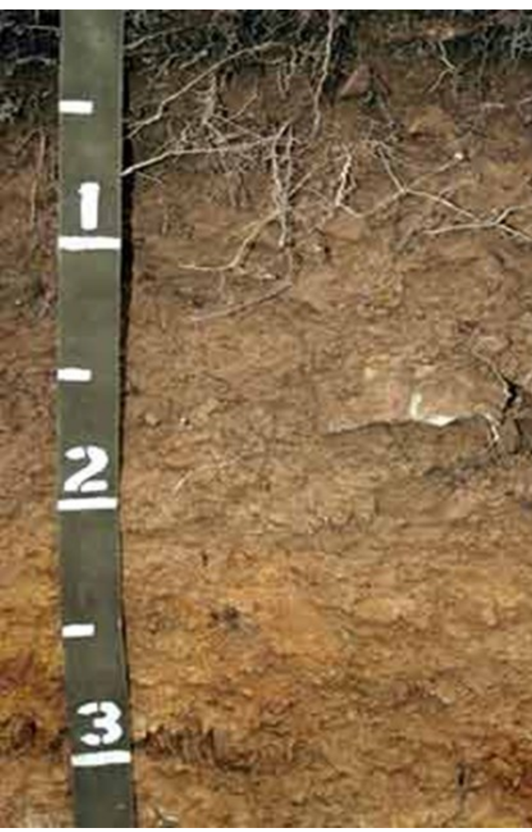
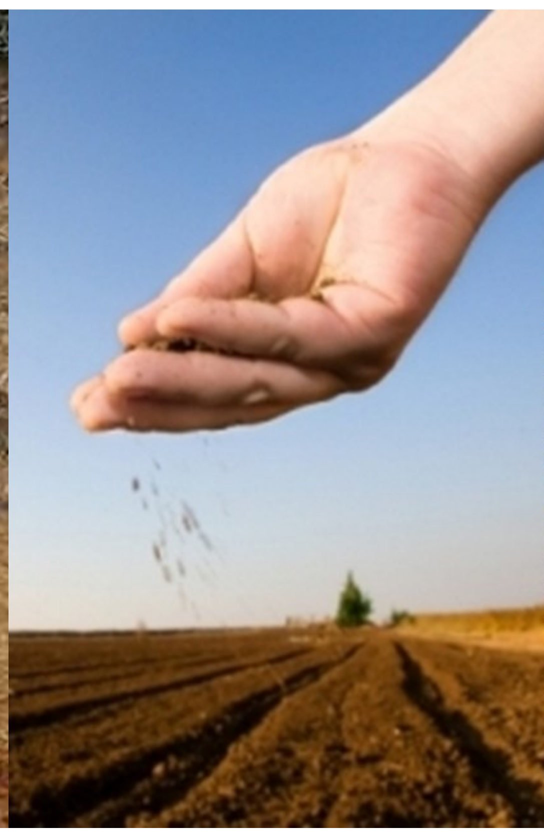
Just the Facts

Introduction *to* Soil Science


National Agricultural Institute

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number on the pH scale, the stronger the acidity of a substance. Each pH point multiplies acidity by a factor of 10. A pH of 5.0 is 10 times more acid than pH 6.0 and 100 times more acid than pH 7.0.

Development of Soil pH

- Soil does not reach the extreme pH limits.
  - Growers more commonly find that soil ranges between pH values of 5.0 and 8.0.
  - Soil pH results from the interaction of soil minerals, ions in solution and cation exchange.
  - High pH is caused by the reaction of water and the bases calcium, magnesium and sodium to form hydroxyl ions.
  - Low pH caused by the percolation of mildly acidic water, which results in the replacement of exchangeable bases by hydrogen ions.
  - Very basic soils (pH greater than 8.0) are more than 100% base-saturated – all exchange sites are filled with bases.
  - pH of very alkaline soils results from the reactions of carbonates with water to form hydroxyl ions:

$$CaCO_3 + 2H_2O \text{ ---------> } Ca^{+2} + H_2CO_3 + 2OH^-$$
$$Na_2CO_3 + 2H_2O \text{ ---------> } 2Na^+ + H_2CO_3 + 2OH^-$$

