organisms and their parts)



If we take a closer look ….

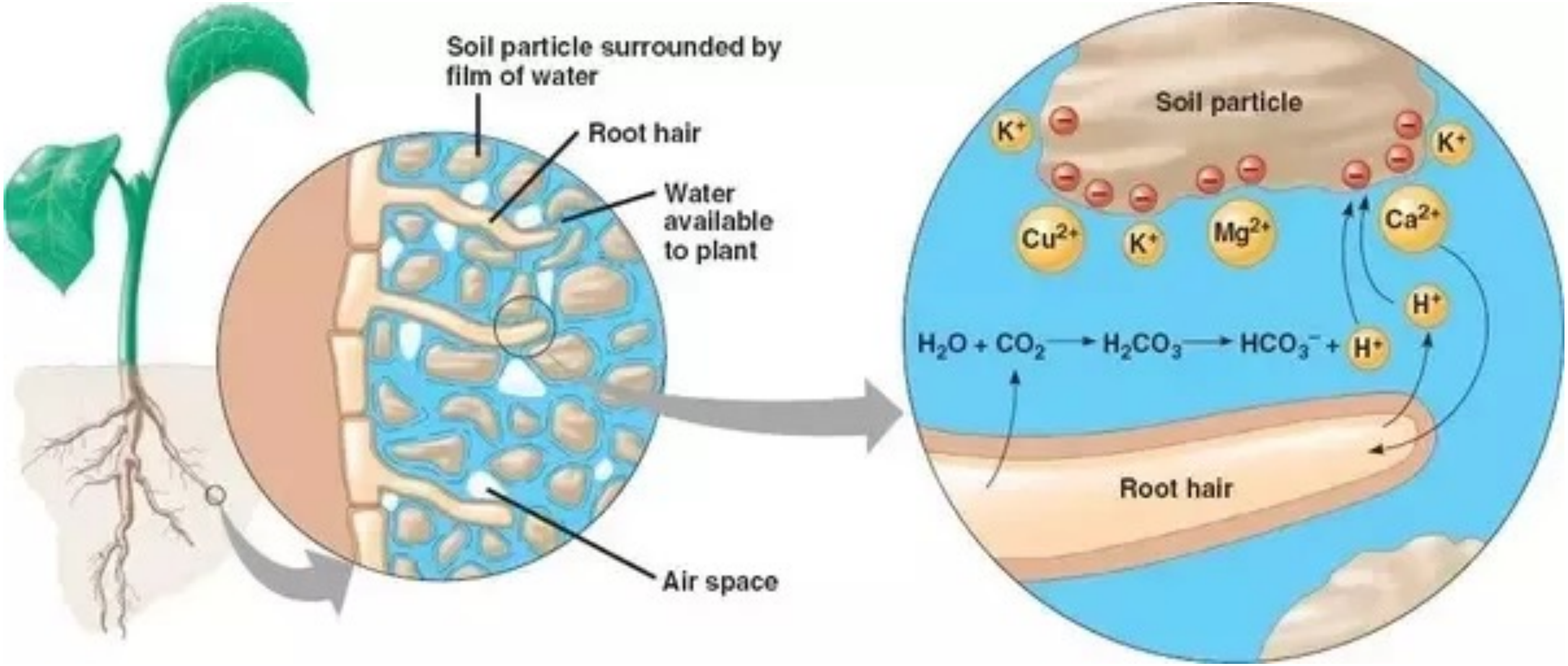


And closer still…..



Soil clay minerals and organic matter tend to be negatively charged, attracting positively charged ions (cations) to their surfaces.

When plant roots penetrate the spaces between soil particles, they can exchange (positive) hydrogen ions for (positive) nutrient ions.

