Module 2

How are soil properties affected when soil is submerged?

This is the 2nd module of training course titled:
Submerged Soils for Rice Production

An interactive version of this presentation can be viewed at this site:

http://www.knowledgebank.irri.org/submergedsoils

Intro to Module 2

While most soil is exposed to air, much of the world's population depends on a crop grown in soil submerged by a layer of water.

- Purpose: Explain what happens to soil properties when soil is submerged for rice production.

- Organization:
  - Lesson 1 & 2 - Oxygen supply in soil
  - Lessons 3–6 - Effects of submergence on the biological, chemical and physical properties of soil

Module 2

Lesson 1 – Soil oxygen supply

- Lesson 1: How does submergence affect oxygen supply in soil?
- Objective: Be able to explain what happens to oxygen in soil after submergence.

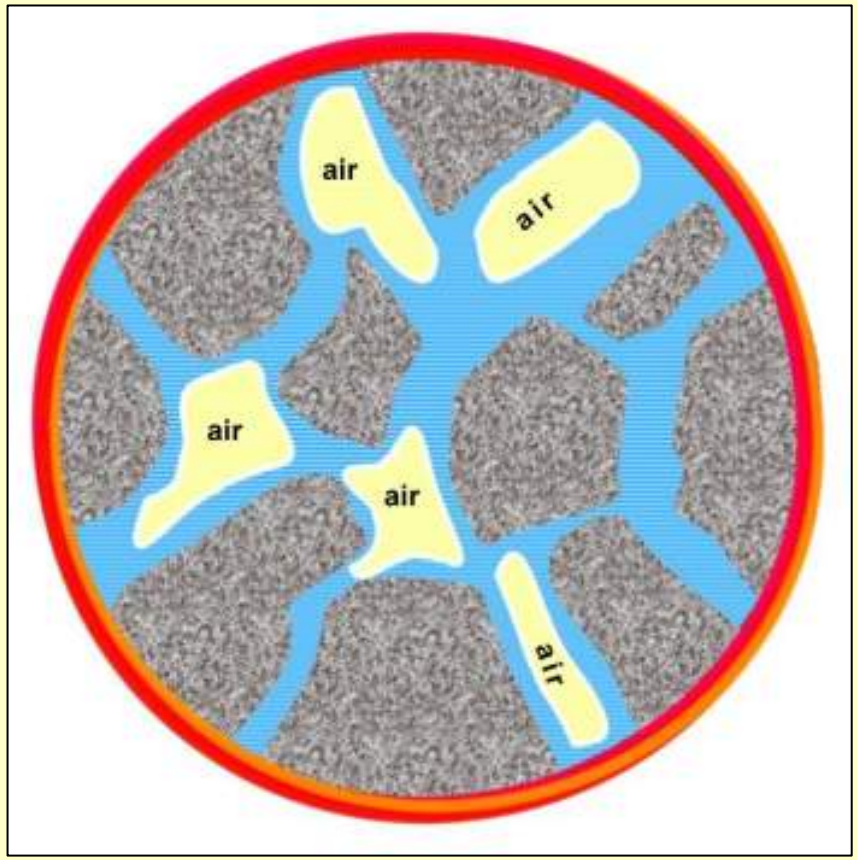
Lesson 1 – What is soil composed of?

- If you were to divide soil into its component parts, you would have:
  - a mineral component
  - organic matter
  - and pore space – composed of air and water. Air contains 21% oxygen (O_2)
- The relative proportions of these components change depending on soil type and soil water content

Module 2

Lesson 1 - Air and water in the pore space

- The proportion of air and water in the pore space changes with soil water content
- Most crops grow best when the amount of air and water in the pore space is about equal



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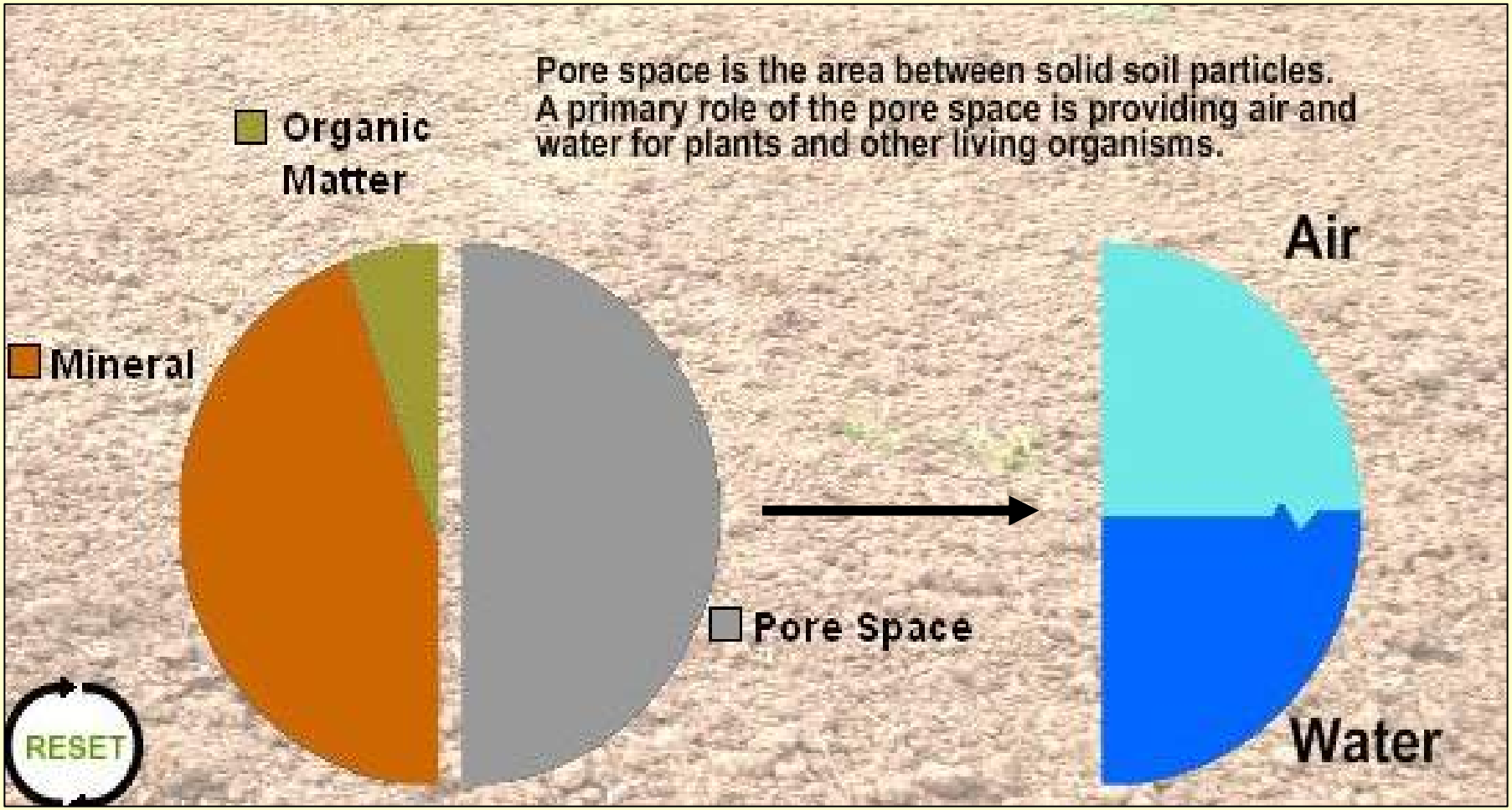
Lesson 1 - Optimum composition for most crops