    - ✓ Reaction with water is called **hydrolysis.**
  - The hydrolysis of calcium carbonate in the reaction results in a pH range of about 8.0–8.5.
  - Soils in this range (100% base-saturated and contain enough free calcium carbonate) are called **calcareous soils.**
    - ✓ Can be tested with dilute hydrochloric acid; producing a fizz from carbon dioxide given off by the reaction between the mineral and the acid.
    - ✓ Result from the weathering of calcareous parent materials like limestone.
  - If the sodium saturation exceeds 15%, then the hydrolysis of sodium produces lye (sodium hydroxide, NaOH), which can raise the pH to 10.0
    - ✓ High-sodium soils are called **sodic soils.**

- Causes of Acidity
  - Relatively young soils – those not exposed to long periods of weathering and leaching – share the pH of their parent materials.
  - Acidic parent materials include granite, sandstone and shale.
  - Soils of many states developed from calcareous parent materials like limestone, with a pH of 7 or higher as a "young soil".
  - pH of most soils is controlled by the percolation (or lack of percolation) of acidic water.
    - ✓ Percolating water leaches away bases and replaces them on the exchange sites with hydrogen and aluminum ions.
  - Percolation occurs in humid climates, when precipitation exceeds evapotranspiration.
  - In semi-arid or arid zones, net water movement is upward, since water is being pulled out of the root zone by evaporation or transpiration.
  - With little or no percolation, soils of dry regions tend not to become acidic and may become quite alkaline from calcium or sodium being carried upward into the root zone by capillary movement.
- Processes that produce the hydrogen ions making soil more acidic include:
  - Respiration of plant roots and other soil organisms.
  - During respiration, carbon dioxide is produced which reacts with water to produce carbonic acid.
    - ✓ Carbonic acid, breaks down to release hydrogen ions:

$$CO_2 + H_2O \text{ -----------> } H_2CO_3 \text{ ----------> } HCO_3^- + H^+$$

  - Both plant growth and organic matter decay produce hydrogen ions.
  - Rainfall is a second cause of soil acidity.
  - When roots take up cation nutrients like potassium, they “give back” an equivalent number of hydrogen ions.

- Growers take calcium and magnesium with each crop harvested. For example, every ton of alfalfa hay is a loss from the soil of 30 pounds of calcium and 8 pounds of magnesium.
    - ✓ Removal of magnesium and calcium during harvest increases the acidification of soil.
- Nitrification also contributes hydrogen ions to the soil. When nitrifying bacteria oxidize ammonium ions ($NH4^+$), hydrogen ions result:

$$NH_4^+ + 2O2 \text{ --------> } NO_3^- + H_20 + 2H^+$$

- Ammonium fertilizers are called acid forming fertilizers.

Effects of pH on Plants

- Each crop grows best in a specific pH range.
    - Most plants growing on mineral soils do well at a pH range of 6.0–7.0.
    - For organic soils, most crops prefer a pH of 5.5 to 6.0.
        - ✓ Exception is a group of acid-loving plants that includes mostly woody plants such as blueberry and azaleas and many evergreens.
    - Alfalfa is one of a few crops that prefer a slightly basic soil.
    - Soil conditions related to pH important to plants, include:
        - ✓ Effect of pH on nutrient availability.
        - ✓ Buildup of toxic levels of aluminum or other metals.
        - ✓ Effects on soil microbes.
    - Greatest effect on limiting crop growth varies from soil to soil and from crop to crop.
- Effect of pH on Nutrient Availability
    - Many soil elements change form as a result of reactions in the soil.
        - ✓ Reactions, controlled by pH, alter the solubility, and therefore the availability of nutrients.

    - Major nutrients and molybdenum are most available in near-neutral or higher pH soil.
        - ✓ Other trace elements are more available in acid soil.
    - pH in the range of 6.0–7.0 is a good average level for all nutrients and the best pH range for most crops.
- pH and Element Toxicity
    - At low pH, particularly below 5.5, aluminum and manganese can reach toxic levels in the soil.
        - ✓ Aluminum toxicity also increases water stress during dry periods because of poor root growth.
    - In greenhouses, iron toxicity may occur on certain crops like geraniums if the pH of the potting mix drops too low.
- pH and Soil Organisms
    - Soil organisms grow best in near-neutral soil.
    - Generally, acid soil inhibits the growth of most organisms, especially bacteria and earthworms.

Liming Soil

- In many situations, crops or landscape plants should be selected that tolerate the existing soil pH.
    - Plant breeders are also creating crop varieties tolerant of poor pH conditions.
        - ✓ To change the soil pH to match crop needs, liming is practiced to counteract soil acidity.
- Benefits of Liming
    - Improves crop response to fertilizers by improving nutrient uptake, especially phosphorus.
    - Reduces aluminum toxicity, and promotes the activities of such desirable organisms as the *Rhizobia* bacteria that fix nitrogen for legumes.
    - Lime is also a fertilizer, especially for high-calcium crops such as alfalfa.

