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Natural Resources
Conservation Service

Soil Quality Institute

Soil Quality Test Kit Guide

July 2001

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PREFACE

Soil quality is simply defined as "the capacity of a specific kind of soil to function." It is generally assessed by measuring a minimum data set of soil properties to evaluate the soil's ability to perform basic functions (i.e., maintaining productivity, regulating and partitioning of water and solute flow, filtering and buffering against pollutants, and storing and cycling nutrients). This guide describes a kit of selected field procedures to evaluate or indicate the level of one or more soil functions.

When measuring soil quality, it is important to evaluate the physical, chemical, and biological properties of the soil. Physical properties addressed by the kit include bulk density, water content, infiltration rate, aggregate stability, slaking, and morphological estimations. Biological properties measured include soil respiration and earthworms. Soil chemical properties measured include pH, electrical conductivity (EC), and soil nitrate levels. The chemical tests are also useful to evaluate water quality of well-water, tile drainage waters, and other water bodies related to farm activities.

Section I of this guide provides a list of supplies and instructions for conducting a number of on-farm tests to assess soil quality. Section II provides background and interpretive information for each test described in Section I. These tests, or indicators, are designed as a screening tool to provide immediate results for comparing management systems, monitoring changes in soil quality over time, and for diagnosing possible soil health problems due to land use and management.

These tests can be easily conducted on the farm by NRCS field personnel or by landowners themselves to assess the quality of their soil. Use of the kit allows NRCS staff to be an active participant with the landowner in the assessment of soil health. The assessment will provide the opportunity to discuss management options when the need arises.

The kit was developed by John Doran and associates, Agricultural Research Service, Lincoln, NE. The Soil Quality Institute has continued the development, enhancement and testing of the kit (with NRCS field staff) by adding tests, modifying the manual, and writing an interpretations guide. The NRCS Soil Quality Team in Akron, CO (Manuel Rosales, Josh Saunders, and Mike Sucik) were instrumental in the field testing of the test kit and this guide. The Soil Quality Test Kit Guide is a dynamic document. The Institute welcomes suggestions for additional tests and interpretive information to incorporate in future versions of the guide.

The Institute gratefully acknowledges the contributions of the following individuals: John Doran, USDA-ARS, Lincoln, NE, for the development of the original soil quality test kit from which this guide is based. Bob Grossman, USDA-NRCS, NSSC, Lincoln, NE, for the development of the soil structure index and penetration resistance tests. Jeff Herrick, USDA-ARS, Las Cruces, NM, for the development of the soil slake test procedure and aggregate stability test design. Dennis Linden, USDA-ARS, St. Paul, MN, for the development of the earthworm procedure. Bob Hanafin, Auburn University, for the development of the design and layout of this guide. Cathy Seybold and Lee Norfleet, USDA-NRCS, Soil Quality Institute, for the development of this guide and testing of kit procedures.

The mission of the Soil Quality Institute is to cooperate with partners in the development, acquisition, and dissemination of soil quality information and technology to help people conserve and sustain our natural resources and the environment.

For more information about the Soil Quality Institute and its products and services, visit our website at **http://www.statlab.iastate.edu/survey/SQI/**.

Soil Quality Institute Staff

1. Measuring Soil Quality

Soil quality integrates the physical, chemical, and biological components of soil and their interactions. Therefore, to capture the holistic nature of soil quality or health, all of the parameters in the kit should be measured. However, not all parameters have equal relevance to all soils and situations. For example, the EC test for salinity may not be useful in the eastern part of the U.S. where salinity is not a problem. A minimum data set of soil properties, or indicators, from each of the three soil components are selected based on their ability to indicate the capacity of the soil to function for a specific land use, climate, and soil type. Indicators in the soil quality kit are selected primarily for agricultural soil quality assessments. The kit should be used as a screening tool to give the general trend or direction of soil quality--whether current management systems are maintaining, enhancing, or degrading the soil. Proper use of the kit and interpretation of results depends on how well the indicators are understood with respect to the land use and environmental goals.

There are two fundamental ways to assess soil quality:

- take measurements periodically over time to monitor changes or trends in soil quality;
- compare measured values to a standard or reference soil condition.

By making use of the two ways of assessing soil quality, the kit can be used to:

- make side-by-side comparisons of different soil management systems to determine their relative effects on soil quality;
- take measurements on the same field over time to monitor trends in soil quality as affected by soil use and management;
- compare problem areas in a field to the non-problem areas;
- compare measured values to a reference soil condition or to the natural ecosystem.

Field or Site Characterization

It is important to gain as much information about the area and soils as possible. Indicators of soil quality must be evaluated within the context of site and climatic characteristics. A "**Soil Quality Site Description**" recording sheet, located in the appendix, should be completed during the soil quality assessment. The following are items that should be considered when making an on-farm soil quality assessment:

Soil series - The soil series name can be found in the county soil survey.

Signs of erosion - Signs of erosion include gullies, rills, development of pedestals, exposed areas of subsoil, damage to plants caused by wind blown materials, etc.

Management history - This item includes a description of past and present land and crop management; kind, amount, and method of fertilization; prior tillage; and land leveling.

Slope and topographical features of the field - Record percent slope at the sampling sites within the field, and note any hills, knolls, ridges, potholes, depressions, etc.

Location of the field and sampling areas - Record longitude and latitude (if GPS unit is available), a description of the location (feet from landmarks), and a drawing of the field showing sampling areas.

Climatic information - This item includes precipitation and high and low average tempera-

tures for each month (data from a county or watershed level will often be sufficient).

Location of environmentally sensitive areas - This item includes location of ponds, creeks, wetlands, or other environmentally fragile sites adjacent to the field.

Sampling Guidelines

Important: When, where, and how deep to sample and how many samples to take is primarily dependent on the questions being asked or problems being addressed by the farm or land manager.

When to sample?

Timing of sampling is important, because soil properties vary within a season and with management operations, such as tillage. In general, for the overall assessment of soil quality, an **annual sampling of the field** is recommended. Sampling once a year will allow for the detection of long-term changes in soil quality. A good time of year to sample is when the climate is most stable and there have been no recent disturbances, such as after harvest or the end of the growing season.

Where to sample?

An important consideration in determining where to sample in a field is the variability of the area. Soil properties naturally vary across a field and even within the same soil type. Soil variability across a field is also affected by management operations. General field characteristics to consider are:

- row versus inter-row areas,
- differences in soil type,
- differences in management,
- wheel versus non-wheel tracked areas,
- differences in crop growth,
- salt affected versus non-salt affected areas,
- eroded versus non-eroded areas,
- differences in slope, and
- wet versus non-wet areas (drainage).

Some general guidelines on selecting sampling sites are as follows:

(1) For a general assessment of soil quality, select sample sites within a field that are representative of the field. Refer to soil maps of the area (Soil Survey) to identify soil type differences and variations within the map unit

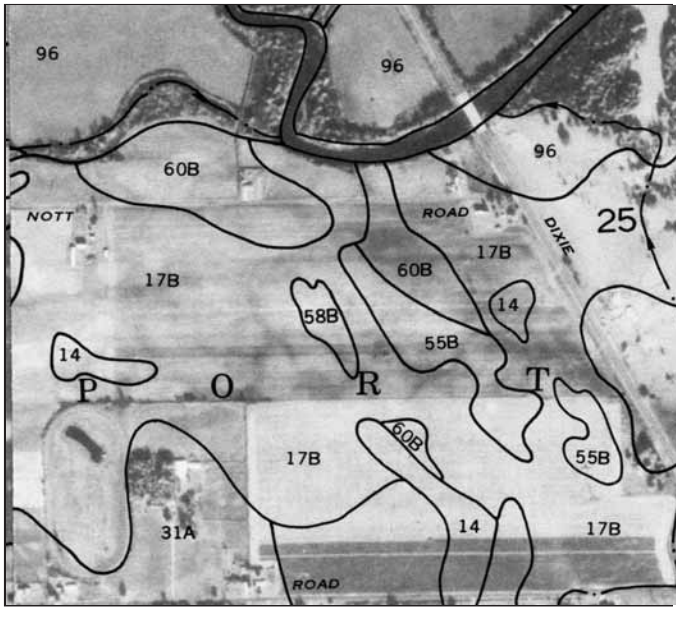


Figure 1.1

(Figure 1.1). A hand auger can be used to make a number of borings to establish locations of the most representative areas of the field.

(2) For assessment of trouble spots within a field, sample areas that are representative of the trouble spots **(Figure 1.2)**.

(3) When comparing management systems, make sure sites selected for comparison have the same soil type and are located on the same topographical features in both fields. For example, if sites are measured in the wheel tracks in one field, wheel tracks sites should be selected in the comparison field.

(4) When monitoring changes in soil quality over time, make sure the same sites within the field are measured at each sampling time. Also, try to take measurements at the same soil moisture conditions at each sampling time to reduce variability.

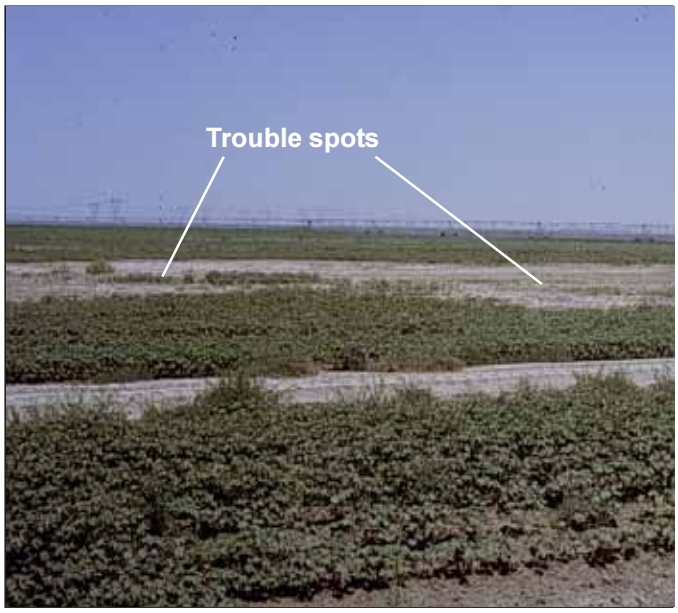


Figure 1.2

In some cases it might be helpful to compare sampling points if the field is sampled at different points across gradients of soil type, soil moisture, slope, or other factors rather than just at a fixed point **(Figure 1.3)**.

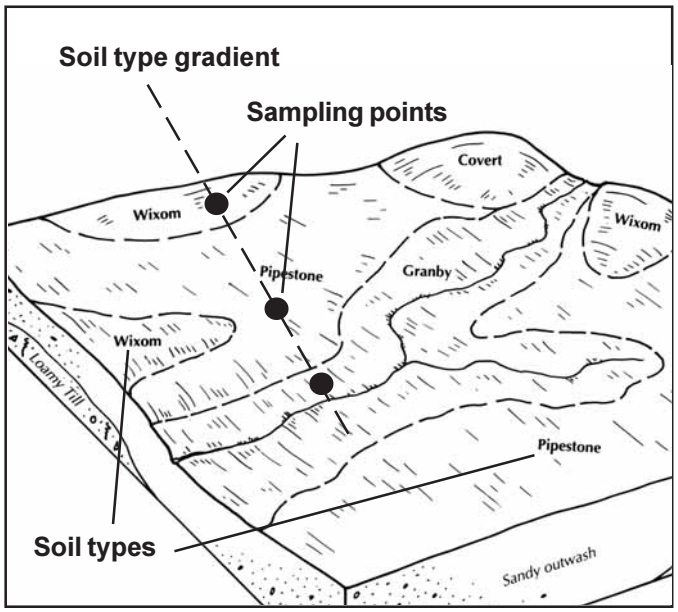


Figure 1.3

How many samples?

The number of samples or measurements to take will depend on the variability of the field. It is recommended that **a minimum of three samples or measurements** be collected on any one soil type and management combination. In general, the greater the variability of the field, the greater the number of measurements are needed to get a representative value at the field scale. When measuring EC, pH, and soil nitrates at the field scale, eight or nine sample cores from across the field could be bulked and mixed, and two subsamples from the mixed cores could be analyzed. When taking cores from across the field, stay away from areas that are distinctly different and are not representative of the field, such as farm lanes and field borders, fertilizer bands, areas within 150 feet of a gravel road, potholes, eroded spots, etc.

2. Soil Respiration Test

For efficient sampling, the soil respiration test is performed first, followed by the infiltration test (Chapter 3) without removing the 6-inch diameter ring. The best time to run the soil respiration test is when soil moisture is at field capacity (the amount of water the soil can hold after drainage). Otherwise, soil respiration should be measured before and after the infiltration measurement or soil wetting (6 to 24 hours after wetting).