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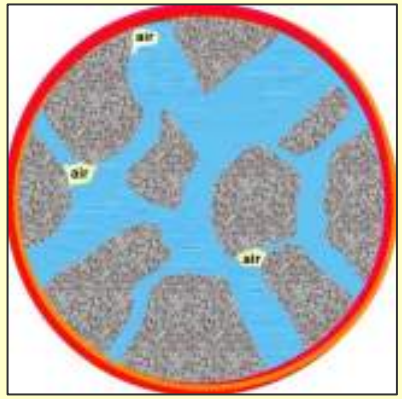
Lesson 1 – When soil is submerged

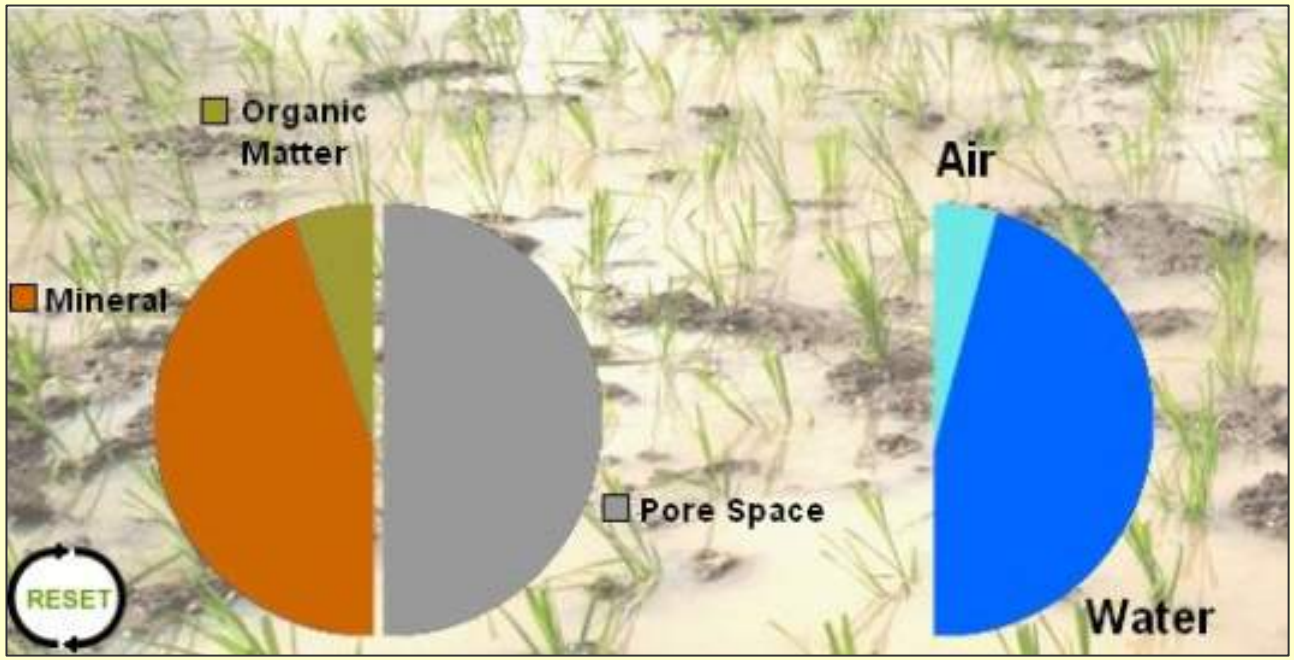
- Water quickly displaces air in the pore space
- Water creates a barrier between the submerged soil and the atmosphere
- Remaining soil O_2 is used by biological organisms
- The amount of O_2 in soil is insignificant a few hours after submergence

Module 2

Lesson 1 - Soil oxygen supply

Only a small amount of O_2 remains in submerged soil





Module 2

Lesson 1 – Summary slide

- Soil consists of a mineral component, organic matter, and pore space (air and water)
- Most crops grow best when the volume of air and water in the pore space is about equal
- When soil is submerged, water creates a barrier limiting O_2 movement into soil
- The pore space is mostly filled with water
- O_2 in soil becomes insignificant a few hours after submergence

Module 2

Lesson 2 – Aerated soil zones

- Lesson 2: Does O_2 enter soil following submergence?
- Objective: Identify zones of different O_2 content in submerged soil.

Module 2

Lesson 2 - Can oxygen penetrate into submerged soil?