- ✓ Certain limes also supply magnesium, which is important to many acid sandy soils.

- Liming Materials

  - **Agricultural lime** is ground limestone or other products made from limestone.

    - ✓ Common liming materials include calcitic limestone, dolomitic limestone, burned lime and hydrated lime.

  - **Calcitic limestone** is nearly pure calcite or calcium carbonate ($CaCO_3$).

    - ✓ Forms on the sea floor as deposits of calcium drop out of solution in seawater. Limestone deposits are widespread in the U. S.

    - ✓ Deposits are mined and ground into agricultural lime.

  - **Dolomitic limestone** is a mixture of calcium carbonate and magnesium carbonate ($CaCO_3$ and $MgCO_3$).

    - ✓ Especially helpful in sandy soils, because it lacks sufficient magnesium.

  - **Burned lime**, or quicklime, is made by heating limestone. Heating drives off carbon dioxide resulting in the lighter calcium oxide:

$$CaCO_3 \bullet \text{ -----> } CaO + CO_2 \text{ (gas)}$$

    - ✓ Less has the same effect as a larger weight of ground limestone.

    - ✓ Reacts more quickly in the soil.

    - ✓ Costs more and is hard to handle.

    - ✓ Caustic and may cake during storage.

    - ✓ Can be used where fast action is needed but not usually recommended.

  - **Hydrated lime**, or slaked lime, is produced by adding water to burned lime, forming hydrated lime, or calcium hydroxide:

$$CaO + H_2O \text{-------> } Ca(OH)_2$$

    - ✓ Unpleasant and hard to handle, but fast acting.

    - ✓ Used more often than burned lime.

    - ✓ More expensive than regular ground lime, but may be used where speed of reaction is needed.
  - Growers may find other locally useful materials:
    - ✓ **Marl**, a soft, chalky freshwater deposit in swamps, sometimes locally mined.
    - ✓ Ground seashells, a by-product of shellfish industries.
    - ✓ Wood ashes can be used by gardeners.
  - Gypsum ($CaSO_4$) does not change soil pH, so is not used as an agricultural lime.
- How Lime Works
  - Neutralizes soil in two ways.
    1. Calcium replaces hydrogen and aluminum ions on exchange sites by mass action thus raising the percent base saturation.
    2. Converts hydrogen ions to water.
- How Much Lime to Apply
  - Four factors tell the grower how much lime is required:
    1. Present pH
    2. Desired pH
    3. Cation exchange capacity of the soil
    4. Liming material to be used
- Effect of Cation Exchange Capacity on Liming
  - The larger the cation exchange capacity (CEC), the more hydrogen a soil can hold, and the more lime it needs.
- **Buffering** – resisting pH change
  - Buffering capacity of a soil depends on the amount of clay in the soil, the type of clay and the amount of humus.
    - ✓ Clay can be estimated by knowing the textural class of a soil.

- Type of clay modifies the effects of texture; highest for vermiculite and lowest for sesquioxides.
- Buffering capacity increased by the amount of organic matter in the soil.
- Lime requirement of an acid soil depends on both pH and buffering capacity.
- Total lime requirement measured directly by a buffer test and buffering indexes.

- Neutralizing Power of Lime
  - Two factors affect the comparison:
    1. Chemical nature or weight
    2. Purity
  - Most states regulate the purity of agricultural lime to protect the customer.
- Lime Fineness
  - Fineness of the grind affects how rapidly lime acts.
    - ✓ Finer the grind, the more rapidly it can neutralize acidity.
- Lime Application
  - Spread evenly over the field and then mixed well into the soil.
  - May also be applied in pelletized form.
  - Some is finely ground and mixed with water or a fertilizer solution and sprayed on the field – **fluid lime** – which acts more quickly but remains active for a shorter time.
  - Growers may lime at any convenient time.

Acidifying Soil

- Crop growth can be inhibited by alkaline soils.
  - Zinc, manganese, iron and other trace elements are tied up in basic soils.
  - Free molybdenum can reach toxic levels.
  - For longer-lasting pH reduction, and for larger areas, sulfur is preferred.