Materials needed to measure respiration:

- **6-inch diameter ring**
- **lid with rubber stoppers**
- **hand sledge and wood block**
- **soil thermometer**
- **two sections of plastic tubing**
- **2 needles**
- **Draeger tubes**
- **140 cc syringe**
- **stopwatch or timer**

Did You Know?

Soil breathes! Soil respiration is an indicator of biological activity (i.e., microbial and root), or soil life. This activity is as important to the soil ecosystem as healthy lungs are to us. However, more activity is not always better; it may indicate an unstable system (i.e., after tillage).

Considerations: Microbial activity is greatest when the soil is moist (at or near field capacity). If the soil is dry, a second respiration measurement should be made at a minimum of six hours (preferably 16 to 24 hours later) after the infiltration test or wetting of the soil. If the soil is saturated, soil respiration is inhibited, and this test should not be run.

1 **Drive Ring into Soil**

- Clear the sampling area of surface residue, etc. If the site is covered with vegetation, trim it as close to the soil surface as possible.
- Using the hand sledge and block of wood, drive the 6-inch diameter ring, beveled edge down, to a depth of three inches (line marked on outside of ring) **Figure 2.1.**

Figure 2.1

- If the soil contains rock fragments, and the ring can not be inserted to depth, gently push the ring into the soil until it hits a rock fragment. Measure the height from the soil surface to the top of the ring in centimeters (cm). **[See note below]**

NOTE: For a more accurate measurement of soil respiration, the chamber head-space should be measured. Inside the ring, take four measurements (evenly spaced) of the height from the soil surface to the top of the ring, and calculate the average. Record average on the Soil Data worksheet.

2 Cover Ring with Lid and Wait

- Cover the ring with the lid as depicted in **Figure 2.2** and note the time.
- Wait exactly 30 minutes* (to allow CO_2 to accumulate in the chamber).

Figure 2.2

[If this is the SECOND respiration measurement, briefly remove the lid and replace it before timing to allow the release of gases that have built up over the 6-24 hour waiting period. Proceed with Step 3.]

***NOTE: During the 30-minute wait, other tests such as Bulk Density (Chapter 4) can be run.**

3 Insert Soil Thermometer

- Insert the soil thermometer into the soil adjacent to the ring with lid (about one inch away from ring and one inch deep). If the thermometer can easily be inserted into the rubber stoppers, insert it into one of them to a 1-inch depth into the soil.

4 Assemble Draeger Tube Apparatus

- Assemble the Draeger tube apparatus just before the end of the 30-minute wait.
- Connect a needle to one of the sections of tubing.
- Break open **both** ends of a CO_2 Draeger tube, either by using the hole at the end of the syringe handle as depicted in **Figure 2.3**, or by clipping the tube ends with a finger nail clipper.

Figure 2.3

- Connect the Draeger tube to the **other** end of the needle's tubing**.** The arrow on the side of the Draeger tube should point **away** from the needle.
- With the second piece of tubing, connect the Draeger tube to the syringe as shown in **Figure 2.4**

Figure 2.4

5 **Insert Apparatus Needle into Stopper**

After 30 minutes, insert the Draeger tube apparatus needle into a stopper as shown in **Figure 2.5**. Insert a second needle into one of the other stoppers on the lid to allow air flow into the head space during the gas sampling. The second needle should be inserted just before the head space is sampled.

Figure 2.5

6 **Draw Head Space Sample**

Over a 15-second span, draw the syringe handle back to the 100 cc reading (1 cc = 1 mL) as shown in **Figure 2.5.** [If the reading is less than 0.5%, take four additional 100 cc samples of the head space through the same Draeger tube. To do this, disconnect the tube from the syringe to remove the air, and reconnect the tube to the syringe. Take another 100 cc sample. Repeat.]

7 **Record Soil Temperature and % CO_2**

On the Soil Data worksheet, record the temperature in Celsius at the time of sampling. On the Draeger tube, read the "n=1" column if 100 cc was sampled or the "n=5" column if 500 cc was sampled. The % CO_2 reading should be an estimate of the highest point that the purple color can be easily detected. Enter this reading on the Soil Data worksheet. In the example in **Figure 2.6**, the reading would be approximately 0.75%.

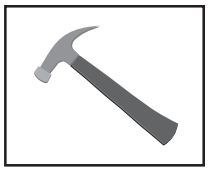
Figure 2.6

8 **Remove Lid**

Remove the thermometer, Draeger apparatus needle, air flow needle, and the lid from the ring.

If this is the **first** respiration measurement, leave the ring in the soil for the **infiltration measurement** (Chapter 3).

Maintenance Tips: Seal any holes in the chamber lid that may cause leakage. Also to prevent leaks, replace the stoppers in the lid if they become worn or loose.



CALCULATIONS:

Soil Respiration (lb CO_2-C/acre/day) = PF x TF x (%CO_2 - 0.035) x 22.91 x H

PF = pressure factor = 1
TF = temperature factor = (soil temperature in Celsius + 273) ÷ 273
H = inside height of ring = 5.08 cm (2 inches)

3. Infiltration Test

The infiltration test is generally performed after the **first** respiration measurement. The same 6-inch diameter ring left in place from the soil respiration test can be used for the infiltration test. If soil respiration was not determined, follow the instructions in Step 1 of the soil respiration procedure (Chapter 2) for inserting the 6-inch diameter ring.

Materials needed to measure infiltration:

- **6-inch diameter ring (left in soil from respiration test)**
- **plastic wrap**
- **500 mL plastic bottle or graduated cylinder**
- **distilled water**
- **stopwatch or timer**

Did You Know?

Infiltration rate is a measure of how fast water enters the soil. Water entering too slowly may lead to ponding on level fields or to erosion from surface runoff on sloping fields.

Considerations: If the soil is saturated, infiltration will not occur. Wait for one or two days to allow for some drying. Also, if the respiration test is not performed, make sure the sampling area is free of residue and weeds or that vegetation is trimmed to the soil surface before inserting the ring.

1 **Firm Soil**

With the 6-inch diameter ring in place, use your finger to gently firm the soil surface **only** around the **inside edges** of the ring to prevent extra seepage. Minimize disturbance to the rest of the soil surface inside the ring.

2 **Line Ring with Plastic Wrap**

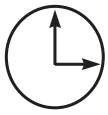
Line the soil surface inside the ring with a sheet of plastic wrap to completely cover the soil and ring as shown in **Figure 3.1.** This procedure prevents disturbance to the soil surface when adding water.

Figure 3.1

3 **Add Water**

- Fill the plastic bottle or graduated cylinder to the 444 mL mark with distilled water.
- Pour the 444 mL of water (1" of water) into the ring lined with plastic wrap as shown in **Figure 3.1.**

4 Remove Wrap and Record Time



- Remove the plastic wrap by gently pulling it out, leaving the water in the ring **(Figure 3.2)**. N**ote the time.**

- Record the amount of time (in minutes) it takes for the 1" of water to infiltrate the soil. Stop timing when the surface is just glistening.

Figure 3.2

- If the soil surface is uneven inside the ring, count the time until half of the surface is exposed and just glistening **(Figure 3.3)**.

- Enter the amount of time in minutes on the Soil Data worksheet.

Figure 3.3

5 Repeat Infiltration Test

In the same ring, perform Steps 2, 3, & 4 with a second inch of water. On the Soil Data worksheet, enter the number of minutes elapsed for the second infiltration measurement. If soil moisture is at or near field capacity, the second test is not necessary.

[The moisture content of the soil will affect the rate of infiltration; therefore, two infiltration tests are usually performed (if soil is dry). The first inch of water wets the soil, and the second inch gives a better estimate of the infiltration rate of the soil.]

6 Replace Lid

If a second respiration measurement will be performed, set the lid loosely on the ring and leave it covered for preferably 16 to 24 hours (6-hour minimum) before beginning the second test (Chapter 2). (Remove lid and replace it before beginning the second soil respiration measurement).

> **!** **Reminder**: If you still need to perform the second respiration measurement, remember to loosely place the lid back on the ring before leaving the field.

4. Bulk Density Test

The bulk density measurement should be performed at the soil surface and/or in a compacted zone (plow pan, etc.) if one is present . Measure bulk density near (between 1 and 2 feet) the site of the respiration and infiltration tests. To get a more representative bulk density measurement of the area, additional samples may be taken.

Materials needed to measure bulk density:

- **3-inch diameter ring**
- **hand sledge**
- **wood block**
- **garden trowel**
- **flat-bladed knife**
- **sealable bags and marker pen**
- **scale (0.1 g precision)**
- **1/8 cup (30 mL) measuring scoop**
- **paper cups**
- **18-inch metal rod**
- **access to a microwave oven**

Did You Know?
Bulk density is the weight of soil for a given volume. It is used to measure compaction. In general, the greater the density, the less pore space for water movement, root growth and penetration, and seedling germination.

Considerations: For rocky or gravelly soils, use the alternate procedure on page 11.

1 **Drive Ring into Soil**

- Using the hand sledge and block of wood, drive the 3-inch diameter ring, beveled edge down, to a depth of 3 inches **(Figure 4.1)**.

- The exact depth of the ring must be determined for accurate measurement of soil volume. To do this, the height of the ring above the soil should be measured. Take four measurements (evenly spaced) of the height from the soil surface to the top of the ring and calculate the average. Record the average on the Soil Data worksheet.

Figure 4.1

NOTE: Use the metal rod to probe the soil for depth to a compacted zone. If one is found, dig down to the top of this zone and make a level surface. Proceed with Step 1.

2 **Remove 3-inch Ring**

Dig around the ring and **with the trowel underneath it,** carefully lift it out to prevent any loss of soil.

3 Remove Excess Soil

Remove excess soil from the sample with a flat-bladed knife. The bottom of the sample should be flat and even with the edges of the ring **(see Figure 4.2).**

Figure 4.2

4 Place Sample in Bag and Label

Touch the sample as little as possible. Using the flat-bladed knife, push out the sample into a plastic sealable bag. Make sure the entire sample is placed in the plastic bag. Seal and label the bag.

NOTE: Steps 5-7 can be done in a lab or office if a scale is not available in the field. Step 8 requires access to a microwave.

5 Weigh and Record Sample

- Weigh the soil sample in its bag. [If the sample is too heavy for the scale, transfer about half of the sample to another plastic bag. The weights of the two sample bags will need to be added together. Enter the weight (sum of two bags, if applicable) on the Soil Data worksheet.

- Weigh an empty plastic bag to account for the weight of the bag. Enter the weight (sum of two bags, if applicable) on the Soil Data worksheet.

6 Extract Subsample to Determine Water Content and Dry Soil Weight

- Mix sample thoroughly in the bag by kneading it with your fingers.

- Take a 1/8-cup level scoop subsample of loose soil (not packed down) from the plastic bag and place it in a paper cup (a glass or ceramic cup may be used).

7 Weigh and Record Subsample

- Weigh the soil subsample in its paper cup. Enter the weight on the Soil Data worksheet.

- Weigh an empty paper cup to account for its weight. Enter the weight on the Soil Data worksheet.

8 Dry Subsample

Place the paper cup containing the subsample in a microwave and dry for two or more four-minute cycles at full power. Open the microwave door for one minute between cycles to allow venting. Weigh the dry subsample in its paper cup and enter the weight on the Soil Data worksheet.

NOTE: To determine if the soil is dry, weigh the sample and record its weight after each 4-minute cycle. When its weight does not change after a drying cycle, then it is dry.

CALCULATIONS (See page 13)

Bulk Density Test for Gravelly and Rocky Soils

This method is to be used when rocks or gravels prevent sampling bulk density by the core method described in the first part of this Chapter. This excavation method will require the user to sieve out the coarse material greater than 2 mm in size.

Materials needed to measure bulk density:

- **Plastic wrap**
- **140-cc syringe**
- **water**
- **garden trowel**
- **sealable bags and marker pen**
- **2-mm sieve**
- **scale (0.1 g precision)**
- **1/8-cup (30 mL) measuring scoop**
- **paper cup or bowl**
- **access to a microwave oven**

Considerations: Choose a spot that is as level as possible to allow water to fill the hole evenly. If the soil is too wet to sieve, ignore the part in Step 2 about replacing rocks, and proceed to Step 3. Soil will have to be dried and sieved later. The volume of gravel will need to be determined and subtracted from the total volume of the soil sample taken in the field.

1 **Dig Hole**

- Dig a bowl shaped hole three inches deep and approximately five inches in diameter using the trowel (**Figure 4.3)**. Avoid compacting the soil in the hole while digging. Place **all** of the soil and gravel removed from the hole in a plastic bag.

