Introduction to Soil Science

Amber Anderson

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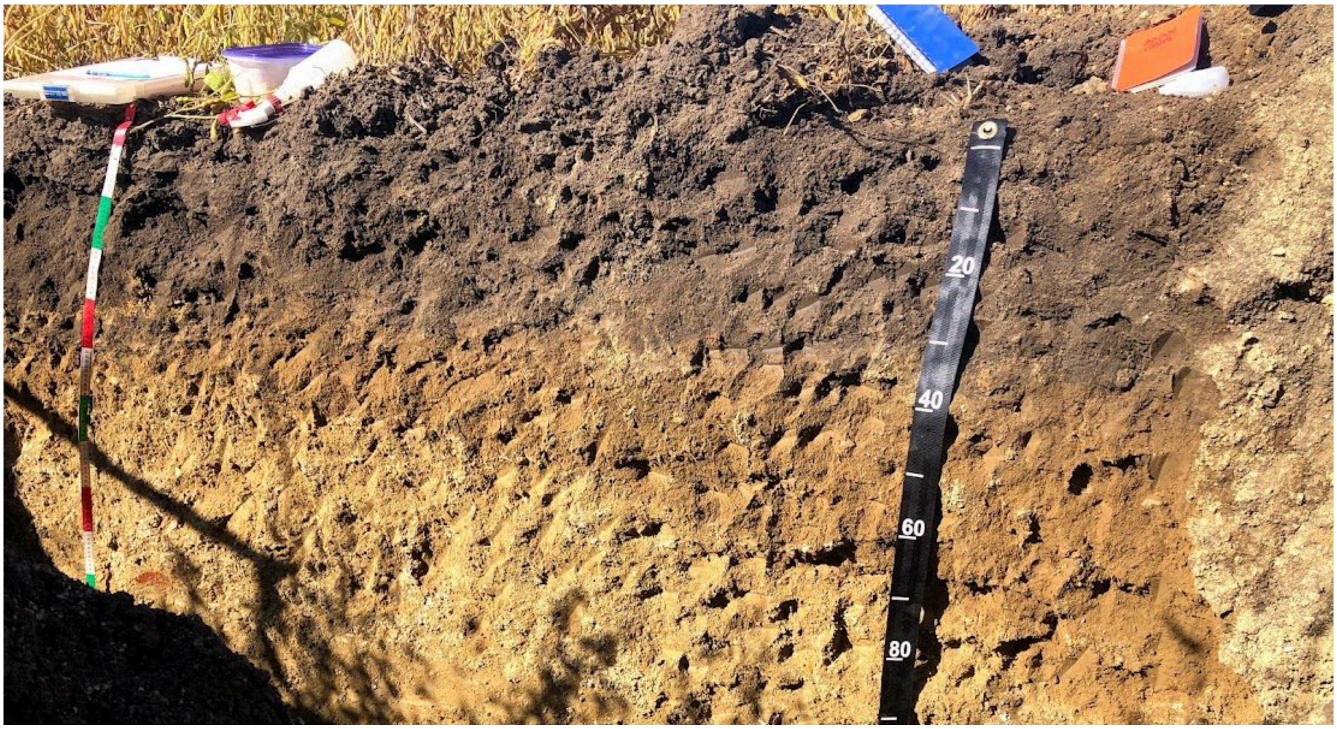

Welcome soils students!

My name is Amber Anderson, I'm an associate teaching professor at Iowa State University in the Agronomy Department as well as coach of ISU's soil judging team. I look forward to sharing my knowledge of soils and interacting with those of you both at Iowa State University and beyond. To those outside of Iowa State-hope you have a great soils learning experience, and feel free to contact me!

I would like to acknowledge the contributions, review, and support of Abbey Elder, Dr. Lee Burras, Dr. Rivka Fidel (University of Arizona), Dr. Cole Dutter, Dr. Bradley Miller, Heidi Ackerman, Dr. Ala Khaleel, Arturo Flores-Godoy, Adam Subora, Francis Akitwine, Becky Wokibula, Hallie Sandeen, Casey Luke, and many others at Iowa State University Department of Agronomy. Thank you to external reviewer Sam Indorante and other instructors who have sent helpful comments. Cover illustration by Audrey Jenkins.

Amber in her preferred habitat. Photo Credit: Lee Burras.

GETTING STARTED

Introduction: Function of soils

AMBER ANDERSON

Learning Objectives

- Define soil and soil science
- Discuss soil functions
- Summarize the importance of soil

Keywords: ecosystem services, soil science, soil functions

We may take what lies below our feet for granted, but soils are critical to our everyday life. From the food we eat, buildings we take refuge within, products we use, even to antibiotics we rely on, soils supply far more than we initially imagine.

What is soil?

Several definitions exist. We will start with the pair below:

"**The unconsolidated mineral or organic matter on the surface of the Earth** that has been subjected to and shows effects of genetic and environmental factors of: climate (including water and temperature effects), and macro- and microorganisms, conditioned by relief, acting on parent material over a period of time. A product-soil differs from the material from which it is derived in many physical, chemical, biological, and morphological properties and characteristics."

— Soil Science Society of America[1]

"Soil is **a natural body comprised of solids** (**minerals and organic matter**)**, liquid, and gases that occurs on the land surface**, occupies space, and is characterized by one or both of the following: horizons, or layers, that are distinguishable from the initial material as a result of additions, losses, transfers, and transformations of energy and matter or the ability to support rooted plants in a natural environment."

— Soil Taxonomy, second edition [2]

Overall, we see the important components, a medium that supports a variety of functions on which plants and

1. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/edu/?cid=nrcs142p2_054280
2. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/edu/?cid=nrcs142p2_054280

animals rely. These diverse functions can be grouped into a few major categories according to the Soil Science Society of America: products, resources, culture, and environment.[3]

Products

Straightforward uses like the majority of food production, building materials like clay to make bricks, and unexpected items like many of the antibiotics that we rely on are all derived from the soil. In the case of plant growth, soil provides the physical structure, many nutrients, water, and insulation from changing temperatures that allow for plants to grow and produce.

Clay being harvested near Kamuli, Uganda, is being made into bricks in this oven on site. Photo credit: Amber Anderson.

Resources

Holding water and carbon are also critical functions of soil. Consider a situation where the soil did not hold water for plant growth. Management and production of crops would suddenly be far more complicated. Carbon is also important within the soil and will be covered in a later chapter of this book.

Culture

While it might not be obvious, soils are also important for cultural aspects such as recreation. Central campus with its open space for enjoying nice weather, the intramural fields that host a variety of activities, or Reiman Gardens displaying a diversity of plants, flowers and artistic displays, all rely on soil properties and functions to exist.

Environment

Additional benefits of soil come from the soil's ability to filter water, hold water to avoid flooding, recycle waste, and other ecological services. A variety of interactions will be covered over the course of this semester.

Soil science, or **pedology**, is the study of this amazing resource.

I'm looking forward to sharing with you this semester, and looking forward to you sharing your observations as well!

3. https://www.soils.org/files/science-policy/issues/reports/sssa-soils-eco-serv.pdf

Check it out!

Soils don't all function the same, even for a similar use, or in a similar area:

Soil Your Undies Challenge: Assessing your soil health[4]

Marion county, Iowa comparison[5]

Key Takeaways

- Soils are critical in a variety of different ways
- General functions can fall into production, resource, cultural, and environmental categories
- Wooo! Soil! Get excited to learn more about soil this semester!

4. https://www.nrcs.usda.gov/conservation-basics/conservation-by-state/oregon/soil-your-undies-challenge
5. https://www.marioncountyiowa.gov/files/conservation/soil_your_undies_for_soil_health_70282.pdf

SOIL DEVELOPMENT AND CLASSIFICATION

Parent materials

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Learning Objectives

- Match depositional forces and the resulting material/properties
- Predict properties of an area based upon parent materials
- Identify potential management challenges based upon a given parent material

Keywords: Parent material, glacial till, outwash, alluvium, lacustrine, marine, colluvium, loess, aeolian sand, residuum

Parent material

A **parent material** is the substance in which a soil develops. The properties of the original substance will significantly influence the resulting soil profile and properties.

Transporting forces

Several different forces transport materials to the places we find them today. Sometimes, multiple forces combined to deposit the material, such as ice or gravity plus water. Other times, one force deposited a new material on top of an existing, like loess over glacial till, or alluvium over other material. High-energy transporters, like ice, don't sort the particles as low-energy transporters, like water and wind. Therefore, low-energy transported materials tend to be well-sorted, whereas high-energy transported materials tend to be unsorted.

Ice

During past ice ages, parts of the central US were covered in thick sheets of ice. The massive weight and power of these sheets ground down bedrock in Canada, transporting both small particles and huge boulders. This history of material deposition, along with the following prairie vegetation, have given Iowa the fertile soils present today.

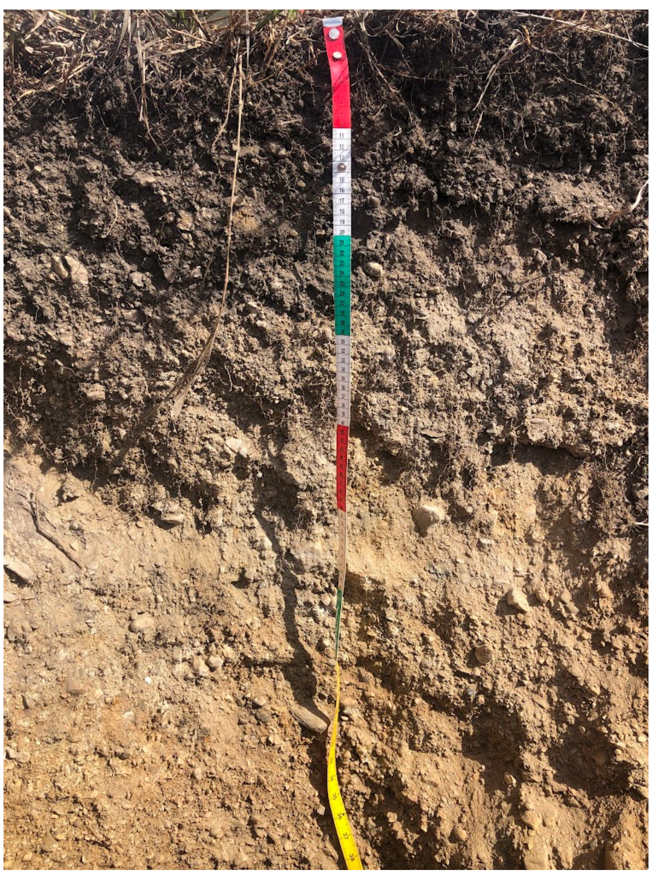
Glacial Till

This material was both carried and deposited by ice. Glaciers covered much of the northern part of the United States, and down into the Northeast corner of Kansas and northern part of Missouri in the central US. Since the ice crossed a variety of bedrock on its trip, these materials usually contain loamy textures (indicating mixed sand, silt, and clay), as well as assorted shapes, colors, and sizes of rocks. Management concerns could be related to the rock fragments found in the material.

This glacial-till derived slope has exposed rocks on a rolling landscape in NW Iowa. Photo credit Amber Anderson. Click to enlarge

Glacial Outwash

This material was carried by ice but sorted by water as it was rushing out of the glacier. Small particles that could stay suspended in water, like silts and clays, were washed away. Larger particles, like sands and gravels, were sorted and deposited at the edge of the current glacier. Management concerns may include low water or nutrient holding capacity. Deposits of outwash can be found across the same region as glacial till, but in pockets or slopes across rather than across a widespread area.



Outwash profile in Northwest Iowa

Close up of outwash profile, Northwest Iowa. Photo credits: Amber Anderson.

Water

Water is considered a low-energy transporter, leading to sorted materials. These could be coarse or fine. These might have alternating layers if periods of high and low flow normally occur.

The alternating horizon color shows that water was a transporting force in this soil. Photo Credits Amber Anderson. Click to enlarge.

Alluvium

Alluvium deposits are formed from running water, as might be found next to a river. Since the size of the material potentially transported is highly dependent on the speed or energy of the water, these are well sorted materials. They can also change in short distances both vertically or horizontally, as rivers may move or carry different amounts of water over time. Alluvial deposits can be found near streams or sometimes upland drainageways, generally on the flat part of the landscape or steps above the stream or channel. Management concerns could include active flooding or may differ in short distances across the field.

This soil, found on the Kansas river flood plain, shows significant recent deposits burying the prior surface.
These materials are relatively unchanged since deposition. Photo Credit: Amber Anderson

Stony alluvium in Costa Rica indicates very fast-moving water when these were deposited. Photo credit: Amber Anderson.

Lacustrine

Lacustrine materials were deposited in lake environments. Since these were former lake beds, they tend to occur on lower parts of the landscape and be relatively flat. Rivers flowing into lakes may be carrying significant sediment, but larger materials are dropped as soon as the water enters the lake and slows. Therefore, lacustrine deposits are generally composed of smaller particles, such as silts and clays. As water flowing into the lake has periods of higher and lower flow, small alternating layers can frequently be found in the C horizon of these deposits as can be seen in the photo. Management concerns are likely related to the fine textures and low/wet part of the landscape.

Pictured is an example of lacustrine parent materials. Photo Credit: Amber Anderson. Click to enlarge

Marine

This marine-derived soil profile was found in Arkansas. Photo credit: Amber Anderson. Click to enlarge

These deposits are found along former coastal areas, not necessarily where coasts exist today. Fertility may be a concern since materials remaining after water movement may be high in resistant minerals like quartz, which is low in weatherable plant nutrients.

Gravity

Colluvium

Colluvium is highly variable, as it depends what was uphill at the time of deposition. These are most commonly found on current or former footslopes, where material slowed down due to the decrease in slope. Management concerns may be stability of the landscape or vary based upon the uphill material's properties.

Recent colluvium in Ames, IA, due to destabilization of the soil surface above this location. Photo credit Amber Anderson.

Wind

Wind has shaped this landscape next to the Platte River, near Grand Rapids, NE. Photo credit: Amber Anderson

Loess

Loess is wind-blown silt materials. Western Iowa is known as one of the deepest accumulations of this material, in the Loess Hills. These deposits are generally both fertile and highly erodible, leading to need for careful management. As one moves away from the source, the depth thins and the texture becomes finer. Across the state of Iowa, this means a shift from over 100 feet to just a few feet, while the texture shifts from silt loams to silty clay loam textures. The material may appear slightly yellow, as seen in the photo.

Loess showing irregular erosion pattern as water moves through a surface small feature, like animal burrow, and removes additional material. Locally, near Maywood, Nebraska, these were called 'jugs' and were indicated to get 'large enough to swallow a side by side or horse'. Photo credit: Amber Anderson.

Thick loess exposure found in western Iowa south of Sioux City. Photo credit: Amber Anderson

Aeolian Sand

Aeolian sand can be found downwind of a source, such as near a sediment heavy river, especially during periods of low water flow when the sediments would be exposed. These are generally found closer to the source, and are fine sands rather than larger or mixed sands, due to the weight of the sands-coarse sands being too heavy to transport in the wind column.

Aeolian sand bedding layers, found in Nebraska. Photo credit: Amber Anderson.

Aeolian deposits rising above the flatter floodplain of the Platte River near Grand Rapids, NE. Photo credit: Amber Anderson

Residuum

Soils with a parent material of residuum form into bedrock that was brought to the surface. In some cases, that may be at significant depths as in highly weathered tropical conditions found in the picture (left). In conditions where less weathering has occurred, it may be found at shallow depths. Properties are based upon the original parent material properties, like sandstone resulting in a soil with low water and nutrient holding capacity, but high aeration.

This profile in Southern Ghana is due to weathering of bedrock, in spite of no bedrock physically being present within visible depth. Photo credit: Andrew Manu.

This shallow profile in Northern Kansas was not able to be dug more than 2 feet thick due to the solid bedrock underneath. The upper part of the profile was derived from the underlying sedimentary bedrock. Photo Credit: Amber Anderson.

Organic accumulation

Occasionally noted in soil descriptions, some surface materials are due to organic accumulation. This may occur when anaerobic conditions have prevented decomposition at a rate equal to plant production. If drained, as in the picture on the right, decomposition can occur and **subsidence** may be a significant concern.

Found in a lacustrine area in NE Minnesota, the upper portion of this profile is organic accumulation due to previous lack of decomposition. In some cases, this can be tens of feet thick, and be the primary material into which a soil can develop. This area was drained for peat harvest. Photo credit: Amber Anderson. Click to enlarge

Key Takeaways

- Soil materials can be deposited by a variety of forces under different conditions
- Depositional differences (high energy, low energy) influence the resulting soil properties
- Parent material properties can significantly influence management concerns

Soil development

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Learning Objectives

- Identify soil forming factors
- Relate factors to increased or decreased rate of soil development
- Predict how soil profiles change over time or space

Keywords: weathering, soil forming factors, material, topography, organisms, climate, time

Soil Development

Soil develop, or weathering, is the amount of change that has occurred since the material was originally deposited. In order to get change, energy is put in, materials are added or taken away. Rainfall moving through the soil may carry away calcium; plant growth may add organic material to the soil; biological as well as physical interactions change the soil structure; clays may accumulate or break down.

Factors

A variety of factors influence the amount of change that has occurred since deposition. Generally referred to as soil forming factors, the following five aspects of a soil's history significantly influence what it looks like today.

Watch this overview video at: https://iowastate.instructuremedia.com/embed/71f7214c-ffb0-4f58-abfd-65dc4e604911

Material

The type of material makes a significant difference in the rate of development. One example is a loose material, like glacial till, compared to a shale bedrock. As the material receives rainfall, water can move into the loose material, whereas the shale will take first breaking up the material before it can start the same process. Water can move most easily through (and therefore change) sands most easily, then other loose materials, then a loosely cemented material (like sedimentary sandstone), and very hard materials (like slate) will be slowest to change, given identical other factors.

Topography

While material may be consistent across an area, the same hillslope will not develop or change at the same rate. Stable upper parts of the landscape will have water moving through them, changing the profile (moving or transforming clays, carbonates, etc), and the organic-rich surface or residues are likely to stay in place. In the steeper slopes, water may run off or erosion may remove the top layer of soil. Additionally, low parts of the landscape may receive deposits from above (erosion) or below (flooding) and then need to start developing or changing those materials. Therefore, holding other factors equal, we see the most development on the stable upper portion of the landscape.

Organisms (including humans)

Organisms can have a significant impact on changes. In former prairie regions, like across Iowa, areas where prairie dominated have or had A horizons of significant thickness with less developed B horizons, whereas areas where trees dominated are more likely to have an O-A-E-Bt or A-E-Bt horizon sequence. Humans drastically alter the landscape and soil processes as well, moving A material, removing cover that significantly increases the rate of erosion, compacting soil (on purpose for structural support or unintentionally), to name a few.

Climate

Since energy to change a soil and reactions require both moisture and warmth, warmer and wetter conditions lead to more development. Changes are slow or non-existent if the soil is in a frozen state-as water can't move through, biological activity is minimal, and chemical reactivity is generally decreased.

Time

As one might expect, more time since deposition means more time for changes to occur. Therefore, time is a significant factor, with more time leading to more development if other factors are the same.

Key Takeaways

- Soils change over time
- The five major soil forming factors that influence soil development are parent material, topography, organisms, climate, and time

Soil orders

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Learning Objectives

- Distinguish basic features of the 12 NRCS soil orders

Keywords: classification, soil order

NRCS Soil Taxonomy

This system organizes soils into twelve major groups, or orders, that each end in -sol. Orders are determined by major climate factors, dominant materials, or degree of weathering. Underlined letters are what is used to indicate that order in further classification.

US map of soil order extent[1]

Watch this overview video at: https://youtu.be/0mCaCFUxM9Q

Gelisol

These soils, found under permafrost conditions, have unique features from the freeze-thaw cycles. They are quite challenging to build on, but interestingly, can have organic accumulations due to slow decomposition.

Cold temperatures are the most limiting factor for plant growth.

Photo Credit: Amber Anderson

1. https://www.nrcs.usda.gov/resources/education-and-teaching-materials/the-twelve-orders-of-soil-taxonomy

Histosol

These soils form when organic matter accumulates rather than decaying. Common areas to find them include saturated conditions, where organic matter is unable to decompose due to anaerobic conditions. Northeast Minnesota contains some of these soils, as does parts of Florida.

Histosol in NE Minnesota in a lacustrine area. This area had been drained for peat harvest, would otherwise be submerged. Photo Credit: Amber Anderson. Click to enlarge

Limitations for plant growth are likely whatever is slowing organic matter decomposition, like an extremely shallow water table.

Spodisol

Photo Credit: Amber Anderson. Click to enlarge

These soils are formed from organic matter complex with a metal like aluminum and move down in the profile. They are found under conditions that allow for movement-generally under acidic vegetation and sandier or coarse materials. In the US, these are found in the Northeast, Northern WI and MI, as well as parts of Florida. Challenges for management are likely fertility.

Andisol

This organic vegetable farm is on volcanic ash in Costa Rica, a volcanically active area. Click to enlarge

These soils are derived from volcanic ash, giving them unique structural and chemical properties. They are quite stable (see farm in picture found in Costa Rica), until saturated. The amorphous crystal structure also changes chemical and physical properties. In the US, these are found in the Pacific Northwest.

Oxisol

Deeply weathered and dominated by iron and other resistant minerals, these soils are only found in the most weathered conditions on Earth-near the tropics where warm and wet conditions dominate along with long-term stability in the soil surface. These soils can have meters and meters of B horizon materials, with no C or R within diggable depths. Fertility is more dependent upon the rapid decomposition of the prior crops than the soil releasing weatherable minerals.

Amber examining an Oxisol in Southern Ghana Photo Credit: Andrew Manu. Click to enlarge

Vertisol

ISU soil judgers examining a vertisol in Southern California near San Luis Obispo. Photo Credit: Amber Anderson. Click to enlarge

Vertisols are challenging soils to manage. Composed of high amounts of shrink-swell clays, these soils crack when dry, and swell up when wet. This can crack roads or foundations built upon these soils without proper precautions. Fenceposts in the picture are tilted, in spite of it being a recent installation. Field operations have a narrow window between too wet and too dry. If excavating, these are also unstable, so should be shallow with wide access.

Aridisol

This aridisol in Southern California has significant calcium carbonate accumulation, cementing soil particles together. Unconsolidated soil can be seen under this cemented layer. Photo credit: Amber Anderson. Click to enlarge

These are soils in arid conditions that contain developed features (not shifting sands). The low rainfall means materials can accumulate, such as the significant amounts of calcium found in this example. Water is the primary limiting factor for plant growth in these soils. In the US, these are found in the Southwest.

Ultisol

This soil near Martin, Tennessee, shows characteristic red colors common with more red soils, along with having the base saturation needed to be characterized as an ultisol. Photo Credit: Amber Anderson. Click to enlarge

These are highly weathered soils, but not to the extent found in the tropics. They have low base saturation (associated with low fertility) and have many of their weatherable minerals removed. In the US, these are found dominantly across the Southeastern states.

Mollisol

This central Iowa soil has almost 80 cm of dark soil (far more than minimum for a Mollisol) before redox features are visible. Photo credit: Amber Anderson. Click to enlarge

These soils are characterized by the depth and color of the A horizon, as an indicator of organic matter accumulation. Found dominantly under areas with prairie as their native vegetation, these soils are generally quite fertile. Limiting factors for crop growth may be wetness or limited growing season. Across the US, these are found across the great plains region. In most cases, 25 cm of colors with value and chroma 3 or less are required, along with high base saturation.

Alfisol

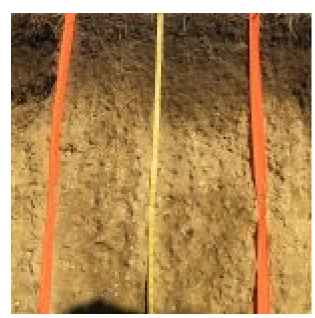
This soil face shows both an E and Bt horizon, indicating a movement of clay from the upper portion to the lower. Photo Credit Amber Anderson. Click to enlarge

These soils generally have a Bt horizon, but still a high base saturation, generally associated with higher fertility. They generally have an E and Bt horizon, indicating a movement of clay from the upper portion to the lower.

If under an established forest, they may also have an O horizon.

Inceptisol

These soils are young, but show some development. They normally have an A-Bw-C or similar horizonation, showing weak development in the lower profile. These may be found on stream terraces, where soils are fairly young, but no longer being flooded. They also may be found in areas that lack sufficient rainfall, time, or temp to have changed the soil from the time of the last deposit.



This soil face has young development , it also shows weak development in the lower profile. Photo Credit: Amber Anderson. Click to enlarge

Entisol

These are underdeveloped soils. Recent deposition or instability mean that the soil hasn't had enough time to change since deposition. These are common along flood plains, and can be found in other unstable areas, where erosion or deposition has removed the prior soil horizons.

This soil, found on the Kansas river flood plain, shows significant recent deposits burying the prior surface.
These materials are relatively unchanged since deposition. Photo Credit: Amber Anderson

This soil, found at the base of a hill in Iowa, shows evidence of recent instability uphill, as the surface 25-30 cm are on top of the prior surface. Photo credit: Amber Anderson

Key Takeaways

- 12 major soil orders exist in the US system of soil taxonomy, by either degree of development or special cases
- These broad categories are based upon degree of weathering (change from when deposited) or special circumstances.

Soil classification

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Learning Objectives

- Understand structure of both NRCS and FAO classification systems
- Discuss major soils features given a classification at the great group or subgroup level

Keywords: classification, soil order, suborder, great group, subgroup, reference soil groups

Classification

As for classification systems of living organisms, classification for soils helps organize our knowledge and communicate important information. Different systems have been developed in different countries, so in this section we will cover the basics of the classification system commonly used in the US, as well as the younger world reference base classification.

Using the system

This system works on the first-fall out principle, accept whatever order you cannot reject first when moving down the list as ordered above.

- **Order**-most broad group, 12 options (ex: Mollisol, Entisol)
- **Suborder**-adds one more distinct trait, usually related to water/climate (ex: udoll, aquent)
- **Great group**-adds another trait for a total of three syllables (ex: hapludoll, fluvaquent)
- **Subgroup**– additional trait (ex: Typic Hapludoll, Aeric Fluvaquent)
- **Family**-adds temperature, mineralogy, and textural info (Fine-loamy, mixed, superactive, mesic Typic Hapludolls)
- **Series**-locally described soil with a range of properties and horizons within a described range: (ex: A Clarion series is a Fine-loamy, mixed, superactive, mesic Typic Hapludoll)

Watch this overview video at: https://youtu.be/sQ8O4rTF9cY

World Reference Base Classification system

View full WRB documentation and versions online[1]

The international classification system, developed more recently than the NRCS system, to create an 'international units' for communicating soil properties globally. This system incorporates aspects of several national systems, including the US and Russian systems.

Instead of soil orders, 32 reference soil groups (RSG) are used instead of soil orders. Principal and supplementary qualifiers are used to communicate additional information.

Key Takeaways

- Soils are classified by major features, generally that impact management
- Classification helps us to communicate significant amounts of information quickly

1. https://www.fao.org/soils-portal/data-hub/soil-classification/world-reference-base/en/

SOIL PHYSICAL PROPERTIES

Soil texture

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Learning Objectives

- Define soil texture
- Match the three major sizes of particles to influences on other soil properties
- Given percentages of sand, silt, and clay, provide a textural class
- Predict potential management concerns with a given textural class

Keywords: Sand, silt, clay texture, textural class

Soil particles

Watch the overview video at: https://www.youtube.com/watch?v=80DmbTZyWr4

Particle sizes

Sand

The largest of the fine soil materials since anything larger is considered a rock fragment. Like marbles, these particles don't fit tightly together, leading to plenty of space for air and water to move through. Normally, this means good drainage and higher gas exchange for roots. Don't assume that a sandy soil will be dry though, as even a sandy soil at the water table will have water-filled pores. Think of a beach when the tide is high; the sand is wet or under water, but when the tide goes out, the sand can quickly drain.

Silt

These are medium-sized particles, that generally feel soft and like flour. While they are considered more erodible and low strength for building purposes, they are generally favorable for plant growth. A higher percentage of water held in this soil is available for plants, and these are normally younger soils with weatherable minerals to provide some fertility for plant growth. Erosion can be a significant challenge to manage in a high-silt soil.

Clay

These are the smallest particles, and generally feel 'sticky' to the touch. The surface area per gram is significantly higher than sand, leading to more ability to interact with other things in the soil, such as water. Think of clay more like sheets of paper in a book; there is a lot of surface area in a given weight or volume and it would take a long time to dry out or move water through. While they hold significant amounts of water, not all is available for plant uptake. Timing field operations, providing aeration, and improving drainage can all be challenging aspects in a clay soil.

Textural Class

Textural classes group soils with similar sand, silt, and clay amounts into categories that help with management decisions.

While we may say 'clay' as a particle, a 'clay texture' requires over 40% of the soil to be in the clay-sized particle range. Generally, the most important word for management is last, with modifiers added to the front.

For example, consider a sand, loamy sand, and a sandy loam. Following the axis at the bottom of the triangle, we see that a sand needs at least 85% sand, whereas a loamy sand needs 70% and a sandy loam could have as low as 45% sand if it also has low clay. We would therefore expect the management challenges associated with the sand-sized particle, like low water holding capacity, to be most limiting in a sand, followed by a loamy sand, and then a sandy loam.

Watch the overview video at: https://www.youtube.com/watch?v=jBEzgvxHC5A

Links to Learn More

Visit the NRCS Soil Texture Calculator to calculate a single point texture for soil class based on the percent of sand, silt, and clay.