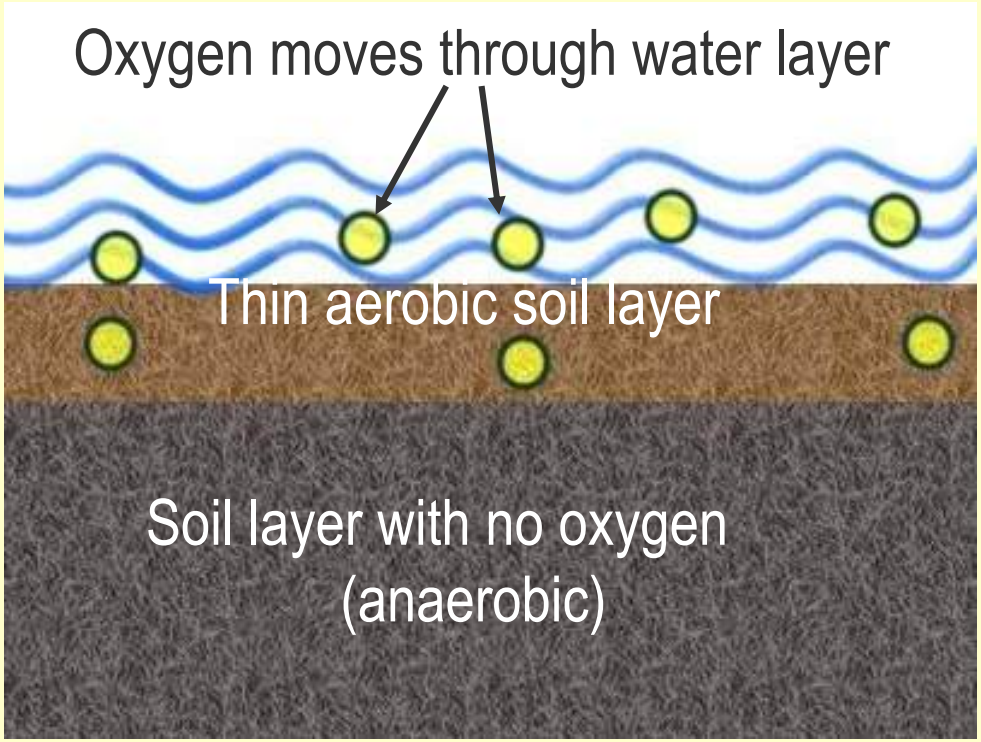
- There are two ways for O_2 to enter submerged soil
  1) O_2 moves slowly through the water layer and creates a thin surface layer of aerobic soil
  2) O_2 moves through the porous tissue of aquatic plants (like rice) into the roots and creates an aerobic zone of soil surrounding the roots

The next 2 slides explain these processes.

Module 2

Lesson 2 - Oxygen moves through the water layer

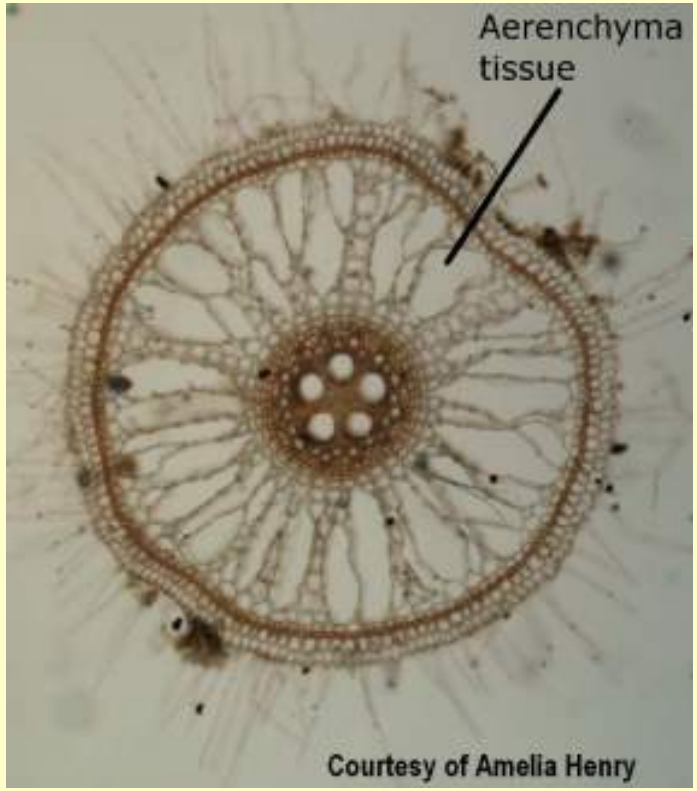
1. O_2 from the atmosphere dissolves in the water
2. Dissolved O_2 moves through the water layer by diffusion.
3. As O_2 reaches the soil surface, it is used by soil compounds and microorganisms
4. A thin layer of soil (often about 1 mm thick) develops with aerobic properties