- Using the 2-mm sieve, sieve the soil in the plastic bag to separate the gravel. Collect the soil in a plastic sealable bag. Put the gravel aside to be used in Step 2. Seal and label the plastic bag. **[Note: See Considerations above if soil is wet.]**

Figure 4.3

2 Line the Hole

Line the hole with plastic wrap as shown in **Figure 4.4**. Leave some excess plastic wrap around the edge of the hole. Place the sieved rocks and gravel carefully in the center of the hole on top of the plastic wrap. Assure that the pile of rocks **do not** protrude above the level of the soil surface.

Figure 4.4

3 Add Water to Hole

- Use the 140 cc syringe to keep track of how much water is needed to fill the lined hole. The level of the water should be even with the soil surface.

- The amount of water represents the volume of soil removed. Record the total amount of water in cubic centimeters (1 cc = 1 cm^3) on the Soil Data worksheet.

NOTE: Steps 4-6 can be done in a lab or office if a scale is not available in the field. Step 7 requires access to a microwave.

4 Weigh and Record Sample

- Weigh the soil sample in its bag. [If the sample is too heavy for the scale, transfer about half of the sample to another plastic bag. The weights of the two sample bags will need to be added together. Enter the weight (sum of two bags, if applicable) on the Soil Data worksheet.

- Weigh an empty plastic bag to account for the weight of the bag. Enter the weight (sum of two bags, if applicable) on the Soil Data worksheet.

5 Extract Subsample to Determine Water Content and Dry Soil Weight

- Mix sample thoroughly in the bag by kneading it with your fingers.

- Take a 1/8-cup level scoop subsample of loose soil (not packed down) from the plastic bag and place it in a paper cup (a glass or ceramic cup may be used).

6 Weigh and Record Subsample

- Weigh the soil subsample in its paper cup. Enter the weight on the Soil Data worksheet.

- Weigh an empty paper cup to account for its weight. Enter the weight on the Soil Data worksheet.

7 Dry Subsample

Place the paper cup containing the subsample in a microwave and dry for two or more four-minute cycles at full power. Open the microwave door for one minute between cycles to allow venting. Weigh the dry subsample in its paper cup and enter the weight on the Soil Data worksheet.

NOTE: To determine if the soil is dry, weigh the sample and record its weight after each 4-minute cycle. When its weight does not change after a drying cycle, then it is dry.

CALCULATIONS (for both bulk density methods):

Soil water content (g/g) = $\frac{\text{(weight of moist soil - weight of oven dry soil)}}{\text{weight of oven dry soil}}$

Soil bulk density (g/cm^3) = $\frac{\text{oven dry weight of soil}}{\text{volume of soil}}$

Soil water-filled pore space (%) = $\frac{\text{volumetric water content x 100}}{\text{soil porosity}}$

Volumetric water content (g/cm^3) = soil water content (g/g) x bulk density (g/cm^3)

Soil porosity (%) = $1 - \left(\frac{\text{soil bulk density}}{2.65}\right)$

Volume of Rocks (cm^3) = Fill 1/3 of a graduated cylinder with water, and record the amount. Add the rocks to the cylinder and record the change in the water level. The difference is the volume of rocks (1 mL = 1 cm^3).

Volume of Soil (cm^3) = Total soil volume - volume of rocks

5. Electrical Conductivity Test

Soil samples for the electrical conductivity (EC) test are taken from the 0- to 3-inch depth. Bulked soil samples from across the field can be collected, and two subsamples can be taken for analysis (See Chapter 1, Sampling Guidelines). **Electrical conductivity, pH, and soil nitrate are all measured from the same soil subsample.**

Materials needed to measure electrical conductivity (EC):

- **1/8-cup (30 mL) measuring scoop**
- **120-mL plastic containers with lid**
- **EC pocket meter (blue with black cap)**
- **squirt bottle**
- **calibration solution (0.01 M KCl)**
- **distilled water**

Did You Know?
Excess salts in soil can be a detriment to plant health. Salts can also hamper water movement into the soil and increase the occurrence of surface compaction.

1 Extract Subsample

The soil sample should be thoroughly mixed before taking a subsample. Measure a 1/8-cup level scoop subsample of soil and place it in the plastic container. If soil nitrates will be measured on this subsample (Chapter 7), weigh the subsample for a more accurate estimate of soil nitrates. Enter the subsample weight on the Soil Data worksheet.

2 Add Water to Subsample and Mix

- Add 1/8-cup (30 mL) of distilled water to the container with the subsample. The resulting soil/water mixture equates to a 1:1 soil to water ratio on a volume basis.
- Put the lid on the container and shake vigorously about 25 times.

Calibration Tip: Make sure the EC meter is calibrated before making a measurement. See Appendix C for calibration instructions.

3 Measure and Record EC (See Calibration Tip)

- Open the container and insert the EC pocket meter into the soil-water mixture. Take the reading while the soil particles are still suspended in solution. To keep the soil particles from settling, stir gently with the EC pocket meter. Do not immerse the meter above the immersion level (See Appendix C, Figure 1c). Allow the reading to stabilize (stays the same for about 10 seconds).
- Enter the EC reading on the Soil Data worksheet in decisiemens per meter (dS/m). The DiST WP 4 meter gives readings directly in dS/m. For the Microsensor 4 meter, divide the reading by 10, and for the Microsensor 3 meter, divide the reading by 100 to get readings in dS/m.
- Save the soil-water mixture for the pH measurement (Chapter 6).

4 Turn the meter off. Thoroughly rinse meter with distilled water and replace cap.

6. Soil pH Test

Use the same soil-water mixture prepared in the EC test to conduct the pH Test. **If you are starting with a fresh soil sample, read the introduction and follow Steps 1-3 in the EC Test Chapter on preparing the sample.**

Materials needed to measure pH:

- **1/8-cup (30 mL) measuring scoop**
- **plastic specimen bottle**
- **calibration buffer solutions**
- **squirt bottle**
- **pH pocket meter (red with black cap)**
- **distilled water**

Did You Know?
Soil acidification can also be an indication of excessive N fertilizer applications and N leaching loss.

Considerations: If the soil sample is saturated or very wet, a 1:1 ratio, on a volume basis, of soil to water will not be obtained in the soil-water mixture (See Step 2, Chapter 5). Let the soil dry before proceeding with Step 1 in Chapter 5. Also, a small amount of salts diffuse out of the pocket pH meter; therefore, **EC measurements should always be taken first when measuring both EC and pH on the same sample**.

① Measure and Record pH

- Make sure to periodically calibrate your pH meter (See Appendix C for instructions). If the meter has not been used in a while, place the meter in tap water for about 5 minutes before calibrating or taking a reading.

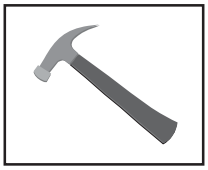
- Wait about 10 to 15 minutes after the EC measurement before measuring the pH. This gives the soil particles time to settle. Insert the pH pocket meter into the topmost portion of the solution and turn the meter on. Wait until the reading stabilizes (0-30 seconds), and record the digital reading on the Soil Data worksheet.

② Rinse Pocket Meter

- Thoroughly rinse the electrode with distilled water.

- Store the electrode with a few drops of the **pH 7** buffer solution and replace the cap. (See Appendix C on storage of pH meter)

Maintenance Tips: Check the batteries and calibrate the EC and pH meters periodically. Be sure to clean the meters thoroughly to keep them working properly.



7. Soil Nitrate Test (NO_3^-)

Use the same sample prepared for the EC and pH tests to measure soil nitrates. **If you are starting with a fresh soil sample, read the introduction and follow Steps 1-3 in the EC Test Chapter on preparing the sample.**

Materials needed to measure soil nitrate:

- **filter paper**
- **120-mL plastic container with lid**
- **eye dropper**
- **nitrate/nitrite test strips**
- **stopwatch or timer**
- **distilled water**

Did You Know?
Soil nitrates are good measures of plant-available nitrogen, but they can be readily lost from the soil by leaching and volatilization.

1 Fold Filter

Fold the filter paper in half (into a semicircle). Fold it again, but not quite into a quarter-circle. Leave the edges a little uneven as in **Figure 7.1** (A black line is drawn for demonstration purposes.)

Figure 7.1

2 Insert Filter Paper into Subsample

Open the filter paper into the shape of a cone and push it (pointed part first) quickly into the jar with the soil/water mixture until it touches the bottom of the jar **(Figure 7.2)**. **Wait** until about an eye dropper-full of the solution has seeped through to the inside of the filter paper. **(Note: Inserting the filter paper quickly prevents it from wetting up and tearing as it is inserted.)**

[For Steps 3 & 4, it would be helpful to first familiarize yourself with the directions on the side of the bottle of nitrate strips.]

Figure 7.2

3 Place Drops on Nitrate Strips

Using the eye dropper and one nitrate/nitrite test strip, place 1 or 2 drops of the filtered solution on each of the strip's two pads. **Note the time.**

NOTE: One pad measures the amount of nitrite, and the other measures the amount of nitrite and nitrate combined. Nitrite rarely occurs in measurable amounts in soils, so nitrite readings from the test strips are not recorded.

4 Measure and Record Nitrate

- Align the nitrate/nitrite test strip with the bottom of the bottle with your thumb corresponding to the diagram on the bottle.

- **After 60 seconds,** compare the first pad (furthest from your thumb) along the nitrate scale as shown in **Figure 7.3**. Estimate the nitrate amount according to the degree of color change. Enter the value from the nitrate scale on the Soil Data worksheet in ppm. This value is an estimate of nitrate-N concentration in the extract.

Figure 7.3

NOTE: The nitrate test strips have a shelf-life. Check the expiration date on the bottle.

CALCULATIONS:

Estimated (lb NO_3-N/acre) =

$$\frac{\text{(ppm extract } NO_3\text{-N) x (depth of soil sampled in cm) x bulk density x 0.89}}{10}$$

Exact (lb NO_3-N/acre) =

$$\frac{\text{(ppm } NO_3\text{-N) x (volume water used) x (depth of soil sampled, cm) x bulk density x 0.89}}{\text{(dry weight of soil) x 10}}$$

Volume water used = 30.0 mL + [dry weight of soil x soil water content (g/g)]

Note: The maximum nitrate-N reading on the nitrate/nitrite test strip container is 50 ppm. If the sample reading falls into the 50 ppm category, the sample can be diluted to get a better estimate of the actual amount over 50 ppm. To dilute the sample, fill the eye dropper with filtered solution and place five drops in a plastic container. Add five drops of distilled water; mix gently by swirling the container. Take a reading with a new test strip as stated in Step 4. Multiply the estimated nitrate-N in ppm by 2 before using the calculations. If the nitrate reading falls into the category of 50 ppm again, repeat the dilution steps, and multiply the estimated nitrate-N in ppm by 4.

Did You Know?

Water samples may be taken from drinking water, well water, tile drainage, drainage ditches, and ponds. Dip a nitrate/nitrite test strip into the water and estimate the nitrate or nitrite concentration from the color chart on the test strip bottle. This test can give you an idea of how much N fertilizer is lost from the soil. **(See Chapter 12).**

8. Aggregate Stability

Aggregate stability measures the amount of stable aggregates against flowing water. It is recommended that aggregate stability be determined on the top three inches of surface soil. The soil sample should be air-dried before determining aggregate stability.

Materials needed to measure aggregate stability:

- **2-mm sieve (3-inch diameter)**
- **0.25-mm sieves (2.5-inch diameter)**
- **terry cloths**
- **400-watt hair dryer and drying chamber**
- **calgon solution (about 2 tbsp of calgon per 1/2 gallon of tap water)**
- **bucket or pan**
- **scale (0.1 g precision)**
- **distilled water**

Did You Know?
Soil aggregates protect organic matter within their structure from microbial attack. Formation and preservation of aggregates allows organic matter to be preserved in the soil.

Considerations: If the soil is moist, air-dry a sample before determining aggregate stability. When taking a soil sample, care should taken not to disrupt the soil aggregates.

1 **Sieve the Soil Sample**

Transfer about a 1/4 cup of air-dried soil to the 2-mm sieve. Shake the sieve gently and collect the soil passing through the sieve. Try to pass all of the soil through the sieve by gently pressing the soil through with your thumb **(Figure 8.1)**.

Figure 8.1

2 **Weigh Sieved Soil Sample**

Weigh the 0.25-mm sieve, and record its weight on the Soil Data worksheet. Weigh out about 10 g of the sieved soil from Step 1 (make sure the soil is mixed well before taking a subsample). Record the exact weight on the Soil Data worksheet.

3 **Slowly Wet the Soil Sample in Sieve**

Saturate one of the terry cloth sheets with distilled water and lay it flat. Place the 0.25-mm sieve containing the soil on the wet cloth, allowing the soil to wet up slowly **(Figure 8.2)**. Wet the soil for five minutes.