Key Takeaways

- Particles are grouped into sizes: sand, silt, and clay
- Each particle is associated with different soil functions or properties
    - Sand is associated with high aeration, low water and nutrient holding capacities
    - Silt associated with low strength and high erodibility, but high available water
    - Clay is associated with high nutrient and water holding capacity, low aeration
- Texture is an important factor for determine function and management challenges for a soil

Soil horizons

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Learning Objectives

- Match soil horizons with processes occurring within the zone
- Identify horizons given characteristics
- Predict potential management or use challenges based upon given horizon sequence

Keywords: Horizons, development, subhorizons

Horizon overview

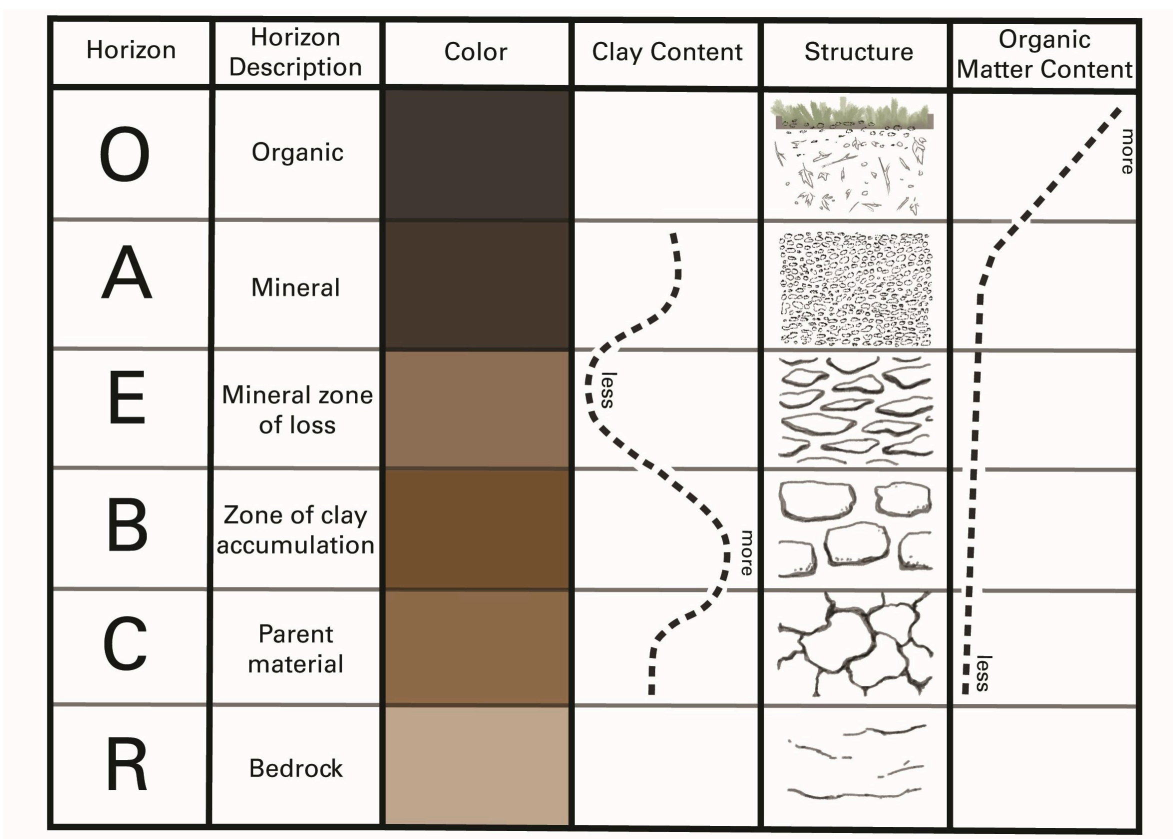


Illustration by Madeline Schill. 2021 in [Soils-Iowa's Nature Series.](#)

Watch the overview video at: https://www.youtube.com/watch?v=BUt9gAvb_1o

Transition horizons

Sometimes a layer is not clearly one process or another, but rather where two are combining. These are called transitional horizons, and indicated by two capital letters like AB or BA. The first of the two is the more dominant of the two processes. A similar-looking notation but with an added /, like E/B or B/E mean that there are distinct areas of each in the layer rather than a smooth transition.

Check it out!

Visit the NRCS Official soil series description page to find a soil series description and the horizons found in that soil. **Hint**: see if your name or home town/favorite town in the US have their own soil series.[1]

Subhorizons

Additional lowercase letters are used to further differentiate horizons.

Watch the overview video at: https://youtu.be/XrN68MEAy4M

Check it out!

Descriptions of all horizons and subhorizons used in NRCS classifications can be found on page 46–51 in this reference.[2]

Numbering

In order to distinguish one horizon from another, numbers at the end indicate multiple of the same zone, split by other differences like structure, redox features, or color.

Numbers at the beginning of the horizon indicate it is part of a different deposit or parent material. Because we might not know how many exist or be able to dig down far enough to find all parent materials, we start numbering from the surface even though the older deposit is on the bottom.

1. https://soilseries.sc.egov.usda.gov/osdname.aspx
2. https://www.nrcs.usda.gov/resources/guides-and-instructions/field-book-for-describing-and-sampling-soils

Key Takeaways

- Horizons are general concepts used to describe the major process(es) happening in the layer
- Not all horizons are found in every soil, sometimes multiple of the same horizon are found in one profile

Soil structure

AMBER ANDERSON

Learning Objectives

- Identify soil structures and factors influencing their development
- Predict what structure might be present given additional information such as soil conditions or horizon
- Explain how structure may impact plant growth or other soil functions
- Predict how management factors might impact structure

Keywords: Structure, aggregation, granular, platy, blocky, prismatic, columnar, massive

Structure

Soil structure is the shape in which soil particles group together and form aggregates. A soil aggregate, or conglomerate of sand, silt, clay, and sometimes organic material, may be a variety of different shapes.

Even in the same soil or area, management practices can influence structure. Photo Credit: Amber Anderson. Click to enlarge.

Structure is important because it allows critical areas of open space, vital for water to move, roots to grow, and soil organisms. Consider a classroom or the space in which you are currently viewing this: when the materials are put together effectively, it allows space for interactions. If only a pile of building materials, the space doesn't serve the same function.

Factors influencing aggregation

A variety of factors influence how soil particles aggregate or group together. Biological activity, organic addition, wetting/drying cycles, freezing/thawing cycles would be expected to increase aggregation, whereas tillage, compaction, and chemical properties such as sodium would decrease aggregation.

Shapes

Granular

These rounded groups of particles don't pack together well, allowing more space for water to move through. They are most commonly found in A horizons with higher levels of organic matter, healthy root growth, without significant compaction.

This forest A horizon has primarily granular structure, with a few small blocks. Photo credit: Amber Anderson. Click to enlarge

Platy

Commonly found in E horizons, the natural breaks in this soil are horizontal rather than vertical. These are easily destroyed by tillage. Note that this is different from 'plates' formed by operating equipment when a soil is wet. Although they look somewhat similar, this structure is naturally formed over time.

Although fragile, platy structure can be seen here, especially around 7-8 cm as the lines in the soil run horizontally rather than vertically. Photo Credit: Amber Anderson. Click to enlarge

Blocky

Blocky structural units are common to find in a B horizon or cultivated A horizon. They can be grouped by either angular blocky having sharp angles likely found in higher-clay soils, or subangular blocky, the more rounded corners.

The impact of tillage can be seen here, with more blocky structure found in the right, cultivated core, while more granular structure is found on the left core, taken from a permanent pasture. Photo credit Amber Anderson. Click to enlarge

Prismatic

These have longer natural breaks vertically in the soil rather than horizontally. As was the case with this large prism in the photo, they are generally found in B horizons. Water and roots in this soil will likely move preferentially through the breaks between these units.

A very large prismatic structural unit found in NW Minnesota. Photo credit: Amber Anderson. Click to enlarge.

Columnar

Columnar are a special type of structure created when sodium impacts a prismatic structure. A ‘muffin top’ or ‘popcorn’ looking appearance on the top of a prism develops from sodium dispersing particles. These are agronomically challenging soils to manage. Both water and roots will likely have problems moving through this soil easily.

Columnar structure on a sodium-impacted soil in South Dakota. Significant sodium accumulation above the orange nail, around 25 cm of depth. Photo Credit: Amber Anderson. Click to enlarge

Massive or Single grained

These units of ‘non structure’ indicates there has been limited changes to this soil since deposition. In glacial till materials, a large piece will likely break between the points of pressure applied, rather than falling apart on pre-determined lines. A midwestern soil at perhaps five feet of depth may not have developed structure because this takes something acting on it. Roots, freeze-thaw, wetting-drying and other factors are less active here, slowing down changes.

For single-grained soils, a lack of fine particles or organic matter means that there are not significant forces to hold sand grains together. This is an effect you may have seen in a sandbox or beach, as a small disturbance will cause the sand to fall apart to individual grains.

This soil has been recently deposited, and has not had time for structure to develop, so would be classified as massive. Photo Credit: Amber Anderson. Click to enlarge

Management Impacts

Since plant growth tends to increase soil structure, more plant growth tends to lead to a better structure. In prairie ecosystems, a strong granular structure is expected.

Tillage can have negative impacts on soil structure, particularly when done in poor (generally too wet) conditions. Consider the building construction of the earlier example in this discussion. When being built from that pile of building materials, a wall is removed or damaged, so this must be rebuilt first, slowing down progress.

Key Takeaways

- Structure is important as it indicates the arrangement of soil particles
- Soil structure can change over time due to changing conditions or disturbance
- A variety of shapes exist, these tell you where water and roots are likely to move along those natural breaks
- Management has an impact on soil structure

Soil color

AMBER ANDERSON

Learning Objectives

- Identify major factors contributing to soil color
- Outline how to use a munsell soil color book
- Use the soil color to potential challenges to management for a given use

Keywords: Color, hue, value, chroma, Munsell soil color book, redox features

Unique soil colors found in Tennessee. Photo Credit: Amber Anderson. Click to enlarge

Soil color is one of the first properties many people identify when asked to describe a soil. Although we may think of it as uniform, soil color can change quickly, both when moving down into the soil and across the landscape. These changes can be indicators of important processes happening in the soil. For example, grey colors may indicate wetness, and it therefore may not be a good place to construct a basement.

Major factors contributing to soil color include accumulation of organic material and accumulation of materials. This is described in more detail below.

Accumulation of organic material

Accumulation of organic material turns the soil darker, as is commonly found in the surface layers. This may be several feet in some prairie-derived soils as pictured to the left, or even the whole visible depth, especially in cases like a floodplain or footslope receiving additional materials.

This image shows a large accumulation of organic matter in the top horizon.

Photo Credit: Amber Anderson.

Redox reactions

Redox, short for reduction-oxidation, is due to changes in soil oxygen levels, generally from having water-filled pores rather than air-filled pores. Oxygen diffuses slowly through standing water, and microbial activity can use up existing supplies causing reduced or anaerobic conditions. If the reduced iron reaches oxygen, like a root channel or near the top of the water table, it will oxidize, creating a red spot in the soil. These spots are visible even in dry conditions, providing a record of normal conditions, regardless of recent rainfall.

Strong redox features are present in this ped. Photo Credit: Amber Anderson. Click to enlarge

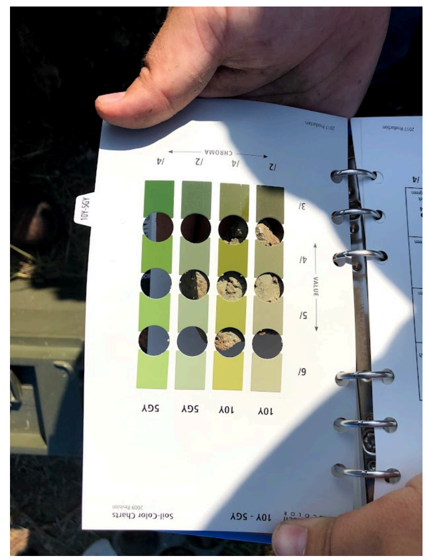
Accumulation of materials

White calcium accumulation in the B horizon of a Kansas soil. Photo Credit: Amber Anderson. Click to enlarge

Accumulations of materials, such as calcium or gypsum, can also color soil in certain circumstances. In the case of calcium or gypsum, white colors appear, frequently in the B horizon in semi-arid conditions or places on the landscape where water moves in carrying calcium, gypsum, or other salts, and evaporates off. Since the salts cannot evaporate, they remain in the soil.

In semi-arid regions, rainfall is sufficient to carry materials, such as calcium, out of the surface layer, but insufficient to leach materials completely out of the profile, leading to an accumulation generally in the B horizon.

Munsell soil color book



Holding a ped under the Munsell Soil Color Book helps identify the color of the soil, as demonstrated in the pictures. Photo Credit: Amber Anderson.

Since simple color description works like "dark" or "red" won't mean the same thing to different people, soil scientists use a standard notation to indicate a soil's color.

Soil color is formatted this way: Page/Value/Chroma

Example: 10YR 2/1

- **Page:** mix of colors or hue
- **Value:** lightness or darkness
- **Chroma:** intensity

How to use a Munsell Soil Color book

Watch this overview video at: https://iowastate.instructuremedia.com/embed/3f0f8ff0-f570-4635-8df1-0d1ce0ced869

Key Takeaways

- Color is important as it indicates potential processes occurring in the soil
- Accumulations of material, redox reactions, and minerology impact observed colors
- The Munsell soil color book is a tool used to standardize soil color across locations

Bulk Density/Idealized soil

AMBER ANDERSON

Learning Objectives

- Identify what components might be found in an idealized soil
- Discuss impacts of compaction and management
- Calculate bulk density when given appropriate measurements

Keywords: bulk density, compaction, available water, unavailable water, pore space

Idealized soil

Watch this overview video at: https://www.youtube.com/watch?v=iDx45_h23SM

Bulk Density

Bulk Density is the oven dry weight of the soil over the total volume of the soil. Since we expect particle density to be somewhere around 2.65 grams/cm3, in an idealized situation with 50% pore space, we would expect bulk density to be about half of that value. Bulk densities significantly higher slow or stop root growth.

Watch this overview video at: https://youtu.be/2UTwNJqmv0w

Compaction

Watch this overview video at: https://youtu.be/ixgtfZu1ZZk

Key Takeaways

- An idealized soil has a balance of pore space filled with air, available, and unavailable water
- Compaction has a variety of negative impacts if managing for plant growth
- Bulk density is a measurement of soil density, and high values may be helpful for building but stop plant growth

SOIL GEOGRAPHY

Geography

ARTURO FLORES AND BRADLEY MILLER

Learning Objectives

- Discuss the concept of geography.
- Understand the relationship between geography and soil science.

Keywords: geography, human and physical geography, spatial distribution.

Introduction to geography

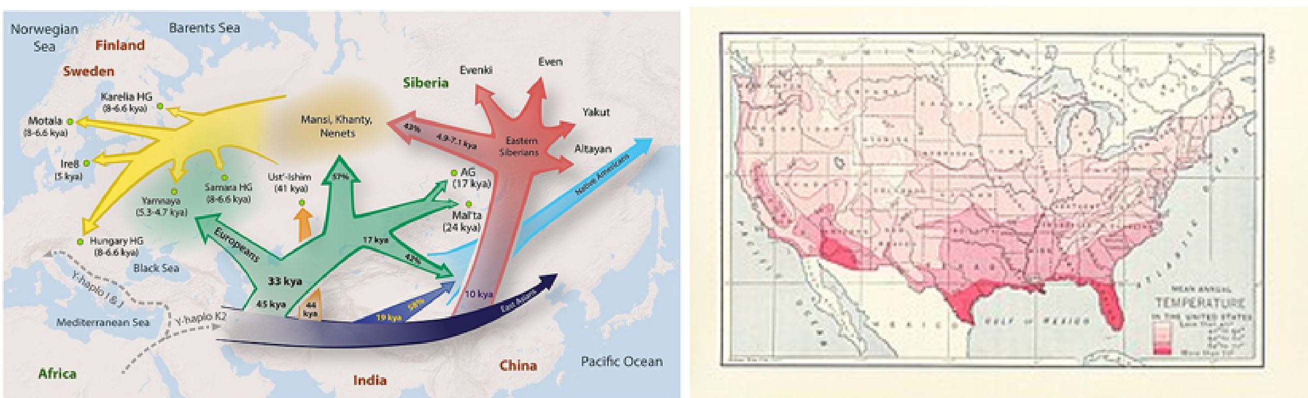
The most basic form of geography answers to "Where are things located." However, it is more complex and dynamic than that. **Geography** is the science that studies the Earth's surface and the phenomena occurring in it from a spatial perspective. It explores 'where' phenomena occur and tries to explain the 'why' it occurs there. Geography studies single and independent features, like geographic landforms and places, or complex events, like human migrations and soil type distribution.

World Map by Gerard van Schagen (1698)

The geographic space includes a delimited area where natural elements from the environment (eg., rivers, mountains, vegetation, climate) interact with humans or with other environmental elements. In the beginning, human settlements and cultural expansion occurred to where natural conditions where more favorable for agriculture, thus, for nourishment. Geographically speaking, soil fertility tends to be higher in alluvial systems (next to big rivers or regions prone to flooding). It was expected that cities would develop closer to this fertile land enriched with alluvial sediments brought in by water bodies, such is the case of the Egyptians in the Nile River and the Southern Asia cultures along the Mekong River. Higher precipitation rates and higher average temperatures throughout the year tend to facilitate and boost agricultural yield. Whilst the Norse struggled to grow few crops during the relatively 'warm' summer months in Greenland, people in Mesoamerica where able to harvest corn up to three times per year. This is the result of different geographical conditions, including climatic patterns and topography that regulate soil development and weather. From a different point of view, more 'favorable' geographic conditions are not always so beneficial. Mayans exploited fertile soils so intensely, that soil quality decreased, fertility was reduced, and agriculture significantly limited to new deforested land through slash-and-burn systems. This caused massive Mayan migrations towards more 'fertile' land (south) and started a slow but constant decay of the civilization, leaving behind impoverished soils. Also, closeness to river systems may facilitate navigation and communication between cities. However, catastrophic flows have limited the rise of human settlements along them, such is the case along the Yangtze River basin in China. This shows how the geographical space is a 2-way system, in which natural elements and human distribution affect and are affected by their own action.

Focus areas

Geography has two main focus areas: humans and the Earth. Human geography emphasizes human activities in the geographical environment, and physical geography focuses on the landscape and the process occurring in it. Yet, both try to provide an explanation for phenomena correlated with space and sometime with time as well.



LEFT: Example of Human geography map about the [Eurasian expansion](). RIGHT: [Physical geography map]() representing the temperatures across the Unites States.

Human geography

Human geography is emphasized in the spatial distribution of people in respect to the natural environment. Some of the subdisciplines include cultural, economic, historic, political, and urban geography. It is commonly associated with social sciences because they work together to understand the human behavior. It differs from conventional social sciences in that human geography also includes the spatial dimension of the feature being studied. For example, economics is focused on understanding how the market operates, but economic geography also wants to explain how wealth and markets are distributed within a country. Embedded in human geography, some understanding of the landscape becomes useful to understand human distribution or cultural spatial patterns.

The landscape is all the visible space captured by the human eye at one specific moment in time. Each one of the shapes that exist in the landscape are called landforms, and some include mountains, volcanos, valleys, and plateaus. Because landforms regulate the flow of wind and water through the landscape and these are eroding and weathering factors, it is possible to conclude that landforms are the reason why landscapes are the way they are. However, the explanation for this is much more complex and requires a good understanding of the Earth's surface and processes. This is where physical geography takes place.

Physical geography

Physical geography aims to explain why the landscape has a particular shape in the place where it is located. It is focused on all the natural features and processes shaping the Earth. To do so, physical geography needs to understand how the different environmental elements interact with each other and affect the Earth's surface. Hence, it studies the different layers that constitute the Earth: air, soil, water, and biology (atmos-, litos-, hydros-, and biosphere, respectively). Some of the subdisciplines include pedology, geology, geomorphology, hydrology, and biogeography. All of these emphasize the study of the physical features of the Earth and the dynamic interaction among them.

Key Takeaways

- Geography studies spatial patterns of phenomena.
- Geography is not only applied for natural environments, but also in social sciences.

Cartography and maps

ARTURO FLORES AND BRADLEY MILLER

Learning Objectives

- Discuss the importance of maps for geography.
- Define the concept of geographic maps.
- Identify the different elements of a map.

Keywords: cartography, map, scale, legend, coordinates.

Cartography and map creation

Cartography is a subdiscipline of geography that graphically represents geographic data on flat surfaces. The preferred method of geography to represent spatial phenomena is with maps. A **map** is defined as a flat representation of spatial phenomena. Maps support visualizing data that is linked to a specific location within a geographic extent. These are easily interpreted by the users and help explain how features are spatially distributed.

A person is seen on a desk using a contour finder to delineate a map from a photograph (Source: Wikimedia).

Maps represent topographic features (related to the landscape) or thematic themes (quantitative or qualitative data). Topographic maps represent landforms or geographic accidents in the landscape. Thematic maps include cities and roads, land use, soil properties, and even religions distribution. It includes the absolute location of a feature (position in the Earth's surface using coordinates) or a relative location (position using another object as reference). A map of a 10-acre farm with a pond next to a field may be useful to navigate through space locally. However, it will lack context about where that farm is located in respect to the world. On the contrary, a world map may provide the location of the farm on the Earth's surface but will fail to be a precise navigation tool when trying to locate features, e.g., the pond.

Elements of a map

For a map to be efficient in transmitting spatial information, it has to include at least the following items:

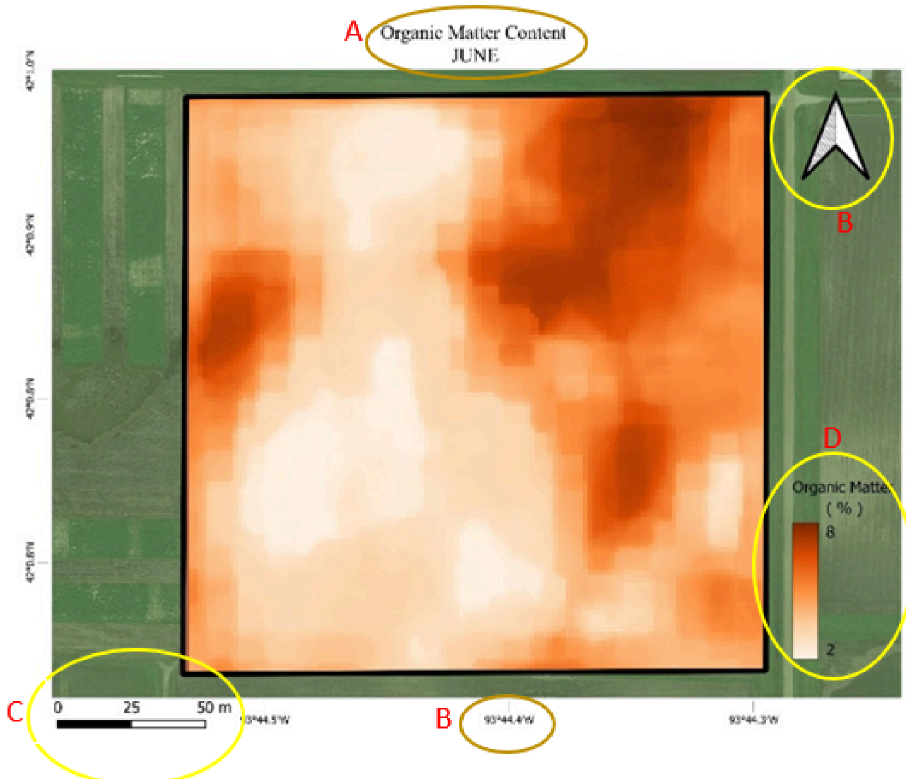
Data. Also, the actual map. It is the flat representation of the geographic space and the spatial phenomena occurring in it and is the most important part because without it the map would not exist.

Title. The title is the first approximation of the user to the map's content. It should provide some background on what the map represents. The title "Organic Matter Content" provides enough information to know which soil property is being mapped. However, it may not be completely clear where this field is located for someone other than the author. Hence, other guidance is required.

Coordinates and Reference Point. The coordinates help locate the geographic feature in the world. They are commonly included in the border of the map as ticks or as a grid overlaying the image. Different coordinates systems exist, and it should also be included in the map. A reference point can include a compass or arrow pointing towards the north, letting the reader situate itself better in the geographic space.

Scale. A basic concept of cartography for paper maps (fixed map scale) is that the level of detail is dictated by the map scale. For example, if we made a map of Polk County, Iowa, it would make sense to delineate the city boundaries of Des Moines. In contrast, if we made a map of the world, we would only mark the locations of cities with dots and only include the largest cities. The scale explains the relationship between the map and the real world. It describes the ratio at which an area was reduced to be fitted on the map. For example, a scale of 1:100,000 means that 1 measuring unit in the map represents 100,000 units in the real world. Such units can be meters, centimeters, feet, yards, or even kilometers and miles. Small-scale maps cover big areas like the whole world, and large-scale maps cover smaller areas like farm fields. The level of detail present in small-scale maps is significantly lower than on greater scales. Large-scale maps can go as low as 1:1, but they would not be practical. Therefore, a scale of 1:5,000 can provide a good level of detail to navigate through the streets of a town. Small scales of around 1:1,000,000 can be optimal to represent a country boundary, perhaps not for precise land management but for a broad understanding of the region's physical geography.

Legend. A map without a legend provides little context on what the visuals represent. A legend is a reference guide to decode the symbology of the map and includes a description of what each color or icon represents. Remember to include the units when quantitative values are mapped.



Map items: A) Title, B) Reference point and coordinates, C) Scale bar, D) Legend (Map by: Arturo F.).

Key Takeaways

- A map is the preferred tool of geography to share spatial data.
- A map should contain a title, a reference point and coordinates, the scale, and a legend for the reader to properly understand it.
- Images are not maps but can be used as base "maps" to reference and locate features in space.

Soil geography

BRADLEY MILLER AND ARTURO FLORES

Learning Objectives

- Define soil geography as a tool of soil science.
- Understand the importance of spatial variability of soil.
- Discuss the interest of soil science to create soil maps.

Keywords: soil geography, spatial variability, soil map, dynamic properties.

Soil geography

If not all soil is the same and different soils have different capabilities, then it becomes important to know where these different soils exist. So, to match land use and management planning to the capability of soil, we need to understand the spatial distribution of soils. In addition, the soil is changing. Some soil properties change faster than others and they are dynamic both in space and time.

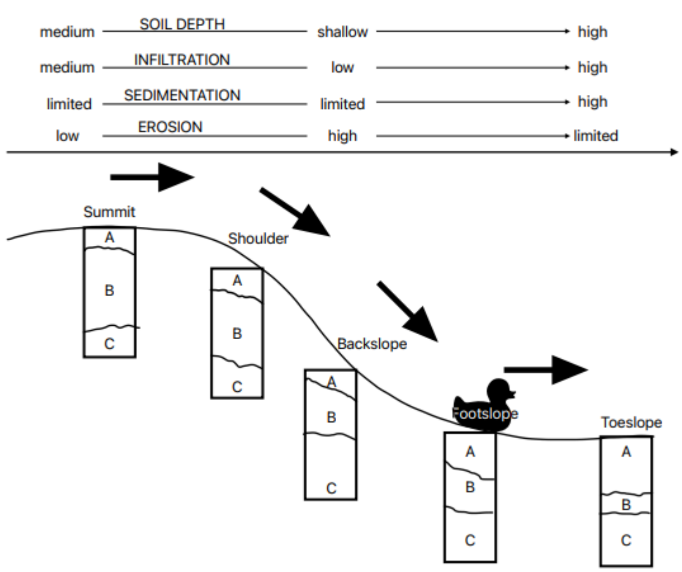
LEFT: Soil heterogeneity across a corn field in Boone, Iowa. Notice the change in colors depending on the position on the landscape, especially the hillslope position. RIGHT: Soil variability in a forest trail in Crosby, Minnesota. Even on a 1 m2 of soil, it is possible to have diverse content of materials, colors, and possibly chemical properties (Pictures by: Arturo F.).

The spatiotemporal variability of soil is the result of different forming factors, weathering rates, time of development, and human intervention. It is known that soil not only varies vertically (soil profile), but laterally (across the landscape). Variability is easily observed from one place to another (macroscopic variability), or it can exist at a microscopic level. However, despite the level of detail at which soil is being evaluated, heterogeneity exists and is critical for land management. Therefore, it is possible for geography to study soil as a geographic unit.

Soil geography applies geographic principles into the spatial study of soil heterogeneity. Soil properties or characteristics are a response to their location. Soil forming processes occur differently across the landscape. The location of a point the geographic space is determinant for weathering intensity. The fundamental concept of 'catena' was explained by Geoffrey Milne, who defined it as 'the regular repetition of soil profiles in association with certain topography.' This concept captures the impact slope has on hydrology, and how the last serves as a critical factor for soil dynamics.

The most influential factor in weathering and sediment translocation is slope gradient. This is the inclination or degree at which a slope gains or loses elevation compared to the horizontal level. It can be measured in degrees (45°) or in percentage (100 %), meaning that a slope of 100 % has an inclination of 45 ° and gains one unit of elevation for every horizontal unit. Steeper slopes increase water kinetic energy and its erosive potential, whilst gentle slopes or almost level ground decrease the speed of water fluxes and increase material accumulation.