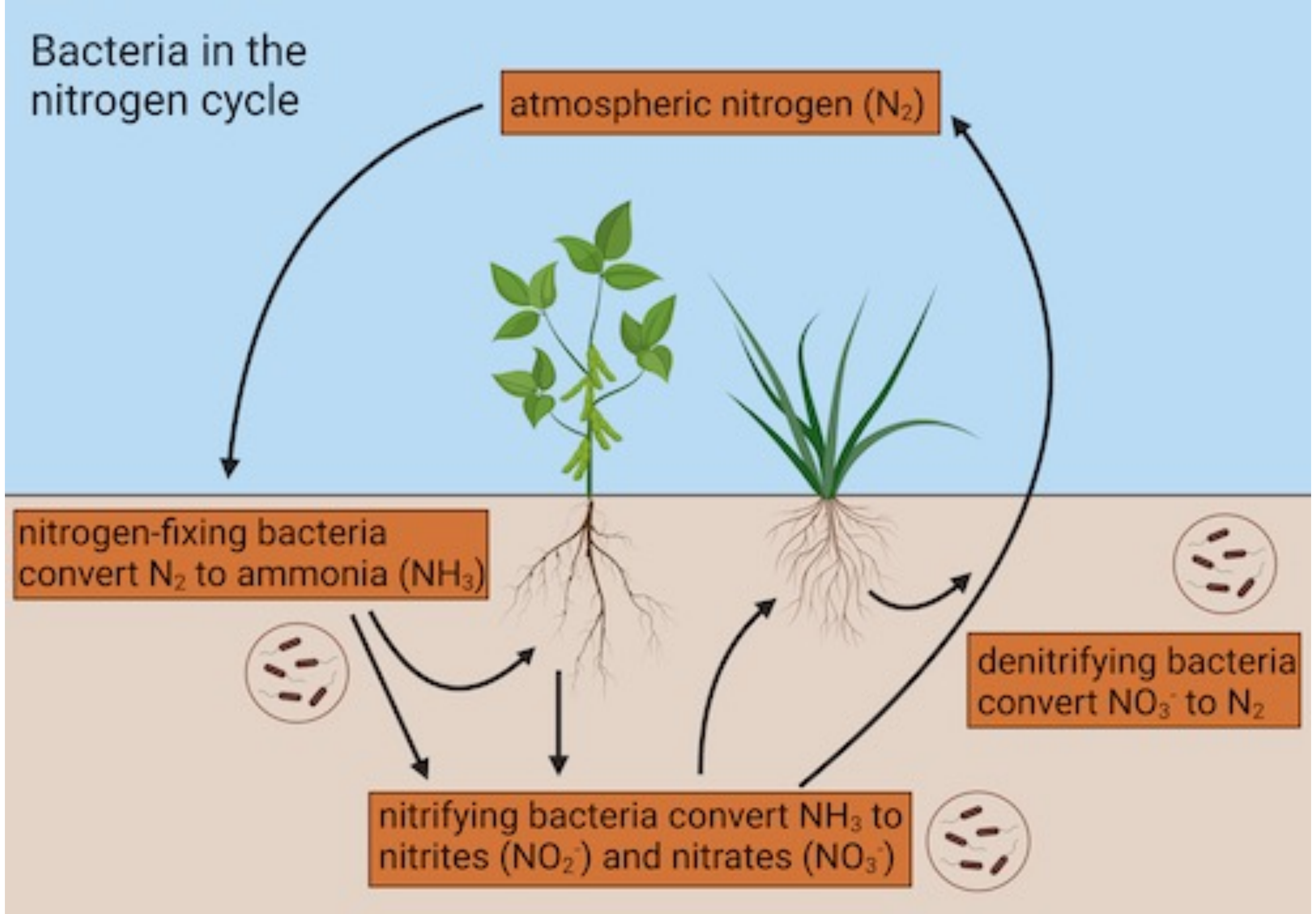


The amount of clay particles and organic matter in soil determine its **cation exchange capacity**, i.e. the amount of soil nutrients it can hold.

How do these nutrients get into soil in the first place?

- Wind and rain carry air-borne molecules to earth
- Mineral particles in the soil slowly dissolve, releasing ions
- Certain soil bacteria can break the triple bond of atmospheric nitrogen present in air pockets and convert it to chemical forms that plants can use (nitrogen fixation)
- Certain other nitrogen-fixing bacteria live in nodules on the roots of legumes (peas, beans)