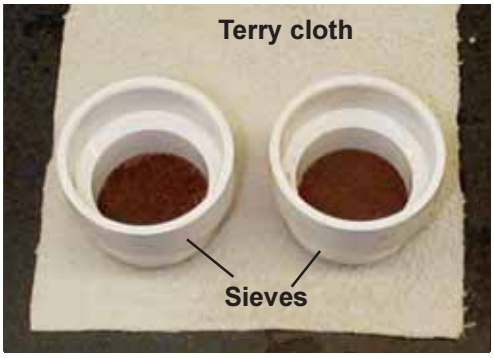


Figure 8.2

NOTE: A container (bucket or pan) of distilled water is needed for Step 4. The water temperature should be at or near the temperature of the soil.

4 Wet Sieve the Soil

- Place the 0.25-mm sieve with soil in the container filled with distilled water, so that the water surface is just above the soil sample.
- Move the sieve up and down in the water through a vertical distance of 1.5 cm at the rate of 30 oscillations per minute (one oscillation is an up and down stroke of 1.5 cm in length) for three minutes. **Important: Make sure the aggregates remain immersed in water on the upstroke.**

5 Dry Aggregates

After wet sieving, set the sieve with aggregates on a dry piece of terry cloth, which will absorb the excess water from the aggregates in the sieve. Then place the sieve containing the aggregates on the drying apparatus **(Figure 8.3)**. Allow the samples to dry using the low power setting.

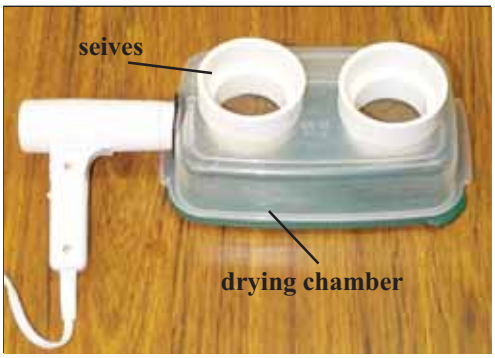


Figure 8.3

NOTE: Be careful when drying the soil to prevent particles from blowing out of the sieves. It may be necessary to put a cover over the top of the sieves to keep aggregates in place.

6 Weigh Aggregates

After drying, allow the aggregates and sieve to cool for five minutes. Weigh the sieve containing the aggregates. Record the weight of the sieve plus aggregates on the Soil Data worksheet.

7 Disperse Aggregates in Calgon Solution

- Prepare calgon solution. Immerse the sieve containing the dried aggregates in the calgon solution **(do not completely immerse the sieve)**. Allow the aggregates in the sieve to soak for five minutes, moving the sieve up and down periodically. Only sand particles should remain on the sieve.
- Rinse the sand on the sieve in clean water by immersing the sieve in a bucket of water or by running water through the sieve.

8 Dry and Weigh Sand

- Remove excess water by first placing the sieve containing the sand on the dry terry cloth, then placing it on the drying apparatus. Allow sand to dry.
- After drying, allow the sand and sieve to cool for five minutes. Weigh the sieve containing the sand. Record the weight of the sieve plus sand on the Soil Data worksheet.

CALCULATIONS:

Water Stable Aggregates (% of soil > 0.25mm) = $\frac{\text{(weight of dry aggregates - sand)}}{\text{(weight of dry soil - sand)}} \times 100$

9. Slake Test

The slake test measures the stability of soil when exposed to rapid wetting. This test is qualitative and should be measured on air-dried soil fragments or aggregates.

Materials needed to measure slaking:

- **complete soil stability kit**
- **sampling scoop**
- **distilled water (1 L)**

Did You Know?
Soil stability serves as a qualitative indicator of soil biological activity, energy flow, and nutrient cycling. Binding of soil particles must constantly be renewed by biological processes.

Considerations: The soil should be **air-dry** when performing this test. If the soil is not dry, collect surface fragments as described in Step 1 and allow them to dry. Be careful not to destroy the soil fragments while sampling.

1 Collect Surface Fragments

- Carefully remove soil fragments or aggregates from the soil surface. If there is a surface crust, carefully sample pieces of it. Use the **flat end** (handle) of the scoop to lift out surface and subsurface fragments. If the soil has been tilled, collect some aggregates (about 1 cm in size). Be careful not to shatter the soil fragments or aggregates while sampling.

- Collect 16 separate soil fragments. If there is a surface crust, collect eight fragments of the crust and eight fragments from below the crust.

Figure 9.1

2 Fill Box with Water

- Remove all sieve baskets from the stability kit.

- Fill the compartments in the box with water. The water should be 2 cm deep and at approximately the same temperature as the soil.

Figure 9.2

3 Test Soil Fragments

- Place soil fragments in the sieve baskets **(Figure 9.1).**

- Lower one of the sieves into a box compartment filled with water **(Figure 9.2)**.

4 Observe Fragments

- Observe the soil fragment for **five minutes**. Refer to the stability class table below to determine classes 1 and 2.
- After five minutes, raise the basket out of the water, then lower it to the bottom. It should take one second for the basket to clear the surface and one second to return to the bottom.
- Repeat immersion four times (total of five immersions). Refer to the stability class table below to determine classes 3 through 6.

5 Record Ratings

- Soil stability is rated according to the time required for the fragment to disintegrate during the five-minute immersion and the proportion of the soil fragment remaining on the mesh after the five extraction-immersion cycles. **[See table below.]**
- Record the stability ratings for all 16 soil fragments or aggregates on the Soil Data worksheet.

Stability class	Criteria for assignment to stability class (for "Standard Characterization")
0	Soil too unstable to sample (falls through sieve).
1	**50 %** of structural integrity lost within **5 seconds** of insertion in water.
2	**50 %** of structural integrity lost **5 - 30 seconds** after insertion.
3	**50 %** of structural integrity lost **30 - 300 seconds** after insertion or **< 10 %** of soil remains on the sieve after 5 dipping cycles.
4	**10 - 25%** of soil remaining on sieve after 5 dipping cycles.
5	**25 - 75%** of soil remaining on sieve after 5 dipping cycles.
6	**75 - 100%** of soil remaining on sieve after 5 dipping cycles.

10. Earthworms

Earthworms are most active during the spring and fall, which are the best times to observe their activity.

Materials needed to measure the number of earthworms:

- **tap water (2 L)**
- **hand trowel or shovel**
- **large jar or container for worm collection and cleaning**
- **mustard solution (2 tablespoons mustard powder in 2 liters of tap water)**

Did You Know?
Earthworm burrowing improves infiltration and their casts improve aggregation. Earthworms also break down larger bits of residue for use by other soil organisms.

Considerations: When examining the soil for earthworms, avoid places where their populations might be affected, such as near mulch or compost piles. The abundance of earthworms is usually patchy within a field and varies with season. Therefore, count earthworms several times during a season and use the average to gauge changes from year to year.

1 **Dig Plot**

Measure a square-foot plot and dig down 12 inches with the hand trowel or shovel (**Figure 10.1**). Try to minimize the number of cuts with the shovel to avoid damage to the earthworms. **Dig the hole first, then sort for earthworms.**

Figure 10.1

2 **Count the Number of Earthworms**

Sort the soil samples against a pale-colored background to help locate the earthworms. Separate and count the number of earthworms.

3 **Add Mustard Solution (optional)**

To facilitate extraction of deep burrowing earthworms, add two liters of mustard solution to the hole. **First**, make sure the bottom of the hole is level. The deep burrowing worms should appear within five minutes (**Figure 10.2**). Count the number of worms.

Figure 10.2

4 **Record Total Number of Earthworms**

Record the total number of earthworms (those found in the hole and after adding the mustard solution) on the Soil Data worksheet. **[The mustard solution should not harm the worms. Rinse them in water before returning them to the soil.]**

11. Soil Physical Observations and Estimations

Materials needed in observing the soil physical properties:

- **tape measure**
- **sharpshooter spade or shovel**
- **18-inch metal rod**
- **tap water**

1 **Dig hole**

Dig a hole to a depth of 1 foot. Make it wide enough to cut out a slice of soil.

2 **Cut Slice of Soil**

Using the shovel, cut a slice of soil from a wall of the hole and lay it on the ground.

Figure 11.1

3 **Measure Depth of Topsoil**

- Measure the depth of the topsoil. Look for color changes from the soil surface downward through the soil profile. The topsoil is usually distinguished by a darker color than the underlying material **(See Figure 11.1)**.

- Record the depth of topsoil on the Soil Data worksheet.

4 **Observe Plant Roots**

- Observe plant roots in the hole and the slice of soil. To get a better look at the roots, dig down along a plant stem. The roots should be well branched with lots of fine root hairs.

- Things to look for are balled up roots or roots growing sideways. A lack of fine root hairs indicates oxygen deprivation in the root zone. Lateral root growth indicates a hardpan, or compacted layer.

5 **Determine Resistance**

- Use the metal rod to probe one of the side walls, starting from the soil surface to the bottom of the hole. Determine changes or differences in penetration resistance as you probe the side wall **(See Figure 11.2)**.

- Look for compacted layers that may restrict root growth and water movement.

Figure 11.2

6 Examine Soil Structure

Observe soil structure in the slice of soil to a depth of about 12 inches. Measure and mark, starting at the surface and moving downward; depth increments of 0 to 4 inches, 4 to 8 inches, and 8 to 12 inches. Note and record the type, size, and grade of the soil structural units or aggregates for each depth increment.

Note: Soil structure is how particles of soil are grouped together in stable collections or aggregates.

6a Note the type of soil structure at each of the three depth increments.

- The three general types of soil structure are granular (**Figure 11.3**), blocky (**Figure 11.4**), and platy (**Figure 11.5**).

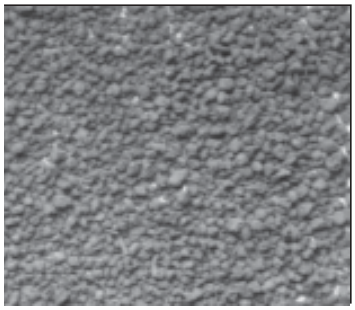


Figure 11.3 Granular: imperfect spheres, usually sand-size.

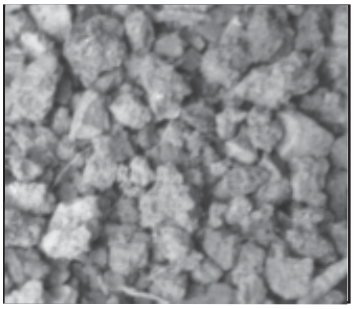


Figure 11.4 Blocky: imperfect cubes with angular or rounded edges.

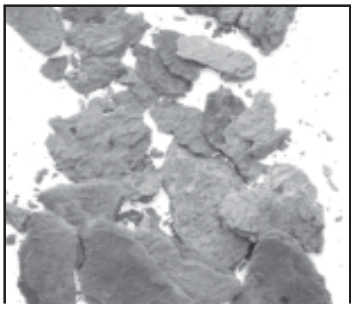


Figure 11.5 Platy: a flattened or compressed appearance.

- If there are no noticeable aggregates or peds, the soil has no structure. It is either single grained (**Figure 11.6**) or massive (**Figure 11.7**).

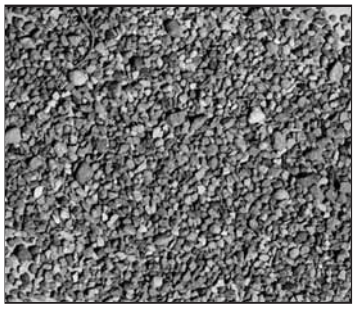


Figure 11.6 Single grain: unconsolidated mass such as loose sand.

Figure 11.7 Massive: cohesive mass.

- Record on the Soil Data worksheet the type of structure observed for each depth increment.

6b **Note the size of the aggregates or peds at the different depths**.

- Estimate the general size of the aggregates or peds. If the structure is granular, choose from fine (**Figure 11.8**), medium (**Figure 11.9**) and coarse (**Figure 11.10**) granule sizes.

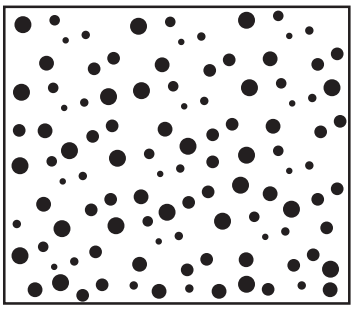


Figure 11.8
Fine: < 2 mm.