Module 2

Lesson 2 - Oxygen moves through porous tissue of aquatic plants

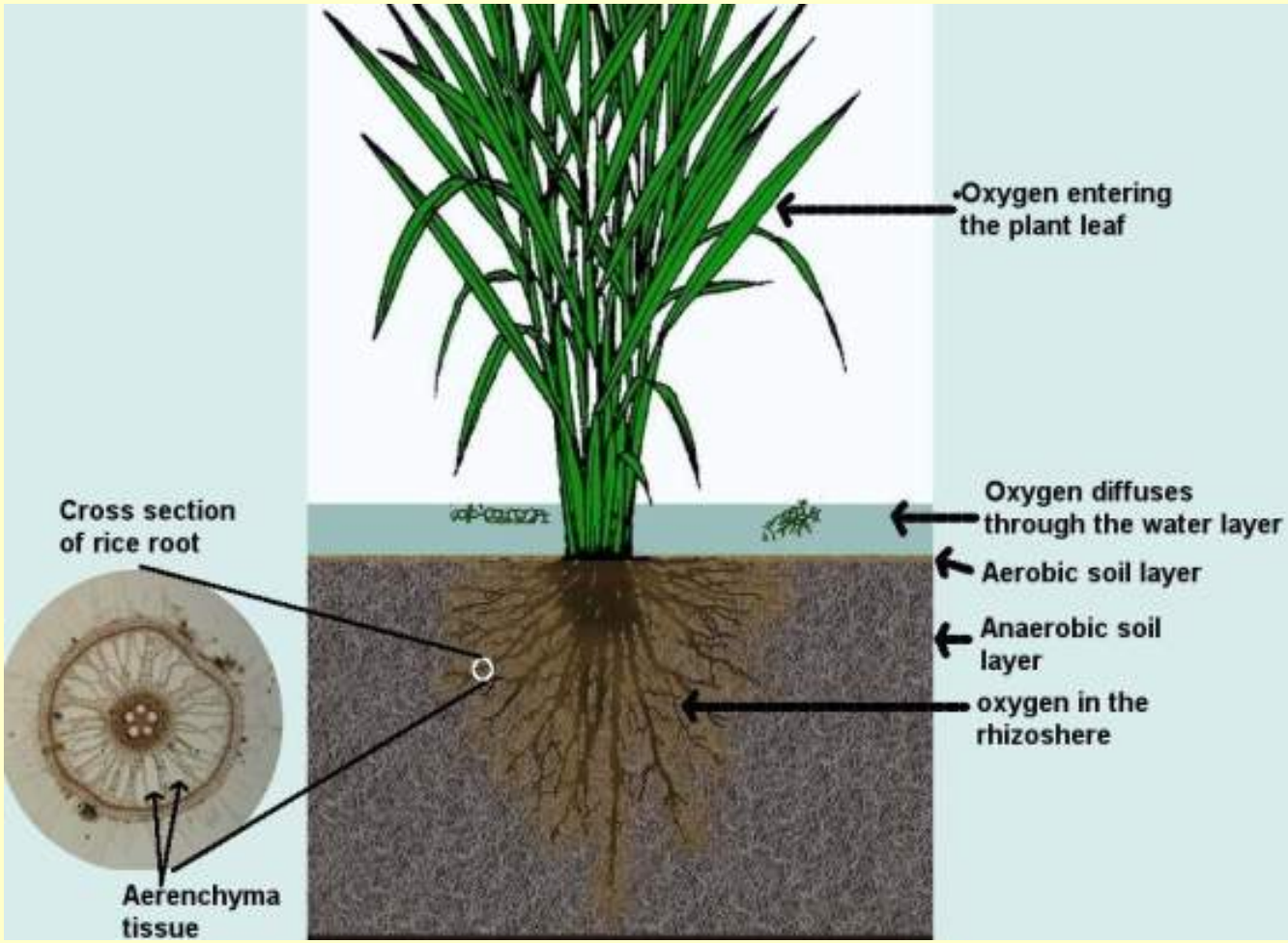
1. O_2 enters a rice plant through pores in the leaves and stem
2. It moves through the stem and roots of the plant in a porous structure called aerenchyma.
3. O_2 not used by the plant may pass from the roots into surrounding soil called rhizosphere.



Root cross section showing aerenchyma. Rice plants use aerenchyma to transport O_2.

Module 2

Lesson 2 – Oxygen movement into submerged soil



Module 2

Lesson 2 – Summary slide

- After submergence, O_2 enters soil in 2 ways:
  - It moves slowly through the water layer by diffusion
  - It moves through the stem and roots of water-adapted plants like rice via aerenchyma tissue.
- Zones of submerged soil that can contain O_2
  - A thin layer of soil at the water surface
  - A zone called rhizosphere, which surrounds plant roots

Module 2

Lesson 3 – Submergence and biology

- Lesson 3: How does submergence change soil biology?

- Objective: Describe the biological changes caused by submergence.