Convex slopes tend to be easily eroded from surface particles that accumulate more in concave regions. Higher deposition may be correlated with high enrichment areas as sediments carry nutrients along. However, they can also be problematic as water tends to accumulate more and optimal rooting conditions can be limited. Slope orientation has a regulating effect on soil properties. Regions facing to the south (in the northern hemisphere) and to the north (in the southern hemisphere) are exposed longer to solar radiation. This results in higher soil temperatures that increase biological activity, production of biomass, and perhaps reduce the time soil remains frozen after freezing winters. Wind also impacts soil development, and the east-west orientation of the slope is therefore critical in wind erosion. Slopes facing directly to the wind current are more prone to suffer from erosion than slopes on the other side of the hill. Assuming that wind is flowing west to east, a slope facing west will be slowly depleted from fine surface particles and will end up with higher accumulation of coarser materials, whether opposing slope (facing east) might end up less disrupted and with more fine sediments.

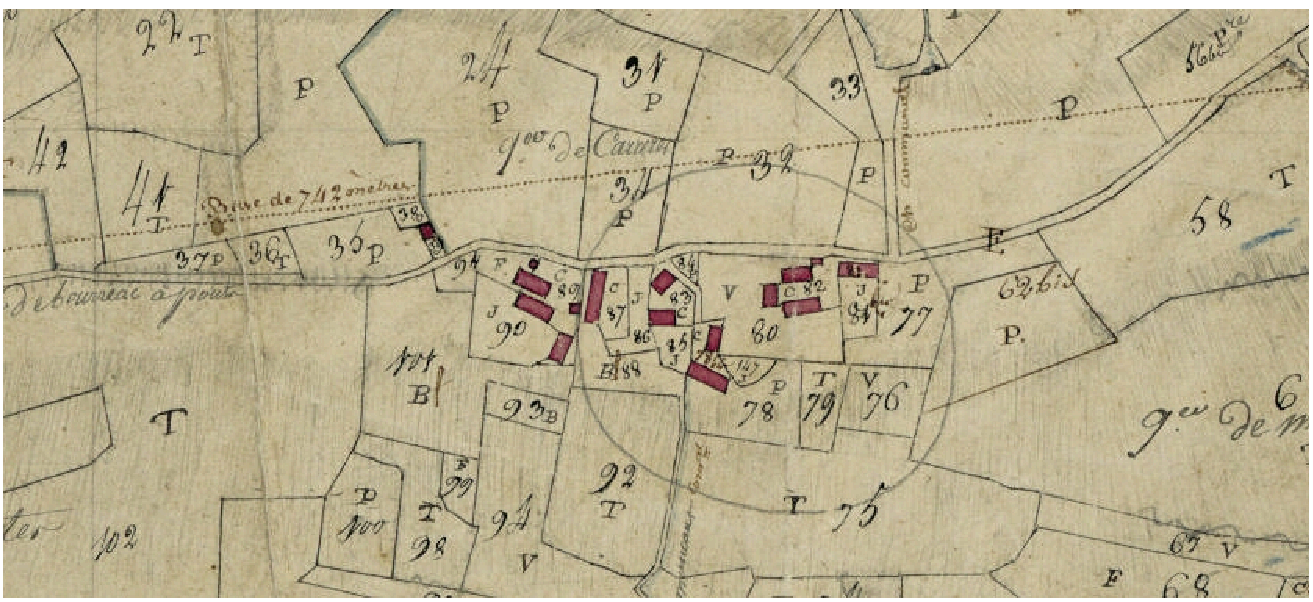


Graphic representation of the hillslope position effect (Image by: Arturo F.)

The position on a slope will also determine the speed at which water can erode surface materials, the infiltration rates, and the accumulation of sediments. From top to bottom, hills can be divided into summit, shoulder, back slope, foot slope, and toe slope. The first two correspond to less slope steepness (inclination) and have higher infiltration rates. Where slope starts to increase, water potential increases and with it, runoff. The back slope is the steepest section of a slope, and this causes finer particles to be carried down through water fluxes (surface water erosion). This region does not allow much time to infiltrate and has higher translocation of finer materials. Therefore, back slopes have higher content of sand or gravel and less developed soil horizons. As the slope starts to settle, the foot slope and toe slope are located at the bottom of it. Here steepness is reduced and water potential decreases as its speed also is reduced. This causes the sediments to settle and increase the thickness of the surface materials, which can include silts, clays, and nutrients carried along. The previous image demonstrates the sections of a slope and what processes are more likely to occur in each one of them.

Soil maps

We use soil maps for many things. The original purpose of soil maps was cadastral, which means land valuation for the purposes of taxation. The idea is that owners of land with more productive soil will have higher yields, higher income, and thus can afford to pay a higher portion of taxes. This use of soil maps is still common today for agricultural land. Another fundamental purpose for soil maps is interpretations for land use capability. Some of the earliest soil surveys were part of geologic reports and were essentially inventories of natural resources. This was especially common for colonies and other lands newly set up for settlement. In the early history of the USA, European settlers were setting up new farms and the soil survey maps provided guidance for which crops were best suited for that land. These reports were typically organized and paid for by county and state governments.



Napoleonian cadastral map from 1809 of Recahorts Hautes-Pyrénées, France.

Another common type of soil map that serves a different purpose than soil survey maps are soil fertility maps. These soil maps focus on soil properties that change quickly and support decisions that are important to the annual economics of field management. To differentiate between long-term and short-term soil properties, we categorize them as static and dynamic soil properties. Soil survey maps focus on static soil properties because they are more reflective of the natural capability of a soil. Also, given that soil survey maps have taken a long time to create for the large extent they cover, they focus on soil properties that won't make the maps out of date only a few years after they are created. In support of the cadastral purpose of soil survey maps, focusing on the natural capability of soils avoids the variability in management. In other words, the taxation rate is based on standard management practices, not if the farmer is especially good or poor at managing their fields.

The dynamic nature of soil fertility properties makes them more challenging to predict. While the factors of soil formation still apply, the relationship with those factors changes over time. For example, the application of a nitrogen fertilizer may level soil nitrate concentrations across a whole field. As time goes by, plants are consuming some of that nitrate and other biological processes are converting it to nitrous oxide gas (denitrification). While the plants may be taking up nitrate at spatially consistent rates, denitrification occurs at different rates depending on spatially variable factors such as soil water content. In addition, water moving through the soil leaches nitrate downward. Sometimes that leaching takes the nitrate straight down and sometimes that water transport is more lateral, causing the nitrate concentrations to decrease in the upper elevations and increase in the lower elevations. At any particular point in time, we could measure soil nitrate concentrations by soil sampling and identify patterns with respect to landscape position. However, as the nitrate migrates down the slopes the relationship with landscape position changes, which makes spatially predicting nitrate concentrations across the field a moving target.

Key Takeaways

- Soil geography studies the formation and distribution of soil on the Earth's surface.
- Soil maps are representations of the spatial variability of soil at one specific moment in time.
- Dynamic properties (which change over time) become challenging to represent on a static map.

Mapping methods

BRADLEY MILLER AND ARTURO FLORES

Learning Objectives

- Understand how maps are created.
- Discuss two mapping methods.
- Define GIS and its importance and relationship with soil mapping.

Keywords: map delineation, spatial autocorrelation, spatial association, GIS.

Creating a map

Thinking about the logistics of making a soil map, we must come to terms with how we map something that by definition exists mostly underground. Making an accurate road map is relatively easy since the advent of aerial photography. All one has to do is trace the roads that one sees in that image and then label them. Unlike road maps, soil maps are a game of spatial prediction. A soil mapper could poke hundreds of holes in the ground and still only directly observe a small portion of the soil landscape. Aerial photographs have played a key role in the creation of soil survey maps, but they don't let the soil mapper see much of the soil.

Traditional soil maps were created using the soil surveyor's knowledge, intuition, and understanding of the available soil information It is impossible for farmers to sample all locations within their fields because it is unpractical and time and cost expensive. To address this problem, maps are created by making predictions at unsampled locations based on scatter observations across the landscape. Soil sampling provides a broad understanding of the soil for that specific point. However, this knowledge is useful to identify patterns and relationships among soil properties.

Spatial predictions

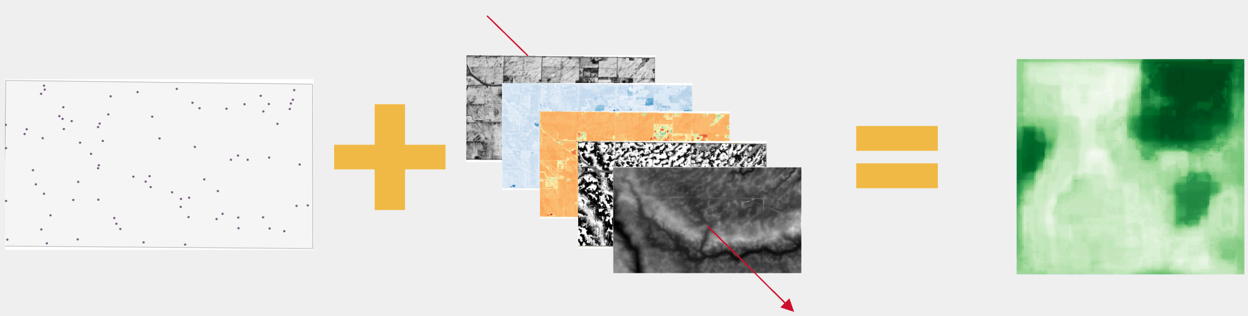
Our best clues for predicting soil properties come from the environment that they formed in. Recall the factors of soil formation that describe environmental variables that influence soil processes. Such factors were probably credited to Hans Jenny, but they were listed sixty years before that by Vasily Dokuchaev when he was describing how to map soil in Russia. Nobody had thought to use combinations of factors to predict soil variation. The environment, including topography, climate, and vegetation, may explain more about soil properties than we can think of. The ancient Greeks knew to look at the vegetation for clues and the German agrogeologists of the 20th century knew to look at texture and mineralogy for clues, but previously these were considered to be competing ideas.

Spatial association

Utilizing the factors of soil information to associate patterns of soil variation is known as the soil-landscape paradigm. This is a specific example of the geographic concept of **spatial association**, which is that some variables covary with each other in space. By looking at variables that are more readily observed, one can infer variables that aren't as easily observed. In the case of the soil landscape paradigm, a soil mapper could observe soil properties in one location and infer that other locations with matching climate, vegetation (the part of organisms that can be seen in an aerial photograph), landscape position, and parent material would also have the same combination of soil properties. For example, the Clarion soil series is mapped on the tops of the gentle hills of the Dows geologic formation (region known as the Des Moines Lobe). Within a county scale map, climate doesn't change very much. However, there are measurable differences in climate across multiple counties. For this reason, the Clarion soil series is not associated with exactly the same soil properties from one county to the next. Although parallel in the other factors of soil formation, the Clarion soil series is associated with slightly different soil properties as observed in each county and the same is done for all soil series. This strategy allows for a general concept of soil series to be easily communicated, while also helping the county soil maps to be more accurate.

Spatial association with a machine learning approach

Artificial intelligence is a power and modern tool that has supported and improved the creation of high-quality maps. The idea behind this method is make spatial predictions at unsampled locations by recognizing relationships between known values and some ancillary data (covariates). Such covariates include topography, vegetation, satellite imagery or even other soil maps that may provide enough background information to explain soil's behavior at the locations where predictions want to be made. Different machine learning algorithms arrange the data at a specific known location and associate it with the covariates for that same point. The machine learning algorithm fits a model over that data and help make predictions of unknown values at unsampled locations. The following image represents the process:



Use known locations where samples were taken and associated those values with covariates for that specific location. This way a model is fitted on the data and a soil map can be created based on spatial associations between the property being mapped and the covariates explaining its behavior (Image by: Arturo F).

Spatial autocorrelation

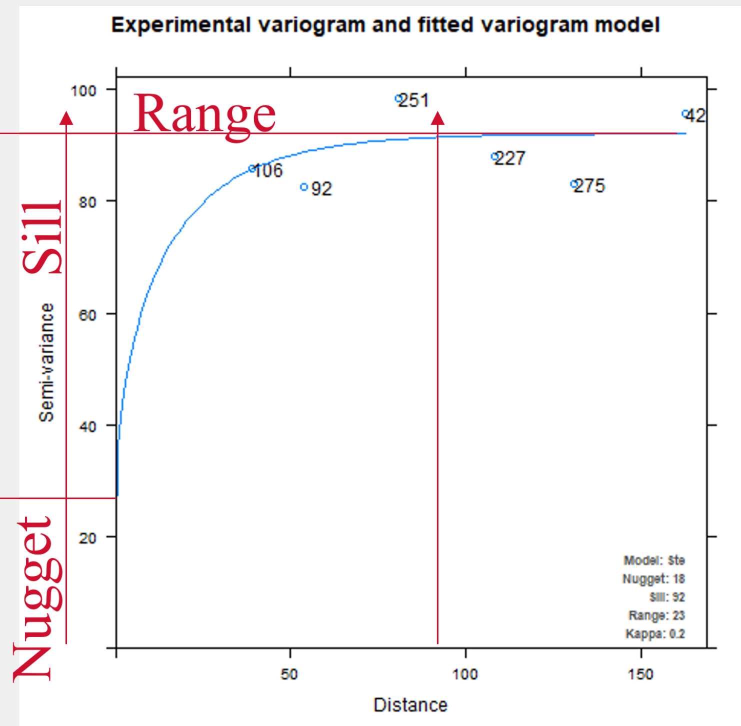
To make soil fertility maps, all the same basic principles apply for mapping something that we can only directly observe in a few locations while wanting to know the spatial distribution of that target variable across the whole map area. We still must predict the status of the soil belowground based on a small proportion of samples and whatever clues we can find aboveground. Because dynamic soil properties are changing quickly and with them their relationships to aboveground variables, soil fertility mapping tends to lean on a different geographic principle. This other principle is **spatial autocorrelation**, which means that things that are close together tend to be more similar to each other than things that are farther away. By this principle, two measurements of soil nitrate concentrations taken 3 feet (1 meter) apart are more likely to be similar that two samples taken 100 feet (30 meters) apart. Now, any soil scientist will tell you that you can be surprised by differences in soil cores taken almost side by side, and in the case of soil fertility you want to be careful not to sample on a hot spot where fertilizer was recently applied (e.g., the thin band produced by targeted side-dressing). However, part of being a dynamic soil property is being relatively more mobile than static soil properties and that lends to more diffuse spatial distributions. Not having hard breaks in concentrations works better for the spatial autocorrelation approach to mapping.

The most basic method for using spatial autocorrelation to create a map is to take the sample points and then draw polygons identifying the area closest to the respective points. This identifies the areas that are likely to be similar to each of those measured points. Then we assign the measured value of each point to its respective surrounding area. In doing this, we are predicting values in an area based on the nearest measured location. A common practice in soil fertility mapping is to take soil samples on a regular grid, and then assign sample results to equally size squares surrounding each of the sample points. Although variability likely exists within those squares, if the squares are not larger than the size of area that a farmer can vary their management practices, then a finer resolution would not be useful.

In the era of precision agriculture, rates of applying soil amendments can be increasingly targeted. This means that a 2.5-acre grid (100 x 100 m squares) or even a 1-acre grid (60 x 60 m squares) may be too coarse of a resolution to supply the information needed to fully utilize the capabilities of precision agriculture. With the basic spatial autocorrelation approach described above, making a finer resolution map would require taking more soil samples. Instead of a sample in every acre, maybe management zones of 0.5 acre can have unique fertilizer prescriptions. In which case, a sample in every 0.5 acre would double the quantity of samples needed. However, spatial autocorrelation can be more useful than single value blocks. Spatial interpolation uses the concept of spatial autocorrelation to predict a smoother gradient of values in between observed locations. Within a geographic computer-based software, algorithms such as inverse distance weighting (IDW) or kriging can create prediction surfaces at any resolution the user specifies.

Spatial autocorrelation approach (variogram)

The variogram is the statistical tool used with kriging methods to predict values at unsampled locations based on distance from a known point. It tells how much two samples can vary based on the distance that exists between them. The range is the distance at which the variogram levels off and points at this distance or farther apart are not spatially correlated. The nugget effect is a representation of the small-scale variability, and the sill is the maximum variability between a pair of points. In this example, a model was fitted into a variogram while performing an ordinary kriging analysis for Phosphorus content in the soil. The model fitted into the variogram is telling us how much the data is expected to vary as the distance from a point starts increasing (lag distance in x axis).



Variogram showing the range, the sill and the nugget (Image by: Arturo F.).

Geographic Information Systems (GIS)

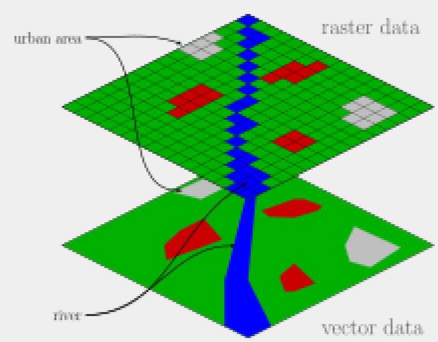
The acronym GIS stands for ***Geographical Information Systems***. GIS is the implementation of software and hardware for the storage and manipulation of spatial data. Digital geographers combine computing power and computer-based analysis to store, modify, analyze, and present geographic data using digital maps. Its capabilities allow users to even tie non-spatial data to a specific location and obtain geographical results. For example, a list of coffee shops does not provide much information beyond the name of each and probably an idea of what they sell. However, if a set of coordinates is assigned to each of those names, it is possible to locate them in space and navigate towards each.

To store and manipulate data, GIS utilizes layers of information to simplify the process. Each one of these layers includes objects with georeferenced data (data assigned to a fixed location), and values (quantitative or qualitative). Objects include:

- **Vector data**, or discrete objects. Each one of the items in each vector layer contains a fixed value for a certain location, it assumes the feature remains constant throughout space. Vector data can be represented by points (simple set of coordinates), lines (continuum of points), or polygons (objects that form a closed area defined by connecting lines). Commonly these are used to represent soil sample locations, stores, cities, roads, streams, or regional boundaries.
- **Raster data**, or continuous objects. Because object values can vary over space (e.g., soil properties), independent locations are included at all locations of the study area. A raster is an image created by a composition of grid-arranged squared cells. Each one of the cells is called a pixel, has a unique absolute location, an individual value, and the same size as all other cells. More pixel density per area increases the level of detail, resulting in smoother images. When pixel size increases, the resolution of the map reduces and gives it a blockier appearance.

The process of obtaining data is either done by directly evaluating the object by touching it or evaluating it from a certain distance. Direct measurements of certain feature are obtained with in-field sensors. In agriculture such measurements can be either from the soil (e.g., moisture readings) or the crop (e.g., chlorophyll-meter). As an alternative, remote sensing allows farmers to obtain data from a distance. This includes images from drones, planes, or satellites, which can measure topography or spectral bands (color). Actually, both are being combined with GIS and artificial intelligence methods to increase the quality of the maps.

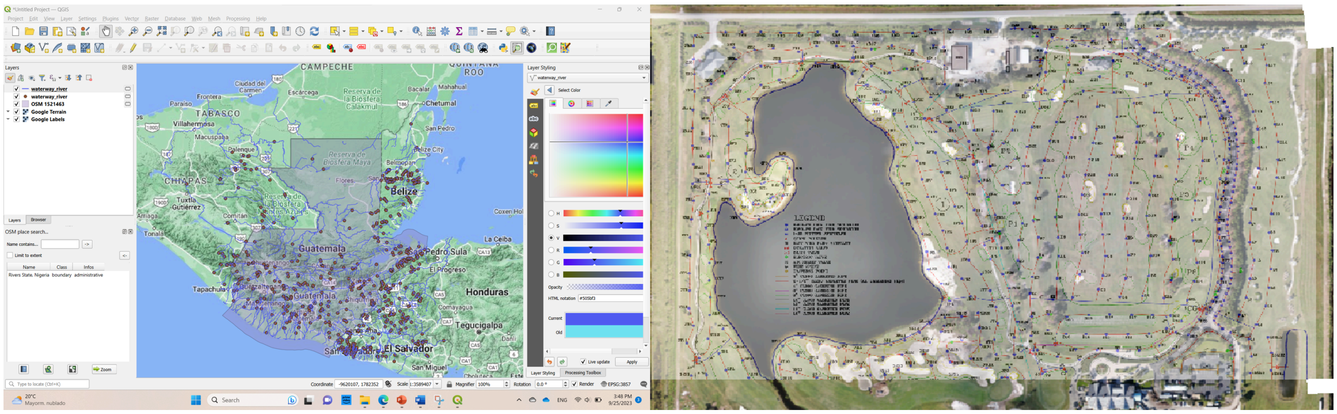
Raster vs. Vector data



Difference between raster data and vector data for any geographic space.

Because raster pixels have a square shape, they cannot represent other geometry than that. Therefore, rasters fail to perfectly delineate non-squared objects. Instead, vector objects can delineate any figure better because the main unit is the point and by arranging infinite amounts of points, any shape can be delineated. Vector polygons may provide a better alternative for delineating irregular objects, but they assign a uniform value to the are enclosed within and detail is lost. On the contrary, because rasters can include infinite number of pixels, they are able to capture all the variability that exists within certain area. Soil survey maps that have been digitized are composed of vector objects. Each one of the lines enclosing a certain region assumes that all the area inside is homogeneous. Instead, rasters allow to capture any kind of heterogeneity that exists, especially with dynamic soil properties like nitrogen.

One of the most valuable things about GIS is that scale is no longer a problem. Instead of scale being limited by the map's extent, in GIS it is possible to zoom in and out of the object and increase the level of detail that can be seen. This does not mean that GIS has better resolution than paper maps. Resolution is still limited by the availability of data and density of it. The difference with paper maps is that to fit a large region within a paper, the level of detail was compressed so intensely that it lost usability, especially with new Precision agriculture technologies. Now, GIS allows the user to zoom in and be able to see that detail that was lost in the transcription to paper maps. Nevertheless, if the smallest unit of sampling represents 1km2, for example, GIS won't be able to see beyond that and all the area will be represented by a big pixel of 1 km2 of resolution.



Examples of GIS technologies. LEFT: screen of QGIS (free access GIS software) where a base topographic map is being used to overlap vector layers of the Guatemalan political boundary and the waterways within the country. RIGHT is a base map created using a drone image to georeferenced an irrigation map for a golf course in Florida (Pictures by: Arturo F.)

Key Takeaways

- Making spatial predictions is required because it is not possible to sample soil at every location, therefore, soil maps are realistic representations of soil heterogeneity and can involve error.
- Soil spatial patterns may be explained by landscape position associations or by distance to known soil locations.
- GIS integrates software and hardware to boost the mapping process and spatial data analysis.

Soil maps around the world

BRADLEY MILLER AND ARTURO FLORES

Learning Objectives

- Compare the difference between soil maps in the United States versus the rest of the world.
- Discuss the available alternatives for the lack of soil maps.

Keywords: soil survey, site specific maps,

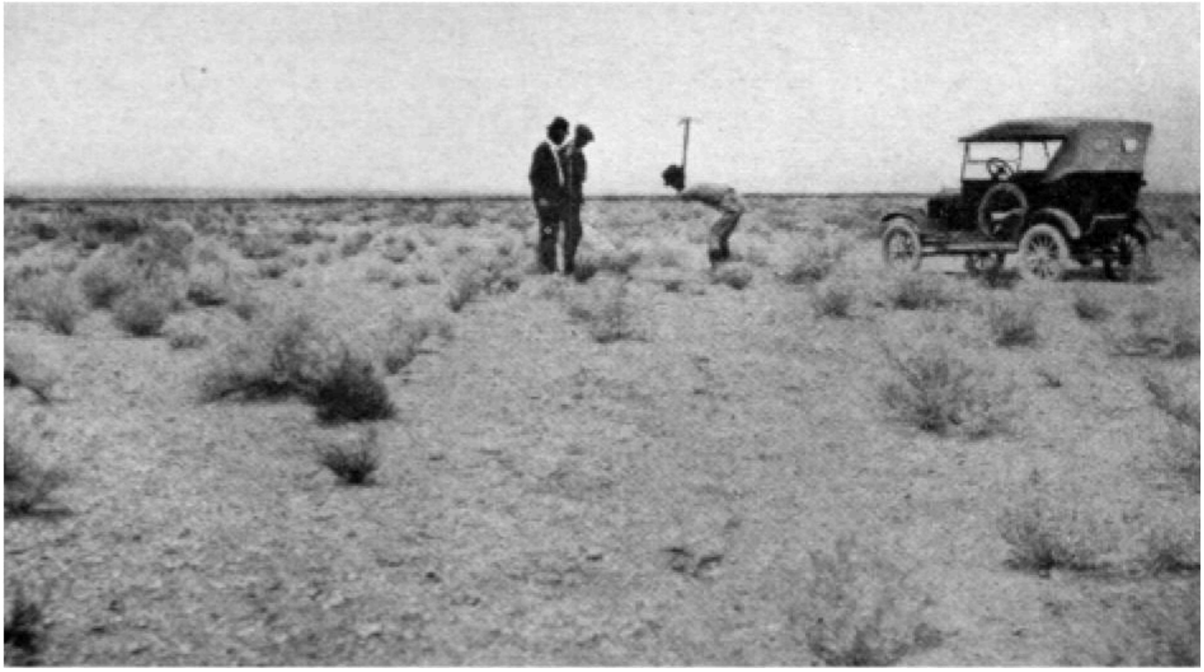
Soil maps around the world

A paradox in public support for soil mapping is that users are increasingly asking for the maps to do more. Then, when the soil maps fall short of those expectations, opinions shift to the soil survey maps not being useful. For example, many farm managers have sought to be more strategic with their sampling for soil fertility by dividing a field into management zones (the core concept of Precision Agriculture). A common approach to identify those management zones is to use the delineations from the soil survey maps. Sometimes this works well, and sometimes the soil survey maps do not include important variations. Note that sub-field management was not included as one of the purposes for soil survey maps.

Given the many purposes of soil maps and the large success of the soil survey program in the USA, many Americans take for granted that they can go online and look at a soil map for around 99% of the land in the USA. Few countries have soil maps with the coverage extent and level of detail provided by the USA soil survey program. At least part of this achievement can be explained by synergistic public investments, such as soil conservation efforts and providing jobs for veterans after major wars/conflicts. Many countries shut down their soil survey programs during the Farm Crisis of the 1980s (Farm Crisis). The USA stands out in its continued funding of soil surveys through that time.

Soil maps in the United States

In 1899 the USA's federal government established the Bureau of Soils to conduct a consistent and coordinated soil survey. Today, the USA soil survey maps include a plethora of interpretations to help translate the knowledge of soil scientists into information needed by landowners to make management decisions. These interpretations can include the suitability for recreational facilities (e.g., campgrounds or golf courses), wildlife habitat, building site development (e.g., basements or streets), sanitation facilities (e.g., septic tanks or landfills), as a construction material (e.g., source of fill dirt or gravel), and water management (e.g., reservoirs or irrigation).



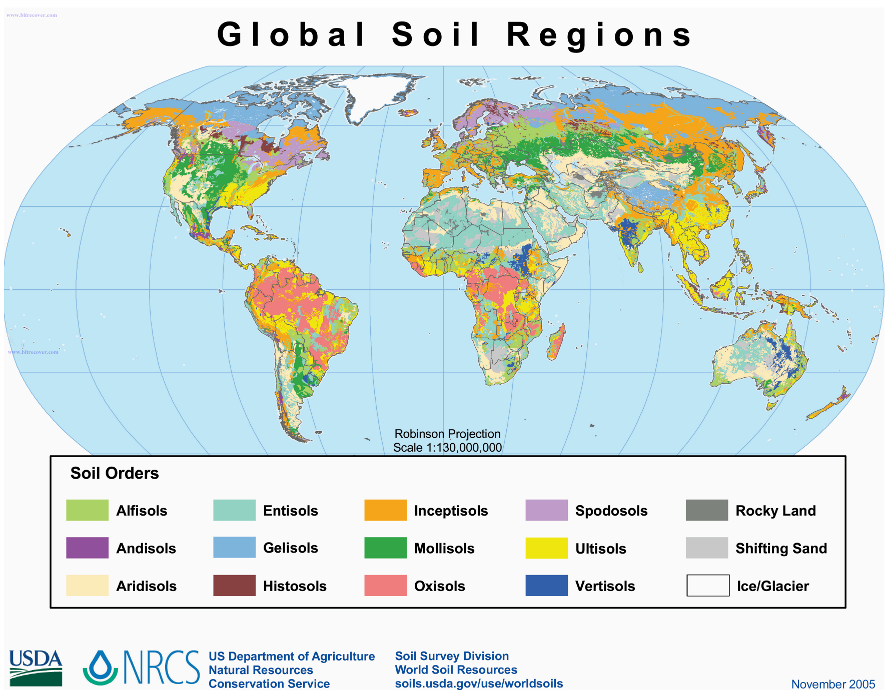
Early soil mappers in 1923 from the Berau of Soils (USDA).

One of the early soil surveyors for the USA's Bureau of Soils was Hugh Hammond Bennet. During the soil mapping of Louisa County, Virginia in 1905, he was directed to investigate declining crop yields in the area. He was struck by the differences in the condition of soil under virgin timberland compared to cultivated fields. His advocacy for soil conservation led to him becoming the first director of the Soil Erosion Service in 1933. Although the degradation of soil has always been a challenge for human civilizations, the USA experienced a particularly cataclysmic series of events in the 1930s. Coincidently, on the day that Bennet testified before congress in 1935, a dust storm event from the central USA occurred so dramatically that it darkened the sky in Washington D.C. Commonly referred to as the Dust Bowl, the combination of management practices not suited for dryland ecosystems and multiple droughts wiped out tens of thousands of farms. Spurred by the start of the Dust Bowl and investment in public works to stimulate the economy during the Great Depression, Congress elevated the Soil Erosion Service in the USDA and renamed it the Soil Conservation Service. By 1938, the Soil Conservation Service –known today as the Natural Resource Conservation Service – subsumed the Bureau of Soils, making soil conservation the supervisor of soil mapping. While all the previously mentioned needs of a soil survey have remained in place, the lead purpose of soil survey in the USA has been to support soil conservation policy since that time.