Nitrogen fixation

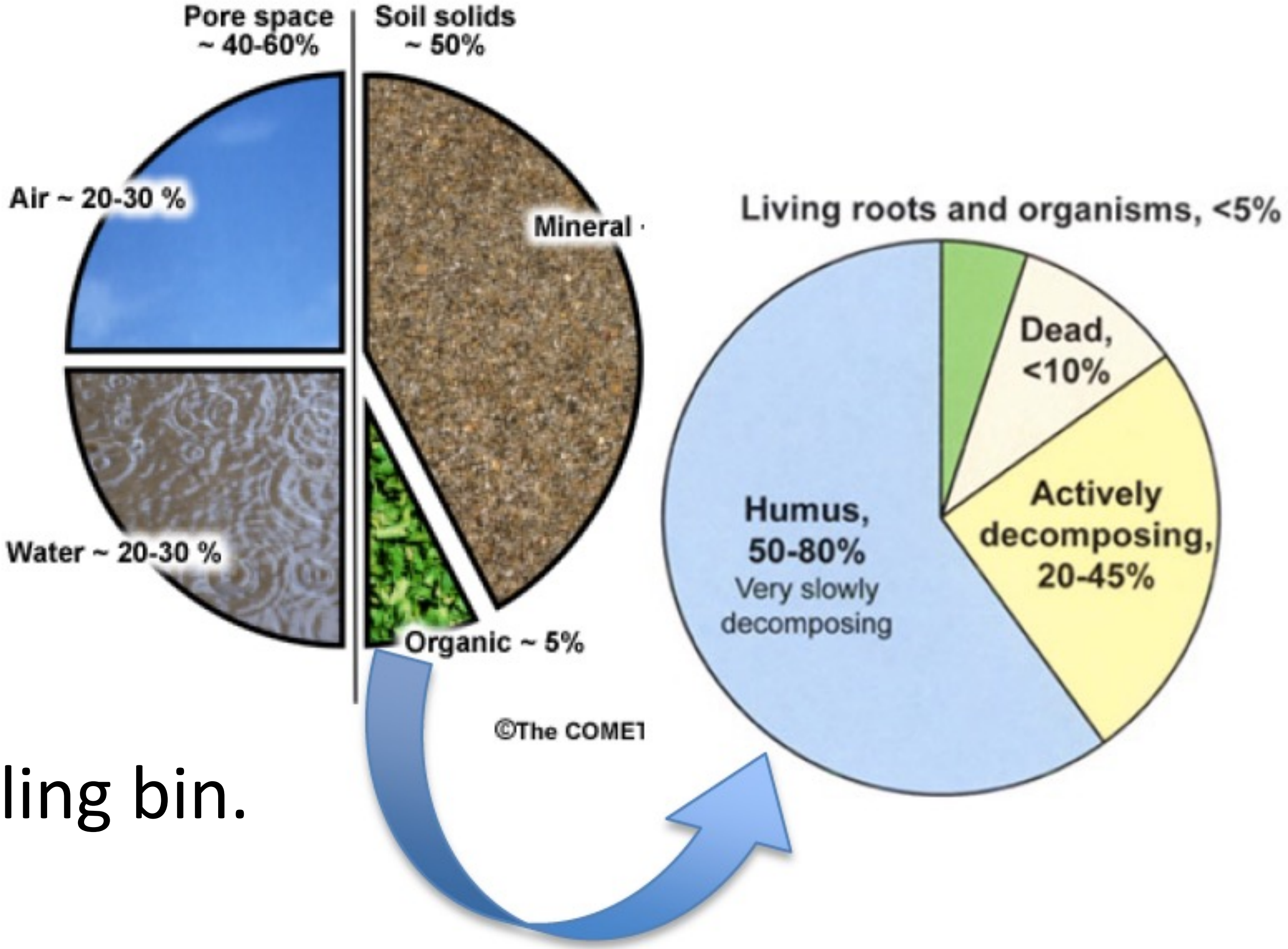


How do these nutrients get into soil in the first place?

- Wind and rain carry air-borne molecules to soil surface
- Mineral particles in the soil are slowly dissolved by water
- Nitrogen fixation by bacteria in soil and legume root nodules

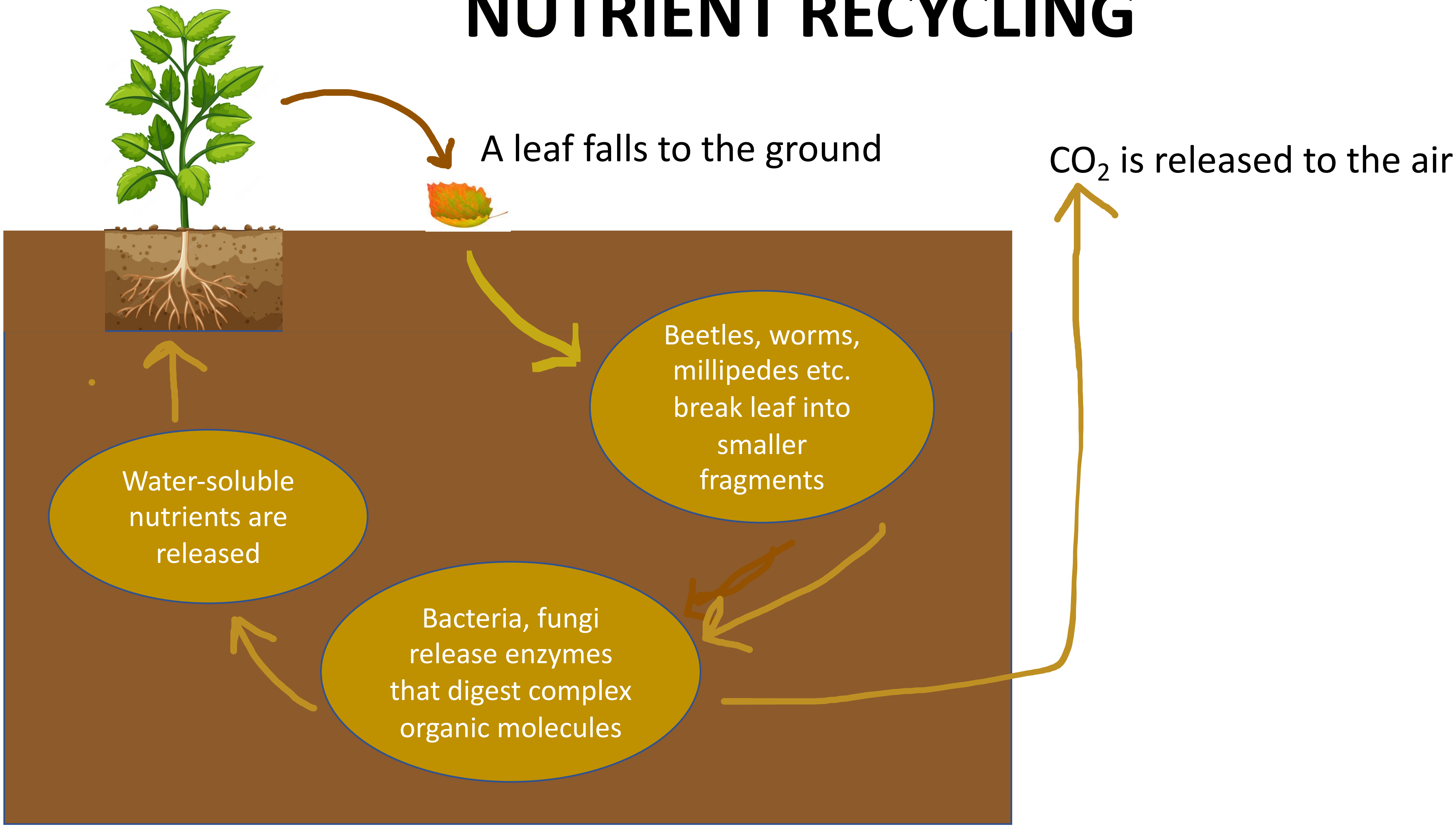
- **The decomposition of once-living organisms and their parts (leaves, seeds, flowers, insects, frass, etc.)**