- ✓ Once applied and mixed into the soil, Thiobacillus bacteria alter sulfur to sulfuric acid:

$$2S + 3O_2 + 2H_2O \text{ -----> } 2H_2SO_4 + \text{energy}$$

- Sulfuric acid releases hydrogen ions, and the soil becomes more acid.
- Sulfur is available in granular and powdered forms and as a flowable liquid.
- Other chemicals also acidify the soil including iron sulfate, $Fe_2(SO_4)_3$, and aluminum sulfate, $Al_2(SO_4)_3$.
  - ✓ Materials are less powerful than sulfur and usually more expensive.
- Calcareous soils may be very difficult to acidify because there is such a large reserve of lime that must be leached out.
- Where pH reduction is impractical, fertilization and crop selection for high pH required.

Soil Salinity

- Growers in more arid areas encounter the problem of the accumulation of **soluble salts** (salts that are readily dissolved in water).
  - A salt is a chemical that results from the reaction of an acid with a base.
  - A soluble salt is at least, or more soluble in water than gypsum (calcium sulfate, CaSO4).
    - ✓ Soluble salts of greatest concern are sulfates (SO_4^{-2}), bicarbonates ($HCO3^-$) and chlorides (Cl^-) of the bases calcium, magnesium and sodium.
  - Salts may come from parent materials, irrigation with salty water or even deicing salts.
    - ✓ Salinity problems affect about 25% of the irrigated lands of the United States.
    - ✓ Growers of potted plants – greenhouses, nurseries, and interior landscapers – also experience soluble salt problems.
  - Three types of problem soils based on the types of soluble salts:
    1. Saline

2. Sodic
3. Saline-sodic

- **Saline Soils**
  - Have high levels of soluble salts except sodium.
  - Measured by passing an electrical current through a solution extracted from a soil sample.
    - ✓ Greater the salt content, more electricity will pass.
    - ✓ Electrical flow amount is called electrical conductivity.
    - ✓ Measured by the unit millimhos per centimeter (mmhos/cm).
    - ✓ Being replaced by siemen per meter, which equals 10 mmhos/cm.
  - Electrical conductivity of saline soil is 4 or more millimhos per centimeter.
- Effect of salinity
  - Makes it more difficult for plants to absorb water from the soil (osmotic potential).
  - Soils can be classified for use based on salinity:
    - ✓ Non-saline
    - ✓ Slightly saline
    - ✓ Moderately saline
    - ✓ Strongly saline
    - ✓ Very strongly saline
  - Crops vary in their salt tolerance
- Sodic Soils
  - Low in the kinds of salts found in saline soils but high in sodium.
    - ✓ Exchangeable sodium percentage (or sodium saturation) is 15 or more, and pH is in the range 8.5 to 10.0

- Sodium is often measured by the **sodium adsorption ratio** (SAR).
  - ✓ SAR compares the concentration of sodium ions with the concentration of calcium and magnesium.
  - ✓ Sodic soil has an SAR greater than or equal to 13.
- Has a number of effects on plant growth, effects varies according to soil and crop.
  - ✓ Resulting pH, 8.5 or higher, limits growth of many crops.
- Main effect of sodium is the destruction of soil structure.
  - ✓ Colloids separate and disperse soil aggregates.
  - ✓ Tiny soil particles lodge in the soil pores, sealing the soil surface and creating wet “slick spots.”
  - ✓ Tilth suffers and crusts hard enough to stop seed germination.
  - ✓ May also show a poorly drained columnar subsoil structure.
  - ✓ Most extreme on fine-textured soils and least extreme on coarse soils.
- Crop plants may take up enough sodium to injure plant tissues.
  - ✓ Crops vary in their tolerance to sodium.

- Saline-Sodic Soils
  - Contain high levels of both soluble salts and sodium.
    - ✓ Electrical conductivity greater than 4.0 millimhos per centimeter, the SAR is greater than 13, and pH is less than 8.5.
  - Physical structure of these soils is normal.
    - ✓ With leaching of soluble calcium and magnesium leaving behind the sodium salts, soil may then become sodic.
- Reclaiming Salted Soils
  - Needs to be practical and pay for itself.

- Basic step to reclaiming soil is to leach out salts with acceptable high-quality water.
- Ensure good drainage.
- Sub-soiling to break up hardpans may be required.
- Saline soils most easily reclaimed.
- Ponding is one way to apply leaching water.
- Reclamation of saline soils improved by the use of organic mulches.
- Sodic soils cannot usually be reclaimed simply by leaching; sealed soil surface inhibits drainage.
  - ✓ Sodium first removed by treating soil with gypsum.
  - ✓ Gypsum enters the soil, dissolves and calcium replaces sodium on the cation exchange sites.
- Sodium sulfate leaches out of the soil.
- On soil containing some lime ($CaCO_3$), finely ground sulfur will add calcium indirectly.
  - ✓ Bacteria convert the sulfur to an acid.
- Acid forms and reacts with soil lime to make gypsum:

$$CaCO_3\ \ H_2SO_4 \text{ -------------->} \bullet\ CaSO_4 + H_2O\ + CO_2 \text{ (gas)}$$

- Conversion takes time, so sulfur treatment is relatively slow.
  - ✓ Sulfuric acid can be added directly for faster action but is more expensive and dangerous.