Prior to the adoption of aerial photography for soil mapping, most of the maps made by the USA soil survey were made at the county scale. Because of this relatively small extent (large map scale), USA soil survey maps can include more detail. However, until they started using aerial photographs, these maps were more like geologic maps because they could only recognize differences in soil parent material (e.g., bedrock, till, or alluvium) but could not see where different topographic positions occurred in the map. After World War I, aerial photography became more readily available, and the USA soil survey was then able to differentiate landscape positions.

In the USA Midwest, where single season crops were grown, it was possible to have aerial photographs of bare soil. Seeing patterns of lighter and darker soil allowed soil mappers to delineate the tops of hills and the swales between them. This style of soil mapping is called high-low mapping. In areas where there was continuous vegetation cover, the aerial photographs enabled soil mappers to see the type of vegetation growing in different areas and delineate differences in expected soil series based on that. In this way, the level of detail that could be included in a map depended on the map scale, availability of information in base maps, and the purpose of the map.

The USA method of fully utilizing the factors of soil information to associate patterns of soil variation is known as the soil-landscape paradigm. This is a specific example of the geographic concept of spatial association, which is that some variables covary with each other in space. By looking at variables that are more readily observed, one can infer variables that aren't as easily observed. In the case of the soil landscape paradigm, a soil mapper could observe soil properties in one location and infer that other locations with matching climate, vegetation (the part of organisms that can be seen in an aerial photograph), landscape position, and parent material would also have the same combination of soil properties. For example, the Clarion soil series is mapped on the tops of the gentle hills of the Dows geologic formation (region known as the Des Moines Lobe). Within a county scale map, climate doesn't change very much. However, there are measurable differences in climate across multiple counties. For this reason, the Clarion soil series is not associated with exactly the same soil properties from one county to the next. Although parallel in the other factors of soil formation, the Clarion soil series is associated with slightly different soil properties as observed in each county and the same is done for all soil series. This strategy allows for a general concept of soil series to be easily communicated, while also helping the county soil maps to be more accurate.

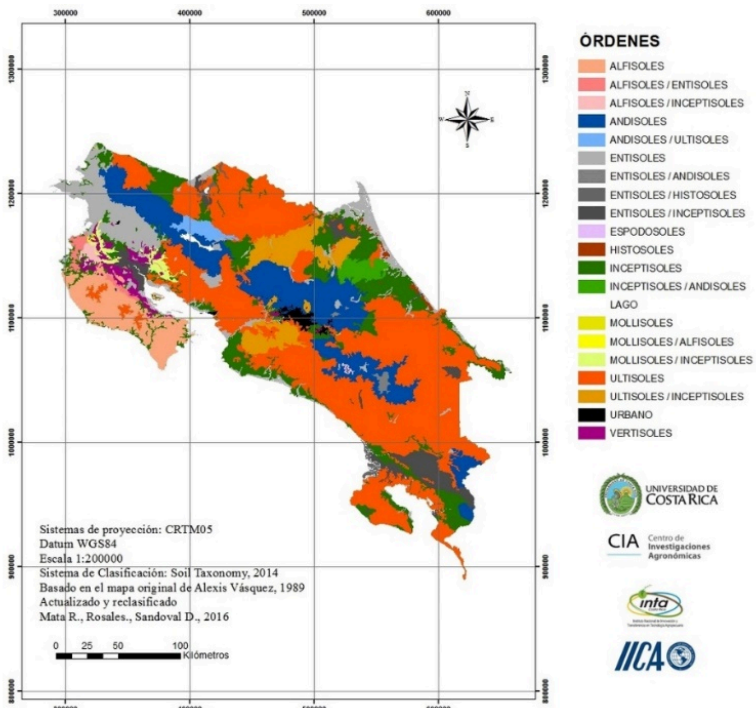


Soil map of the world using soil taxonomy classification.

Soil maps elsewhere

The intensive and constant improvements on the USA Soil Maps have produced high-quality and reliable sources of information both for agricultural development and policy making. However, the reality is different outside of the United States. Underdeveloped countries, especially, rely on existent soil classification systems to map their own soils. There is no one concrete reason for the nonexistent efforts on mapping the regions soils in detail as the US has done with their own. Perhaps lack of economic resources, competent politicians, or even disinterest caused by underestimating soil. However, despite the lack of regional soil maps, Central America has thrived and managed soil so efficiently that agriculturally it is one of the most productive regions in the world.

Contrary to the popular use of public available soil maps in the USA, private parties have created their own maps to suit their interests, rather than complying with the national demand. In Guatemala, significant efforts have been made by the sugar cane industry to create reliable soil maps that otherwise are not available. However, these maps have a limited geographic extent, that is, the region that falls within the sugar cane producing region. Also, because those maps are created with private interests, their accessibility is limited to the general public. Private universities have tried to provide useful data regarding the status of Guatemalan soils, but they are not widely spread and are little known even among farmers. A similar situation occurs in other tropical countries, such as in Honduras and Costa Rica, where banana and pineapple companies invest in their own soil and topography departments to evaluate their land, map their soils, and try to enhance agricultural production. Overall, the private sector efforts are always with the intention of increasing the economic benefit that soil maps can provide. These situations leave small and medium-sized farmers relying on scarce soil maps.



Costa Rica soil map using Soil Taxonomy classification system. Map created by Universidad de Costa Rica and other institutions.

Soil survey maps provide an overview of the distribution of soil variability; however, they fail to represent fertility parameters and any kind of abnormalities, temporal or permanent, of greater importance mainly for agriculture. This situation puts every farmer in the world at the same starting point: specific soil maps for their land with enough detail to make decisions. Precision agriculture (PA) has slowly gained importance and acceptance among farmers because it relies only on data gathered for that specific field, instead of using regional soil maps. Agriculture is undergoing a paradigm shift in which conventional agriculture is turning into a more data-supported method. Whereas conventional agriculture treats fields as a whole homogeneous unit, PA addresses the local and independent variability that may explain A) soil's fertility, and B) soil's dynamic behavior.

Different technologies are being adopted to practice PA at different scales. Portable equipment, like Veris® technologies (Figure3), that can instantly measure soil pH, EC, and organic carbon by just dragging the equipment once over the field. The most valuable feature of this type of sensors is that the observations are directly transformed into spatial maps. Sugar cane companies in Guanacaste, Costa Rica, are seeing benefits of just tilling compacted soils and doing localized fertilizer applications, as input efficiency increases, and yield is boosted while reducing costs.

The more detailed maps are, the more specific agricultural treatment can be. Conventional sprayers used in pineapple farms are not able to easily adjust their settings once they start working. Drones with individual nozzle control allow adjustments on-the-go depending on treatment maps previously created based on field observations. Dota in Costa Rica is the region of the country known for its coffee production. It is in the mountains and the soil is derived from volcanic materials. Accessibility is limited to machinery and conventional agriculture becomes harder because of the steep topography. Now, drones are being used to evaluate coffee plantations and determine fertilizer requirements based on spectral data captured by the UAV. In Guatemala, sugar cane, pineapple and banana producers use UAVs to also spray fertilizers and pesticides in access-restricted zones, close to urban development's and where planes are not able to reach. A revolutionary company called DISAGRO® works in Latin America and offers PA services that combine meteorology, soil, vegetation, and satellite data to create site-specific management plans. Many other companies and technologies are being developed in the region, demonstrating that the lack of detailed soil maps is not a limiting factor for the region's agricultural success.

Key Takeaways

- The United States soil maps provide an adequate level of detail to evaluate soil properties and determine management concerns; however, despite their quality and public availability, they are not suitable for site-specific management.

SOIL WATER, AERATION AND TEMPERATURE

Soil water

AMBER ANDERSON AND ARTURO FLORES

Learning Objectives

- Describe where water is held in the soil
- Match water potentials to plant growth conditions
- Discuss factors involved in water movement into and throughout the soil
- Predict how water will move given soil conditions or properties

Keywords: soil water potential, plant available water, soil water classification.

Overview

Water is intrinsically related to soil. It is a crucial resource for life, and an essential component of soil. Soil water is the content of water in an unsaturated system (also, the vadose zone), that is, the soil above the groundwater or the water table. Of particular importance is the nature of water and its interaction with the soil particles.

Water is held in the soil because of hydrogen bonding between water molecules and electronegatively charged soil particles (Gardiner and Miller, 1998). The water molecules consist of two hydrogen atoms and one oxygen. The way the atoms are arranged causes one side to be more negatively charged than the opposite, creating a polar molecule (Gardiner and Miller, 1998). The positively charged hydrogens ($H+$) are attracted to oxygens from other water molecules and/or to oxygens on the surface of the soil minerals and organic matter. Adhesion is the bonding between water molecules and solid particles. Cohesion is the ability of water to bond to other water molecules. The combination of these forces results in the capillary suction of a soil, which refers to the ability of water to move through the soil pores without the assistance of external forces, that is, in opposition to gravity.

Water flow is directly dependent on the soil texture and its pore distribution. First, water enters the soil by infiltrating through the soil surface, and then it percolates through the profile. For instance, water flow is faster with more granular and sandy soil than when the profile has a platy structure and heavier texture (clay). Several factors may be used to indirectly evaluate the hydraulic conductivity. However, for the purpose of understanding soil water content, the pore space is one of the main driving factors.

Soil porosity is classified according to the size of the individual pores. It is important to remember that water is held in between the soil particles due to the combination of adhesive and cohesive bonds. Capillary pores or micropores are the smallest of the system; mesopores are medium size; and macropores the biggest of all. Well-structured soils have an ideal pore distribution where micropores exist within the soil aggregates and larger pores in between aggregates (Schoonover and Crim, 2015).

Water potential

The **water potential** refers to the ability of water to do work and it could be an indirect measure of plant available water. It is measured in kilopascals or bars, and it is commonly expressed with negative value because water held in the soil has limited energy to freely move or react when compared to that of a saturated system (a pool for example). Water movement within the soil is limited by adsorption forces, solute or salt concentration, pressure, and gravity. The **total water potential** considers the effect of the following factors, and plants must overcome this tension to uptake water:

- **Matric potential**: water adsorbed to the surface of soil particles, or the one held in hygroscopic pores, has less potential energy. The matric potential is an indicator of the adsorption or retention force that the soil exerts over water molecules. In a saturated soil it generally has a value of zero. But, in unsaturated soil water is more tightly held and its value becomes more negative as the soil dryness increases. This means that the more negative the value is, or the higher its absolute value, water is less free and more energy is required to make it available. The matric potential is a measure of how hard water needs to be pulled to take it out of the soil system.
- **Osmotic potential**: the concentration of dissolved solutes or salts in the soil restricts the movement of water, especially if there is a membrane like a plant cell through which water must pass. It is always negative and its absolute value increases with higher loads of solutes. Plants need an extra load of energy to absorb water high in soluble salts.
- **Pressure potential:** pressurized water is more able to do work. Gasses and overhead water columns put pressure over underlying films of water. This causes water to flow faster and further than in a non-pressurized system. The pressure potential is zero when no additional pressure is applied, and it is positive when the system gets pressurized.
- **Gravitational potential:** refers to the effect of gravity on the energy of water. This is calculated based on the vertical position relative to a reference point. It has a positive value when the water is above the reference plane, and a negative value when it is below. For example, if a water reservoir is located 5 meters above-ground the potential energy will be positive, because it can freely flow downward due to gravity pull. The opposite occurs when water wants to be brought to a higher elevation. In this case, extra energy will be required to make it flow upward, and therefore, the gravitational potential will be negative.

Naturally, water is expected to move in favor of the water potential gradient, that is, from high water-potential (wet) regions to lower water-potential (dry) regions. This gradient indicates that water will flow following the difference in potential between two regions. Equilibrium exists when the water potential is equal throughout the system and there is no more water flowing across it.

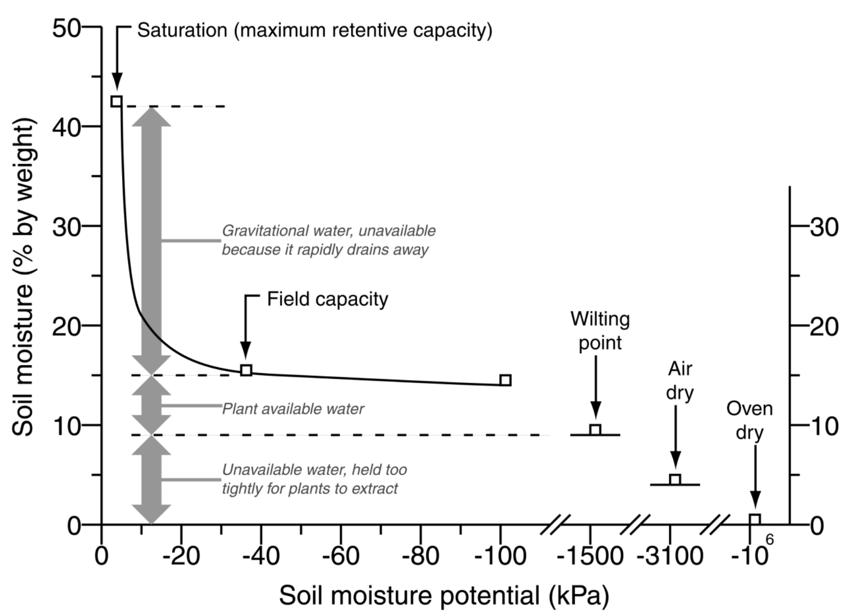
In agriculture, water potential needs to be understood to guide irrigation management and achieve successful yields. The most common method to measure it is with a *tensiometer* (Ochsner, 2024). This is a device with a ceramic cup on one end that is connected to a water reservoir and a pressure gauge. When it is installed in the soil, water flows from the reservoir to the cup, and then out to the soil to equilibrate the moisture content between the cup and the soil. The pressure gauge measures the suction force applied by the soil to pull water out of the ceramic cup (referred to as tension). This occurs because as soil dries down there are more available charges that pull water stronger and closer to the soil's particles, thus, increasing the matric potential. The tensiometer is not affected by solute concentration, it only measures matric potential. Still, for practical purposes, the matric potential is approximately equal to the total water potential (Miller and Gardiner, 1998), and this is a relatively inexpensive and simple device to improve water management decisions such as irrigation timing.

Soil water classification

For practical purposes soil water is classified according to its availability to plants. Soil holds water as films coating soil particles and in the pore space between them. Its availability is directly related to the soil water potential. Water becomes less available when the water potential is higher (more negative values, dry soil), and more available when the water potential is low (less negative, moist soil). In a saturated soil all the pores are filled with water. The water potential at this point is almost zero and it indicates that water flow is not restricted by the matric potential. This occurs after a significant precipitation event and is less dependent on the soil texture. However, the upper horizons do not remain saturated for long and the excess water freely drains away. Drainage takes time and while this happens, plants may used some of this moisture with minimum effort.

The **gravitational water** is that one that drains downward through macropores due to the force of gravity after soil gets saturated. This is temporarily available for plants, there is a low absolute matric potential affecting, and it takes between 24 to 48 hours for it to become negligible. After free drainage the soil remains wet but not saturated, and air occupies pore space, especially that of the macropores. At this point, soil is said to have reached field capacity.

Field capacity is defined as the maximum amount of water that a soil can hold after gravitational drainage (Gardiner and Miller, 1998). Water is held with a tension of -0.1 to -0.3 bar (-10 to -30 kPa), and plants can easily pull it out of the system. The **plant available water** is the moisture content immediately available for plant uptake. Its upper limit is set by the field capacity and the lower limit by the permanent wilting point. Gravitational water is insignificant at field capacity; however, some can still drain but at a much slower rate. Evapotranspiration increases the absolute water potential by reducing the moisture content of the soil and making the remaining less available for plants. The **permanent wilting point** is reached when water is held with a tension that plants cannot overcome, which is about -15 bar (-1,500 kPa). Plants start to wilt and they may not be able to recover their turgor. A considerable amount of water remains in the soil at this point but is not available for plants. The reason for this is that water is held in the soil's micropores, and it is held with a tension that exceeds the plant's ability to remove it. This is called hygroscopic coefficient (also hygroscopic water within capillary pores) and water is held with a tension close to -31 bar (-3,100 kPa).



Soil moisture curve, [Colby Moorberg and David Crouse, 2021]

In practice, plant available water directly depends on the soils texture. Colloidal soil particles (clay and humus) are able to hold more water than sandy soils. In agriculture permanent wilting point should be avoided at all costs to prevent yield reduction. Therefore, soil is allowed to lose only a tolerable percentage of its plant available water before irrigation occurs. This is called **management allowable depletion**. Unlike permanent wilting point that is a set as a function of retention forces, the allowable depletion threshold is set as a function of the crop's tolerance to drought. It is calculated by subtracting a percentage of the plant available water from the field capacity, in terms of tension or volumetric water content. Soil moisture is monitored with soil sensors, like tensiometers, that provide users with an approximation to soil water content. This can be later related to volume of water per volume of bulk soil and help monitor irrigation practices.

Soil water content

Air- and oven-dried soils are two concepts that may be found in literature. These refer to the process applied to reduce the moisture from a soil sample. The air-dry method consists of exposing the sample to ambient air or to room temperature (20 – 25 °C) to let moisture evaporate. This is similar to what will occur naturally in a soil, which is a function of evapotranspiration and gravitational drainage. A thin film of water still remains in the air-dry soil, but it is not readily available for plant uptake. This indicates the water held with a tension of -31 bar (-3,100 kPa) and may be associated with the permanent wilting point. The oven-dry process puts soil in an oven at a temperature between 100 – 110 °C until weight remains constant. The extra energy applied to evaporate moisture from the sample makes the remaining water content be held to a tension up to -100 bar (-10,000 kPa). This process is applied to soil samples when further laboratory analysis is desired, such as particle density or nutrient extraction. Extra temperature applied beyond the recommended ones may risk the composition of the sample, altering the soil's mineralogy and organic matter content. This could be a problem if chemical analysis are performed afterwards. Both of these methods are disruptive procedures, do not allow repeatability, and require time and equipment, limiting its applicability for practical purposes (e.g., crop production).

Another way of communicating soil water content is on a mass or volume basis. Direct measurements include gravimetric (θg) and volumetric water content (θv). The gravimetric method measures the mass of water in a given mass of oven-dry soil (g g^{-1}). The mass of water is the difference in weight between the soil sample before and after drying it in an oven. The volumetric water instead indicates the volume of water contained in a given volume of dry soil. This is calculated by multiplying the gravimetric water content by the bulk density of the soil, assuming that the water density equals 1 g cm^{-3}. It can be expressed as unitless decimals (cm3 cm^{-3}), or as a percentage if multiplied by 100. Additionally, the thickness or depth of water in a soil layer is given as the soil water storage. This one is calculated by multiplying the volumetric water content by the depth of the soil layer (e.g., rooting depth).

In agriculture a popular instrument to measure the volumetric water is called TDR (*Time Domain Reflectometry).* This device sends an electric signal through some metal probes of known length that are inserted into the soil, and measures the speed at which they travel. The time it takes the signal to go back and forth across the probe is proportional to the dielectrical constant of the soil, in drier soil it takes longer than under wetter conditions. The process is more complex than what is explained here, but the advantage of these devices over soil-drying methods is that they allow for instantly repeating measurements at the same location without disturbing the surface. In the golf industry TDRs include also electrical conductivity and temperature sensors that increase the level of detail for managers to take more accurate decisions.

Soil water demonstration

Watch this overview video at: https://youtu.be/m4iHBy5PNY4

References

Miller, R.W. & Gardiner, D.T. 1998. *Soils in our environment.* Prentice Hall. 8th edition. ISBN 0136108822.

Ochsner, T.E. 2024. *Rain or shine An introduction to soil physical properties and processes.* Department of Plant and Soil Sciences, Oklahoma State University.

Schoonover, J.E. and Crim, J.F. (2015), An Introduction to Soil Concepts and the Role of Soils in Watershed Management. Journal of Contemporary Water Research & Education, 154: 21-47. https://doi.org/10.1111/j.1936-704X.2015.03186.x

Key Takeaways

- Water is held in the soil as a result of cohesion and adhesion forces.
- The soil water potential indicates the strength or energy required to remove water from the soil, and it is an indirect measurement of water availability.
- Plant available water is the difference between field capacity and permanent wilting point, and it is readily available for plant uptake.
- Water content may be communicated either as gravimetric or volumetric water content.

Infiltration and permeability

AMBER ANDERSON

Learning Objectives

- Identify factors influencing infiltration and permeability
- Predict how a soil difference, either management or natural, might impact permeability or infiltration rates

Keywords: Infiltration, permeability

Overview from the NRCS

Watch the video at: https://www.youtube.com/watch?v=vmo0FRAVgkM

As seen in the video or during any rainfall, a raindrop hits the ground with significant force. This force could dislodge the particles, leading to runoff and erosion discussed in the following chapters, or it could enter (infiltrate) and move through the soil (soil permeability or hydraulic conductivity).

Infiltration and percolation are two concepts that describe the rate at which water moves into the soil (infiltration) and through the soil profile, vertically and horizontally (percolation). And permeability explains how well water can move through the porous media or the soil.

Water movement in soil video:

This video shows water movement in soil with contrasting particles or other changing scenarios.

Watch the video at: https://www.youtube.com/watch?v=ego2FkuQwxc

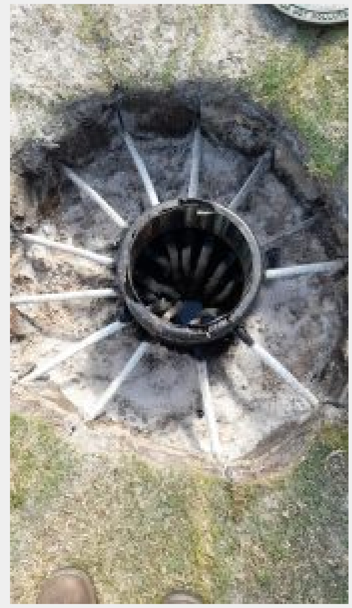
Check it out!

You can measure infiltration in your own field or yard using this method [PDF][1]

Check out more information about infiltration here [PDF][2]

Watch this overview video at: https://youtu.be/XSOWxaW4JG8

Examples



Passive Capillary drainage in a saturated soil in Florida. Picture by: Arturo Flores.

Capillary movement is the water movement through the soil profile thanks to adhesivity and cohesion forces. Adhesion forces allow water molecules to stick together, and cohesion describe the attraction force that bonds water to other surrounding particles different from water (eg., soil particles). Based in this principle, PC-Drainage (passive capillary drainage) is a modern technology being implemented in golf courses.

As the picture shows, rope is buried underground all around the main basin. This rope is porous material with a hollow stainless-steel mesh core that transports water to the basin. When the rope is installed, a layer of sand is poured on top, this creates a different texture barrier that makes water percolate deeper faster than laterally, increasing the water captured by the rope. This method is widely used in golf courses because its installation does not require digging deep trenches for conventional pipe, allowing golfers to play right after its installation. Also, the porous media replaces the conventional tile drainage that is easily clogged with fine soil particles, like silt.

Key Takeaways

- Texture, structure, residue, and crusting influence infiltration or how water move into a soil
- Texture, structure, contrasting particle sizes influence permeability or how water moves through a soil

1. https://www.nrcs.usda.gov/sites/default/files/2022-11/Infiltration%20-%20Soil%20Health%20Guide_0.pdf
2. https://www.nrcs.usda.gov/sites/default/files/2022-10/Infiltration.pdf

SOIL BIOLOGY

Soil organic matter

AMBER ANDERSON

Learning Objectives

- Discuss importance of organic matter in the soil
- Identify mechanisms of addition or loss
- Predict a management change's impact on soil organic matter

Keywords: humus, organic matter

Carbon cycle

Carbon dioxide is all around us, but plants convert that carbon into organic forms and remove it from the atmosphere. The soil is a significant storehouse for previous generation's carbon, in a variety of different forms.

Organic matter

The term 'organic matter' is used to refer to things consisting of organic carbon-so anything that was alive. However, not all of these components are equal when considering function in soil. Some materials break down rapidly, releasing nutrients within a few months or years, while some carbon contained in organic structures have been in the soil for hundreds of years.

Impact on soil properties

Darker soil colors generally correlate to higher levels of organic matter in the soil. Organic matter is also helpful in other soil properties, such as nutrient and water holding capacity, resistance to compaction, and soil structure.

Check it out!

- Check out the NRCS discussion on Organic Matter value in soil here
- Carbon cycle

Decomposition

Decomposition rates vary based on soil conditions. As you make the environment more favorable for various microbes, decomposition will increase. Therefore, the most significant deposits of organic material are found where decomposition is slowed or stopped, but plant growth or other addition still occurs. One place might be a wetland-where anaerobic conditions slow decomposition, but water-tolerant plant species or even organisms like mosses are adding to the carbon pool.

- **Oxygen:** Anaerobic conditions decrease microbial activity and efficiency, so decomposition slows down significantly in these circumstances.
- **Food source:** In addition to being present, the food source will influence the rate of decomposition. For example, materials with large amounts of carbon per unit nitrogen-like wood-are harder to break down than fresh grass clippings.
- **Temperature:** Microbial activity, and therefore decomposition, is generally highest in the moderate temperatures.

Organic Matter Accumulation in the Rainforest

Organic matter accumulation in the tropical rainforest. Picture by: Arturo Flores

Waterlogged soil in Costa Rica. Picture by: Arturo Flores

The first picture shows a thick layer of leaves accumulated on the soil. The exuberant vegetation is constantly growing throughout the year and rarely reduces its biomass production. The second picture shows how soils tend to be underwater when high precipitation events occur in a short period of time. It is possible to see how the organic matter is submerged with little to non-decomposition at all. High environmental humidity and waterlogged soils have low decomposition rates as microbial activity is limited. Also, the constant accumulation of new materials buries the old materials, and the process of decomposition starts again. However, it is important to know that although the soil might appear to have a high organic matter content, this is not completely true. Of more importance is the active soil organic matter, which has already been decomposed to some degree and actively contributes to the soil properties, such as in CEC and physical aggregation.

For further thought:

Think about a compost pile. What happens when only leaves are there? What happens if you add a pile of fresh greens (or leave them out on your counter/in the bottom of the fridge for too long)?

Exercises

Assume that a 2 million pound acre furrow slice of soil (an acre to approximately 6 2/3″) contains 5% organic matter. How many pounds of organic matter exist in the area?

(2,000,000 x 0.05)

Since organic matter contains approximately 5% nitrogen, how much nitrogen is contained within that organic matter? To get this answer, we would take the previous question's answer, as that is how much organic matter is contained in the acre furrow slice and multiply by the percent nitrogen.

(100,000 x 0.05)

If 3% of this was released per year, about how many pounds could be released? To get this answer, we would take the previous answer (lbs of nitrogen) and multiply by the amount released per year.

(5,000 x 0.03)

Key Takeaways

- The soil is an important carbon store
- Soil organic matter has a variety of benefits in the soil
- Management decisions impact organic matter levels and distribution

Soil life

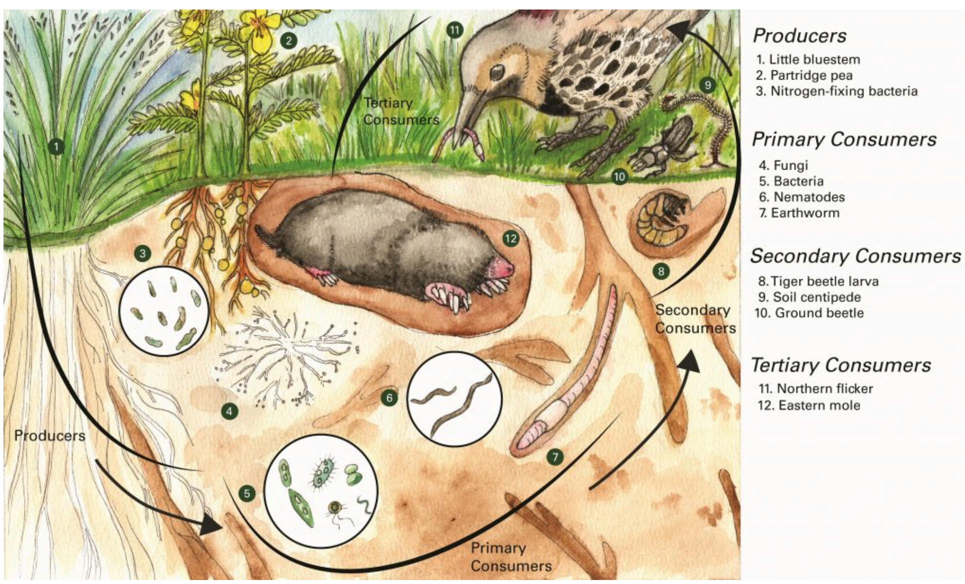
COLE DUTTER

Learning Objectives

- Explain the importance of soil life
- Compare major classes of organisms found in the soil
- Identify interactions of other soil properties and organisms
- Predict impacts of a management decision on soil organisms

Keywords: primary producers, primary consumers, secondary consumers, ecosystem engineers, symbiosis, rhizobacteria, mycorrhizae, rhizobium

Soil Life is important for the breakdown and stabilization of organic matter, breakdown of toxic compounds, nitrogen fixation and nutrient cycling.



Click to enlarge the image

Primary Producers

Primary producers is the term used for organisms that use energy from the sun to create organic molecules (autotrophs). Vascular plants are the most commonly known form of primary producers, however in the soil, other primary producers are mosses, algae, and certain photosynthesizing bacteria. Primary producers hold a central role in soil due to their importance to synthesize and produce new compounds and introduce them to the soil environment. In other words, they are the base of the food web.