Remember that ~ 5% of soil is organic matter: living, dead, decomposing and decomposed organisms and their parts.

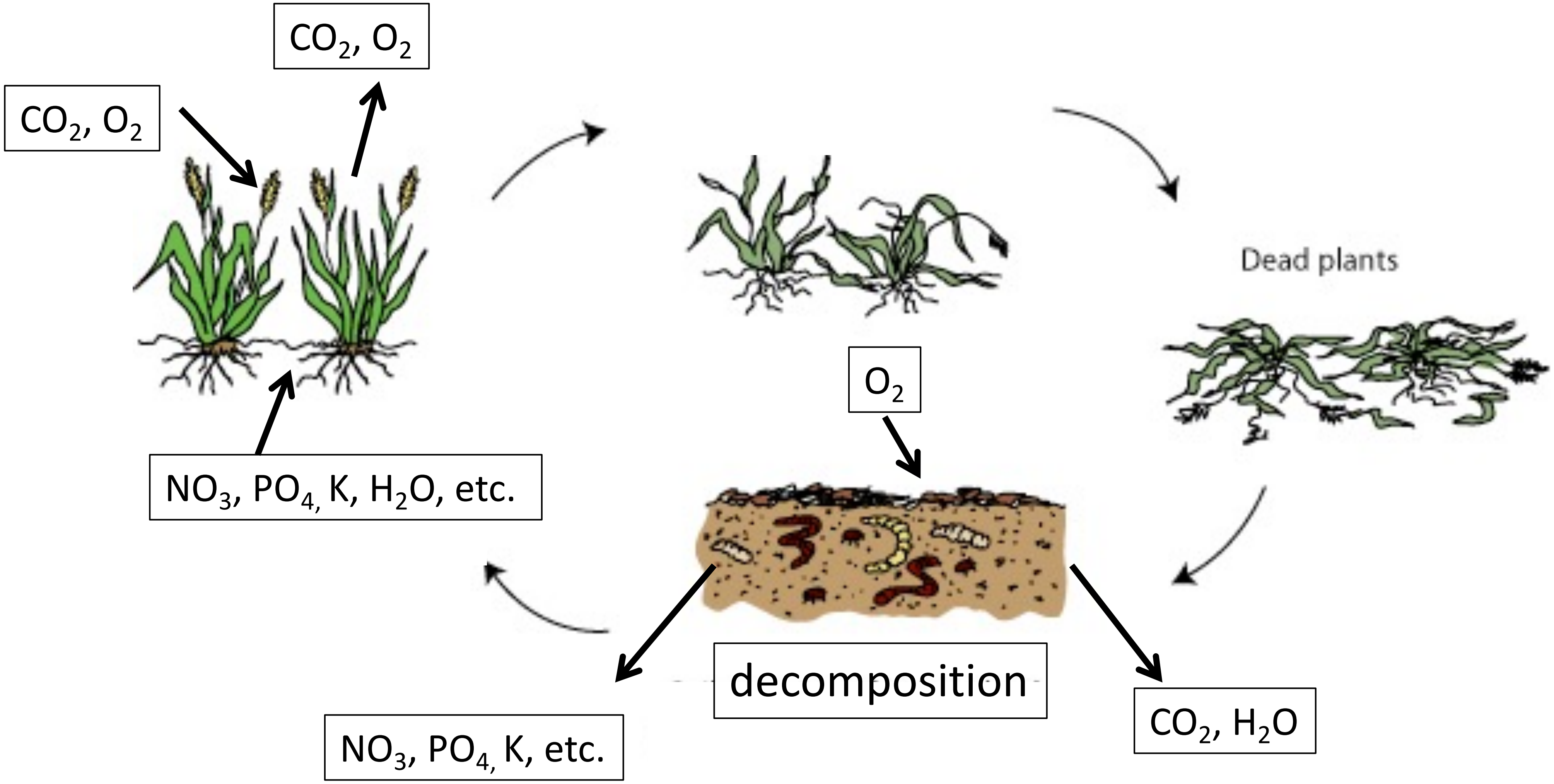


The soil is a giant recycling bin.