Module 2

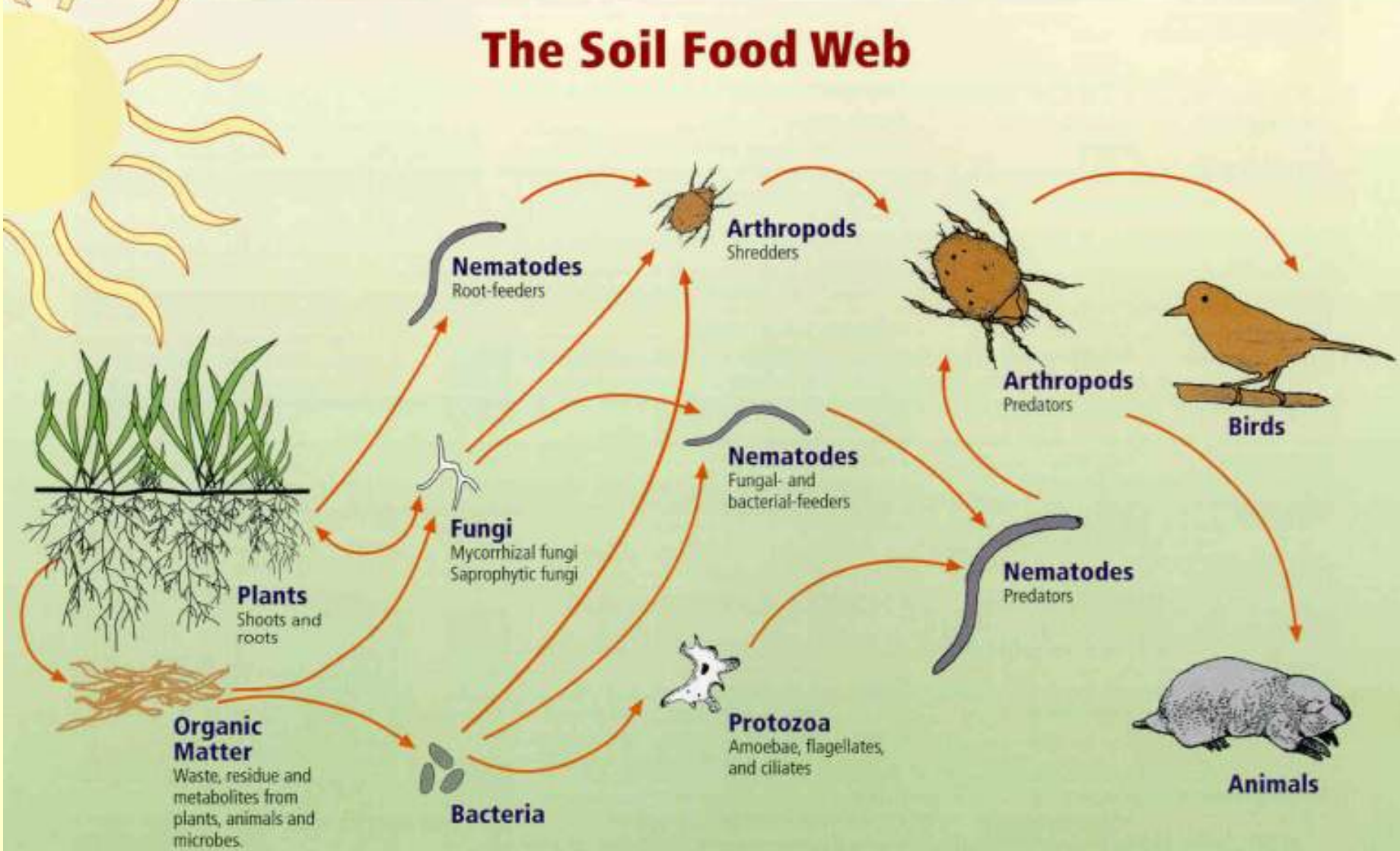
Lesson 3 - Soil biology

- Aerated soil contains a tremendous diversity and quantity of organisms and microorganisms
- These play an important role in the process of decomposition
- The slide on the next page introduces some of the biological diversity found in aerated soil

For pictures and an overview of soil organisms living mostly in an aerobic environment, check this site:

http://soils.usda.gov/sqi/concepts/soil_biology/soil_food_web.html

The Soil Food Web



First trophic level:
Photosynthesizers

Second trophic level:
Decomposers
Mutualists
Pathogens, parasites
Root-feeders

Third trophic level:
Shredders
Predators
Grazers

Fourth trophic level:
Higher level predators

Fifth and higher trophic levels:
Higher level predators

Image courtesy of the USDA-NRCS

Module 2

Lesson 3 - How does submergence change soil biology?

After submergence, soil O_2 is depleted. This starts a biological transition:

- Aerobic organisms die or become dormant
- They are replaced by microorganisms surviving without O_2
  - facultative anaerobes can live with or without O_2
  - obligate anaerobes only live where no O_2 is present
- The predominant anaerobic organisms in submerged soil are bacteria
- Some aerobic organisms continue living in the aerobic zones of submerged soil

Module 2

Lesson 3 – Summary slide

- Aerated soil contains a large diversity of organisms and microorganisms – many of these contribute to decomposition
- When soil is submerged, aerobic organisms are replaced by facultative or obligate anaerobes that can live without O_2
- Anaerobic bacteria are the main microorganisms in submerged soil and they contribute most to decomposition in submerged soil
- Some aerobic organisms continue living in aerobic zones of submerged soil

Module 2

Lesson 4 – Submergence and chemistry

- Lesson 4: How is soil chemistry effected by submergence?

- Objective: Identify chemical changes taking place after soil is submerged.

Module 2

Lesson 4 - Surviving without oxygen

- Organisms get energy by respiration
- Respiration is the process where energy is created as carbon compounds are broken down
- Respiration involves oxidation of carbon compounds and the reduction of:
  - O_2 in aerobic soil
  - chemical compounds other than O_2 in anaerobic soil

The next 3 slides provide an explanation of oxidation and reduction.

Module 2

Lesson 4 - What is oxidation and reduction?

- Oxidation and reduction are chemical reactions involving the exchange of electrons from one compound to another
- Oxidation and reduction always happen together - when one compound loses an electron, another compound gains it
  - Oxidation happens when electrons are lost
  - Reduction happens when electrons are gained

Module 2

Lesson 4 - Oxidation and Reduction in an Aerobic Setting

$$4\ e^- + O_2 + 4\ H^+ \rightarrow 2\ H_2O$$

The equation above is an example of an oxidation/reduction reaction taking place in aerobic soil.

- Organic matter in soil gives up 4 electrons (e^-) which are received by O_2. As a result, O_2 is reduced.
- Hydrogen ions (H^+) react with the reduced O_2 to form water (H_2O).

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Module 2

Lesson 4 - Oxidation and Reduction in an Anaerobic Setting

$$10\ e^- + 2\ NO_3^- + 12\ H^+ \rightarrow 1\ N_2 + 6\ H_2O$$

The above equation shows an oxidation/reduction reaction in anaerobic soil.

- Electrons (e-) from organic matter in soil are accepted by nitrate (NO_3^-) instead of O_2.
- Nitrogen (N) in NO_3^- is reduced; the N compound becomes nitrogen gas (N_2)
- Hydrogen ions (H^+) react with oxygen from NO_3^- to produce H_2O.

Module 2

Lesson 4 – Summary slide

- Organisms get energy for life through respiration
- Respiration involves an exchange of electrons.
  - One compound gains electrons (reduction)
  - Another compound loses electrons (oxidation)
- Carbon compounds consumed by organisms are oxidized and the electrons are gained by
  - O_2 in aerobic soil
  - Chemical compounds like nitrate or sulfate in anaerobic soil

Lesson 4 – Question to consider

Respiration in anaerobic soil produces less energy than aerobic respiration.

- Learn more about this by studying the difference between aerobic and anaerobic respiration.

- How might this affect decomposition in submerged soil?

Module 2

Lesson 5 – Chemical effects of submergence

- Lesson 5: How is soil chemistry affected by submergence?

- Objective: Identify chemical changes taking place after soil is submerged.