- Managing Salted Soils
  - Grow salt-tolerant crops.
  - Practices help reduce salt problems.
    - ✓ Proper leveling to avoid low spots that collect salts.
    - ✓ Installing drainage during field preparation.

  - ✓ Using high-quality irrigation water.
  - ✓ Keeping the soil moist dilutes soil salts, lowering the effect of osmotic potential.
  - ✓ Over-irrigating enough to leach salts out of crop root zones.
  - ✓ Adding organic matter to the soil including manures, crop residues, and green manures.
  - ✓ Avoiding over-fertilization.
  - ✓ Maintaining a good soil-testing program to monitor salinity.
  - ✓ Planting crops on ridge shoulders in furrow-irrigated fields.
  - ✓ Using drip irrigation.

- Salted Water Disposal
  - Growers have some options to help reduce saline discharges from their fields:
    - ✓ Improve water delivery systems to reduce seepage and evaporation from canals.
    - ✓ Use techniques to improve irrigation efficiency, such as surge irrigation and careful budgeting to reduce percolation and tailwater losses.
    - ✓ Adopt drip irrigation where possible.
    - ✓ Practice minimum leaching to carry salts below the root zone but not into the drainage system.
    - ✓ Reuse salty water on salt-tolerant crops such as barley or sugarbeets.

Summary

Soil pH depends on the balance of hydrogen and hydroxyl ions in the soil solution. Alkaline soil, with a pH between 7.0 and 10.0, results from the reaction of calcium and sodium with water to form hydroxyl ions. Acid soil, with a pH between 4.0 and 7.0, results from the leaching of these bases by mildly acidic water and from the release of hydrogen ions by aluminum hydrolysis.

Acid soils affect plant growth by lowering the availability of phosphorus and other nutrients, freeing toxic levels of aluminum, and inhibiting helpful soil organisms. Alkaline soils render several micronutrients unavailable and create many problems associated with salted soils. Most plants grow best between pH 6.0 and 7.0. Acid soils are treated with agricultural lime. Lime replaces hydrogen and aluminum on the cation exchange sites with calcium and converts hydrogen ions to water. The amount of lime needed depends on the amount of pH change required, the buffering capacity of the soil, and the form of lime. Soils, too alkaline for a specific crop, may be treated with sulfur.

Salted soils may be saline, sodic, or saline-sodic. Saline soils, which are high in soluble salts but low in sodium, reduce the water available to plants. Saline soils can be treated by flooding to leach out salts. Sodic soils are high in sodium and exhibit poor physical structure. They are treated with gypsum to displace the sodium. Saline-sodic soils contain both soluble salts and sodium. After treated, a soil must be managed carefully to reduce salt problems.

Resources

Free complementary PowerPoint: http://www.tagmydoc.com/dl/2B0iry/gjUp

Scan. Get the doc.

Soil and Water Conservation Society
http://www.swcs.org/

Soil Science Society of America
https://www.soils.org/
National Resources Conservation Service
http://soils.usda.gov/technical/nasis/

Plaster, E.J. 2008. Soil science and management. 5th Ed. Albany, NY: Delmar Publishers.

Assessment

1. The neutral point, neither acid nor base of the pH scale is _________.
   a.) 3.0   b.) 5.0   c.) 7.0   d.) 11.0

2. T or F? Relatively young soils, those not exposed to long periods of weathering and leaching, share the pH of their parent materials.

3. T or F? Liming inhibits crop response to fertilizers by improving nutrient uptake.

4. A mixture of calcium carbonate and magnesium carbonate is called__________.
   a.) agricultural lime   b.) calcitic limestone   c.) dolomitic limestone
   d.) hydrated lime

5. Salinity problems affect about ______% of the irrigated lands in the U.S.
   a.) 10   b.) 25   c.) 40   d.) 60

Take assessment online here:

http://tinyurl.com/soilsci-q11

Note: The assessment won't allow you to move to the next question unless you select the correct answer. When the answer is incorrect, you will see: "Wrong answer! Try again!

Notes