Primary Consumers

Primary consumers are organisms that feed off of the primary producers. Some may try to term these organisms herbivores, but that is only a portion of the group considered primary consumers. Herbivores are organisms that eat live plants and contain parasitic nematodes, insect larva, ants, and larger vertebrates. Detritivores are organisms that consume debris from live tissue. Detritivores include larger mesofauna: springtails and mites. A third group is the saprophytic microorganisms. These microorganisms consume dead tissue and include bacteria and fungi. These consumers' purpose is to break down (decompose) plant and animal tissue and begin to facilitate the cycling of nutrients.

Secondary and Tertiary Consumers

Secondary and tertiary consumers are the predators of the soil, they feed off of other consumers. These consumers include bacteria, fungi, and larger fauna considered carnivores (centipedes, nematodes, snails, etc.). This group can also contain parasites of other animals. This group is titled after the old "food chain" paradigm, thus we distinguish between secondary and tertiary consumers. In the newer paradigm of the "food web" there is less distinction between these two groups. This group helps cycle the nutrients that are stored in the primary consumer group.

Ecosystem Engineers

Ecosystem engineers are larger animals that are capable of altering the physical environment that influence other soil fauna habitat. In the Midwest, these are primarily burrowing animals such as ants, worms, or gophers. These animals affect air and water movement through the soil, as well as create channels for plant roots.

Not all earthworms help the soil: Check out this study!

Invasive earthworms erode soil biodiversity: A meta-analysis

Producer Consumer Symbiosis

Symbiotic relationships occur between the plants and microbes because they are both benefiting from each other. The plant is able to provide a food source and home for the microbes and, in exchange, the microbes provide the plant with nutrients it requires.

Soil fungi that have formed symbiotic relationships with plants is one of the most economically important groups of soil organisms. **Mycorrhizae** have been studied for benefits such as increased drought tolerance and increased phosphorus uptake in crops. Mycorrhizal fungi also help soil structure by contributing to aggregation through the production of glomalin.

Rhizobium or Bradyrhizobium bacteria species are best known for their relationships with legumes. These species are not generalists but are either host specific or have a range of hosts, however they do not inoculate all legume species. These species are responsible for the root nodules on legumes that fix nitrogen. Fixing nitrogen is a critical function because it takes nitrogen from the air and makes it available for the plants to use.

Rhizobacteria is a term for the bacteria that have adapted to living along the root surface. These species are the most common symbiosis, yet are seldom studied. The root surface becomes so encrusted with bacteria that little soil actually interacts with the root without some intervening microbial influence. These species assist in cycling nutrients near the root, including nitrogen. Rhizobium are the face of nitrogen fixation yet Rhizobacteria also help supply nitrogen to the plant as well.

There are also pathogenic species as well! Sudden Oak Death is a Phytophthora species that kills trees. Named for the fact that early victims of this disease were oaks, this species can also prey on agriculturally important species such as Almonds. Sudden Death Syndrome is caused by a Fusarium species and is common in soybeans. Phytophthora and Fusarium are two genera that contain many diseases that attack economically important plants. Examples include: damping off disease, root and stem rot, crown rot, fusarium wilt, and fruit rot. These diseases are commonly controlled through crop rotation and planting resistant varieties.

Management and Soil Life

Soil life, in general, needs two things to thrive: minimized disturbances and an adequate food source. In terms of management this means that practices that increase soil organic matter, decrease erosion, and increase soil structure are the key to increasing microbial communities and thus nutrient cycling. This can take many forms but there are two easy management practices that fulfill this: no-till and cover crops. Generally speaking, it can be said that "life creates life." One interpretation of this is that the more plants there are on the ground, the more microbial activity there is in the ground. In California, farmers are often concerned with weeds competing for water with the crop. Which leads to the implementation of strip spraying (pictured below).

Removing the plants around the trees may reduce the amount water used, but it also reduces the amount of nutrients cycled near the tree in the early years of the orchard. As a consequence of this, many nutrients need to be applied either by pelletized fertilizer or foliar application. Similarly cover crops may cost the farmer a little more, but the plants contributions to microbial food sources or food complexity is important for a sustained robust microbial community.

Soil aggregation, facilitated by no-till agriculture, is not simply for better drainage and less erosion. Soil aggregation is important for niche complexity within the soil environment. Niche complexity allows for community complexity. Soil life, much like all forms of life, is not homogenous. Certain microbes may do well in saturated soils, others like drier spaces. A stable aggregate allows for the microbes to find their niche, the moisture desiring microbe will colonize the outside of the aggregate while the other will colonize the interior of the aggregate.

Disease pressure in the soil can be tricky to manage, however, one of the best methods to simply manage it is to rotate crops or plant resistant varieties. Soil fumigants can be used but commonly are expensive and difficult to employ. In California, the threat of nematodes have caused farmers to fumigate their fields with methyl bromide. This procedure was effective for two reasons, the farmers deep rip the field to open up the soil and the soil texture is sand to sandy loam. This allowed for effective use of the fumigants. Methyl bromide has now been phased out and farmers are struggling to find effective fumigants for the soil borne diseases. The new fumigants are targeted towards specific pests within the soil and are not generalists. While farmers complain about the ineffectiveness of the new fumigants, the overall effect will be for a healthier soil.

Key Takeaways

- Soil Life is important for a variety of reasons:
  - Breakdown and stabilization of organic matter
  - Breakdown of toxic compounds
  - Nitrogen fixation
  - Nutrient uptake and cycling
- Mycorrhizal associations with plants influence:
  - Drought tolerance
  - Nutrient uptake
  - Soil Structure
- Management effects soil life in three ways:
  - Food sources
  - Disturbances
  - Disease cycles

SOIL CHEMISTRY AND MINEROLOGY

Importance of Soil Chemical Properties

RIVKA FIDEL

Learning Objectives

- Define: pH, EC, solution
- Explain the importance of soil chemical properties and surfaces
- Sort the solution, surfaces, and solids in order of relative chemical reaction rates

Why are soil chemical properties important?

Soil chemical properties have widespread impacts on countless soil processes, and therefore their importance cannot be overstated. The chemicals in soil, from solid minerals to nutrients and other salts in solution, affect not only plant growth and microbial diversity but also soil greenhouse gas emissions and the transport and breakdown rate of nearly any chemical from nutrients to hazardous substances. Therefore, understanding soil chemistry is vital to understanding and managing soil.

Chemicals are found everywhere in the soil – in fact, soil is *made* of chemicals. As such, soil contains countless chemicals, reacting with each other constantly. The enormous diversity of both chemicals and their reactions in soil can become quite overwhelming but becomes much more understandable when we organize them according to phase: **solids**, **liquids** (here, **aqueous solutions**), and **gases**. Of particular importance in this course are the solids and liquids, and their interactions at the **solid-solution interface**.

Soil Solids

You may recall that an average soil is about 50% solid particles, where some of these are mineral and some are organic. In soil science, minerals are **inorganic**, meaning they do not contain carbon (with the major exception of carbonates). **Organic** particles on the other hand, do contain carbon – specifically carbon atoms bonded to other carbon atoms, or to hydrogen atoms (thus, carbonates are excluded, as CO_3^{2-} has only C-O bonds).

Minerals are important not only for providing nutrients as they **weather** and dissolve, but also for providing structure to the soil and surfaces for other chemicals to adhere or "adsorb" to (more on this later). Some minerals weather faster, whereas others resist weathering, and as such their chemical properties affect the overall rate of soil formation.

Organic particles release nutrients into the solution as they break down during the **decomposition** process (distinct from weathering, see Soil Life or Soil Organic Matter chapter). Organic matter also has a very high surface area and water holding capacity, helping it to hold onto water and nutrients.

Both mineral and organic particles are found in a wide range of sizes, from >2 mm down to less than 1 micron (that's 0.001 mm). Different size fractions of these particles behave differently in soil, especially in the way they affect the soil solution.

The Soil Solution

The soil **solution** is all liquid water within the soil and the solutes dissolved within. Solutes include ions, as well as neutrally charged species like sugars and select acids and bases. Gases such as carbon dioxide (CO_2) and oxygen (O_2) can also dissolve into the solution and react with other solutes, as well as water. During the dissolution process, each molecule of solute is surrounded by water molecules, affecting the behavior of the overall solution.

Review: what is a solution?

A solution is a **homogenous** mixture that is made when a solid or gas has dissolved into a liquid. During **dissolution**, liquid molecules completely surround each molecule of solid (or gas). For example, when table salt (NaCl) dissolves, each Na^+ ion is fully surrounded by a sphere of water, and so is each Cl^-.

In figure **x**, notice how each dissolved molecule of the solid (red) becomes fully surrounded by water molecules (blue).

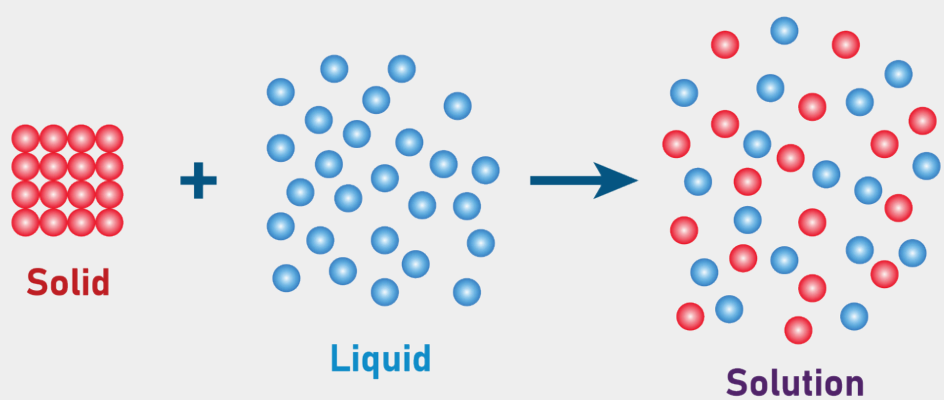


***Figure x** Diagram showing how dissolving a solid in a liquid creates a solution. [from Adobe Stock images*

In soil, solid mineral salts like $CaCO_3$, $CaSO_4$ and NaCl are relatively soluble and therefore dissolve readily, becoming part of the soil solution in most soils (albeit at widely varying concentrations depending on the soil's mineral composition and formation factors). Greenhouse gases like carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), as products of microbial metabolism, are nearly ubiquitous in soils.

Because solids react very slowly compared to solutes and liquids, and because water is required for most reactions, the solution is where the majority of soil reactions occur. Thus, soil solution properties dramatically affect soil reactions.

Three very important soil solution properties that have cascading effects on soil behavior are pH, redox status, and electrical conductivity. We'll discuss these further in other chapters, but here is a brief overview for now:

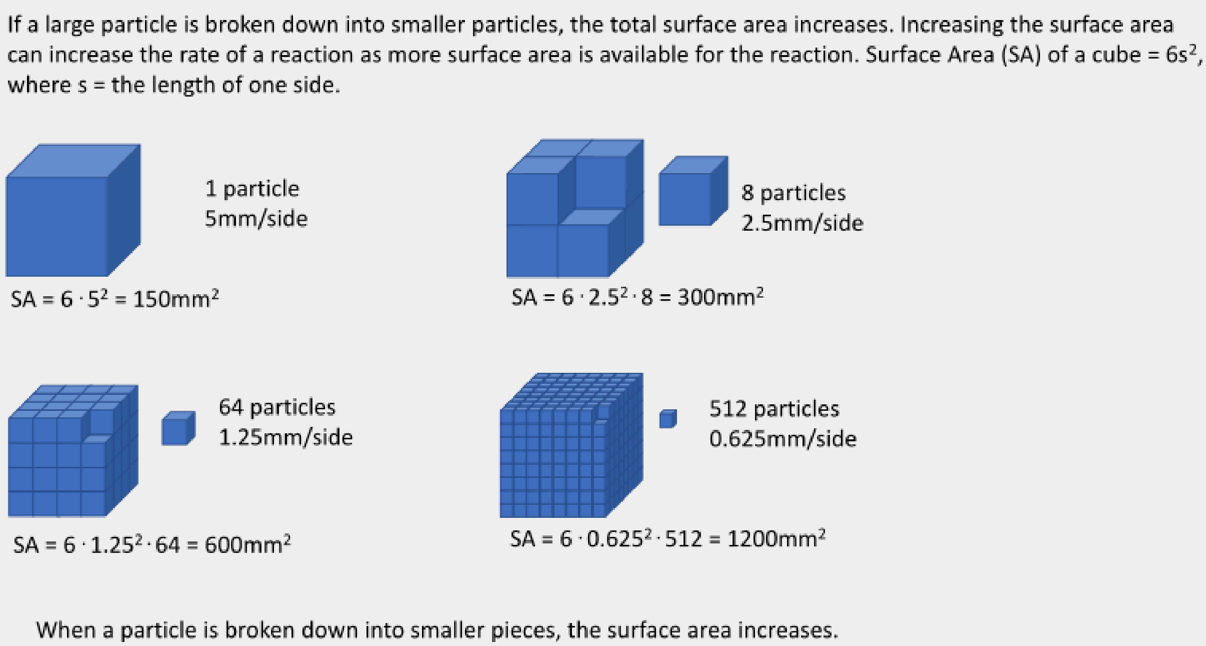
- Soil **pH**, an measure of soil acidity and basicity that is calculated as the negative log of the hydrogen ion concentration: *pH = -log[H]*
- **Redox status**, as measured by redox potential (Eh), [O_2], or [CO_2].
- Redox reactions are greatly influenced by the amount of oxygen and other oxidizing agents in soil such as nitrate.
- Soil **redox potential** (**Eh**) is a measure of the electrical potential of soil due to the tendency of the chemicals within it to donate or accept electrons. The more oxygen present, for example, the more important nutrients like nitrogen and iron can become oxidized by donating an electron to oxygen.
- **Electrical conductivity** (EC), a measure of how easily electrons can flow through soil.
- EC is directly proportional to the total concentration of ions in solution, and thus EC is a good measure of **salinity** or soil "saltiness." Salinity affects numerous soil properties such as aggregation, infiltration, and drainage. It also affects soil osmotic potential and therefore water uptake by plants.
- The total ion concentration in soil also affects reaction rates, but that is beyond the scope of this class. See [LINK].

Soil Surfaces: The Solid-Solution Interface

Due to the very slow reaction rates of solids, the vast majority of reactions with solids occur at the *solid-solution interface*, aka the **surfaces** of soil particles where they meet soil water. These reactions include dissolution of the solids into the solution, precipitation of new solids onto the solution, and adsorption of solutes onto surfaces. (This one of the reasons why particle size and **surface area** are so important in soil science – see below review box for more details).

You can picture **adsorption** as the "sticking" or adherence of solutes to solid particle surfaces. Nutrients and contaminants alike can both adsorb to soil particle surfaces, enabling soil to retain nutrients for plants while keeping contaminants out of the groundwater. Thus, soil surfaces support three important soil ecosystem services: supporting plant growth, providing nutrients, and filtering water. We will learn how this works in upcoming chapters.

Review: Surface Area & Particle Size Relationships



Key Takeaways

- Soil chemical properties affect the soil's ability to provide important ecosystem services such as supporting plant growth and filtering water.
- Important soil chemicals are found in **solids**, the **solution**, and on soil **surfaces** at the *solid-solution interface*.
- Of these, the solution and surfaces are much more reactive than inner portions of solid particles.
- **pH**, **redox status**, and **EC** are all very important soil solution properties that each affect numerous soil behaviors.
- Soil surfaces are unique in enabling **adsorption**, the process by which soil retains nutrients and contaminants. This keeps nutrients in the soil where plants need them while keeping contaminants out of groundwater.

Mineralogy

C. LEE BURRAS

Learning Objectives

- Discuss types of minerals present in the soil.
- Understand the importance of mineralogy for soil science.
- Relate mineralogy with Cation Exchange Capacity

Keywords: minerals, clays, soil mineralogy.

Introduction

Soils are minerals. Even the O horizon of a Histosol is more than 70% minerals on a dry mass basis. In any other soil, minerals account for 95 to even 99.99% of the dry mass. The importance of a given mineral in soil is dependent on its prevalence and, especially, its degree of reactivity. It is important to note that soil minerals can be inherited, lost (e.g., dissolved), gained and/or moved in the profile and the landscape depending on natural and human-controlled processes.

What are minerals?

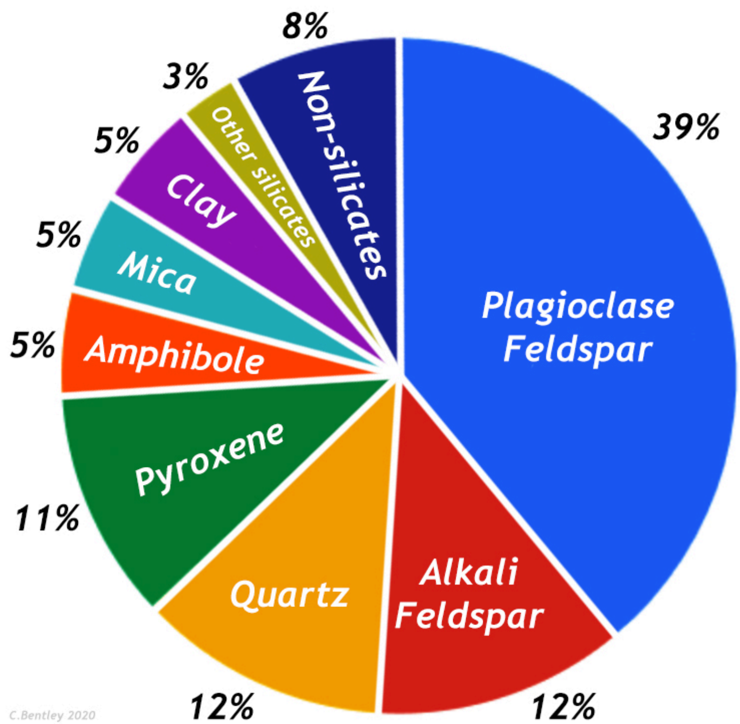
Minerals are crystalline solids. Most are naturally occurring and inorganically formed. Individual minerals ("species") are identified and distinguished from one another based on their chemical composition and atomic framework. Restating that, a mineral cannot be uniquely identified from just its chemical composition even though on a day-to-day basis that is often how they are identified. In reality the atomic lattice is a key feature and must be known. For example, "diamond" and "graphite" are independent isomorphic mineral forms of pure "C", yet – as everyone realizes – they have tremendously different physical and chemical properties. Their isomorphic differences are what control their hugely different value in human societies. Those difference are the function of their bonding strengths across their respective crystalline lattices – aka "atomic frameworks."

Types of minerals

"Calcite" and "aragonite" are more mundane mineral polymorph in soils. Both are composed entirely of "CaCO3" but only calcite is the one commonly found in soil parent materials and calcic horizons. Calcite is also the one mined for ag liming and such. Aragonite is interesting in its own right, though, given it is biologically created mineral. Snails, mollusks, and other gastropods manufacture it into their shells.

Most soils have tens to hundreds of mineral species comprising their solid fabric. Those minerals commonly fall into three common groups: (a) silicates, (b) carbonates and (c) oxides/hydroxides. It is important to note that soil regions in the world also contain significant sulfate, halide and/or phosphate minerals; however, this chapter focuses on the silicates, carbonates and oxides/hydroxides. Two important subgroups within the silicates are the tectosilicates (3D lattice framework of Si-tetrahedrons) and phyllosilicates (2D framework of aluminosilicates comprised of Si-tetrahedral layers bonded to Al- or Mg-octahedral layers – e.g., see Nelson. 2015., Gaston. 2015).

Learn more about soil minerals, their composition, and main functional importance: Soil minerals[1]



"The most abundant minerals in Earth's crust. The crust is dominantly composed of just a few mineral groups, the vast majority of them silicates." *(Callan Bentley 2020, Open Geology Textbook)*

Importance of soil minerals

The importance of a mineral in soil is dependent on its prevalence and/or its degree of reactivity. Prevalence matters because minerals they form the soil's physical framework, accounting for 99.9% of the dry mass in most B and C horizons. In other words, it is the mineral fraction that controls a soil's solid phase characteristics A mineral's reactivity – aka, dynamism – is controlled by its chemical composition, kinetic reactivity, solubility, and/or charge.

There are three pathways whereby a mineral is present in a soil. The most common is inheritance from the parent material. As a result, whatever mechanism that caused the glacial till, loess, volcanic ash, alluvium, colluvium, lava flow – whatever – to be located in a location is what brought or created the original minerals in that soil. The second pathway is some kind of subsequent physical addition. Two common examples of this are aeolian dust and human additions, e.g., ag lime or some fertilizer including fillers within the fertilizer. The third pathway is pedogenesis during which time an inherited or added mineral dynamically changes form.

1. https://iastate.pressbooks.pub/app/uploads/sites/68/2022/02/Soil-minerals-Burras.pdf

The dynamic nature of minerals in soils takes many forms. It can be as simple as hydration – e.g., anhydrite ($CaSO_4$) sorbs (loosely bonds) water molecules onto its surface and creates gypsum ($CaSO_4$*nH20). Hydrolysis is another simple process involving water – e.g., quicklime (CaO) sorbs water molecules, which then split, and the resulting mineral is portlandite ($Ca(OH)_2$). In this process the soil solution gains two H^+, which will at least temporarily acidify the soil solution and likely initiate the weathering of another mineral. Hydration and hydrolysis of feldspars are important steps in the conversion of feldspars into phyllosilicates. More broadly, hydration and hydrolysis of rocks and stones coupled with wetting and drying and/or heating and colling results in large soil solids (think boulders, cobbles and gravel) disintegrating into sand or even silt and clay. Oxidation-reduction reactions are likewise simple reactions that routinely dissolve, form or do both with iron- and manganese-bearing minerals. Carbonation drives change in many minerals whenever carbon dioxide (CO_2) is introduced in the soil solution. An astute reader will immediately realize that plant and microbial life is constantly added CO_2 throughout the root zone with the result always being mineral weathering.

Mineral weathering and CEC

A more commonly discussed example of mineral weathering is that of the phyllosilicates, a.k.a., "clay minerals. Soil weathering of illite routinely causes the interlayer potassium (K^+) to pop out of its atomic lattice and move into soil solution, where it is routinely uptaken by a plant root. The resulting illite crystal has a slight shift in its tetrahedral basal oxygens and has its layer charge from Al-substitution turn immediately into CEC. Without going into huge detail that simple loss of K^+ is the cause of the incredible differences between illite and vermiculite vis-à-vis surface area, CEC and shrink-swell. The vermiculite crystal produced as a result of K^+ removal from illite can be highly stable, or, – depending on the distribution of Al-substitution in the Si-tetrahedrons – can rapidly break into smaller pieces where some of the A^{3+} escapes the atomic lattice. When that happens smectite forms (Burras, 1992). That smectite has huge physical and chemical differences from its vermiculite parent, just as the vermiculite parent differs from its illite parent. Additionally, the smectite being a very small crystal is able to lessivage deeper into the soil profile; thereby, contributing to the formation of an argillic horizon. Alternatively, if the smectite stays in place it can contribute to vertic horizon characteristics.

Returning to the vermiculite, if its layer charge is remains high (e.g., no escape of Al^{3+} at its crystal edges) then the addition of K^+ fertilizers can result in "K-fixation" and the recreation of an Illite crystal. Importantly, if ammonium (NH_4^+) fertilizer is added to that high charge vermiculite then "ammonium fixation" can occur, resulting in a pseudomorph of Illite. Either form of fixation results in less fertilizer nutrient being available than otherwise expected.

To sum the previous paragraphs up, minerals change in soil. They change due to natural processes. They change due to human impacts. Some changes are physical movement. Some changes are chemically driven. Some changes are congruent, which means the complete dissolution of the original mineral. Some changes incongruent, which means the original crystal only partially dissolves, but as a result it turns into a new mineral. In summary, soils are predominately composed of minerals with every one of those minerals prone to change as the soil forms and/or is used by humans. With enough time those changes will drive an incredibly fertile Entisol to become a challenging Ultisol or even an Oxisol.

References

Allen, B.L. and D.S. Fanning. 1983. Composition and Soil Genesis. Chapter 6. In: L.P. Wilding, N.E. Smeck and G.F. Hall (Editors). Pedogenesis and Soil Taxonomy. Volume 1: Concepts and Interactions. Elsivier, Amsterdam. p. 141-193.

Burras, C.L. 1992. Origin of Smectite in Soils of Western Ohio. PhD Dissertation, 334 p. The Ohio State University Library. Available at: https://etd.ohiolink.edu/acprod/odb_etd/etd/r/1501/10?clear=10&p10_accession_num=osu1487777901658994 , reviewed December 07, 2023.

Gaston, L. 2015. Soil Colloids. Agro/EMS 2051. Soil Science. Available at: http://www.agronomy.lsu.edu/courses/agro2051/chap08.htm , reviewed December 07, 2023.

Nelson, S.A. 2015. Phyllosilicates (Micas, Chlorite, Talc, & Serpentine). EENS 2110. Mineralogy. Available at https://www2.tulane.edu/~sanelson/eens211/phyllosilicates.htm , reviewed December 07, 2023.

Key Takeaways

- Soils are mostly minerals.
- In the A horizon, soil mineralogy influences root growth through nutrient dynamics and available water dynamics.
- In the B and C horizons, soil mineralogy controls soil physical and chemical properties.
- Clay mineralogy is especially reactive although all minerals in soil change at least slowly.

Phyllosilicate Colloids and their Surface Chemistry

RIVKA FIDEL

Learning Objectives

Upon completing this chapter, you should be able to:

- Define phyllosilicates
- Explain:
  - the difference between **colloids**, **clays** and **phyllosilicates**
  - the difference between a **2:1** and **1:1** phyllosilicate
  - what happens when phyllosilicates swell and why **swelling** is important
  - where phyllosilicates get their surface charges from
- Match types of charges (permanent and pH-dependent) with their definitions and where they come from

Review of Colloid Types

Recall from the previous chapter that colloids are all particles less than 1 micrometer in diameter, and that there are 4 types:

1. **Crystalline silicate clays** (**phyllosilicates**): layered minerals containing SiO_4
2. **Poorly crystalline silicates**: sphere and tube-shaped minerals containing SiO_4
3. **Oxides and hydroxides:** highly weathered minerals containing O^{2-}, OH^-, and OOH^{3-}, bonded to transition and post-transition metals (mainly Fe and Al)
4. **Organic colloids:** particles of biological origin <1 μm in size that contain C-H and/or C-C bonds, also called "colloidal humus"

Here we will focus on the first type, **crystalline silicate clays**. The remaining types will be discussed in the next chapter.

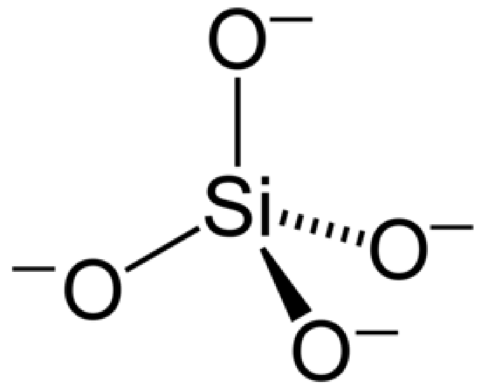
Crystalline Silicate Clays (Phyllosilicates)

Crystalline silicate clays are the most abundant colloids in most soils, and have a disproportionate effect on soil properties. We've learned that the term "clay" can refer to any mineral particle less than 2 μm in diameter. The majority of these clay particles are **crystalline silicate clays**, also known as **phyllosilicates**. From Greek, "phyllo-

" refers to layer, and "silicate" refers to SiO_4^{2-}. As reflected in their two names, these important minerals have 3 main properties:

- **Crystalline**: all phyllosilicates have atoms arranged in a regular, near-infinitely repeating structure
- **Layers**: the crystal structure of phyllosilicates is arranged in flat, paper-like layers
- **Silicate**: phyllosilicates all contain **silicate tetrahedra**. Each **tetrahedron** has the formula SiO_4^{2-}, but since oxygens are shared, the stoichiometric formula of silicate is frequently written as SiO_2 (this is the formula of quartz for example, the dominant mineral in most sand particles).

Baklava is made from phyllo dough, which has layers just like phyllosilicates. The prefix "phyllo-" stands for "layers" in Geology, and is Greek for "leaf" (as in having a thin, leaf-like shape). Geologists adapted the term in modern times, as each layer is thin and broad like an average leaf.



*A **silicate tetrahedron**. When the oxygens are not bonded to other silicon atoms, it bears a 4- charge. When all oxygens are bonded to other silicon atoms, it becomes neutral.*

Check it Out

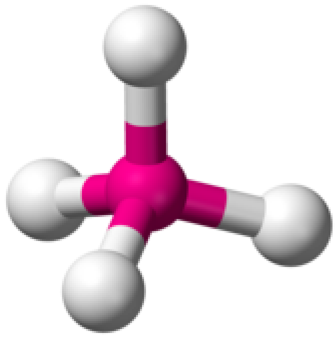
More on silicate minerals in general can be found in *Physical Geology*, "5.4 Silicate Minerals"[1]

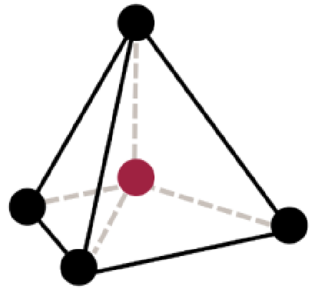
Phyllosilicate sheets and layering patterns

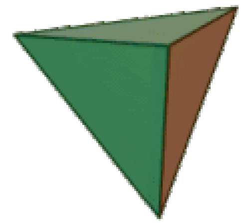
Phyllosilicates, also known as "layer clays," can be classified according to their layering pattern and chemical composition. Layering patterns are defined by how tetrahedral and octahedral sheets are arranged.