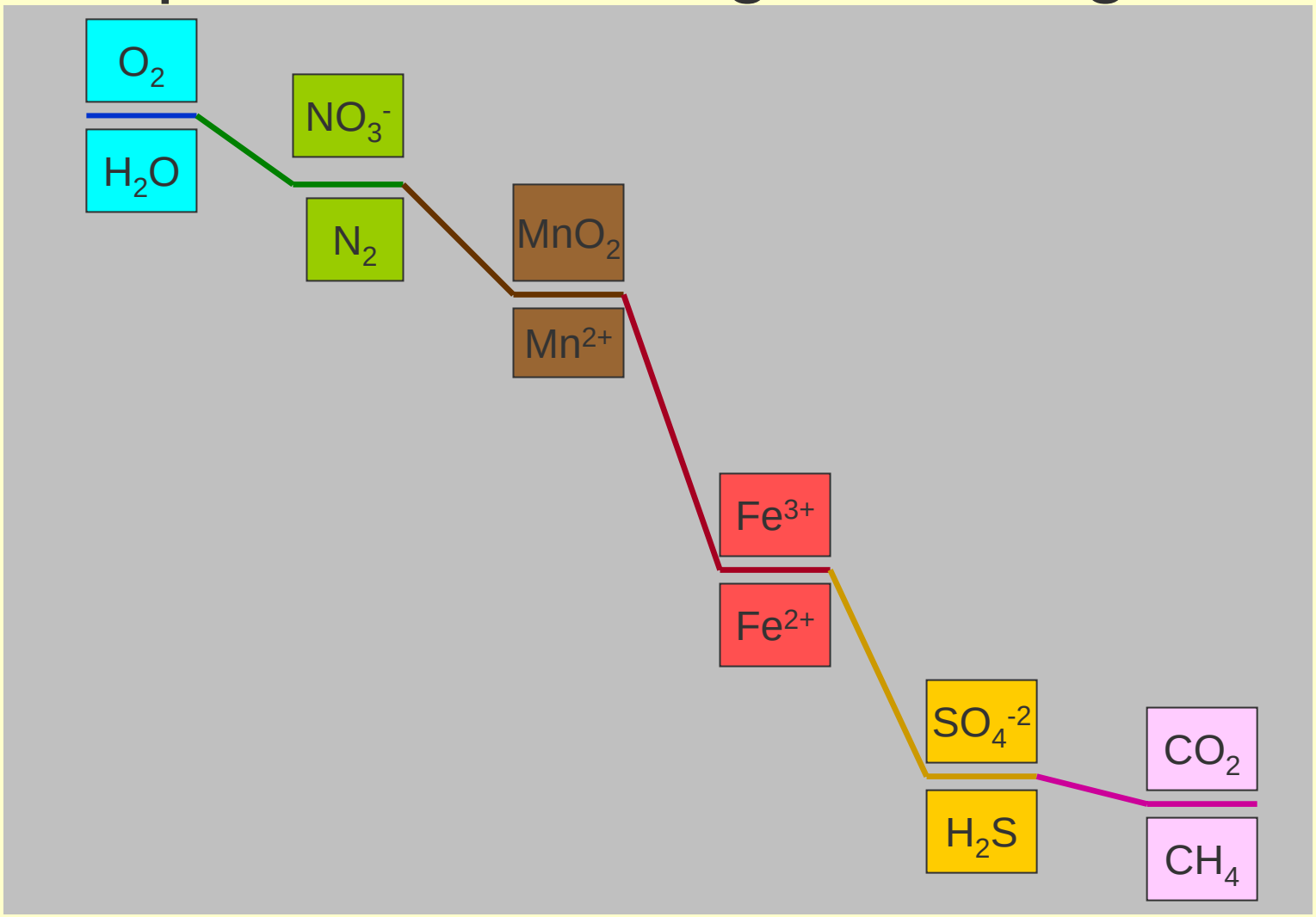
Module 2

Lesson 5 - A change in soil chemistry

- A review of the soil biological transition:
  - Lack of O_2 in submerged soil causes a shift from aerobic to anaerobic organisms
  - Respiration of anaerobic organisms causes chemical compounds other than O_2 to be reduced.
- Chemical compounds in soil are reduced in a predictable sequence.
  - The compound requiring the least energy for reduction is reduced first (i.e. nitrate)
  - After the first compound is nearly all reduced, the compound requiring the next lower energy for reduction is reduced

Module 2

Lesson 5 - Chemical Reduction Sequence Following Submergence



Module 2

Lesson 5 - Form of compounds in aerated versus submerged soil

Element	Aerated soil (Oxidized)	Submerged soil (Reduced)
Oxygen (O)	Oxygen gas (O_2)	Water (H_2O)
Nitrogen (N)	Nitrate ion (NO_3^-)	Nitrogen gas (N_2)
Manganese (Mn)	Manganese IV ion (Mn^{4+})	Manganese II ion (Mn^{2+})
Iron (Fe)	Iron III ion (Fe^{3+})	Iron II ion (Fe^{2+})
Sulfur (S)	Sulfate ion (SO_4^{2-})	Hydrogen sulfide (H_2S)
Carbon (C)	Carbon dioxide (CO_2)	Methane (CH_4)

The left column has 6 elements common in soil. The middle column shows the typical form of the element when it is in aerobic soil. The right column shows the element's typical form in submerged soil.