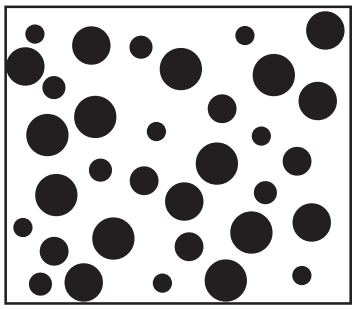


Figure 11.9
Medium: 2 to 5 mm.

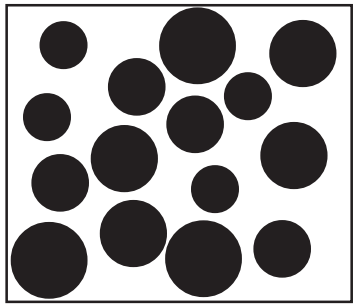


Figure 11.10
Coarse: 5 to 10 mm.

- If the structure is blocky, choose from very fine (**Figure 11.11**), fine (**Figure 11.12**), and medium (**Figure 11.13**) block sizes.

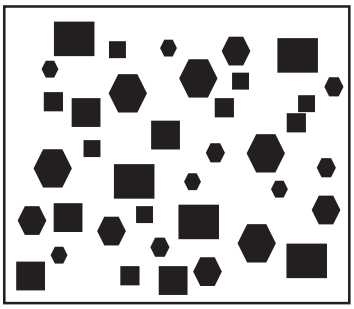


Figure 11.11
Very fine: < 5 mm.

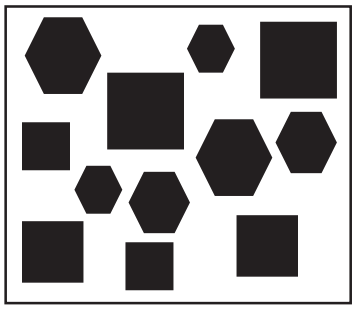


Figure 11.12
Fine: 5 to 10 mm.

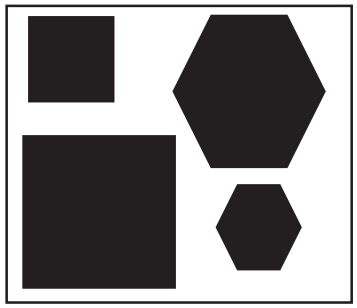


Figure 11.13
Medium: 10 to 20 mm.

- If structure is platy, choose from thin (**Figure 11.14**), medium (**Figure 11.15**), and thick (**Figure 11.16**) plate sizes.

Figure 11.14
Thin: < 2 mm.

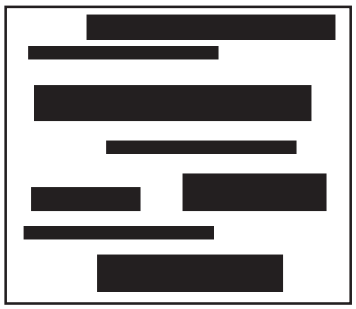


Figure 11.15
Medium: 2 to 5 mm.

Figure 11.16
Thick: 5 to 10 mm.

- Record on the Soil Data worksheet the size of the aggregates or peds observed for each depth increment.

6c **Note the distinctness (grade) of the aggregates in place and when removed from the slice of soil.**

The distinctness of the aggregates is either weak, moderate, or strong.

Weak structure:

- Aggregates or peds are barely observable in place in moist soil.
- When removed, the structure breaks into a few observable aggregates or peds **(Figure 11.17)**.

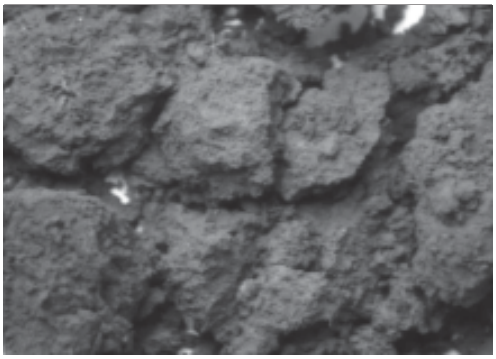


Figure 11.17

Moderate structure:

- Aggregates or peds are moderately well-formed and distinct in place.
- When removed, many well-formed aggregates are observable **(Figure 11.18)**.

Figure 11.18

Strong structure:

- Aggregates or peds are well-formed and very evident in place.
- When disturbed, the structure breaks into quite evident aggregates or peds **(Figure 11.19)**.

Record on the Soil Data worksheet the grade of the aggregates or peds observed for each depth increment.

Figure 11.19

7 **Determine soil textural class**

- Perform the Texture by Feel procedure **(See page 27)** on the top three inches of soil.
- Record on the Soil Data worksheet the soil textural class.

TEXTURE BY FEEL PROCEDURE

Making a Ribbon

Place approximately 25 grams in palm. Add water dropwise and knead the soil to break down all aggregates. Soil is at the proper consistency when plastic and moldable, like moist putty.

Add dry soil to soak up water

Yes

Yes

Does soil remain in a ball when squeezed?

No

Is the soil too dry?

No

Is the soil too wet?

No

Sand

Yes

Place ball of soil between thumb and forefinger, gently push the soil with the thumb, squeezing it upward into a ribbon. Form a ribbon of uniform thickness and width. Allow the ribbon to emerge and extend over the forefinger, breaking from its own weight.

Does the soil form a ribbon?

No

Loamy Sand

Yes

Does soil make a weak ribbon less than 1 inch long before breaking?

No

Does soil make a ribbon 1 inch long before breaking?

No

Does soil make a strong ribbon two inches or longer before breaking?

Yes

Yes

Yes

Excessively wet a small pinch of soil in palm and rub with forefinger.

Sandy Loam

Yes

Does soil feel very gritty?

No

Silt Loam

Yes

Does soil feel very smooth?

No

Loam

Yes

Neither gritty nor smooth?

Sandy Clay Loam

Yes

Does soil feel very gritty?

No

Silty Clay Loam

Yes

Does soil feel very smooth?

No

Clay Loam

Yes

Neither gritty nor smooth?

Sandy Clay

Yes

Does soil feel very gritty?

No

Silty Clay

Yes

Does soil feel very smooth?

No

Clay

Yes

Neither gritty nor smooth?

12. Water Quality Tests

A. Estimation of Water Nitrate and Nitrite levels

Materials needed to determine water nitrate (NO_3^-) and nitrite (NO_2^-) levels:

- **filter paper**
- **120-mL plastic containers with lids**
- **eye dropper**
- **nitrate/nitrite test strips**
- **stopwatch or timer**

Considerations: Water samples may be taken from drinking water, well water, tile drainage, drainage ditches, and ponds. Sample surface runoff from fields, which may be a contributing source of contaminates.

1 **Filter Water Sample (if cloudy)**

- Collect water sample in the plastic container. Fill to about 1/3 full.

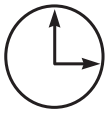
- Fold a piece of filter paper as described in Chapter 7--Soil Nitrate Test. Insert filter paper into the jar and allow the water to seep through the filter paper to the inside. **[If the water sample is clear (no cloudiness or suspended particles), the sample does not need to be filtered.]**

2 **Place Drops on Nitrate and Nitrite Strips**

Using the eye dropper, collect a sample of the filtered water. Place 1 or 2 drops of the filtered solution on each of the strip's two pads. Note the time.

[One pad measures the amount of nitrite and the other measures the amount of nitrite and nitrate combined.]

3 **Measure and Record Nitrate and Nitrite.**



- **After 30 seconds**, measure and record nitrite.
  Estimate the nitrite amount according to the degree of color change. Enter the value on the Soil Data worksheet in ppm from the nitrite scale on the bottle.

- **After 60 seconds**, measure and record nitrate.
  Estimate the nitrate amount according to the degree of color change. Enter the value on the Soil Data worksheet in ppm from the nitrate scale on the bottle.

[Note: Estimate results if colors on test pads fall between two color patches.]

B. Estimated Water Salinity Levels

Materials needed to estimate water salinity levels:

- **EC pocket meter**
- **120-mL plastic containers and lids**
- **distilled water**

Considerations: Water samples may be taken from drinking water, well water, tile drainage, ditches, irrigation water, and ponds.

1 Collect Sample

Collect water sample in plastic container. Fill to about 1/3 full.

2 Measure Electrical Conductivity

- Insert the EC pocket meter into the water sample. Allow the reading to stabilize (stays the same for about 10 seconds). Note the digital reading.

- Enter the EC reading on the Soil Data worksheet in decisiemens per meter (dS/m). The DiST WP 4 meter gives readings directly in dS/m. For the Microsensor 4 meter, divide the reading by 10, and for the Microsensor 3 meter, divide the reading by 100 to get readings in dS/m. Insert the EC pocket meter into the water sample until the reading stabilizes (stays the same for about 10 seconds). Note digital reading.

3 Rinse Pocket Meter

Turn off the meter. Thoroughly rinse the meter with distilled water, and replace cap.

Did You Know?

Healthy soil not only improves crop performance, it also cleans and stores water; and prevents runoff and erosion; and uses nutrients more efficiently, reducing the need for pesticides.

A. References

Arshad, M.A., B. Lowery, and B. Grossman. 1996. Physical tests for monitoring soil quality. p.123-142. In: J.W. Doran and A.J. Jones (eds.) Methods for assessing soil quality. SSSA Spec. Publ. 49. Soil Science Society of America, Inc., Madison, Wisconsin, USA.

Dick, R.P., D.R. Thomas, and J.J. Halvorson. 1996. Standardized methods, sampling, and sample pretreatment. p.107-122. In: J.W. Doran and A.J. Jones (eds.) Methods for assessing soil quality. SSSA Spec. Publ. 49. Soil Science Society of America, Inc., Madison, Wisconsin, USA.

Gershuny, G. and J. Smillie. 1995. The soul of soil: A guide to ecological soil management. 3rd ed. agAccess, Davis, California, USA.

Herrick, J.E., W.G. Whitford, A.G. de Soyza, J.W. Van Zee, K.M. Havstad, C.A. Seybold, M. Walton. 2001. Soil aggregate stability kit for field-based soil quality and rangeland health evaluations. Catena 44(1):27-35.

Parkin, T.B. and J.W. Doran. 1996. Field and laboratory tests of soil respiration. p.231-246. In: J.W. Doran and A.J. Jones (eds.) Methods for assessing soil quality. SSSA Spec. Publ. 49. Soil Science Society of America, Inc., Madison, Wisconsin, USA.

Powell, D. and J. Pratley. 1991. Sustainability kit manual. Centre for Conservation Farming. Charles Sturt University-Riverina, PO Box 588, Wagga Wagga 2650, Australia.

Rowell, D.L. 1994. Soil science: methods and applications. Longman Scientific & Technical, Singapore.

Sarantonio, M., J.W. Doran, M.A. Liebig, and J.J. Halvorson. 1996. On-farm assessment of soil quality and health. p.83-106. In: J.W. Doran and A.J. Jones (eds.) Methods for assessing soil quality. SSSA Spec. Publ. 49. Soil Science Society of America, Inc., Madison, Wisconsin, USA.

Seybold, C.A. and J.E. Herrick. 2001. Aggregate stability kit for soil quality assessments. Catena 44(1):37-45.

Smith, J.L. and J.W. Doran. 1996. Measurement and use of pH and electrical conductivity. p.169-186. In: J.W. Doran and A.J. Jones (eds.) Methods for assessing soil quality. SSSA Spec. Publ. 49. Soil Science Society of America, Inc., Madison, Wisconsin, USA.

B. Soil Respiration (Alternative Method)

This alternative method uses a kit produced by Woods End[1] known as the Solvita Soil Life Kit[1]. Instead of the Draeger tube apparatus, this procedure uses "paddles" inserted into a plastic container with the soil sample (See procedure on page 32). The use of this method eliminates the need for the Draeger tube (carbon dioxide adsorption tube), needle, and syringe. With the Solvita kits, results are given in 24 hours instead of 30 minutes with the Draeger method. The color change of the paddles may also be easier to distinguish than reading the color change off the Draeger tubes. The Solvita kit also requires the soil to be disturbed and will falsely stimulate microbial activity similar to the action of tillage. However, when used to compare sites, both soils are disturbed and the relative differences are noted. This procedure also reduces the effects of root respiration. Picking out as many roots from the sample as possible will further eliminate their CO_2 contribution. The Solvita kit may be preferred if immediate results are not necessary and the microbial activity differences without the influence of plant roots are desired.

The Solvita kit comes with well written and user friendly instructions and interpretations. There is also a trouble shooting guide to help the user. The kit consists of four parts: the sample jar to hold the correct volume of soil for the test **(Figure 1b)**; a foil-pack containing a special color gel paddle **(Figure 2b)**; instruction manual; and a color key for reading results **(Figure 2b)**.