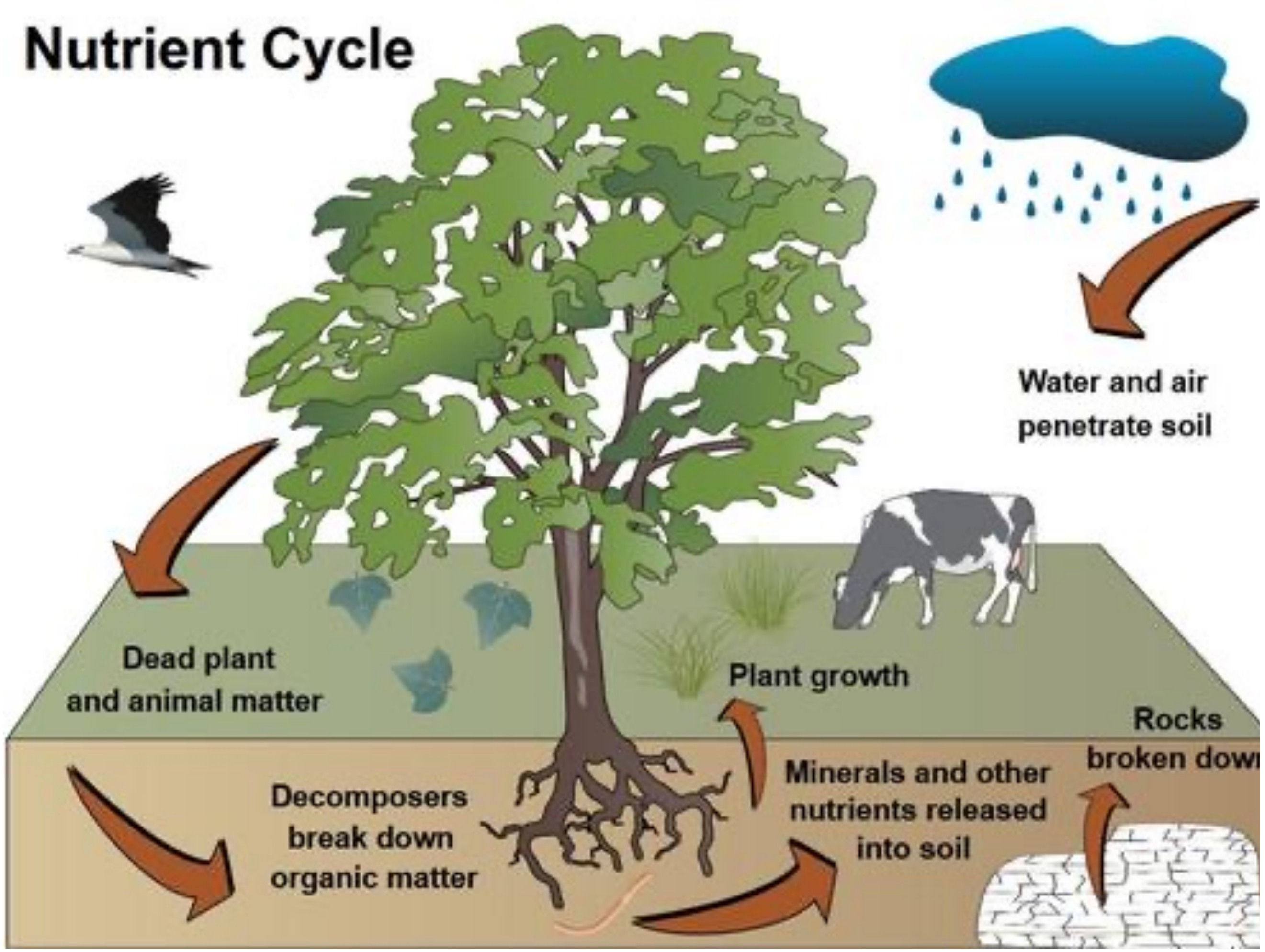
NUTRIENT RECYCLING



Plant growth takes up nutrients; decomposition releases them for re-use



In natural ecosystems, soil nutrients like nitrogen, phosphorus, potassium, etc. are recycled over and over, providing a continuous source of raw materials for plant growth.



Harvesting crops interrupts the cycle, preventing plant nutrients from returning to the soil.

Managing soil for harvest requires replacing nutrients contained in harvested materials.

What can replace the harvested nutrients?

FERTILIZER

“Organic”, “Inorganic”: what do these words mean?

“Inorganic fertilizers are made of chemicals, organic fertilizers are not.”

“Organic”: carbon-containing

Organic fertilizers contain carbon because they are derived from once-living organisms.

“Inorganic”: non-carbon-containing

Inorganic fertilizers contain no carbon because they are made from mined minerals.

Both kinds of fertilizers are made of chemicals – everything is made of chemicals.

"Organic": carbon-containing

Compost, poultry manure, steer manure, fish meal, bone meal, wood ash, peat, etc.

These large, complex molecules are (slowly) broken down by soil micro-organisms, releasing simple nutrient ions that roots can absorb.

"Inorganic": non-carbon-containing

Ammonium phosphate, magnesium sulfate, ammonium nitrate, potassium sulfate, etc.

These simple, soluble molecules immediately dissociate into nutrient ions that roots can absorb.

NH_4^+, NO_3^+, K^+, Mg^{++}, Fe^{++}, Ca^{++}, etc.

A plant gets exactly the same nutrients from both sources.