Module 2

Lesson 5 - Chemistry and color

- A change in chemistry results in a change of soil color
  - bright colors indicate a well-drained soil
  - submerged soils change to a gray or blue-green color (often referred to as gley)

- Why is this?
  - Reddish-yellowish brown colors are an indication of iron oxides in a well-drained environment
  - Submergence causes iron to be reduced resulting in a different iron form and the gley color

Well-drained soil profile

Poorly drained soil profile

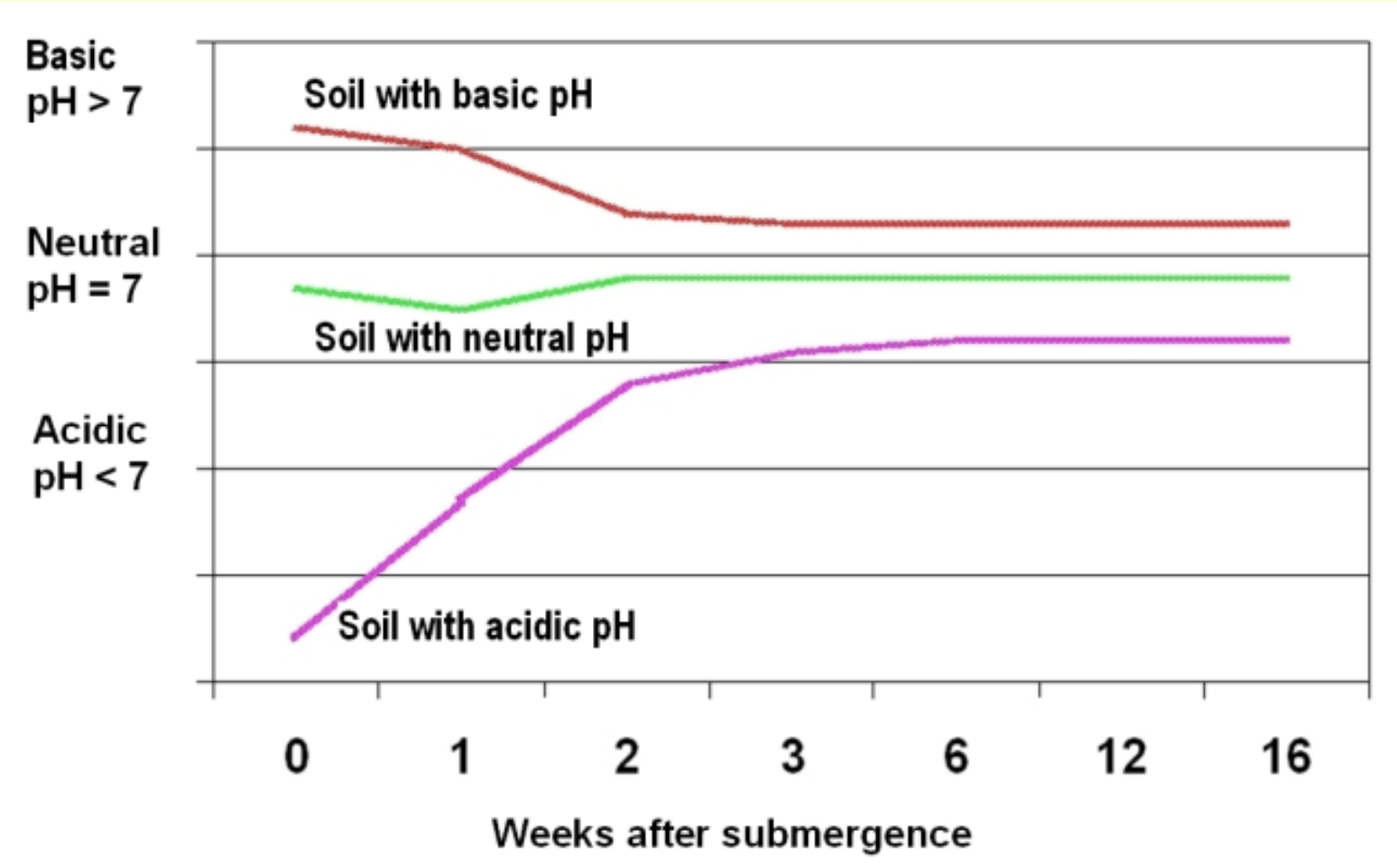
Module 2

Lesson 5 - Submergence affects soil pH

- Soil pH is a measurement of hydrogen ions in the soil and it indicates whether soil is acidic or basic.
- Submergence of soil typically causes a shift towards a more neutral soil pH. This is a result of the change in chemical compounds when soil is reduced
- The graph on the next slide illustrates the typical change in pH after submergence