Solvita Soil Life kits can be obtained from Woods End Research, Mt. Vernon, ME; solvita@woodsend.org.

Figure 1b

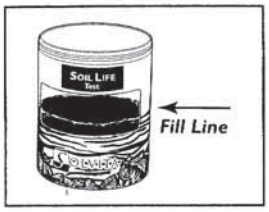
Figure 2b

[1]Trade names are used solely to provide specific information. Mention of a trade name does not constitute a guarantee of the product by the U.S. Department of Agriculture nor does it imply endorsement by the Department or the Natural Resources Conservation Service over comparable products that are not named.

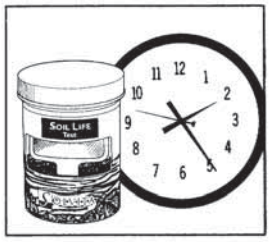
The following is part of the instructions from the SOLVITA SOIL LIFE KIT[1]:

RUNNING THE SOLVITA™ TEST

1. **SOIL SAMPLING:** Soil should be sampled from any garden or field in a fresh, moist condition just before the test is performed. Take many smaller samples from various locations and mix just well enough to be homogenous while removing large stones and organic debris.



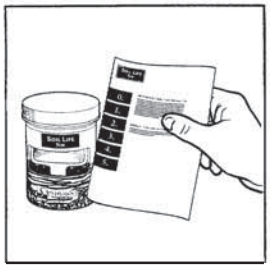
2. **IDEAL SOIL MOISTURE:** The soil should be at the ideal growing condition moisture before it is sampled. If the sample is very dry or very wet, it is best to wait until favorable conditions return. This may mean watering a dry soil and waiting 1-2 days again before sampling. If too wet, make a small pile to drain, or spread out to dry to a moderate moisture level. The idea is to disturb the natural state as little as possible.



3. **PUT SAMPLE INTO JAR:** Put the loose mix of soil into the jar just to the fill line. As you fill, tap the bottom of the jar sharply on a counter; this helps assure the correct density. Fill only to the indicated line. Record the time on the lid.

4. **START THE TEST:** When you are ready to start the test, open the foil-pack by tearing it along the top strip and carefully remove the paddle. *Do not touch the gel surface, and don't allow soil to touch it.* At the start of the test the paddle will be color #0 (bright blue). Once the foil pack is opened, the test should be started within about 30 minutes.

5. **INSERT THE PADDLE:** Push the paddle-stick point into the soil in the jar so that the gel-side can be seen through the back viewing side. Be careful not to jostle or tip the jar. Screw the lid on very tightly, and keep the jar at room temperature (68—77°F) *out of sunlight* for 24 hours.



6. **FIND THE GEL COLOR**: After 20 - 28 hours compare the color of the paddle to the Color Key provided. For this, the paddle should either be left in the jar with the lid on, or removed and laid face-up onto a white surface.

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C. EC and pH Meter Maintenance and Calibration

EC meter maintenance:

- Do not immerse the EC meter above the immersion level **(Figure 1c)**. Under no circumstances should the meter be immersed above the display level.

- When not in use, switch off the meter and replace the protective cap.

- To improve performance, clean the stainless steel electrodes periodically by rinsing them in alcohol for a few minutes.

- Replace all four batteries if the display becomes faint or disappears or if the readings are unstable or constant.

- To change batteries for DiST WP[1] models, unscrew the top with a coin and replace the batteries **(Figure 2c)**.

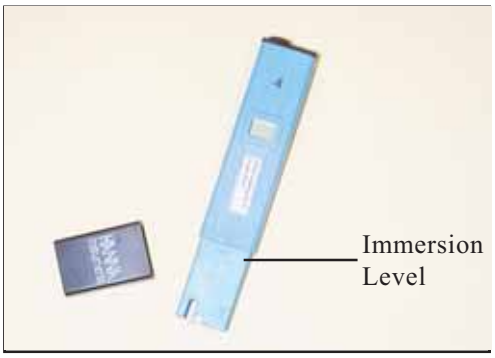

Figure 1c.

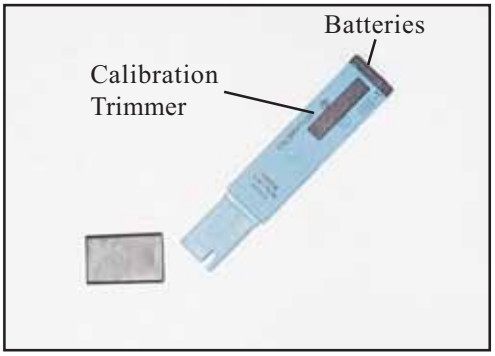

Figure 2c.

EC meter calibration:

- Immerse the meter into the calibration solution (1.41 dS/m).

- Allow the reading to stabilize. Using a small screw-driver, turn the Calibration Trimmer to match the solution value, 1.41 dS/m (normally at 25 C).

pH meter maintenance:

- Crystals may appear around the cap **(Figure 3c)**. This condition is normal. The crystals will dissolve when rinsed with water.

- After use, rinse the electrode with water to minimize contamination.

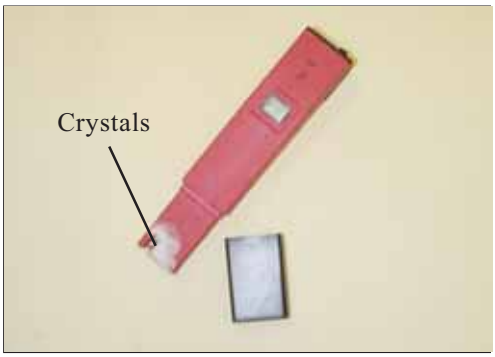

Figure 3c.

- Store the electrode with a few drops of storage solution (HI 70300L) or pH 7 solution in the protective cap. **DO NOT STORE IN DISTILLED OR DEIONIZED WATER.**

- Always replace the protective cap after use.

- Large differences in pH readings (± 0.5 pH) could be due to lack of calibration, dry electrode, or rundown batteries.

- If the pH meter cannot be switched on or if the display fades, unscrew the battery compartment and replace all four batteries, paying attention to their polarity **(Figure 4c)**.

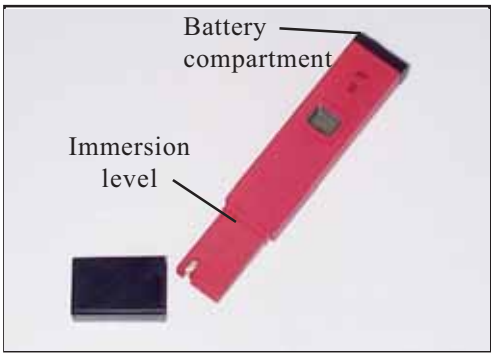

Figure 4c.

pH meter calibration (pHep 3[1]):

- Prepare buffer solutions. Only 2 buffers are needed, pH 7 and 4 or 10, depending on the pH range of your soils (see **Figure 5c**).

- Switch the unit on by pressing the ON/OFF button.

- With the meter on, press and hold the ON/OFF button for about three seconds. The display will start blinking "7.0o" to confirm that you have entered the calibration mode.

- Immerse the pH meter in the pH 7 buffer solution. Stir gently and wait approximately 20 seconds.

- If "Ec" appears on the display, the pH 7 solution is not fresh, or the electrode is not conditioned.

- The pHep 3[1] meter automatically confirms the pH 7 calibration after the meter is adjusted. The display will blink "4.0o". After a few seconds, it will display "Ec" to prompt you to use a second buffer solution.

- Rinse the electrode with water and immerse in pH 4 for acidic samples or pH 10 for alkaline samples. Allow approximately 20 seconds for the meter to auto-confirm the reading. Once the display stops blinking, the meter is calibrated and ready to use. ALWAYS USE FRESH BUFFERS FOR CALIBRATION.

Figure 5c.

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D. Building a Soil Quality Test Kit

Kit Inventory:

____ Two 6-inch diameter infiltration rings, 5 inches tall; cut from 1/8-inch thick aluminum irrigation pipe; beveled edge on one side **(Figure 1d)**. Mark a line around the outside of the ring, 2 inches from the top.
____ 12-inch wide roll of plastic wrap.
____ Two 500-mL plastic graduated cylinders. As a substitute, 500-mL plastic bottles or 16 oz. plastic soft drink containers can be used **(Figure 2d)**. Mark a line around the bottle at the 444 mL level.
____ 2-lb hand sledge or rubber mallet **(Figure 3d)**.
____ 7 3/4-inch long wood block, 2" by 4" **(Figure 3d)**.
____ Two 6-inch lids with septa (stoppers) for respiration chamber; 6-inch diameter stove-top caps can be used **(Figure 4d)**. As an alternative, the bottoms from a #10 can (coffee can) can be cut (1 inch lip) and used **(Figure 5d)**. The lids should be white or silver to reduce absorption of heat. Three holes fitted with red rubber stoppers, for serum or vaccine bottles, are drilled through the top of the lid to allow for gas sampling.
____ Two 6-inch long latex tubing (3/16" x 1/16").
____ Three 18- to 22-guage, 1.5-inch hypodermic needles.
____ 140-cc (mL) plastic syringe **(Figure 6d)**. A 2-mm hole can be drilled at the end of the syringe handle.
____ Pack of 10 Draeger tubes (0.1% CO_2 detection tubes) **[Figure 6d]**.
____ Soil thermometer (Celsius).
____ Two 3-inch diameter sampling tubes, 5 inches tall; cut from 1/8-inch thick aluminum irrigation pipe; beveled edge on one side **(Figure 1d)**. Mark a line around the outside of the ring, 2 inches from the top.
____ Flat-bladed knife.
____ Garden trowel (heavy duty) **[Figure 7d]**.
____ 1-qt sealable plastic storage bags.
____ 18-inch long metal rod, 1/8-inch in diameter. As a substitution, a straightened coat hanger can be used.
____ Calibrated scoop, 30.0 mL (1/8 cup) **[Figure 7d]**.
____ Squirt bottle.
____ Four 120-mL plastic containers with lids **(Figure 7d)**. As an alternative, any container with lid of similar size can be used; e.g., baby food jars.
____ Electrical conductivity meter (0.01-19.99 mS range) **[Figure 8d]**.

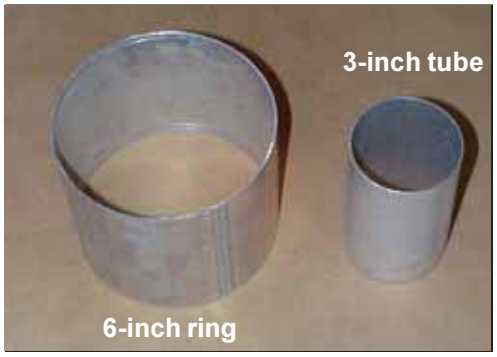

Figure 1d


Figure 2d


Figure 3d

Figure 4d

____ EC calibration standard, 1.41 dS/m (0.01 M KCl).
____ Small screw driver (for EC meter).
____ pH meter (model pHep3[1]) **[Figure 8d].**
____ Packets of 4, 7 and 10 pH buffers **(Figure 9d)**.
____ Bottle of 25 AquaChek[1] nitrate/nitrite test strips **(Figure 10d)**.
____ Box of filter paper, 12.5-cm diameter, Grade 2 - 5 can be used **(Figure 11d)**.
____Three standard plastic eyedroppers.
____Tape measure; 6-foot (metric and English units).
____ Small calculator
____ Permanent marker pen
____ 400-watt hair dryer **(Figure 12d)**.
____ 2-mm sieve, 3-inch diameter **(Figure 13d)**.
____ Two 0.25-mm sieves, 2-inch diameter **(Figure 14d)**.
____ Drying chamber, holds two 2-inch sieves **(Fig. 15d)**.
____ Two 6" x 6" sheets of terry cloth.
____ Calgon[1] (crystal form).
____ Soil stability kit (18 section tackle box with 18 1.5-mm sieve baskets) **[Figure 16d]**.
____ Stopwatch or timer.
____ Finger nail clipper.
____ Paper cups.

Other items needed:
____ Bucket or pan.
____ Mustard powder (optional).
____ Sharpshooter spade or shovel
____ Distilled water.

The kit requires the use of a scale with 0.1 g precision.