Differences between organic and inorganic sources of nutrients:

Organic

- Slower release of nutrients
- Loss of nutrients to water table (leaching) unlikely
- Takes time to see plant growth improve
- Ratios, concentrations of nutrients unknown, variable
- Must be applied in large amounts: bulky, expensive
- Fresh manure can damage plants and carry weed seeds
- No fossil fuel used in manufacture (but transport?)
- Adding carbon-containing material to soil can increase its water-holding capacity and improve soil structure
- (But adding too much carbon-containing material to soil can deplete soil nitrogen via bacterial activity)

Inorganic

- Rapid release of nutrients
- Loss of nutrients to water table possible at high application rates (plant uptake rate < release rate)
- Immediate improvement in plant growth
- Ratios, concentrations of nutrients precisely known
- Applied in small amounts, so inexpensive, but must be re-applied more often
- Overapplication can damage plants
- Fossil fuel often used in manufacture
- Do not add carbon-containing material to soil

If plants take up carbon from the air, not the soil,
why do we care about putting
organic (carbon-containing) material (OM) into the soil?

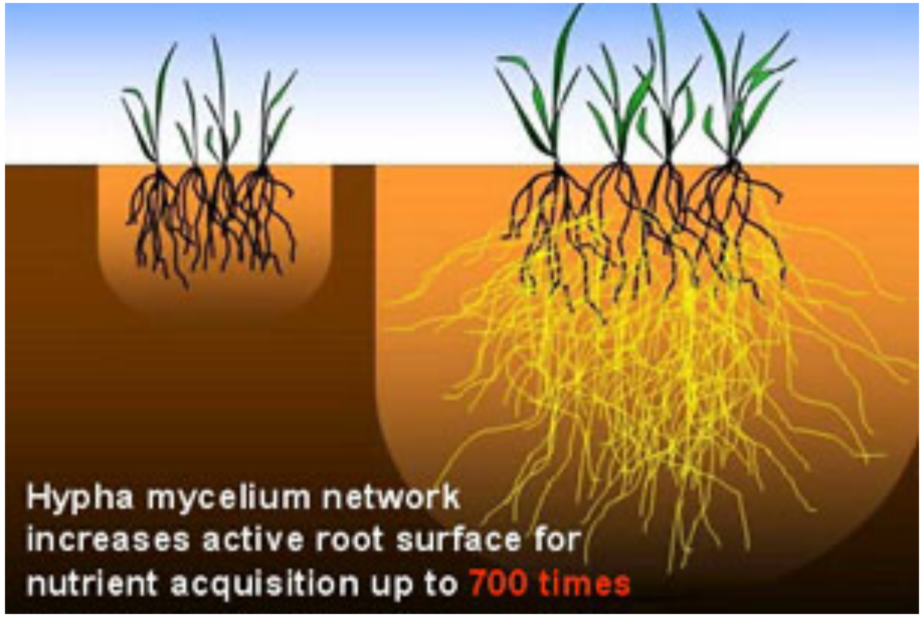
1. Organic matter (OM) absorbs and retains water.
2. OM increases soil's cation exchange capacity (i.e. retains nutrients).
3. OM supports soil bacteria, fungi, and arthropods.
4. OM releases plant nutrients as it decomposes.
5. OM sequesters C from the atmosphere, where there is TOO MUCH.

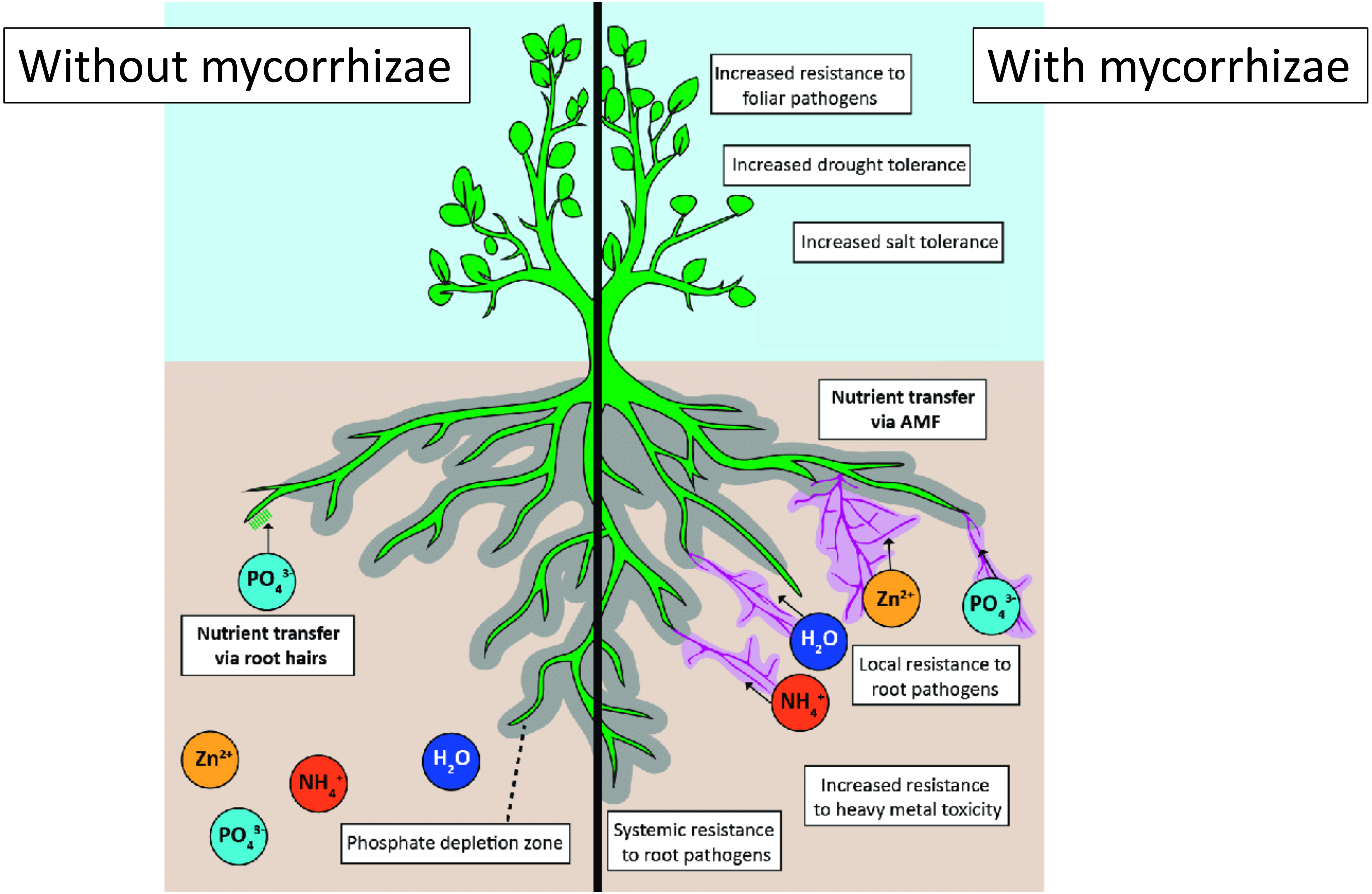
A closer look at soil fungi:

Fungi do not photosynthesize. They obtain carbon and other nutrients by digesting OM in the soil.

Some fungi live freely in the soil. They secrete enzymes and absorb the ions that are released from the breakdown of soil OM.

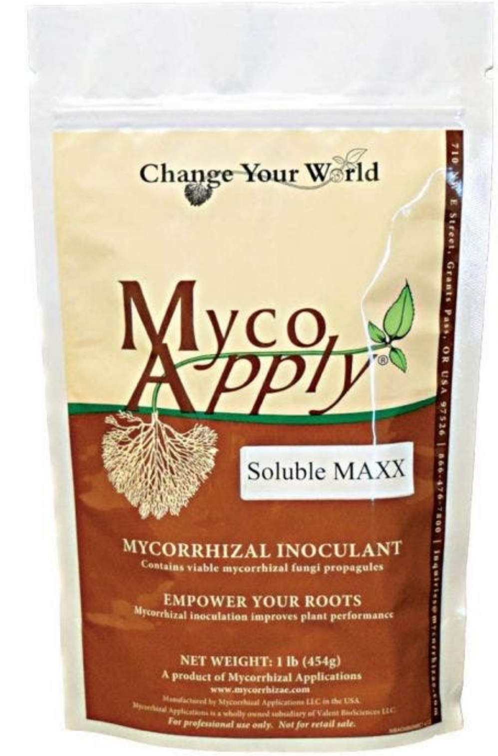
Other fungi (mycorrhizae) live cooperatively with plant roots. In exchange for sugars secreted by roots, they serve as extensions of the plant's root system, harvesting water and soil nutrients and sharing these with their plant host.




Without mycorrhizae
With mycorrhizae
Increased resistance to foliar pathogens
Increased drought tolerance
Increased salt tolerance
Nutrient transfer via AMF
Nutrient transfer via root hairs
PO_4^{3-}
Zn^{2+}
H_2O
NH_4^+
Local resistance to root pathogens
Increased resistance to heavy metal toxicity
Systemic resistance to root pathogens
Phosphate depletion zone