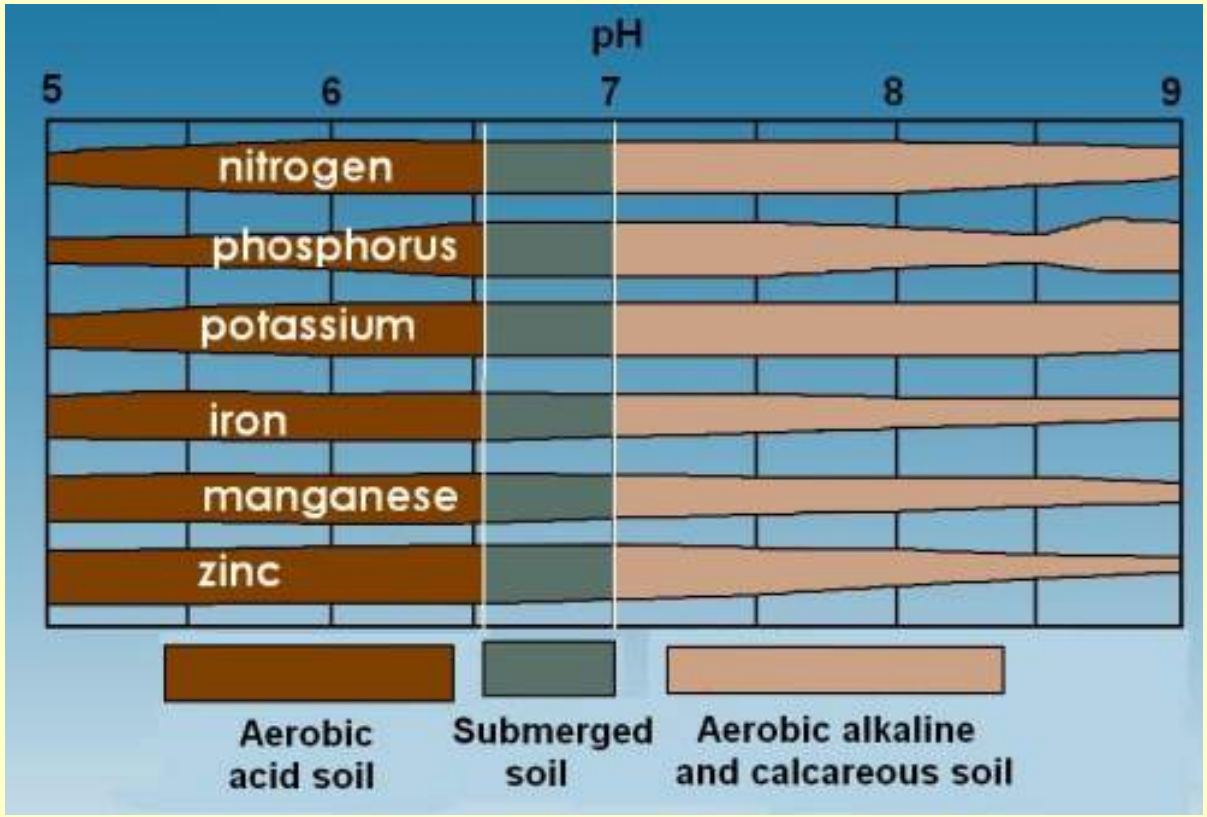
Module 2

Lesson 5 - Effect on soil pH when acid, neutral, and basic soils are submerged



Module 2

Lesson 5 - Availability of nutrients at different pH levels



The typical pH range for many submerged soils is 6.5-7. The 6 important crop nutrients in this chart are collectively more available at 6.5-7 compared to more acidic or basic pH values.

The width of each horizontal bar represents the plant availability of the identified nutrient within the pH range of 5-9.

Module 2

Lesson 5 – Summary slide

- In submerged soil, chemical compounds are reduced during respiration of anaerobic microorganisms
- Compounds are reduced in order based on the amount of energy needed – nitrate is first because the least energy is required
- This reduction process causes a shift in the chemical compounds found in submerged soil
- This change in chemical compounds results in other changes such as soil color, soil pH, and availability of nutrients for plants

Module 2

Lesson 6 – Physical effects of submergence

- Lesson 6: What are the physical effects of submergence?

- Objective: Be able to describe some of the physical changes happening with submergence.

Module 2

Lesson 6 – Puddling soil

What is puddling?

- mixing of saturated soil to create a watertight layer

When is puddling performed?

- it is a standard land preparation activity for rice produced in a flooded field

Why is it done?

- to reduce the downward flow of water (so less water is needed to keep the paddy submerged)

How is it done?

- by a draft animal or tractor pulling an implement like a plow or harrow to mix soil while it is flooded

Module 2

Lesson 6 - Availability of water

- Rice is a semi-aquatic plant
- It is sensitive to water shortage, especially during the flowering period
- Submerging the field helps avoid water stress during periods of critical water need

Lesson 6 - Moderation of soil temperature

- In some rice production areas, modification of soil temperature is an important benefit
- Soil and water respond differently to changes in air temperature
- Submerging the soil:
  - keeps soils cooler where high temperature injury may be a problem
  - helps reduce low temperature injury at night in cooler climates

Module 2

Lesson 6 - Submergence and weed competition

- Submerging soil helps reduce germination of many weed species
- This is an important agronomic and economic benefit for rice farmers

The weed germination experiment at left has containers seeded with Echinochloa colona, a common rice weed. Containers were placed at progressively lower levels (L to R) in a water-filled tank to investigate how submergence depth effects germination.

Lesson 6 – Summary slide

- Puddling is a standard field practice for submerged rice fields. One reason it is used is to slow the downward flow of water in soil and thus reduce water use.

The following physical benefits result from submerging soil for rice production:

- It helps reduce water stress during critical growth stages
- It can help to minimize plant injury from extreme temperatures
- It is an effective way to manage some weed species

Conclusion of Module 2

- After soil is submerged, there are changes in the following soil properties:
  - Soil oxygen supply
  - Soil biology
  - Chemical properties
  - Physical characteristics
- Identify one or two changes taking place, following soil submergence, in each of the properties listed above

Module 2

Review Questions for Module 2

1) Match the compound on the left with the environment it is most likely to be found in:

Methane (CH_4^+)	Aerobic Soil
Oxygen (O_2)	
Nitrate (NO_3^-)	Anaerobic Soil
Hydrogen Sulfide (H_2S)	

2) Which microorganism is most responsible for decomposition after soil is submerged?
   a. protozoa
   b. fungi
   c. bacteria
   d. nematodes

Module 2

Review Questions for Module 2

3) Which of the following is NOT an advantage of submerging soil for rice production?

a) helps reduce cold temperature injury in cool climates

b) extra water is needed to puddle the rice paddy before establishing the seedlings

c) ensures that water is available to the rice plant at critical growth stages

d) germination rate of some weed species is reduced

4) Identify which compound will be reduced first after soil is submerged? Can you explain why this is true?

a) Fe^{3+}

b) NO_3^-

Module 2

Review Questions for Module 2

5) Which of the following is a component of soil?
   a. Minerals
   b. Pore space
   c. Organic matter
   d. All of the above

6) True or False
   After soil is submerged and the O_2 is used up, O_2 will no longer enter soil until the soil is drained.

Answers to Review Questions

1) Aerobic Soil - Oxygen and Nitrate

   Anaerobic Soil - Methane and Hydrogen Sulfide (Lesson 5)

2) c) bacteria (Lesson 3)

3) b) extra water is needed for puddling (Lesson 6)

Answers to Review Questions

4) b) NO_3^- will be reduced first because less energy is required for its reduction compared to Fe^{3+} (Lesson 4)

5) d) All of the above (Lesson 1)

6) False - Oxygen can penetrate soil in two ways:
- It diffuses through the water layer until it reaches the soil surface where it creates a thin aerobic soil layer.
- It enters through the leaves of the rice plant and travels down to the roots of the plant via aerenchyma tissue. Some oxygen passes out of the roots and into the surrounding soil called the rhizosphere. (Lesson 2)