Tetrahedral sheets are composed primarily of **silicate tetrahedra**, SiO_4^{2-}. In each tetrahedron, the Si is at the center, and is bonded to 4 oxygens arranged in a pyramid-like shape with a triangular base. These can be drawn in various ways.

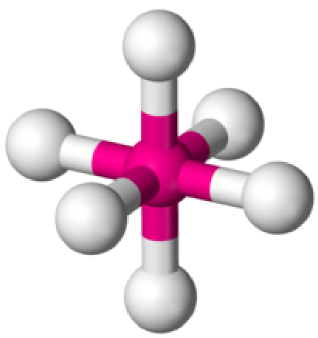
1. https://openpress.usask.ca/physicalgeology/chapter/5-4-silicate-minerals-2/

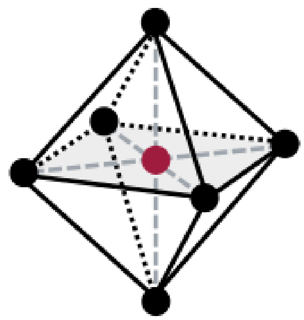

Ball and stick model of a tetrahedron

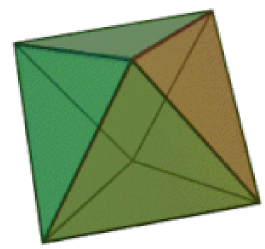

Combination ball & stick and geometric model of a tetrahedron


Animated geometric model of a tetrahedron

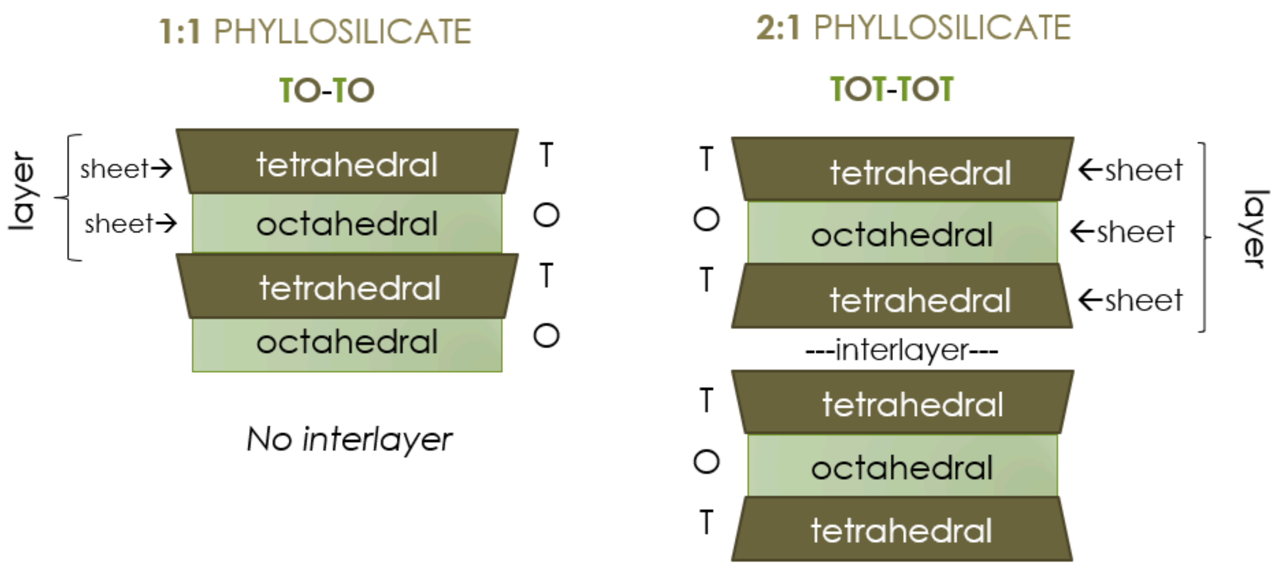
Octahedral sheets are composed primarily of aluminum and magnesium octahedra. In each **octahedron**, the aluminum or magnesium is located at the center, and is bonded to 8 oxygens. The overall shape resembles two pyramids with square bases, fused at the base.


Ball and stick model of an octahedron


Octahedron drawn using a combination ball and stick model with geometric outline

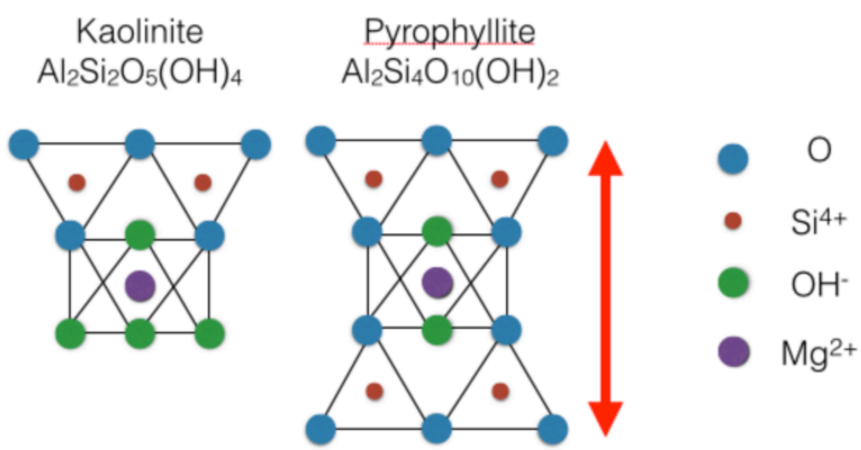

Animated geometric model of an octahedron [Original author Kjell André, cropping by Stigmatella aurantiaca | CC BY-SA]

The two main patterns that these sheets arrange into as minerals form are 1:1 and 2:1. In **1:1 phyllosilicates**, there is a one-to-one ratio of tetrahedral sheets to octahedral sheets. These alternate one after the other: tetrahedral, octahedral, tetrahedral, octahedral and so forth (try abbreviating this as TO-TO in your notes). Each layer contains one tetrahedral sheet and one octahedral sheet. In **2:1 phyllosilicates**, there is a two-to-one ratio of tetrahedral sheets to octahedral sheets. These alternate in the order tetrahedral, octahedral, tetrahedral (try abbreviating this as TOT-TOT in your notes). Thus, each layer of a 2:1 phyllosilicate has 3 sheets. In between each 3-sheet layer is an **interlayer**, a space where ions and frequently also water can be found, depending on the mineral in question.



Phyllosilicates (layer clays) structure comparison between 1:1 and 2:1 layer patterns. Notice how trapezoids represent tetrahedral sheets, and rectangles represent octahedral sheets. This is a convention among simplified drawings that don't show atoms or bonds. [Image Credit Rivka Fidel. CC BY-SA.]

The below figure shows how atoms are arranged in these sheets of two example phyllosilicates. Notice how the oxygens in each tetrahedral sheet are shared with oxygens in the adjacent octahedral sheet.



Structure of a 1:1 phyllosilicate clay, kaolinite (T-O) and a 2:1 phyllosilicate clay, pyrophyllite (T-O-T). The red arrow represents the Z dimension. T-O-T clays are naturally larger in the Z direction because of the extra layer provided by the additional tetrahedral layer. Each silicon is bonded to 4 oxygens and each magnesium is bonded to 8 oxygens, but the some atoms block each other so not all are visible. Note that kaolinite is common in soil, but pyrophyllite is not.

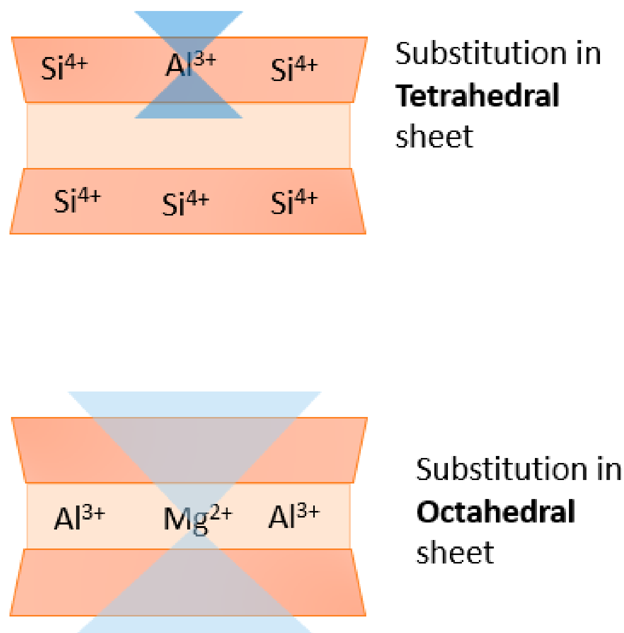
Sources of charge in phyllosilicates

Charges of phyllosilicates and other colloids are very important because opposite charges attract. A negative surface charge will attract positively charge ions (**cations**), and a positive surface charge will attract negatively charged ions (**anions**). Many important plant nutrients like NH_4^+ and K^+ are present as cations in soil, whereas others such as NO_3^- and SO_4^{2-} are anions. **Surface charge sites**, places on colloid or clay surfaces where such ion-attracting unbalanced surface charges occur, develop on both inorganic and organic particles. Typically, these charges are only significant among clay and colloid-sized particles, whereas sand and silt contribute negligible charge due to their low surface area and chemical composition (namely their tendency to be enriched in tectosilicates like quartz and feldspar that have fewer unsatisfied charges per unit surface area).

In phyllosilicates, surface charge sites develop inside clay mineral structures during isomorphous substitution, and at crystal edges that form during physical weathering. These processes result in two different types of charge: permanent charge, and pH-dependent charge.

Permanent charge inside minerals from isomorphous substitution

During the initial formation of phyllosilicates, a process called isomorphous substitution creates what is known as permanent charge inside phyllosilicate crystal structures. In **isomorphous substitution** (or *isomorphic substitution*), a cation of similar size but less positive charge comes in from the solution and replaces the original cation found in the mineral's crystal structure. The name comes from "*iso-*" meaning same, and "*-morph*" meaning shape. Because this substitution occurs when a mineral first forms (*not* during weathering), the degree and location of isomorphous substitution is one of the defining features used to classify phyllosilicates.



The substitution shown here (+3 instead of +4, or +2 instead of a +3) results in a net negative charge. Since the substituted elements responsible for the charge are not on the surface, they cannot react with H+ in the soil solution.

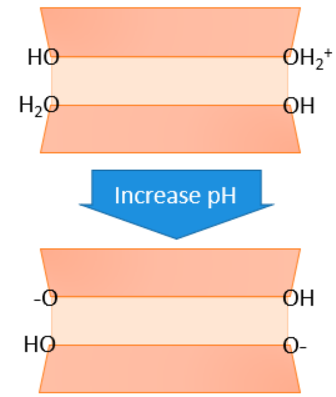
In **tetrahedral** sheets, Al^{3+} commonly substitutes for Si^{4+}. As a result, a Si tetrahedron would become an Al tetrahedron. Because Al^{3+} has a less positive charge than Si^{4+}, the overall charge of the tetrahedron becomes more negative by one unit of charge. Thus, the originally neutral tetrahedron will develop an overall -1 charge.

In **octahedral** sheets, Mg^{2+} commonly substitutes for Al^{3+}. Consequently, an Al octahedron would become a Mg octahedron. Like in the tetrahedron earlier, the Mg^{2+} has a less positive charge than Al^{3+}, so the octahedron's overall charge would decrease by 1, resulting in an overall -1 charge.

In both cases, isomorphous substitution occurs inside a sheet, and so the substituted atoms are *not* in contact with the solution. Thus, the charges that isomorphous substitution creates stay the same despite fluctuations in solution pH and are hence called **permanent charges**.

pH-dependent charge at crystal edges

On edges, oxygens (O's) are not shared, so without an additional bond to share electrons, charges may develop there. Essentially, cleavage of the phyllosilicate crystals at these edges breaks chemical bonds and leaves oxygens unable to share electrons with adjacent metals or metalloids (Si, Al, Mg, or Fe primarily). This creates an unsatisfied negative charge not being balanced by nearby elements. These edge charges are in contact with the solution, and hence can attract H^+ ions when the pH is low. These H^+ bind strongly to the surface, becoming part of the surface, and making the overall surface charge more positive (less negative). For this reason, these sites at the broken mineral edges carry what is called **pH-dependent charge** or **variable charge**. This type of charge is found in all minerals, but tends to be greatest in 1:1 phyllosilicates and oxides/hydroxides of iron and aluminum. We'll revisit this in the chapters on cation exchange and anion exchange.



As pH increases, oxygens at phyllosilicate edges donate H^+ to the solution, resulting in a more negative charge.

Key Takeaways

- **Colloids** are particles less than 1 micrometer in diameter, whereas **clays** are particles less than 2 micrometers in diameter
- **Phyllosilicates** are "layer clays", or crystalline silicate clays. These important minerals have 3 key properties:
    - **Crystalline**: all phyllosilicates have atoms arranged in a regular, near-infinitely repeating structure
    - **Layers**: the crystal structure of phyllosilicates is arranged in flat, paper-like layers
    - **Silicate**: phyllosilicates all contain **silicate tetrahedra**. Each **tetrahedron** has the formula SiO_4^{2-}, but since oxygens are shared, the stoichiometric formula of silicate is frequently written as SiO_2 (this is the formula of quartz for example, the dominant mineral in most sand particles).
- **2:1 phyllosilicates** have (1) a tetrahedral-octahedral-tetrahedral layer pattern, and (2) an interlayer containing cations, and frequently water
- **1:1 phyllosilicates** have (1) a tetrahedral-octahedral layer pattern, and (2) no interlayer
- When water enters the interlayer of select 2:1 phyllosilicates (vermiculite and smectite), they **swell**
- Phyllosilicates get their charges from **isomorphic substitution:**
    - occurs when similar sized cations of different charges replace cations found in the crystal matrix
    - creates **permanent charge**, which stays constant when pH changes and is always negative in soil
- or **broken edges:**
        - charges are unsatisfied due to broken bonds
        - this creates **pH-dependent charge**

CEC

ALA KHALEEL AND AMBER ANDERSON

Learning Objectives

- Identify sources of cation exchange capacity
- Calculate CEC and base saturation given soil test information
- Explain how management may change based upon CEC/AEC
- Predict differences between CEC/AEC could be found given soil characteristics

Keywords: adsorption, cation exchange capacity, anion exchange capacity, buffering capacity, exchangeable cations

Nutrients

Nutrients are held (or not) in different ways in the soil:

- **Ad**sorption: is the retention of ions or molecules to a surface. The prefix “ad” describes a reaction “at” the surface of a solid.
- Cations: positively charged ions (for example, calcium, magnesium, potassium, sodium,,,etc)
- Anions: negatively charged ions (for example, chloride)
- Exchangeable cations: cations that are replaced/exchanged by soil solution.

Ion Exchange in soils:

- Ion exchange involves the movement of anions or cations through the soils.
- In ion-exchange reactions, cations or anions that are adsorbed on soil surfaces are exchanged/replaced by another cations or anions in the soil solution.
- Ion exchange in soils occurs on surfaces of:
    - o Primarily on clay minerals (layer silicate minerals)
    - o Soil organic matter
- Soils in the United States have more negatively charged minerals than positively charged minerals; therefore, cation exchange is much more common.

Cation Exchange Capacity (CEC)

CEC is a measure of the total amount of negative charges on soil surfaces that are available to hold cations, usually plant nutrients. This is based on the organic matter and clay minerals, along with the pH of the soil. Consider it a measure of the soil's ability to attract and hold nutrient cations or the sum of total exchangeable cations that the soil can absorb. Like a positive side of a magnet attracts the negative, and strength is influenced by factors like size and type of material, not all soils hold equally. CEC is very important to plant productivity as it influences what or what quantity of plant nutrients held and made available in the soil. It is reversible and adjusts to be in equilibrium with the soil solution.

Buffering capacity is the ability to resist those changes-higher CEC values mean the system will be slower to change. We call this a higher buffering capacity.

CEC is very important for management because soils with low CEC cannot hold and retain too many important nutrients (ammonium ($NH4+$), and base cations ($Ca2+$, $Mg2+$, $K+$, and $Na+$)) like soils with higher CEC. An anion like nitrate ($NO3-$) is repelled rather than attracted to soil surfaces in most midwestern US conditions and can leach. In areas with anion exchange capacity, like highly weathered soils where CEC is low, nutrient management strategies change. These areas may rely more heavily on forms of nutrients that can be held and released as plants need them, like organic material. In highly weathered, acidic conditions, anion exchange capacity may dominate. This requires different management strategies as well, as different nutrients are likely limiting plant productivity.

Percent Base Saturation (BS)

Cations in the soil can be classified into base (non-acid forming) cations ($Ca+2$, $Mg+2$, $K+1$, $Na+$, and $NH4+$) and acidic cations ($Al+3$ and $H+1$). Most bases are plant nutrients, excluding sodium, so higher BS is generally better. However, base saturation is simply a percentage of the total, rather than a total amount available to the plant. Higher values are also considered to have higher 'buffering capacity' or ability to resist change.

If you have two soils both with a base saturation of 50%, and want to increase it to near 95%, the soil with the higher CEC will require more material to adjust, even though the percentages are the same.

Example

- I have a soil reported to contain 3 cmolc/kg of Ca, 1 cmolc/kg K, 1 cmolc/kg Mg, and 5 cmolc/kg H.
- Since these numbers add up to 10 (assuming this is all of the cations), then my CEC is about 10 cmolc/kg. Five of these (Ca, K, and Mg) are basic cations, resulting in a 50% (5 bases/10 total) base saturation for this soil.

Key Takeaways

- CEC results from organic matter and clays within the soil
- CEC is the measure of cations (usually plant nutrients) held within a soil
- Base saturation is a measure of percentage of charges occupied by basic (non-acid forming) cations

Soil pH

ALA KHALEEL AND AMBER ANDERSON

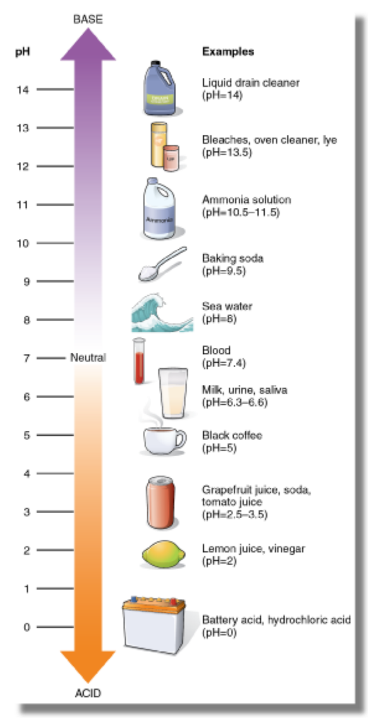
Learning Objectives

- Identify pH values associated with basic or acidic conditions
- Identify basic vs. acid-forming cations
- Discuss the impact of pH on soil and plant growth

Keywords: pH, soil buffering capacity, neutral, alkaline, acidic, ag lime, liming materials

Soil pH

Soil pH is the measure of soil acidity or alkalinity, specifically the inverse log of the Hydrogen ion concentration on a scale from 0-14. Neutral pH is around 7, with 'acids' being below 7 and 'bases' being from 7 to 14. Therefore, a change from a pH value of 5 to a pH value of 4 indicates a 10x increase in H+. Most soils have pH values between 4 to 10. Most soils in Iowa have a pH between 5.5 to 7.5. More weathered soils generally have lower pH values, with soils in arid regions having higher pH values due to accumulations of calcium or sodium.



Source: USGS. Click to enlarge

Some soils have higher 'buffering capacity' or ability to resist change. In higher organic matter or those high in particular types of clays, those with higher CEC values, the same management will have a lesser impact on the pH. Therefore, when trying to raise the pH, additional lime or input will be required.

Example-buffering capacity

Consider a perfectly hot large coffee pot vs. a cup freshly poured in your hand. Predict which would change temperature most quickly if an ice cube were added.

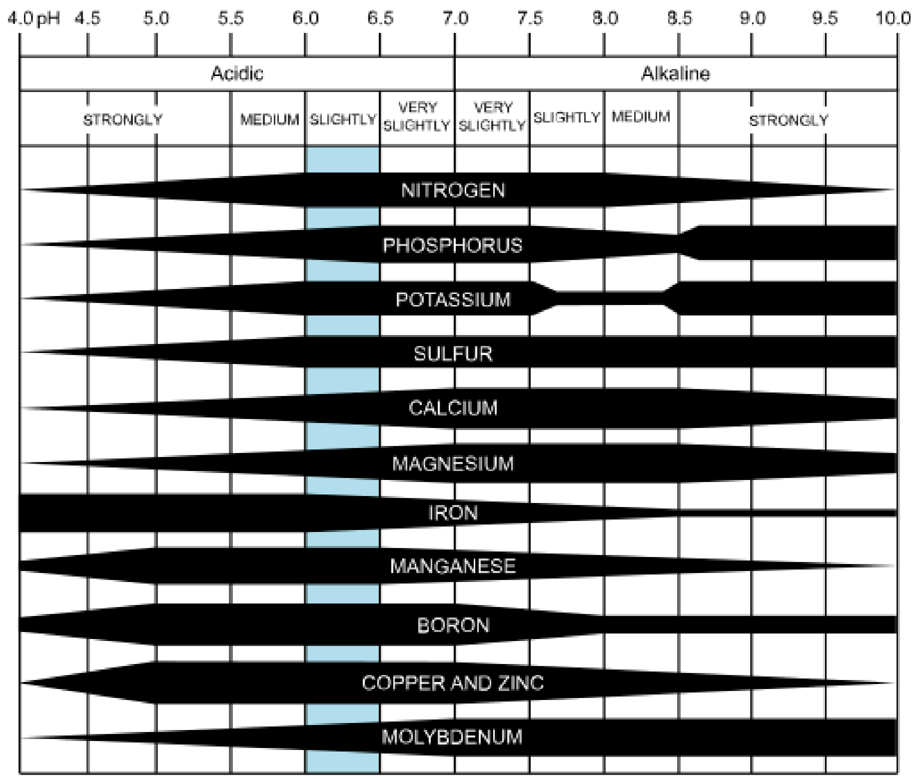
The larger volume of the coffee pot makes the temperature change more slowly than your cup and has a higher ability to resist that temperature change. This would be the higher buffering capacity in the soils example. Small changes in either direction-either an ice cube added or perhaps 30 seconds in the microwave would be expected to have a bigger change on the temperature of your cup than of the large coffee pot.

Importance

Soil pH is sometimes considered the "master variable" that has several impacts on plant nutrients and plant growth. Soil pH also impacts or interacts with other properties in the soil.

Soil pH influences

- Amount and availability of plant nutrients; some plant nutrients are more available under acidic conditions, while others are more available under basic or alkaline conditions
- The activity of soil microorganisms responsible for residue decomposition
- Charges on soil organic matter and on some mineral surfaces, influencing the soil's cation exchange capacity



Source: Wikimedia Commons, CC BY 4.0

Factors influencing pH values in soil

- **Parent material:** original pH of the material.
- **Nitrogen fertilization:** over time, can lower pH values.
- **Management for particular crop:** agricultural lime or 'liming materials' may be added to raise pH, or elemental sulfur or acidifying materials may be added to lower the pH for a particular target crop.
- **Time:** over time, removal of base-forming cations with weathering or cultivation will decrease the soil pH
- **Buffering capacity:** the soil's ability to resist change or a higher buffering capacity, means that a soil pH will be slower to change with the same action that may more significantly lower the value elsewhere.

Did you know?

The color of old-fashioned hydrangeas are an indicator of pH, displaying blue flowers in acidic conditions and pink in higher pH-alkaline soils.

This hydrangea was photographed in the highland regions in Costa Rica:

Photo Credit: Amber Anderson.

Raising the pH

Low pH values in soil may lead to decreased availability of some nutrients-like phosphorus, decreased activity of some organisms-like bacteria, or cause aluminum toxicity in highly weathered soils. Liming materials, such as 'ag lime', generally ground calcium carbonate from limestone, are used to raise pH across the Midwest due to regional mining and presence of limestone bedrock. Dolomitic limestone, or rock containing a higher amount of magnesium carbonate, may be used if magnesium is also needed. Other materials are used if regionally available.

For the lime requirement guidelines, especially for Iowa or the Midwest US, you can consult the Iowa State University soil pH and lime application guidelines (extension publication PM 1688).

How do we measure pH?

- In the lab, the pH of a soil solution is usually measured with a glass electrode. The soil sample is prepared with either water or dilute salt solution, as the electrode only measures acidity in solution rather than H+ ions held on the soil surface.
- In the field, pH paper strips can be used to get an approximate value to determine the need for further testing or management.

Key Takeaways

- Soil pH is an important factor in the soil, influencing nutrient availability and organism activity
- pH value of soil is impacted by management, such as crop removal or limining
- pH value can be increased by application of liming materials, or decreased by sulfur-containing materials

Salts

AMBER ANDERSON

Learning Objectives

- Given an electrical conductivity or exchangeable sodium value, indicate anticipated plant growth impacts
- Match impacts of saline or sodic conditions on soil properties and plant growth
- Understand management practices for sodic, saline, and saline-sodic soil
- Predict management decisions' impact on soil chemical properties

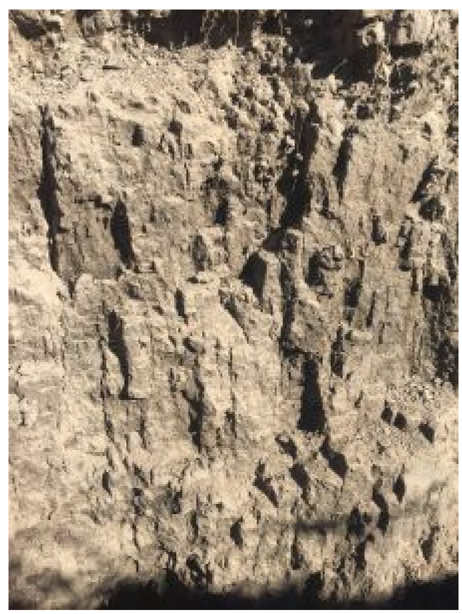
Keywords: Salinity, saline, sodic, saline-sodic

Salts in the soil

Soluble salts have a harmful effect on the soil and over plant growth. Salinity exists when there is an excessive content of soluble salts, which has a significant effect on soil properties and plant growth. It can be caused by different reasons:

- **Primary salinity:** caused by natural conditions, such as weathering of parent materials with high content of soluble salts or at places where evapotranspiration exceeds precipitation rates.
- **Secondary salinity:** as a result of human activities, such as poor irrigation practices and excessive use of fertilizers.

It is important to understand that salinity includes a diversity of soluble salts, some of the most common ions are Ca, Mg, Cl, SO4, HCO3, and Na. However, excessive content of Na is problematic, causing sodic soil conditions with negative effects on soil aggregation. Salinity is measured by Electrical Conductivity, and Sodium through the Sodium Absorption Ratio (SAR) or the Exchangeable Sodium Percentage (ESP), which compares the sodium content to total soluble salts.



Degraded structure at the top of the profile here due to sodium accumulation. Photo Credit: Amber Anderson. Click to enlarge

Salts accumulating on the soil surface in a hoop house. Photo Credit: Amber Anderson.

Assessment

- **Normal soil:** pH < 8.5, EC < 4 mmhos/cm, ESP < 15 %, SAR < 13
- **Saline soil:** pH <8.5, EC > 4 mmhos/cm, ESP < 15 %, SAR < 13
- **Sodic soil:** pH > 8.5, EC < mmhos/cm, ESP > 15%, SAR > 13
- **Saline-Sodic:** pH < 8.5, EC < mmhos/cm, ESP >15%, SAR > 13

Problems with salts in soil

Photo Credit: Amber Anderson.

- Can interfere with water and nutrients uptake
- Poor infiltration/permeability, and aeration
- Sodium degrades structure and aggregation
- Sodium also increases pH and affects nutrient availability

Management of salts in the soil

While saline soils can be leached to remove the salts, that may be challenging due to lack of either quality or quantity of water availability. Sodic soils are more problematic, as gypsum should be applied first, and then leached, but soil properties may be degraded to make water moving through the soil more challenging. In some cases, planting more resistant species is a more viable option.

- [Colorado State Extension publication on managing saline soils]
- [Colorado State Extension publication on managing sodic soils]

Quick overview of testing for salts in soil

Beyond looking for salt rinds on top of the soil, one can also use a fairly simple procedure in a soil lab to find out the salinity of the soil. Below is a summary of how soils are tested for salts using electrical conductivity. A *Thermo Scientific Orion4Star* pH and conductivity bench top meter was used for this example.

Photo Credit: Lydia Brown.

1. Combine soil sample with deIonized water to create a saturated soil in a 1:1 ratio. Allow the soil to settle or centrifuge for 5-10 minutes.

Photo Credit: Lydia Brown.

2. Separate the settled solid soil from the water and remove water from sample tube.

Photo Credit: Lydia Brown.

3. Set up the meter to read electrical conductivity (dS/m or mmhos/cm). Place the meter in the water sample.

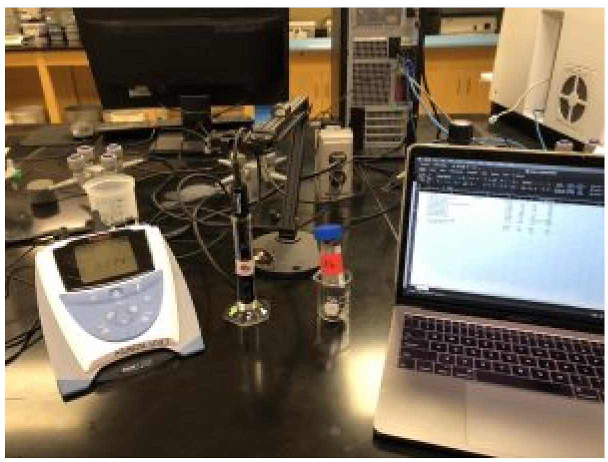


Photo Credit: Lydia Brown.