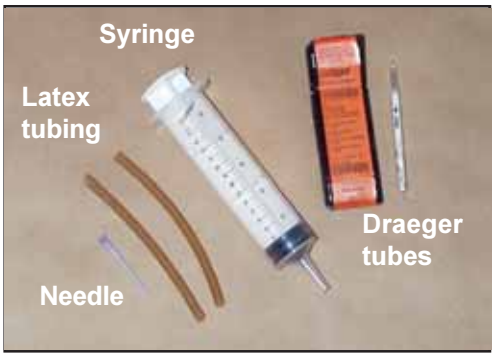

Figure 6d

Figure 7d

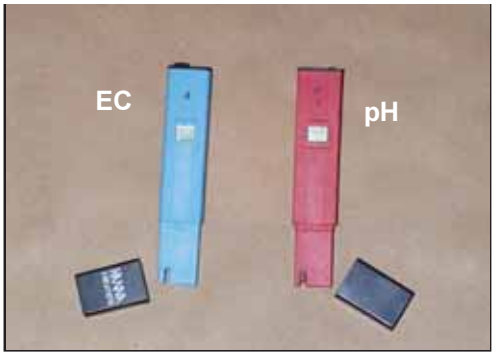

Figure 8d

Figure 5d

Figure 9d

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The list on the previous pages describes all the equipment necessary for building a kit. The following are some listed items that can be easily constructed.

Construction of 2-mm sieves

1. The 2-mm-opening sieve can be made from No. 10 screens (2-mm openings) cut into discs approximately 75 mm in diameter.
2. The disc periphery is soldered with acid-core solder and mounted on the lip of 3-inch diameter PVC bushings.
3. A section of PVC (sleeve), dimensions 75 mm in diameter by 38 mm high (280 lb per inch rating), is made.
4. PVC cement is placed on the outside wall of the PVC sleeve, and on the inside wall of the PVC bushing. The PVC sleeve is pushed down firmly in to the PVC bushing, so they are cemented together (**Figure 13d)**.

Construction of 0.25-mm sieves

The 0.25-mm opening sieves can be made from No. 60 screens (hardware store) cut and mounted on the bottom of 2-inch diameter PVC joints (hardware or plumbing supply stores) using PVC cement, epoxy, or other thick glue **(Figure14d)**.

Construction of drying chamber

1. Any plastic container can be used. The container used here is a 4" x 6" plastic container with lid **(Figure 15d)**.
2. Drill two 2¼-inch holes in the bottom of the container (for insertion of 2-inch sieves).
3. Drill four ¼-inch holes in each side of the container, and a 1-inch hole on one side for insertion of the hair dryer. A 1-inch rubber grommet can be used to line the 1-inch hole to create a good seal when the hair dryer is inserted (**See Figure 15d**).

To accommodate the drying of more sieves (efficient for a large number of samples), a bigger container can be used with more 2¼-inch holes **(Figure 18d)**. The container pictured in Figure 18d is a small, trunk-style tackle box (13.5 x 8 x 6 inches). The inside tray was removed.

Figure 10d

Figure 11d

Figure 12d

Figure 13d

Construction of Soil Stability Kit

Construction of Box

1. Obtain a "parts" or "tackle" box with a lid; 18 cells, each cell at least 1¼" x 1¼" x 1½" deep **(Figure 16d)**. [sporting goods or hardware store].
2. Seal individual cells in the box with a small bead of silicone glue or caulk.

Figure 15d

Construction of Sieve Baskets (**Figure 17d**)

Materials:

- PVC, 1-inch in diameter, thin wall, about 2½ feet long.
- Aluminum window screen (1.5-mm openings), 4" x 8" piece (hardware store).
- Adhesive (epoxy or thick glue) [grocery or hardware store].

I*nstructions:*

1. Beginning at left end of the PVC pipe, make marks at 1½-inch intervals; 20 marks are needed.
2. Make a smaller mark ¼ to 3/8 inches to the *left* of all the first marks.
3. Beginning at left end, cut ¾ of the way through the tube at the first small mark using a hacksaw or bandsaw.
4. Beginning at the left end, use tin snips to make two lengthwise cuts through the tube, leaving a ¼" diameter "tab" (**See Figure 17d**).
5. Using tin snips or hacksaw, cut through the tube at the first large (1½ inch) interval mark.
6. Repeat steps 6-8 for each of the 20 sieves.
7. Cut 20 1¼" x 1¼" squares of aluminum window screen.
8. Glue a window screen square to the bottom of each sieve.
9. After allowing glue to dry, carefully trim screen to edge of sieves.

Figure 16d

Figure 17d

Figure 14d

Figure 18d

Outlet for kit items include:

Supplier[1]	Items Supplied[1]
Murray, Iowa FFA (515) 447-2517 http://www.geocities.com/murray_ffa/	Soil quality test kits (standard and deluxe kits)
Gempler's Inc. 100 Countryside Dr. P.O. Box 270 Belleville, WI 53508 (608) 424-1544 or (800) 382-8473 http://www.gemplers.com	A soil quality test kit as described in this manual. All kit items.
Fisher Scientific Pittsburgh, PA Ph. (800) 766-7000	Draeger tubes Filter paper, pH and EC meters, scales, graduated cylinders, 500-mL bottles, plastic containers, latex tubing, hypodermic needles
Scientific Industries 2207 Blue Bell Ave. Boulder, CO 80302 Ph. (303) 443-7087	Draeger tubes
Spectrum Technologies 23839 W. Andrew Rd. Plainfield, IL 60544 Ph. (800) 248-8873	AquaChek nitrate/nitrite test strips pH and EC meters scales
Markson Labsales Inc. P.O. Box 377 Wayne, New Jersey 07474 Ph. (800) 528-5114	EC standard solution (500-mL bottle, 1413 microsiemens) pH buffer capsules (pH 4, 7 and 10) Filter paper, pH and EC meters, scales graduated cylinders, 500-mL bottles, plastic containers
Walgreens	400-watt hair dryer
Forestry Suppliers, Inc. PO Box 8397 Jackson, MS 39284 Ph. (800) 647-5368	Sieves, scales
ATM Test Sieves West Allis, WI Ph. (800) 511-2096	0.25 mm screen (60 mesh) 2.0 mm screen (10 mesh)
Veterinary or medical supply	140-cc syringe
Hardware store Grocery or discount stores	2-lb hand sledges, tape measures, hand trowels, small screw drivers Plastic-wrap, 1-qt. sealable bags, 30-mL calibrated scoop

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Soil Quality Evaluation Site Description

Site Description		DATE:
Map Location	State:	County:
Geographic Location	Longitude:	Latitude:
Field or site location		
Landowner		
Soil Information		
Soil Series		
Slope %		
Erosion		
Mean Annual Temp.		
Mean Annual Precip.		
Present Management		
Cropping System (Rotations, cover crops, etc)		
Fertilizers/Pesticides (N inputs, pesticide use, etc)		
Tillage/Residue Cover (Type, depth, frequency, timing, % cover, etc)		
Irrigation (Pivot, gravity, amount and timing, etc)		
Other		
Past Management History		
Cropping System (Rotation/fallow history, etc)		
Fertilizers/Pesticides (N inputs, pesticide use, etc)		
Tillage/Residue Cover (Past tillage, frequency and type)		
Irrigation (past irrigation, how long?)		
Unusual Events (Floods, fires, land-leveling)		

Aerial view of field showing sampling sites and location of environmentally sensitive areas, such as ponds, creeks, wetlands, and other fragile sites adjacent to the field.

Scale 1 inch = _____ ft. (NA indicates sketch not to scale).

Additional Specifications and Notes:

Soil Respiration (at Initial Field Water Content)								DATE:	
	Sample site	(**H**) Ring height (cm)	Start time	End time	(**A**) Soil temp. (Celsius)	(**B**) Draeger tube %CO_2 (n=1)	* Soil Respiration lbs CO_2-C/acre/day	(**B**) Draeger tube %CO_2 (n=5)	* Soil Respiration lbs CO_2-C/acre/day
1									
2									
3									
4									
Soil Respiration (at least 6 hours after irrigation or soil wetting)									
1									
2									
3									
4									

* Soil respiration = PF x ((**A** + 273)/273) x (**B** - 0.035) x 22.91 x **H** = lbs CO_2-C/acre/day

H = 5.08 cm (if not measured)

PF = Pressure Factor = 'raw' barometric pressure in inches Hg/29.9 inches.
Note: This adjustment is necessary at elevations > 3,000 ft.; otherwise PF = 1

Conversion: Degrees Celsius = 5/9 x (Degrees Fahrenheit - 32)

NOTES:

Infiltration (for 1 inch of water)								DATE:	
	Sample site	1st inch of water		**(W)** 1st Infiltration time (minutes)	* 1st Infiltration (in/hr)	2nd inch of water		**(W)** 2nd Infiltration time (minutes)	* 2nd Infiltration (in/hr)
		Start time	End time			Start time	End time		
1									
2									
3									
4									

* Conversion of infiltration time to inches per hour (in/hr); in/hr = (1/**W**) x 60

NOTES:

Bulk Density and Soil Water Status (core method)									DATE:	
	Sample site	(h) Height of ring above soil (cm)	(E) Weight of field moist soil + bag (grams)	(F) Weight of bag (grams)	Subsample for determinng soil water content				** (M) Soil H_2O content (g/g)	*** Soil bulk density (g/cm^3)
					(G) Weight of paper cup (grams)	(I) Weight of paper cup + soil (g)	(K) Dry weight of soil + cup	* (L) Dry weight of soil (grams)		
1										
2										
3										
4										
*Dry wt. of soil subsample = (K - G)				**Soil H_2O content = (I - K)/L						
***Soil bulk density = [(E - F)/(1 + M)]/[(12.7 - h) x 42.52] h = 5.08 cm (2 inches) if not measured; volume of soil = 324 cm^3										

Bulk Density and Soil Water Status for Gravelly Soils (excavation method)										
	Sample site	(n) Volume of water (cm^3)	(E) Weight of field moist soil + bag (grams)	(F) Weight of bag (grams)	Subsample for determinng soil water content				** (M) Soil H_2O content (g/g)	*** Soil bulk density (g/cm^3)
					(G) Weight of paper cup (grams)	(I) Weight of paper cup + soil (g)	(K) Dry weight of soil + cup	* (L) Dry weight of soil (grams)		
1										
2										
3										
4										
*Dry wt. of soil subsample = (K - G)				**Soil H_2O content = (I - K)/L						
***Soil bulk density = [(E - F)/(1 + M)]/(n) n = volume of soil in cm^3										

Soil Electrical Conductivity, pH, and Nitrate (NO_3^-)						DATE:	
	Sample site	(X) Weight of field moist soil (grams)	Readings for 1:1 soil:water mix.			* Estimated Soil NO_3-N (1b NO_3-N/acre)	** Exact Soil NO_3-N (1b NO_3-N/acre)
			EC (dS/m)	pH	**(Y)** Soil NO_3-N ppm (est.)		
1							
2							
3							
4							

*Estimated: lb NO_3-N/acre = **Y** x [depth of soil in cm /10] x soil bulk density x 0.89
Depth of soil = depth of soil sampled in centimeters; for kit it is 0 to 3 inches = 7.6 cm

Exact: lb NO_3-N/acre = **Y x C.F. x [depth of soil in cm /10] x soil bulk density x 0.89
C.F. = [30 mL + ((X/(1 + M)) x M)]/[X/(1 + M)] M = decimal soil water content (g/g)
Depth of soil = depth of soil sampled in centimeters; for kit it is 0 to 3 inches = 7.6 cm

Water Quality Measurements			DATE:	
	Sample site	Salinity (dS/m)	Water Nitrite (ppm)	Water Nitrate (ppm)
1				
2				
3				
4				

NOTES:

Aggregate Stability						DATE:
	Sample site	**(A)** Weight of sieve (grams)	**(B)** Weight of sieve + aggregates (grams)	**(C)** Weight of sieve + dry aggregates (grams)	**(D)** Weight of sieve + dry sand (grams)	* Percent water stable aggregates (% of soil > 0.25mm)
1						
2						
3						
4						
* % Water stable aggregates = (C - D)/(B - D) x 100						

Slake Test										DATE:
	Sample site	Individual Soil Slake Ratings								* Average Soil Slake Rating
1										
2										
3										
4										
* Soil Slake Rating = (add all of the individual ratings and divide by the total number)										

Earthworms				DATE:	NOTES:
	Sample site	Surface dwelling earthworms	Deep dwelling earthworms	Total Earthworms (no. per square foot)	
1					
2					
3					
4					

Soil Observations and Estimations	DATE:
	Description
Top soil depth (inches)	
Plant roots	
Compaction layer	
Soil texture	
Other	

Classes for Structure Index

Structure			Class[a]
Type	Size	Grade	
Granular	Fine, Medium, Coarse	Weak	2
Granular	Fine, Medium, Coarse	Moderate	4
Granular	Fine, Medium, Coarse	Strong	5
Blocky	Very fine, Fine, Med.	Weak	1
Blocky	Very fine, Fine	Moderate	4
Blocky	Very fine, Fine, Med.	Strong	5
Blocky	Medium	Moderate	3
Platy	Thin, Medium, Thick	Very friable[b]	3
Platy	Thin, Medium, Thick	Friable[b]	2
Platy	Thin, Medium, Thick	Firm or Stronger[b]	1
Massive			1
Single Grain			1

Note: [a] Class 5 is the best. [b] Substitute horizontal moist rupture resistance.