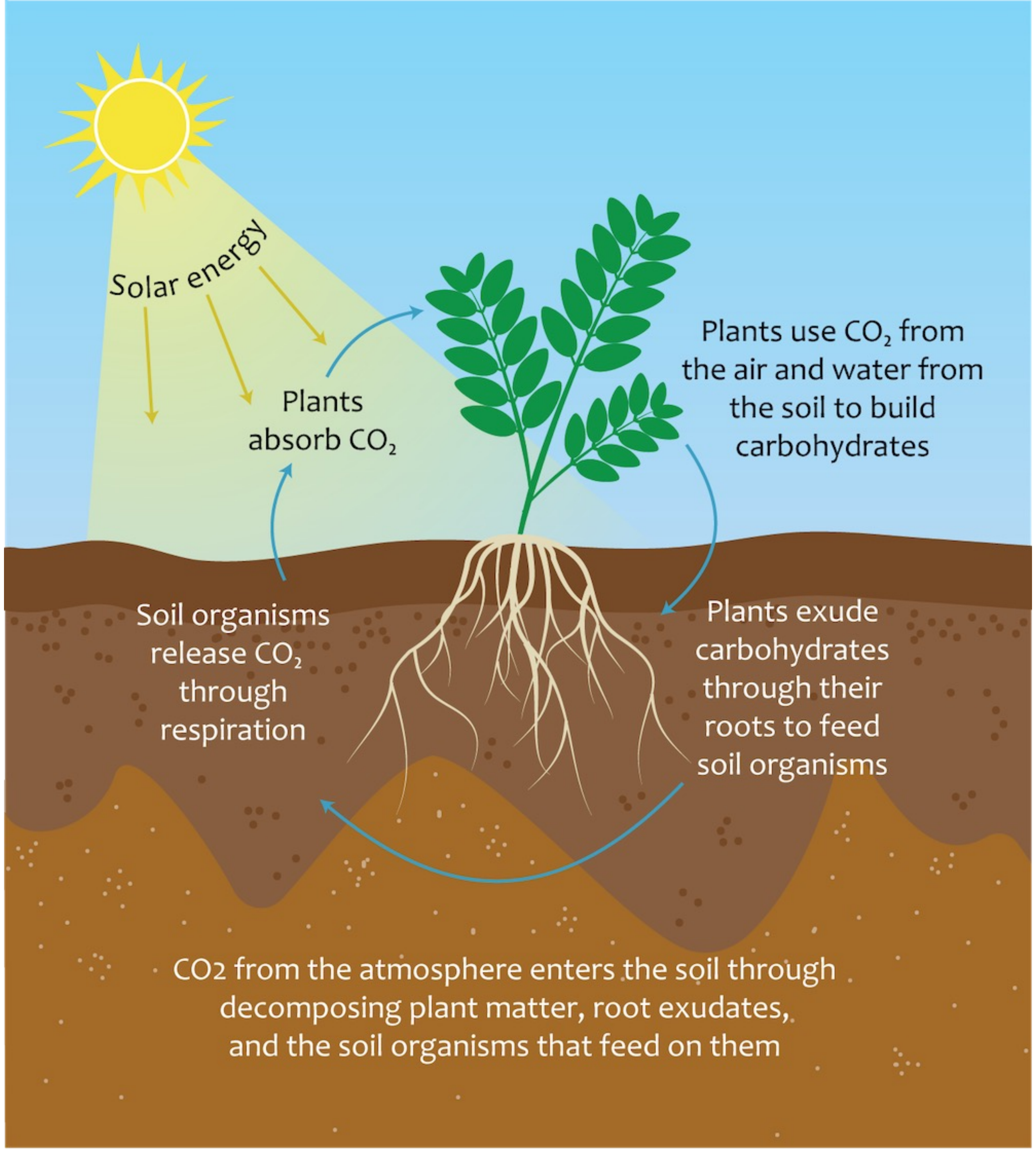
So should I add mycorrhizal inoculants to my garden?

- the commercial inoculant may not be viable (contain living spores)
- they may not be the right fungi for the plant species you are growing
- your soil may already be saturated with fungi
- manufacturers of inoculants rarely provide unbiased test results



Better to cultivate home-grown mycorrhizae in undisturbed soil given plenty of organic matter……

Carbon and Nutrient Cycles: Recap


Solar energy
Plants absorb CO_2
Plants use CO_2 from the air and water from the soil to build carbohydrates
Soil organisms release CO_2 through respiration
Plants exude carbohydrates through their roots to feed soil organisms
CO2 from the atmosphere enters the soil through decomposing plant matter, root exudates, and the soil organisms that feed on them

THANK YOU!

Why does soil pH matter?

Soil pH is a measure of the amount of acidity or alkalinity in the soil (the concentration of H^+ ions)

Soil pH is determined primarily by the type of rock that produced your soil.

Soil pH affects whether positive and negative ions are associated or free – and thus the availability of certain soil nutrients.

Blueberries and rhododendrons “prefer” acidic soil. What does this mean?

These plants and their relatives evolved in woodlands, which have slightly acidic soil. They do not have fine root hairs like most plants do.

Fine root hairs are good at absorbing N in the form of nitrate (NO_3), whereas the roots of blueberries and their relatives are better at absorbing N in the form of ammonium (NH_4). More acidic soil is a better source of ammonium ions.

Audience question: Is it true that plants grown under high CO_2 concentrations are less nutritious?

Here's what I learned:

- Yes, multiple scientific studies comparing the growth of food plants under pre-industrial CO_2 concentrations and elevated CO_2 found lower concentrations of some nutrients in the high-CO_2 plants.
- It is not yet clear what causes these lowered nutrient levels.
- Nutrient levels are not a LOT lower; this effect is likely to matter primarily in populations that are already nutritionally stressed.
- The studies used the CO_2 levels expected to occur by the end of this century, not current CO_2 levels.

Audience question: the soil that we put into raised beds often comes out of bags, and contains too much sand, a lot of organic matter, but not much clay, and no fungi, bacteria, etc . Is there a way to improve it?

Some Internet sleuthing (buyer beware) suggests adding kaolin clay to raised beds to improve the soil's ability to hold nutrients and water. This is apparently a popular solution for gardeners in Australia, which has extremely sandy soil. Worth a try? The fungi and bacteria will arrive naturally via airborne spores, though you can always mix in a little garden soil to speed up the process.