4. Calculate Sodium Absorption Ratio and Exchangeable Sodium Percentage.

- Sodium Absorption Ratio (meq/L) = $Na^{+} / ((Ca^{+2} + Mg^{+2})/2)$
- Exchangeable Sodium Percentage (%) = $(Na^{+}/ CEC) * 100$

Key Takeaways

- Different kinds of salts in the soil can limit water uptake and destroy soil structure and aggregation.
- Above 4 mmohs/cm is a saline soil.
- Exchangeable sodium greater than 15% or Sodium Absorption Ratio (SAR) above 13 is a sodic soil.

SOIL MANAGEMENT

Soil testing

AMBER ANDERSON

Learning Objectives

- Outline steps for taking a reliable soil sample
- Match soil test output levels to recommended management
- Predict expected relative test values given site characteristics

Farmers utilize soil sampling to determine soil fertility, pH, nutrient variability, organic matter, and texture. Soil testing might be recommended for several reasons, including unexplained nutrient deficiencies. When compared to a tissue or sap test, soil sampling is typically a less expensive option but may not be the most appropriate for all situations. The test results are meant to guide your management plan for the current or following year. Several factors should be considered when determining when and where to sample.

When to soil sample

- At a time when application can occur before next cropping season or harvest. Typically late summer or early fall in Midwestern US annual systems.
- Consistent time of year each time you soil sample. Commonly every 3 to 4 years following the same crop in the same environmental conditions.

Places to avoid when sampling:

- Field edges
- Areas near roads
- Near livestock
- Near buildings or former buildings
- Uneven areas or unusual areas, unless they are given their own sample

Factors to remember during sampling:

- History, different past land use can result in different test levels. Sampling the area so one sample does not represent both areas will result in more accurate results.
- Consistent depth, timing, and lab procedures with clean equipment to maintain uniformity and accurate lab results.
- More samples will likely eliminate potential inconsistencies and bias.
- Avoid sampling in poor conditions, like excessively wet or frozen soil conditions.
- Samples should represent a small enough area to be representative, typically no more than 10 acres in

annual row crop systems or an acre in more intensively managed situations.

Best practices for sampling

Follow the specific recommendations of your testing laboratory, but generally:

- Use clean equipment
- Subsamples should be used, mixed, and submitted sample used
- Sampling depth as indicated by your test/laboratory
- Differing areas should have their own soil sample, as combining them will not provide reliable results for either area

Strategies used for sampling

Grid

This method takes samples within regular divisions or zones of equal size, 1, 2.5, 5, or 10 acres. This regular sampling is meant to capture viability across the landscape. The method may be more helpful if the management history is unknown or variable rate application technology will be used. Drawbacks could include the additional cost resulting from more samples and samples less representative of the larger area.

Zone

This method is used when there is some historical knowledge of the area and to assess changes over time. Areas of similar soils, topography, and management are grouped for testing – samples are taken within the "zones". This method can provide some basic information for management decisions at a decreased cost when compared to grid sampling, but may be less reliable if there is a history of manure application or specific concerns across the field.

Assessing your soil sample results

Reports received from testing laboratories generally include both a value and a rating, like 'high' or 'very low' to indicate relative status. Fertilizer application, when a soil test level is very high or high, is unlikely to provide economical return on investment and may be environmentally irresponsible. Fertilizer applications with low or very low values are likely to result in yield increases and should generally be applied at rates higher than anticipated crop removal rates.

Considerations

High pH values may be associated with roads in some areas due to limestone used in road material or the potential transport of liming materials.

Many standard soil tests don't include heavy metals or other potentially harmful contaminants. A test may be warranted if you are producing food in an area with potential contamination (particularly urban areas or former industrial sites).

Previous livestock on the land can contribute to high or very high phosphorus levels long after animals are present. Erosion and/or further application in these areas can negatively impact water quality.

Soil testing publications:

- Taking a good soil sample
- Interpreting results
- Recommendations for Iowa/Midwest US

Soil testing review

Fertilizer analysis

AMBER ANDERSON AND ARTURO FLORES

Learning Objectives

- Identify components of fertilizers
- Calculate quantity of a given fertilizer needed to meet nutrient needs

Guaranteed analysis

Commercial fertilizers sold in the US are required to share amount of nutrients contained in the product on the label. The standard way to share this information is called a guaranteed analysis, like 10-10-10. The first number refers to percent nitrogen by weight, the second phosphorus as P_2O_5, and the third refers to potassium as K_2O. Note that this exact form of nutrient isn't required to be in the bag, but an equivalent amount of P or K is required, so this is simply a standardized way to express quantity of a nutrient.

Other material in a bag

Note that the percentages of N, P_2O_5, and K_2O don't add up to 100% of the bag contents. Other materials that wouldn't be counted in this guaranteed analysis number could be nutrient carriers that contain the nutrient, conditioners that improve some property of the material, or inert materials that may make a small quantity of nutrient easier to spread uniformly over a large area.

Carriers

Not all molecules in a compound are the target nutrient for fertility. In urea, a nitrogen fertilizer, nitrogen is contained, but not all of the molecule.

Other nutrients

Nutrients besides nitrogen, phosphorus, or potassium are still needed by plants, and may be included in a fertilizer mix. Those contents would not be reflected in the guaranteed analysis of the material

Conditioners

Some fertilizers have less than ideal handling or storage properties-so materials to prevent caking, adjust the pH, or otherwise create more favorable conditions for storage or handling may be included.

Example

See this container of fish emulsion fertilizer:

Note the three numbers in the lower part of the label, the guaranteed analysis of this product: 2-3-1

Example

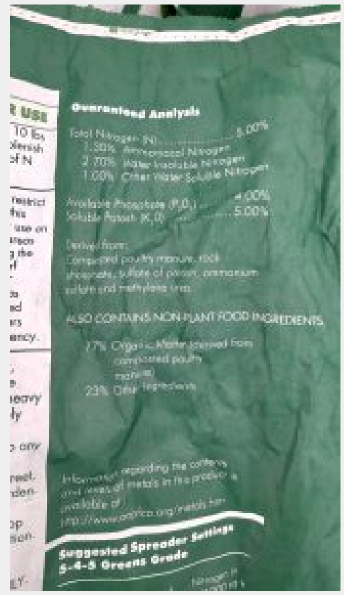
Fertilizer bag from a Costa Rican Coffee Cooperative:

This Costa Rican fertilizer bag has percentages of each nutrient contained instead of the guaranteed analysis required on US fertilizer bags. Note that this label shares nitrogen, phosphorus, potassium, magnesium, calcium, iron, and organic material percentages.

Example

Organic-derived fertilizer used for turfgrass management:

- Compared to commercial syntethic formulas, this product contains significantly lower levels of each nutrient. The reason is they are meant for soil-nutrient maintenance and not for building the main nutrient pool.
- Also important to note, here, Nitrogen is divided into three categories:
  - **Ammoniacal Nitrogen:** represents instant availability for root absorption.
  - **Water Insoluble Nitrogen:** this is some type of slow-release fertilizer, which means it requires a different process to break down and takes longer to be readily available, reducing leaching potential and providing long-term nutrition.
  - **Other Water-Soluble Nitrogen:** also instant available nitrogen but in a different form than ammoniacal nitrogen.



Organic fertilizer bag for turfgrass. Photo Credit: Arturo Flores.

Key Takeaways

- Guaranteed analysis on fertilizer bags indicates percentage of N-P_2O_5-K_2O contained
- Other materials, like conditioners, carriers, or micronutrients may also be found

Problem solving

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Learning Objectives

- Outline a process to determine potential diagnoses in a problem solving scenario
- Utilize knowledge of soils, nutrient behavior, and other factors to narrow down potential causes
- Determine how you might confirm or rule out potential causes of identified problem

How might you go about determining or ruling out soil-related causes for a symptomatic plant?

What is the plant supposed to look like at this stage?

Is it stunted or abnormally colored? Purple leaves in some varieties, particularly horticultural crops, may be normal. However, purple colors in a plant that is not supposed to have that coloration may indicate a phosphorus deficiency.

Pattern?

Is there a pattern in where symptomatic plants are occurring in the field (low spots, edge of field, steep areas)? Area with recent construction or newly replaced topsoil? How about within the plant (new growth vs old growth)?

Conditions?

What have conditions been like in the area recently? Have they been abnormally cold, wet, hot, dry? How about last season (potential herbicide carryover if dry)? Cool springs may contribute to more nutrient deficiency symptoms, as root growth and microbial activity may both be slower than normal.

Field operations?

What has happened to the site recently? Any major disturbance (topsoil removal, compaction, installation that displaced or inverted significant soil)? Application of nutrients or chemical materials?

Testing?

Has any testing been done that may help support a potential nutrient deficiency diagnosis? Soil pH is one that may be helpful if only limited testing has been done, as high pH soils may cause nutrient availability issues with metals like iron. At low pH values, there may be different nutrient deficiencies, or even toxicity of something like aluminum in highly weathered conditions.

Now what?

In order to support your diagnosis, you may want to gather additional evidence. For example, a soil test if you suspect a nutrient deficiency. Some issues may not have a feasible treatment at the point of diagnosis, like an herbicide carryover due to a dry year, but could be considered in future management of the area if another dry year is expected.

In annual crop management, seeing significant deficiency symptoms throughout the season mean that decreased yield is already expected and it may be too late to adjust conditions for the current crop, so adjustments or applications would likely be for the next season or crop. In perennial crops, other strategies might be more desirable, like foliar application, injections, or more intensive methods. Additionally, considering the soil and potential problems before they are planted means that some issues, like iron deficiency of a full-sized pin oak due to high pH soils, could be avoided. As in many things-an ounce of prevention is worth a pound of the cure.

Key Takeaways

- Identifying patterns (across the field or within the plant) is important for determining potential causes of the issue: straight lines are likely human-caused, eroded soil areas may show an issue correlated with low organic matter or high pH first
- Identifying
- Matching

Soil input recommendations

ARTURO FLORES

Learning Objectives

Type your learning objectives here.

- Interpret soil test reports
- Calculate the required fertilizer to amend soil nutrient deficiencies
- Design fertilizer formulas based on the soil needs and materials available

Make soil input recommendations

One of the big questions in agriculture has been and will be 'what and how much should I apply to increase yield?' It is a common question asked by most farmers, with the belief that there is a magic formula to once and for all improve the soil quality and boost yield. However, this is far from being true. As has been discussed throughout this course, soil is a complex and dynamic system. Therefore, improving soil is a holistic process that should consider each one of its factors that could be limiting production. Soil laboratory analysis is an accepted measure performed by farmers around the globe to obtain some insight about what is going on in their soils and use it as a starting point to take management decisions.

The soil test report obtained after analysis may include recommended fertilizer application rates and even recommended products. Nevertheless, this service is not always available or economically accessible for every user. The process of interpreting a soil test report is not rocket science, and with a basic understanding of the overall condition of soil, it is possible for any user to improve the soil quality. It should be noted that a soil test report is not completely accurate and may just represent the condition of the soil where the sample was taken. However, is still valuable to be able to read, understand, interpret and act according to what the report is telling the user. The most important thing to remember when interpreting soil test results, is that soil quality or fertility is not just a matter of nutrient balance, but also about the chemical and physical conditions of soil, including acidity, salinity, and moisture content.

FIRST: Evaluate and improve the physical condition of the soil

Porosity and moisture content are limiting factors that can reduce agricultural productivity. Fine soil textures are good for retaining moisture, but bad for resisting compaction. Conversely, sand and gravel retain low quantities of humidity, but resist compaction better than clays. Compacted soils and not granular structures make root growth, water infiltration and percolation significantly harder. When roots can't penetrate deep and water sits for too long on the root-zone (0 – 12 in), the root system becomes shallow and relies on the surface conditions to thrive. This is a problem, especially when water has trouble draining away because waterlogging near the surface increases nutrient reduction reactions and changes the chemical soil conditions. As a result, crops are more susceptible to drought and nutrient deficiencies.

Moreover, soil physical conditions can be managed temporarily to better adequate the soil with optimal growing conditions. Artificial drainage, such as tile pipe or canals can be implemented to reduce waterlogging and increase draining rates. Canals are built to collect excess water from run-off after high precipitation events, and also to regulate the water table, preventing it from reaching the root-zone. Conversely, when soil is too dry, there is no moisture that can be used to absorb nutrients. Nutrients use water as transport to move through the soil and to be absorbed by the plant's roots. Irrigation can be useful to maintain optimal soil moisture and the effects of drought stress, including plasmolysis and the inability to feed on plant nutrients. Surface structure and compaction are modified with soil tilling with chisel and disc plows, or with rotovators. These technologies increase soil porosity in the short term but may lead to the development of hardpans when mechanization occurs regularly on not optimal conditions (eg., excess soil moisture). Soil texture is hardly altered because it requires large amounts of material. This is seen more often in sport turf management, where the soil is amended with large quantities of sand that increase drainage and reduce the risk of compaction. However, the economic cost represents a significant restriction for conventional agriculture, and the incorporation of organic matter is more common for enhancing texture and structure.

Commonly, these problems are not presented in a conventional soil fertility test, unless otherwise specified. However, they can be the reason for crops not being able to thrive as expected. When the growing medium lacks proper soil physical fertility, the application of other inputs, such as lime or fertilizers, may not result in a significant improvement of yield. If the soil's physical condition is considered optimal, it is time to address the chemical fertility problems identified from the soil test report.

SECOND: Improving Soil Chemical Fertility

Soil pH is the primary chemical property regulating nutrient availability, and most soil test reports include this value. Acid soils (pH<7) tend to have more aluminum readily available, which results toxic for plants, and calcium, phosphorus and magnesium are less available. Alkaline conditions (pH>7decrease phosphorus and micronutrients availability and increase salinity susceptibility. Nutrient deficiencies caused by soil pH can be reduced with the application of lime (increase pH), or with acidifying materials containing sulfur (reduce pH). These solve the problem in the short term and pH will return to the original level if it is not constantly managed. Liming corrects passive acidity but does not change soil natural behavior and mineralogy, which is the reason for the soil's natural pH. For example, in tropical countries like Costa Rica where precipitation rates are very high (>120 in/year), it is common to find soils with pH of 5 or even lower. Thus, for farmers in the region, liming pastures and other agricultural fields becomes a regular practice every one or two years.

Soil salinity negatively affects soil aggregation, structure, infiltration, and salts may be toxic for crops. It's important to remember that soil salinity is not the same as sodic soils. The difference is in the type of salts present in the soil. Sodicity means higher sodium content, and general salinity includes calcium, magnesium, chloride, and carbonate accumulation. Common techniques to deal with these conditions include washing salts away and applying gypsum. When water for irrigation is available, applying large quantities of water help leach salts away from the root zone. However, the constant application of irrigation water or the poor quality of it can help build up the salt accumulation. Therefore, the efficacy of this method will greatly depend on the quality of water. The application of gypsum is done to reduce the effect of sodium. The calcium contained in gypsum replaces the sodium adhered to the colloids, which then reacts with the sulfur creating soluble sodium sulfate in the soil solution that is easily leached away. Soil test reports include salinity obtained through measuring the electrical conductivity of the soil sample. Sodicity is obtained by comparing the concentration of sodium with the total CEC.

Leaching requirement example

To efficiently leach salts away, the soils profile should be wet enough for water to drain and carry salts away. The following are used to calculate the leaching requirement:

- $LR = EC_w / (5xEC_c - EC_w)$
- $WR = ET / (1 - LR)$

where LR stands for Leaching Requirement and the result has no unit it is a factor, EC_w is the electrical conductivity of water to be used (in dS/m), and EC_c is the desired electrical conductivity to achieved or the threshold that the crop can handle. In the second equation WR is the water required to leach salts away, and the ET represent the evapotranspiration of the area which means the total moisture being lost through evaporation and transpiration that has to be compensated for to achieve and optimal salt flush (in mm/day).

Example

There is a hotel in a dry region of the western territory of Costa Rica, where they are having problems with their gardens. The soil and water were sent for analysis, and they obtained that their soil has a ESP of 10% and an EC of 5 dS/m. And their water turns out to have an EC_w of 1 dS/m. They decided to work better with plants that can tolerate up to EC_c of 1 dS/m in the soil, but first they have to determine the water requirement to maintain the soil in the 1 dS/m range. If the ET of the area is 6 mm/day, help them calculate how much water they should apply per day through irrigation.

1. Obtain the Leaching Requirement factor:

```
LR = (1 dS/m) / (5x1 dS/m - 1 dS/m)

LR = 0.25
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2. Calculate the Water Requirement per day:

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WR = (6 mm/day) / (1 - 0.25)

WR = 8 mm/day
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Result: The recommended water requirement is 8 mm/day to maintain optimal growing conditions for their plants. Because they have an ESP < 15%, they don’t have sodium related problems, therefore, the application of gypsum is not critical.

Gypsum requirement example

Gypsum requirement can be calculated with the following equation:

- Gypsum requirement (ton/ha) = Na content (cmol/kg) x 4.5

Example

A farm in Guatemala is having problems growing crops. Soil samples were submitted for analysis and the results showed a ESP of 18% and a CEC of 20cmol/kg. They decided to apply gypsum to improve their soil quality but need help calculating the total requirement. Help them solve the problem.

1. Calculate the sodium content:

```
Na (cmol/kg) = Total CEC x ESP
Na = (20 cmol/kg) x 0.18
3.6 cmol Na / kg
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2. Calculate the gypsum requirement:

```
Gypsum = (3.6 cmol/kg) x 4.5
16-ton Gypsum / ha
```

Result: they need to apply 16 tons of gypsum per hectare.

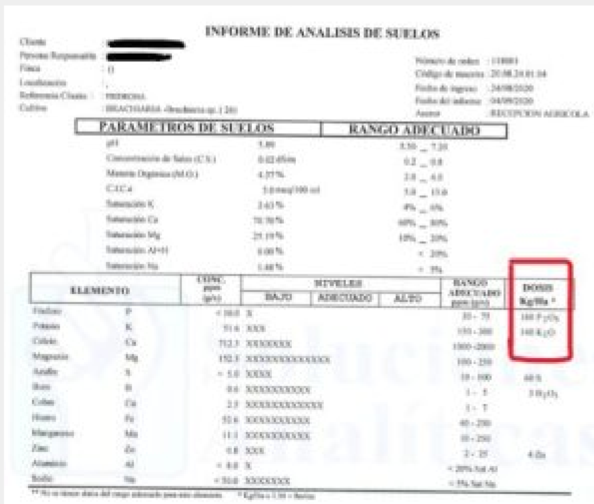
THIRD: Make fertilizer recommendations

Fertilizer application is an alternative solution to compensate for nutrient deficiencies. They can be applied to build up the soil nutrient pool up to a critical threshold, to compensate for the nutrient mining done by the crops, or a combination of both. It is important to remember that over application of nutrient may result in luxury consumption by the crop, which results in toxicity and can be as detrimental as the deficiency of such nutrients. Therefore, it becomes vital to correctly interpret the nutrient levels and apply fertilizing products accordingly. Organic derived fertilizers contained lower levels of nutrients compared to synthetic fertilizers, but they can also help improve microbial activity and provide the benefits of soil organic matter. Conversely, synthetic formulas are intended to provide higher rates of nutrients and make them available more easily compared to organic products. Bulk blended fertilizers contained raw particles of different materials, in which each particle provides a different element. These tend to be cheaper but nutrient distribution is not as even and effective as chemical formulas can be. Granular fertilizers contained particles of equal size and chemical composition that are obtained by mixing together raw materials through chemical reactions. These required some extra processing and prices may be higher, however, they ensure that each particle contains an equal amount of nutrients, providing a more even application. It is on the farmer's judgement and accessibility the preference and acquisition of one over the other.

Nutrient ratio example

Sometimes the nutrient ratio to apply is given in the soil test report, however, this is not always the case. The nutrient ratio indicates the proportion of NPK in the product to apply. For example, a 15-15-15 fertilizer has a ratio of 1-1-1, and the ratio 18-6-12 is 3-1-2. This helps decide on the product to apply and provide guidance when a custom formula is being created.

In this picture we can see the soil test report from a dairy farm in Guatemala. Soil in the region is derived from volcanic ashes and tends to have acidity problems due to high precipitation rates in the region. The results inside the red box show the required nutrients needed to bring the soil to an 'adequate' or optimum level, this means above deficiency.


INFORME DE ANALISIS DE SUELOS

PARAMETROS DE SUELOS | RANGO ADECUADO

ELEMENTO | NIVELES | BAJO | ADECUADO | ALTO | DOSIS Kg/Ha

Soil test report example. Picture by: Arturo F.

To decide in which fertilizer to apply, obtaining the recommended nutrient ratio can help. To do this follow the steps:

1. Obtain the recommended rate of each nutrient by subtracting the actual level from the desired 'optimum' level (Rate = optimum – actual). In this case the lab already reports this result (we just have to transform it into our desired units).

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160 kg P2O5 ha-1 = 142.51 lb P2O5 acre-1

140 kg K2O ha-1 = 124.60 lb K2O acre-1
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2. Nitrogen is not commonly analyzed in this kind of tests because of its mobility and ease to leach and volatize. Therefore, tissue analysis is preferred, and nitrogen fertilization attempts to compensate for the biomass produced in certain are. The image shows the crop here is *Bracharia,* and a commonly accepted rate of N for this is 100 kg N ha-1.

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100 kg N ha-1 = 89 lb N acre-1
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3. The ratio is obtained by dividing the total required of each nutrient by the smallest value, in this case N.

```
89 lb N acre-1 / 89 = 1

142.51 lb P2O5 acre-1 / 89 = 1.6

124.60 lb K2O acre-1 / 89 = 1.4
```

The recommended ratio here will be 1 – 1.6 – 1.4. Knowing this ratio, it is possible to choose from commercial formulas that best fit the needs or to mix fertilizing materials to supply the required nutrients.

Fertilizing recommendation examples

The process of balancing soil nutrients consists in bringing deficient nutrients up to an optimal threshold. The following videos provide a step by step in the process and help understand how to make fertilizer recommendations. When creating a fertilizing mix, it is important to consider the compatibility of the materials to avoid precipitation or insolubility of some nutrients.

Video 1: Calculate the nutrient ratio

Video 2: Calculate how many bags of fertilizer we need

Video 3: Create your own NPK fertilizer

Extra:

SOIL EROSION

Soil erosion

AMBER ANDERSON

Learning Objectives

- Describe the impacts of erosion
- Outline the process of erosion
- Identify soil erosion indicators on the landscape

Keywords: Wind, water, gully, rill, sheet, saltation

Process

Erosion is the removal of the upper layer of soil or topsoil. Since that layer tends to have higher organic matter and nutrients, erosion of the surface layer can cause significant negative effects on the soil for future crops as well as runoff. An inch of soil may take a thousand years to build, but could be removed in one rainstorm. Areas with shallow bedrock (R horizon) are particularly sensitive, as erosion may lead to a loss of the area for agriculture.

Erosion requires three main steps: detachment, transport, and deposition. We separate erosion into two major categories by the force that transports the soil particle.

Detachment

Not all soils or soil particles are equally susceptible to erosion. Sand may be easy to pick up, but is heavier to carry, so tends to stay closer to the source. Clay is hard to detach, but once separated, can stay in the air or water column for significant periods of time. Silt is generally considered the most erodible particle, as it is both reasonable to detach and carry.

Well aggregated soils are also considered less erodible-since the force would have to either break up the strong aggregate, or transport the whole aggregate.

Transport by Wind

Wind erosion during sugarcane harvest, Costa Rica, Spring 2019. Photo credit: Amber Anderson

Transport by Water

Observe from the video:

- When does the water slow down?
- When does the water appear more dirty/less dirty?
- What do you notice about the plants/plant roots? (soybean plants in particular)
- What else do you notice?

In Iowa, water is considered the dominant eroding force, but this does not mean that wind erosion is not occurring.

Check it out!

The Daily Erosion Project is a model based upon the rainfall data received along with soil characteristics to estimate loss after a given storm. Find a watershed of interest and see how much soil they lost in a given storm.

Shapes

Gully

Gully formation near Ames High School. Photo Credit: Amber Anderson.

Most noticeable, gully erosion appears as large channels being cut into the ground, looking like a stream. These are impassable with equipment due to size. If not stabilized, water plunging down the wall will continue to move up the hillslope. It is easiest to deal with before this point, but controlling water as high up on the slope as is feasible. Simply filling the gully with sediment or rock will not solve the issue.

Uphill from the previous gully picture, this shows the slope and how the cut has progressed up the hill. Photo credit Amber Anderson

Gully forming on a farm outside Ames. Photo Credit Amber Anderson

Rill

These are smaller channels, appearing more like fingers on the landscape. They can be destroyed by tillage-however, that is only destroying the evidence, not putting the soil back to the original condition. If the problem is ignored, future erosion will likely occur down the same path.

Water erosion after land shaping in Southern California. This damage started as a smaller rill, and has continued to erode away material significantly increasing in size. Photo credit: Amber Anderson

Water erosion, forming rills, on ISU campus, south of Landscape Architecture and Hamilton Halls. Photo credit: Amber Anderson

Water erosion through a cultivated field, near Martin Tennessee in a particularly wet March. If not controlled, this will continue to erode and likely form a gully. Photo credit: Amber Anderson

Sheet

Least noticeable, this type of erosion takes a small layer equally off the soil surface.

Deposition

As "what goes up comes back down" so does detached and transported soil need to be deposited at some point. Sometimes this is only a few inches, or it could be hundreds of miles away. Additional damage or costs may result at that point, from filling in ditches or lakes, damaging human lungs, or covering other infrastructure-requiring removal or treatment costs as well as the loss to the source. In some cases, the previous A horizon is buried, as in the videos below:

Key Takeaways

- Erosion can occur in a variety of ways, but always includes detachment, transport, and deposition
- Erosion has significant negative impacts on soil properties and productivity, with potential costs of clean up as well.

Soil erosion factors and calculations

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Learning Objectives

- Discuss factors influencing differences in rates of loss
- Estimate erosion loss under a given management scenario
- Predict how management changes could increase or decrease potential erosion losses

Estimating erosion

If the removal or deposit is clearly visible, as may be the case in gully, losses could be roughly estimated based upon the area removed. Generally, the losses are more subtle.

Estimate the weight of soil in one inch across one acre

Estimating erosion after it has occurred, while may be needed to understand the extent of the damage and prevent future damage, is often too late.

Ideally, we would like to know the potential impact of a change before the erosion occurs. We use predictive models like the Universal Soil Loss Equation, or updated Revised Universal Soil Loss Equation (one or two) to predict the erosion under a given scenario. The major differences between these three equations is how conditions are calculated-with the first using one value for the year while updated equations divide up the year to recognize that conditions are not uniform throughout the year.

Soil core from central Iowa showing a shallow depth to C horizon (and calcareous conditions) very shallow due to significant past erosion. Photo credit: Amber Anderson.

This equation only estimates rill and sheet erosion due to water.

$$A = R \times K \times LS \times C \times P$$

Where:
A= estimated erosion in tons per acre per year
R=rainfall erosivity value

K=soil erodibility (between 0.05 for sandy soils and ~0.35-0.4 for more silty materials)
LS=slope factor accounting for both length and steepness
C=cropping factor
P=other practices
T=”Tolerable” erosion

A note on T factor: This is set not at replacement rate, that is much smaller. It is what the soil could lose per year and maintain productivity for a medium term-it shouldn’t be considered sustainable for long-term productivity.

Practice using the equation:

- See the canvas assignment to walk through practice scenarios

Key Takeaways

- USLE is one tool to estimate losses anticipated (water erosion from sheet and rills) under a current or proposed management scenario

Erosion control strategies

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Overall

The main goals of erosion control strategies are simple-control either detachment or transport of soil. Specifics are dependent upon the situation, as what works in one location may not work for another.

Soil health

Maintaining soil health increases resilience to erosive forces. Aggregate stability-as shown in the video below, is one of the factors impacting erosion. If aggregates stay together, water erosion will only take place if there is enough force to move the whole aggregate, rather than the single particle.

Wind erosion control

Major strategies to control wind erosion include protecting the soil from initial detachment, or slowing the wind so it cannot detach or carry the sediment. These may look different depending upon the situation, but a few examples might be windbreaks, eliminating or decreasing tillage, or adding cover crops or a perennial cover.

Windbreaks

A common feature around sensitive sites, like farmsteads or high value crops, is a windbreak. Installed up-wind from the location, the area protected is approximately 10x the height of the windbreak downwind of the feature. Closest to the windbreak is most protected and protection decreases with distance away.

Windbreak resources

- Field windbreak
- Farmstead windbreak

Water erosion

A variety of techniques can be utilized for decreasing water erosion. Main principles are the same, to control detachment and/or slow down the water so it is unable to carry the sediment.

In agricultural fields

Soybeans planting into standing rye cover. The rye was planted in the early fall starting growth then and continuing in the early spring to protect the surface over the fall and increase biological activity/ organic matter. This rye was terminated near the soybean planting time.

Strips project-strip of perennial vegetation meant for erosion, water, and pollinator benefits. Photo Credit: Lisa Schulte-Moore.

This corn has additional plant cover growing under it to protect the soil from excess erosion.

Other practices might include terraces, that break up the slope length allowing infiltration. Waterways, protecting the path of the water off the field instead of allowing rill or gully erosion.

Roads

New construction is particularly sensitive to erosion, this disturbed shoulder off of I-35 near Ankeny is using a few techniques to control erosion-straw waddles and straw to help grass seed establishment. Photo Credit: Amber Anderson.

This road ditch in Uganda has complete covered the area water would run with cement and rocks so it cannot erode and undermine the road. Photo Credit: Amber Anderson.

Construction sites

As the perennial cover of grass gets established next to the new Ames High School, these black strips are used to slow water and stop sediment moving down the hill. Photo credit: Amber Anderson.

During construction, this black bag was used to capture sediment and any other materials that would have otherwise moved into the storm sewer and water system. Photo credit: Amber Anderson.

This reinforced mat is being used on a steeper part of the landscape while grass is being established that will stabilize the area for the long term. Photo credit Amber Anderson

After construction of the business building addition, hydromulch was used to protect the surface and help establishment of the new grass seed. Photo credit Amber Anderson

This mat is used to help protect the soil surface and keep seed in place during establishment. Photo credit Amber Anderson

Runoff off of construction site on ISU campus

Runoff off of a construction site on ISU campus

SOIL FERTILITY

Nutrient basics

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Learning Objectives

- Compare and contrast macro vs micronutrients
- Relate mobility in plant to expected deficiency symptom location
- Identify potential deficiency patterns on the plant or in the field

Macronutrients vs Micronutrients

While both macro and micronutrients are required for plant growth, there are needed in differing quantities. Macronutrients are needed in larger quantities and are usually involved in the structural components of plants. Micronutrients are just as required for healthy plant growth but needed in smaller quantities. They are usually components of enzymes or metabolic functions. A micronutrient deficiency may be corrected with a few pounds per acre, while a significant macronutrient deficiency will likely take significantly more fertilizer.

Deficiency symptoms vs hidden hunger

A plant may not appear clearly nutrient deficient immediately, but may grow or yield poorly. Deficiency symptoms likely indicate a significant issue that should be addressed, but it may be too late to obtain the full yield of an annual crop this season. Deficiency symptoms can include a variety of visual abnormalities, including yellow striping, stunted plants, purple coloration, malformed structures, or others depending upon the plant and nutrient.

Deficiency vs Toxicity

Both too much and too little of a nutrient can significantly impact plant growth. At excessive levels, too much of a nutrient accumulating in tissues can cause damage, or interfering with uptake of other nutrients. This can be more significant of an issue at low pH values, when metals are more soluble.

Mobile vs Immobile

A nutrient can be mobile in the plant and the soil. If a nutrient is immobile in the plant, it can't be moved to new growth if the plant runs out, where as a mobile nutrient couple be transported within the plant to the area of most need. Therefore, a mobile nutrient deficiency will appear in the older growth, where an immobile nutrient deficiency will first appear in the new growth. If a nutrient is immobile in the soil, a root needs to grow to it rather than relying on water to help carry it to the root. Therefore an immobile nutrient deficiency may occur in conditions of poor root growth, such as a cool, wet Midwest US spring.

Examples

- View a table of nutrient availability in the plant vs in the soil here

Remember:

Don't assume that a nutrient deficiency means a soil deficiency. Sometimes soil or plant conditions simply don't allow for sufficient uptake, like iron in a high pH soil. Iron chlorosis is not effectively solved by adding more iron. Depending upon the plant or conditions, management options could include foliar application, adjusting the pH, or simply choosing a more tolerant crop.

What to look for in the field

Patterns can be helpful in determining or narrowing out potential diagnoses. A strip of yellow corn across a field or deficiency symptoms matching the width of the application equipment could be associated with equipment malfunction. Straight lines are unusual in nature, so could point to a human interaction, such as nutrient or chemical application equipment, change in plant hybrid selected, or past fenceline/treatment change.

Alternatively, an area on a steep slope showing a deficiency may be associated with erosion and resulting lower organic matter, significantly different pH value (as is common across calcareous parent materials like in the central US), or some other soil factor. Using the soil map and further soil testing can help problem solving, and may result in multiple issues being discovered.

Key Takeaways

- Nutrients have a variety of properties that influence when and where a deficiency may appear along with how much may be needed to address the deficiency.
- Challenging soil conditions may limit options for addressing the plant nutrient needs.

Phosphorus

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Learning Objectives

- Identify major pieces within the phosphorus cycle and factors impacting plant availability
- Explain potential impacts on the environment from contrasting management
- Recommend practices to decrease the environmental impact of phosphorus fertilization

Phosphorus Characteristics in Soil

There is a small amount of phosphorus in the soil solution and, therefore available to a plant at any point in time. Low total amounts in the soil and low solubility mean that the plant can lack sufficient phosphorus for growth, particularly in cool and wet spring conditions when Iowa's annual crops have a minimal root system exhibiting lots of branching. Availability can be impacted by soil pH, at both low or high ranges, as phosphorus can form calcium phosphates or iron phosphates. Due to low plant availability, mycorrhizal associations can be significant contributors to plant uptake for phosphorus.

Phosphorus fertilizers include animal manures, DAP (Diammonium phosphate) or MAP (monoammonium phosphate) are made by combining ammonia and phosphoric acid. Alternatively, mined rock phosphate or other unique materials such as guano.

Role in Plant Growth

As a part of ATP, phosphorus is important for energy transfer within the plant. Therefore, stunted plants are expected, but purple coloring is also common.

Photo credit: Lizzie Dykstra

The top plant is from the center of a disturbed area (pipeline construction), the edge of disturbed area, and just outside of the disturbed area on the bottom. Photo credit: Lizzie Dykstra.

Phosphorus Loss

Phosphorus loss from Iowa soils or to Iowa water bodies is generally attributed to erosion of the entire soil rather than via water. Therefore, strategies to decrease loss or improve water quality focus on decreasing erosion rather than biological mechanisms for nitrate loss. Decreasing erosion, through decreasing tillage, increasing cover, buffer strips, increasing perennial cover on the landscape, decrease phosphorus loss to water bodies.

Additionally, livestock manure can be detrimental to local water quality, resulting in decreased use and function as can be seen in the photo below. Stream exclusion fencing, keeping livestock from wallowing in the water and adding manure, can decrease the risk to water quality. Application of manure should be incorporated, not applied to frozen ground when it would be more likely to run off, and should be set back from the stream or water body.

By how much do practices decrease loss of N and P?

- Reducing Nutrient Loss-Science Shows What Works—see what expected decrease to N and P levels by potential practices.[1]

Importance in Water Bodies

Significant water quality issues result from phosphorus enrichment, both at local and national scales. Nutrient contribution from the upper midwest contributes to the significant hypoxic or 'dead zone' in the US Gulf of

1. https://store.extension.iastate.edu/product/Reducing-Nutrient-Loss-Science-Shows-What-Works

Mexico. Eutrophication, or the nutrient enrichment of these water bodies causes excessive growth, and then excessive decomposition, which decreases oxygen in the water. Since organisms in the water need oxygen, this causes a collapse in the local ecosystem. Therefore, it is important to minimize loss from our soils and decrease impact on nearby water bodies.

Nutrient Reduction Strategy

- Nutrient reduction strategy details here [PDF][2]

Key Takeaways

- Phosphorus is limiting in many environments and must be carefully managed to ensure successful plants and environmental quality.

2. https://www.iowadnr.gov/Portals/idnr/uploads/water/npdes/Nut_Strat_factsheet.pdf

Nitrogen

AMBER ANDERSON

Learning Objectives

- Outline basic steps in the nitrogen cycle
- Identify potential sources of loss or transformation resulting in decreased available N in the soil
- Predict differences in loss of nitrogen under contrasting conditions.

Importance

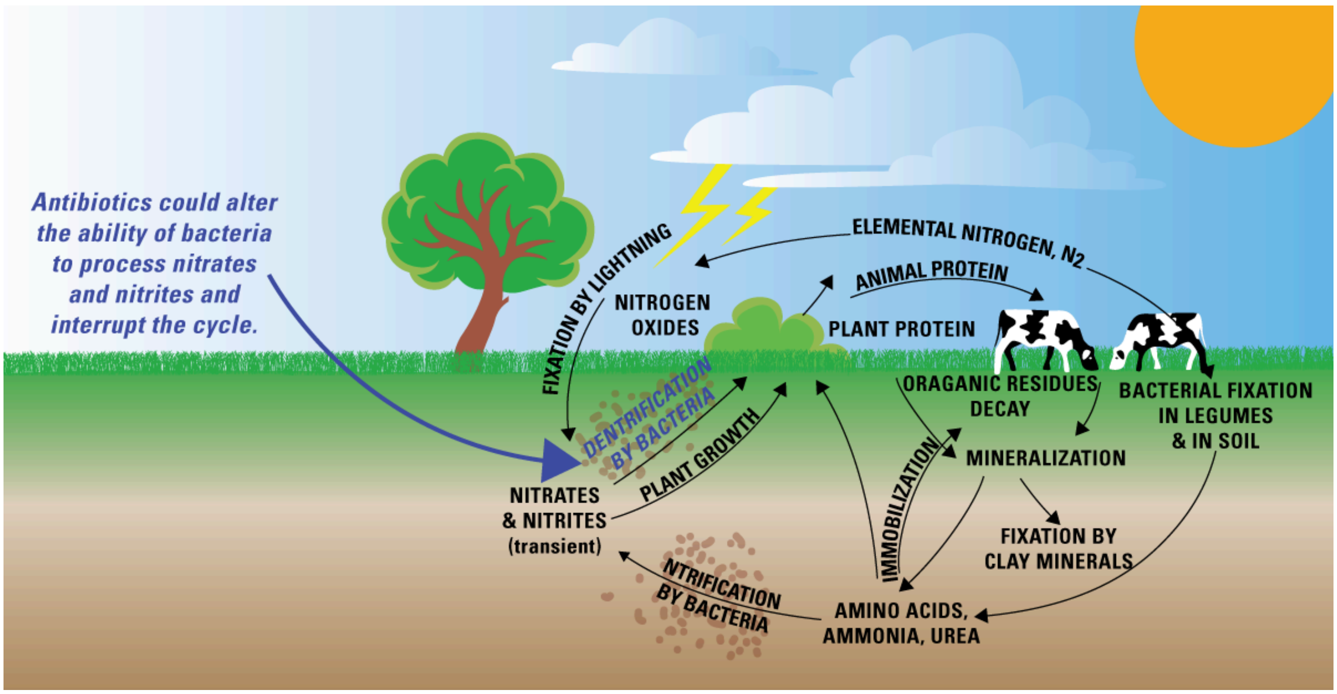
Nitrogen is critically important to plant growth as it is a part of chlorophyll, nucleic acids (DNA), amino acids, and proteins. Therefore, a nitrogen-deficient plant will appear yellow with decreased growth. Despite being a major component of the air around us, nitrogen can regularly be a plant-limiting nutrient. Today, commercial nitrogen fertilizer production, known as the Haber-Bosch process, uses large amounts of energy to convert the nitrogen in the atmosphere to plant-usable forms. Previously, legumes and manures were used for nitrogen management within agricultural systems.

A corn field with a strip of grasses through it.

Nitrogen is a challenge for management due to its significant biological reactivity, interactions with soil, and potential negative impacts on human health and the environment. The US Environmental protection agency (EPA) has set a limit of 10 ppm (10 mg/L) of nitrate in its safe drinking water standard due to the potential negative health implications, such as blue baby syndrome. Environmentally, nutrient enrichment coming from the corn belt contributes to the dead zone in the gulf of Mexico.

Lower leaf of corn (maize) plant showing nitrogen deficiency symptoms

Simplified Nitrogen Cycle



US geological Survey simplified nitrogen cycle

Transformations

- **Fixation:** N_2 gas converted to plant-usable form through either free-living or symbiotic organisms. Commercially or industrially, atmospheric nitrogen can be fixed using significant amounts of energy through the Haber-Bosch process. This nitrogen is added to the soil and/or plant available pool.
- **Nitrification:** N is biologically converted to nitrate (NO_3^-), which can be lost due to leaching.
- **Denitrification:** Nitrate (NO_3^-) to N_2 or nitrous oxide (greenhouse gas), usually occurs due to biological activity and anaerobic conditions, like could exist in a waterlogged soil. This is a loss from both the soil and available pool.
- **Immobilization**: Nitrogen removed from plant-available pool due to uptake by microbial tissues, so a short-term loss from the plant-available pool, but not a long-term loss.
- **Mineralization:** Organic nitrogen converted to plant-available nitrogen, the reverse of immobilization.
- **Leaching**: Nitrate (usually) lost due to moving through water and out of the system.
- **Volatilization:** Ammonia (NH_3) lost from the soil as a gas, like if anhydrous ammonia is applied to dry soil

or with equipment that didn't successfully seal the furrow.
- **Ammonification:** N is converted to NH_4^+ form of nitrogen.

Note that microbial activity is a major component of many transformations, with soil conditions, such as low oxygen or warmer soil temperatures, change the types and rates of transformations present.

Legumes and nitrogen management

Historically, legumes like alfalfa, beans, and peas, in combination with animal manures or composts, were used to add nitrogen or manage nitrogen in agricultural or horticultural settings. Many of these techniques are still used, based upon available resources.

Nitrate testing

In Iowa, any nitrate remaining in August is assumed to be lost before the next cash crop would utilize it, so it is not regularly included in standard fall soil testing. In drier climates, this may not be the case, and fall or winter nitrate testing may occur. The spring soil nitrate test may be used after corn has begun its growth to determine if an additional side-dress application of nitrogen would be warranted.[1] Fall cornstalk testing could be used to assess if nitrogen was sufficient or likely in excess to determine future management. If still possible, a cover crop could be used to uptake the remaining nitrate and prevent it from leaching.

Additional Nitrogen Cycle video

- This video was developed by Dr. John Sawyer with ISU Extension.[2]

Check it out!

- Check out the nitrogen rate calculator here[3]

1. https://crops.extension.iastate.edu/cropnews/2022/06/using-late-spring-soil-nitrate-test-2022
2. https://youtu.be/SVFywwreP0I
3. https://www.cornnratecalc.org/

Key Takeaways

- Nitrogen management is dynamic due to its biological reactivity
- Potential losses can occur to either air or water
- Biological transformations significantly impact the plant-available N

Potassium

AMBER ANDERSON

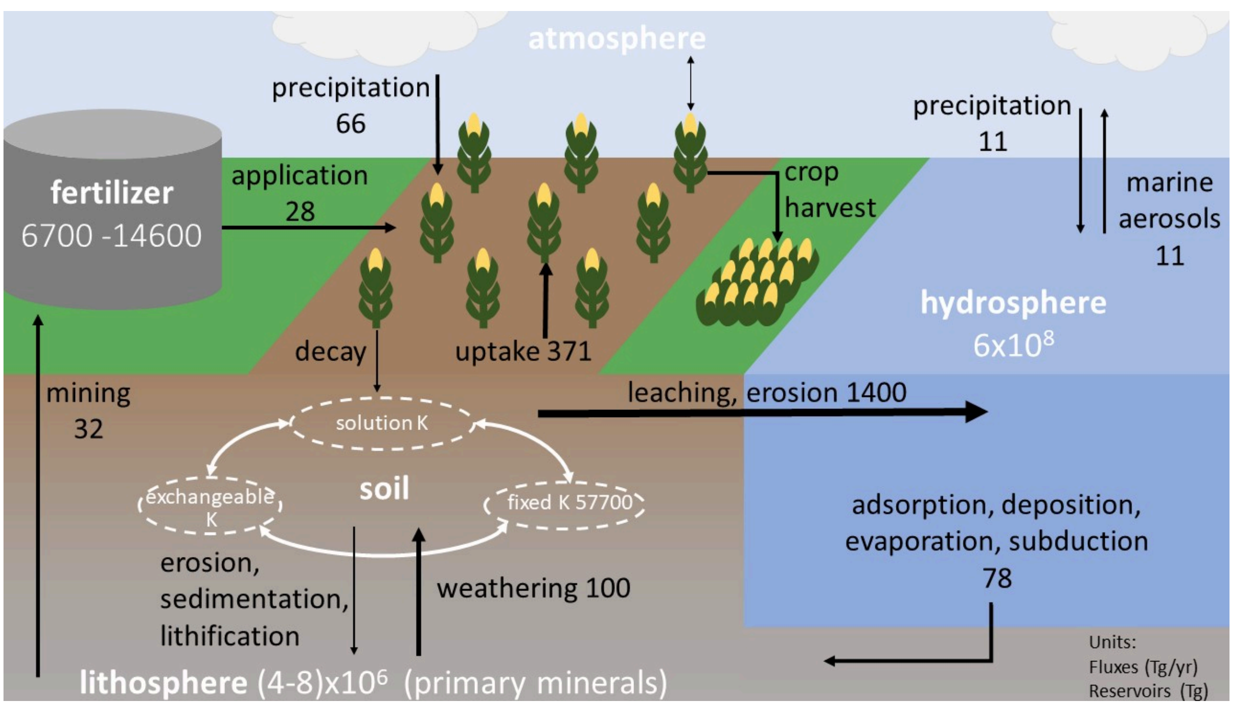
Learning Objectives

- Identify the function of potassium in the plant and potential deficiency symptoms.
- Define the concept of "luxury consumption"
- Identify under what conditions potassium deficiencies might be more likely

Role in the plant

Potassium is contained in the sap rather than structural components of the plant. It is involved in water regulation, such as stomata opening and closing, as well as some enzymatic and energy reactions within the plant. Because of this function, deficiency symptoms may be more evident in hot and dry growing seasons.

Potassium cycle



Potassium cycle illustrated. Image Source: Compost Camel, CC BY SA

The primary location of potassium in soils are the primary minerals. Small amounts are held on the cation exchange capacity, and significantly less of that is available to the plant in the solution at one time. If the soil can't supply potassium, fertilizer application would be required. Historically, materials like 'pot-ash', or ash from burned materials would be used for potassium enrichment.

Potassium deficiency on soybean

Luxury consumption

Luxury consumption is the concept of plant uptake beyond plant needs. If the crop is harvested for grain, this may not be a significant issue. However, if a forage like alfalfa, or silage is produced, this would result in a higher export of potassium from the soil.

Deficiency symptoms

Deficiencies in potassium may be found in areas where the entire plant is removed, while green.

Potassium and forage management:

- Soil potassium and alfalfa[1]

Key Takeaways

- Potassium is important in water regulation within the plant
- Risk of potassium deficiency increases in areas where plants are harvested green and removed
- Symptoms may be more evident in hot and dry years

1. https://www.soils.org/news/science-news/alfalfa-and-potassium-its-complicated/

Micronutrients

MEGAN BLAUWET

Learning Objectives

- Identify functions of micronutrients in the plant
- Match soil properties with potential deficiencies

Micronutrients make up a small percentage of the overall plant, but are critical for growth. Most are used in enzymes rather than structural components of the plant.

Extreme cases, like extreme pH values, peat soils, or otherwise unusual conditions makes deficiencies more likely. Since deficiencies are resolved by small quantities per area, they may be added to other mixes or strategy that allows more effective spreading. Materials such as manure or composts may be used, depending upon analysis.

There are eight micronutrients that are essential for plant growth. These include boron, zinc, manganese, molybdenum, iron, copper, chlorine, and nickel. All micronutrients are needed in small amounts so when soils contain too much of them, toxicity can occur.

Boron (B)

Boron is used in plants for germination, pollination, sugar transport, cell wall development, protein formation, and carbohydrate metabolism. Boron is one of the most common micronutrient deficiencies. Boron is most often limited in alkaline soils and oppositely can have toxic amounts in acidic soils. A deficiency in boron will affect the vegetative and reproductive growth of the plant. Deficiency symptoms include chlorosis, death of buds/flowers, and death of new growth. A fertilizer most often used to add boron to the soil is sodium borate which contains around 10-20% boron.

Zinc (Zn)

Zinc is a part of many enzymes in the plant that are used for metabolic functions. A lack of zinc will create problems with protein, carbohydrate, and chlorophyll formation. Deficiencies are most likely to occur in calcareous soils with low organic matter and high pH. Zinc has a relationship with phosphorus in the soil where too much phosphorus can result in Zn deficiency. Deficiency symptoms include striping of corn leaves or yellowing of leaves. Zinc sulfate is the most common fertilizer used to add Zn to soils.

Manganese (Mn)

Manganese is an important micronutrient involved in critical functions in the plant such as photosynthesis, nitrogen assimilation, and respiration. Deficiency is most likely to occur in high pH soils and toxicity can occur in low pH soils. Manganese competes with iron in the soil so it is important to keep them balanced. The symptoms of Mn deficiency includes yellowing of leaves with wide green areas on the veins. Manganese sulfate is a common fertilizer added to soils that are deficient.

Molybdenum (Mo)

Molybdenum is a part of enzymes that are used in nitrogen fixation, nitrate reductase (converting nitrate into proteins), and the conversion of inorganic phosphate to organic. Unlike most other micronutrients, molybdenum deficiencies occur in acidic soils. Toxic amounts of molybdenum in plants used to feed animals can be quite harmful. Since molybdenum is related to nitrogen functions in plants, deficiencies can look similar and result in yellowing of leaves and stunting of growth. Fertilizers that add molybdenum include sodium molybdate and ammonium molybdate.

Iron (Fe)

Iron is a part of many enzymes and is used for chlorophyll formation, cell division and growth, and oxygen transport. Iron deficiencies are found in soils with high clay content or high pH soils. Interveinal chlorosis is the most typical iron deficiency symptom. Iron added to the soil in fertilizers is often chelated iron which will be available for longer in the soil. A foliar spray of ferrous sulfate is also available and commonly used.

Iron chlorosis on a tree in central Iowa

Copper (Cu)

Copper is a part of enzymes critical for photosynthesis, respiration, and lignin production. Copper deficiencies are not very common in most soils but can be found in sandy soils or peat soils with very high organic matter. Plant deficiency symptoms include slight yellowing of leaves and leaf tip twisting or death. Copper sulfate is a common fertilizer applied to fix copper deficient soils.

Chlorine (Cl)

Chlorine is used in stomata regulation, osmotic regulation, and disease resistance. Chlorine can be problematic in arid regions due to it largely being found in salt forms in soil. Chlorotic or necrotic spots on leaves and wilting are common deficiency symptoms. Potash (KCl) fertilizer is often applied for its potassium, but it also provides chloride to the soil.

Nickel (Ni)

Nickel is the most recently discovered plant micronutrient. Its function in the plant is as a cofactor for the conversion of urea into a plant available form. Nickel deficiency in plants is very rare but can appear as necrosis of leaves (due to buildup of urea) and is most likely to be found in high pH soils. If a soil is low on nickel, nickel sulfate fertilizer can be added.

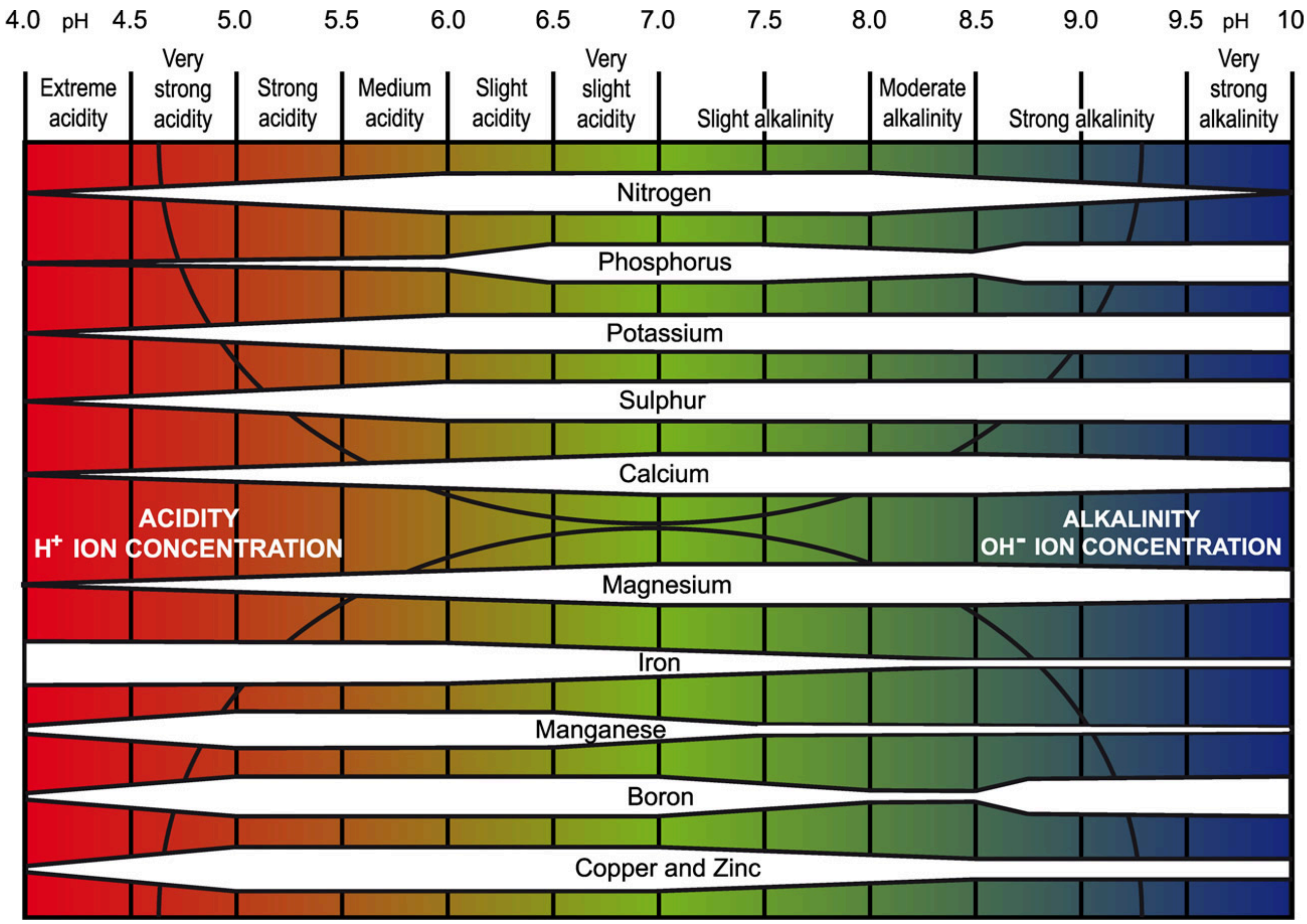


Figure showing pH influence on plant nutrient availability from [Potash Development Association.](#)

Key Takeaways

Type your key takeaways here.

- Micronutrients are essential to plants but needed in small amounts.
- There are 8 essential plant micronutrients and most are a part of enzymes or used in metabolic functions.

CASE STUDIES

Western Iowa hillslope

AMBER ANDERSON

Grass seed was planted equally across the area after road construction was complete, but the upper part of this slope started to establish vegetation when the lower part did not, as shown in this picture. This area is located in Western Iowa, west of the Missouri river valley in fairly sloping area.

1. What soil properties might explain what is seen in this picture? What might the next management step be if you are in charge of the location?

Corn deficiency symptoms

AMBER ANDERSON

This photo was taken at the end of June, in a cool, wet spring. Corn on the slope shows the yellow striping, but corn at the top and bottom of the hill do not show the same pattern, in spite of being the same variety and planted on the same day. These plants were slightly smaller than the ones at the bottom of the hill.

This soil core was pulled from the location showing the deficiency patterns:

Tree with Chlorosis

AMBER ANDERSON

This tree is located in a yard in Ames, IA. Foliage appeared normal as a smaller tree, but has become more pronounced as it has gotten larger. No treatments have been applied to either the tree or the surrounding yard.

1. What soil features might be contributing to this appearance? Why would it be changing as the tree gets larger? What might you recommend for this homeowner?

NC Iowa crops

AMBER ANDERSON

These soybeans are located in North-Central Iowa. This was a particularly dry spring, and this shoulder/backslope area showed yellowing on the leaves.[1]

1. Photo credits Angie Rieck-Hinz, ISU Extension North Central Region Agronomist.

1. What soil factors could be contributing to this? What other questions do you have to figure out the cause of the solution?

Erosion around houses

AMBER ANDERSON

You are asked to look at erosion happening at two different houses:

House one:

This house was built approximately 10-12 years ago, is on a slight slope. Over time, this has developed:

House two:

This front yard has about 1-2″ of sediments over the previously established garden edge, along with a gully forming off the back downspouts off a of a C to D slope into a wooded area.

1. What soils factors may be contributing to these two scenarios?

2. The homeowner asks you what to do about each of these, what do you recommend/why?

Uganda management challenge

AMBER ANDERSON

This corn is in Kamuli District, Uganda, and would normally yield sufficient crop to be used as a staple food for the season and sold in the market, this is not used for animal feed. Fertility/tillage is not significantly different in these pictures than in years with good yields sufficient to sustain the family on the 1-2 acre plot. They can grow multiple crops per year depending upon rainfall and crops chosen, as temperatures do not fall much below 60 degrees F at any point in the year.

Recently, the little purple flowers on the right have appeared at the edge of the field, and the ears in the picture are empty. They have asked you to figure out what is going on and how might they manage this problem so they can produce enough crop.

1. What management recommendations do you have?

2. What significant differences exist when considering management here than in the Midwest US?

Hoop house

AMBER ANDERSON

Tomatoes in this hoop house were reported to yield less this year than the last several years. This hoop is located in central Iowa, and has had a hoop (see below) for approximately 6 years.

Soil samples for calcium and magnesium were the following (mehlich extraction):

	Sample Id	Ca Conc (mg/kg)	Mg Conc (mg/kg)
In irrigation line 3-4″	1	6326	95
Edge of row 0-1″	2	6591	139
edge of row 0-4″	3	6358	171
2-6″	4	5188	80

Samples of the water came back with the following results:

Sample Id	**Ca Conc (mg/L)**	**Mg Conc (mg/L)**
R-1	159	104
R-2	156	10?3

1. What additional questions do you have for this grower? What additional results would be helpful?

2. How might you go about managing soil in this scenario?