Soil Structure DATE:

Depth (inches)	Type	Size	Grade	(A) Class	(B)	(A) x (B)	Structure index*
0 - 4					3		
4 - 8					2		
8 - 12					1		
*Structure index = ((Total - 6)/24) x 100				Total =			

NOTES:

Soil Quality Test Kit

SECTION II

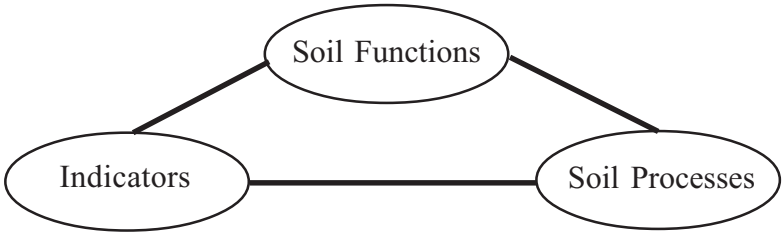
Background & Interpretive Guide for Individual Tests

Section II

INTRODUCTION

Soil quality assessment or interpretation should be considered a process through which soil resources are evaluated on the basis of soil function (what the soil does) and change in soil function in response to a specific natural or introduced stress, or management practice. Five vital soil functions have been proposed. They are: (1) sustaining biological activity, diversity, and productivity; (2) regulating and partitioning of water and solute flow; (3) filtering, buffering, degrading, immobilizing, and detoxifying organic and inorganic materials, including industrial and municipal by-products and atmospheric deposition; (4) storing and cycling of nutrients and other elements within the Earth's biosphere; and (5) providing support of socioeconomic structures and protection for archeological treasures associated with human habitation (Karlen et al., 1997).

It is also important to emphasize that soil quality evaluations must consider biological, chemical, and physical properties and processes. For interpretation, the measurements must be evaluated with respect to their long-term trends or signs of sustainability. A general sequence of how to evaluate soil quality is to (1) define the soil functions of concern, (2) identify specific soil processes associated with those functions, and (3) identify soil properties and indicators that are sensitive enough to detect changes in the functions or soil processes of concern (Carter et al., 1997).



Section II provides background and interpretive information for each test described in Section I. Each test is considered to be an indication of the level of functioning. However, indicator data is not meaningful unless a baseline or some reference condition is available for comparison or unless relative comparisons between management systems are made.

References

Carter, M.R., E.G. Gregorich, D.W. Anderson, J.W. Doran, H.H. Janzen, and F.J. Pierce. 1997. Concepts of soil quality and their significance. p. 1-20. In: E.G. Gregorich and M.R. Carter. (eds.) Soil quality for crop production and ecosystem health. Elsevier Science, Amsterdam.

Karlen, D.L., M.J. Mausbach, J.W. Doran, R.G. Cline, R.F. Harris, and G.E. Schuman. 1997. Soil quality: A concept, definition, and framework for evaluation. Soil Sci. Soc. Amer. J. 61:4-10.

1. Soil Respiration

Introduction

Soil respiration is the production of carbon dioxide (CO_2) as a result of biological activity in the soil by microorganisms, live roots, and macroorganisms such as earthworms, nematodes, and insects (Parkin et al., 1996). Carbon dioxide emitted from soil is a colorless and odorless gas that enters the atmosphere and annually exceeds the amount emitted by all human activities (Volk, 1994). The activity of organisms in the soil is considered to be a positive attribute for soil quality.

Soil respiration is highly variable both spatially and seasonally, and is strongly affected by moisture and temperature conditions. Because this variability can complicate interpretations, certain sampling precautions must be taken.

Knowing the history of the sampling site and characteristics of nearby soils becomes very important when evaluating respiration. Soil color may provide some assistance when interpreting respiration rates. A light colored soil with a high respiration rate may be indicative of a soil being depleted of organic matter. A relatively darker soil with the same rate could be considered healthy. The dark color indicates the presence of organic matter. Tillage or cultivation can result in loss of soil carbon (C) and increases in the amount of CO_2 released. The soil is loosened, which creates better accessibility of oxygen necessary for organic matter decomposition and respiration, resulting in CO_2 release (Reicosky and Lindstrom, 1995).

Interpretations

When comparing soil respiration rates from different sites or from the same site at different times, differences in soil temperature and soil water content must be taken into account. Soil temperature corrections can be performed using the general rule that biological activity increases by a factor of 2 with each 10°C increase in temperature (Parkin et al., 1996). The following equation can be used to standardize (to 25°C) for differences in soil temperatures that are between 15 and 35°C:

$$\text{Standardized soil respiration rate} = \text{soil respiration rate} \times 2^{[(25-T)\div 10]}$$

For soil temperatures between 0 and 15°C, the following equation is used:

$$\text{Standardized soil respiration rate} = \text{soil respiration} \times 4^{[(25-T)\div 10]}$$

For example, if you had a soil respiration rate of 15 CO_2-C lbs/a/d and soil temperature of 22°C, the first equation listed above would be used, and the standardized soil respiration rate would be calculated as follows:

1. $[(25 - 22) \div 10] = 0.3$
2. $2^{0.3} = 1.2$
3. (15 CO_2-C lbs/a/d) x 1.2 = 18 CO_2-C lb/a/d (standardized respiration rate at 25°C)

Standardization for differences in soil water content must also be taken into account. Maximum

microbial activity generally occurs when 60% of the soil pores are filled with water (Parkin et al., 1996). The amount of water in the pore space is referred to as **water-filled pore space** (WFPS), and gives an indication of how well aerated the soil is at the time of sampling.

Water-filled pore space (%) = (volumetric water content x 100) ÷ [1 - (soil bulk density ÷ 2.65)]

Soil respiration can be adjusted to equivalent values at 60% WFPS through the following equation for WFPS values between 30 and 60% (Parkin et al., 1996):

$$\text{Soil respiration}_{60} = \text{soil respiration rate} \times (60 \div \text{measured \%WFPS})$$

For WFPS values between 60 and 80%, the following equation is used:

$$\text{Soil respiration}_{60} = \text{soil respiration rate} \div [(80 - \text{\%WFPS}) \times 0.03] + 0.4$$

When the soil water content or WFPS exceeds 80%, soil respiration may be restricted by the wet conditions and should not be measured. The relationship between WFPS and soil respiration has been evaluated primarily in the laboratory and remains to be tested in the field (Parkin et al., 1996).

Table 1. General soil respiration class ratings and soil condition at optimum soil temperature and moisture conditions, primarily for agricultural land uses (Woods End Research, 1997).

Soil respiration (lbs CO_2-C/a/d)	Class	Soil condition
0	No soil activity	Soil has no biological activity and is virtually sterile.
< 9.5	Very low soil activity	Soil is very depleted of available organic matter and has little biological activity.
9.5 - 16	Moderately low soil activity	Soil is somewhat depleted of available organic matter, and biological activity is low.
16 - 32	Medium soil activity	Soil is approaching or declining from an ideal state of biological acitivity.
32 - 64	Ideal soil activity	Soil is in an ideal state of biological activity and has adequate organic matter and active populations of microorganisms.
> 64	Unusually high soil activity	Soil has a very high level of microbial activity and has high levels of available organic matter, possibly from the addition of large quantities of fresh organic matter or manure.
Conversion of Woods End Solvita respiration levels: (mg CO_2/kg/wk) x 0.039 x (1.2 g/cm^3) x (7.6 cm depth) ÷ 10 x 0.89 = (lbs CO_2-C/acre/day). It was assumed all respiration was coming from a 7.6 cm depth with an average bulk density of 1.2 g/cm^3 (Doran et al., 1997).		

A high soil respiration rate, indicative of high biological activity, can be a good sign of rapid decomposition of organic residues into nutrients available for plant growth. However, decomposition of the stable organic matter is detrimental to many physical and chemical processes such as aggregation, cation exchange, and water holding capacity. Also, immediately following a tillage operation, CO_2 evolution can rise dramatically due to exposure of organic matter to organisms and oxygen. Also, soil respiration can rise dramatically after rainfall (Rochette et al., 1991). The rise in soil respiration is affected by the length of time the soil is dry before the rainfall event.

Under dry conditions, soil respiration tends to be higher in the crop row than in the interrow (Rochette et al., 1991). The higher respiration rates are attributed to the contribution from plant roots. Under wet conditions, there tends to be no difference in respiration between the row and interrow. When the soil interrow is compacted (wheel track) and the soil is wet, soil respiration tends to be lower than in the row. The lower soil porosity accounts for the lower respiration rate under compacted conditions.

Biological activity is a direct reflection of the degradation of organic matter in the soil. This degradation indicates that two processes are occurring: (1) loss of soil carbon and (2) turnover of nutrients (Parkin et al., 1996). Some optimum soil respiration rate, that balances the long-term detrimental aspects of soil carbon loss and soil nutrient turnover, must be defined .

Conversions

kg CO_2-C/ha/d = lbs CO_2-C/a/d x 1.12

g CO_2-C/m^2/d = lbs CO2-C/a/d ÷ 11.2

kg CO_2-C/ha/d = g CO_2-C/m^2/d x 10

References

Doran, J.W., T. Kettler, M. Liebig, and M. Tsivou. 1997. Solvita soil test evaluation, personal communication.

Parkin, T.B, J.W. Doran, and E. Franco-Vizcaino. 1996. Field and laboratory tests of soil respiration. p.231-246. In: J.W. Doran and A.J. Jones (eds.) Methods for assessing soil quality. Soil Sci.Soc. Am. Spec. Publ. 49. SSSA, Madison, WI.

Prochette, P., R.L. Desjardins, and E. Pattey. 1991. Spatial and temporal variability of soil respiration in agricultural fields. Can. J. Soil Sci. 71:189-196.

Volk, T. 1994. The soil's breath. Natural History November/94.

Woods End Research. 1997. Guide to solvita testing and managing your soil. Woods End Research Laboratory, Inc., Mt. Vernon, ME.

2. Infiltration

Introduction

Infiltration is the process of water entering the soil. The rate at which water enters the soil is the infiltration rate, which is dependent on the soil type; soil structure, or amount of aggregation; and the soil water content (Lowery et al., 1996). The initial soil water content at time of measurement affects the ability of the soil to pull additional water into the soil. Therefore, the infiltration rate will be higher when the soil is dry than when it is wet. This factor is important when comparing infiltration measurements of different soils. The soils should have similar moisture content when taking the measurements.

Tillage will affect the infiltration rate. Immediately after tillage, improved infiltration may occur due to the loosening of surface crusts or compacted areas. Tillage fluffs up the soil. However, tillage further disrupts aggregates and soil structure, creating the potential for compaction, surface crusting, and loss of continuous surface connected pores. Compacted soils will have less pore space, resulting in lower infiltration rates. Soils that tend to form surface crusts, which seal the soil surface, can have severely reduced infiltration rates.

Interpretations

Since infiltration is affected by the initial water content at the time of measurement, it is important that the soil water content be similar when comparing infiltration rates from different sites. The infiltration test in the soil quality kit requires two 1-inch depths of water to be applied consecutively. Application of the first inch of water is used to wet the soil, and the second inch of water determines the infiltration rate. This procedure is an attempt to standardize the soils for differences in initial water content. Infiltration rates are best determined when the soil is at or near field capacity, usually 12 to 48 hours after the soil has been thoroughly wetted (i.e., soaking rain or irrigation).

The infiltration rate is sensitive to near-surface conditions and is subject to significant change with soil use, management, and time. It is affected by the development of plant roots, earthworm burrows, soil aggregation, and by overall increases in stable organic matter (Sarrantonio et al., 1996). Infiltration is rapid into large continuous pores in the surface. Infiltration is decreased when the size

Table 2. Steady infiltration rates for general soil texture groups in very deeply wetted soil (Hillel, 1982).

Soil type	Steady infiltration rate (inches per hour)
Sands	> 0.8
Sandy and silty soils	0.4 - 0.8
Loams	0.2 - 0.4
Clayey soils	0.04 - 0.2
Sodic clayey soils	< 0.04

or amount of pore space is reduced from conditions such as structure breakdown, pore clogging by lodged particles, or slower movement of deeper water as it reaches denser subsoils (Donahue et al., 1977).

Texture, or the percentage of sand, silt, and clay will affect the infiltration rate. Usually sandy soils will have rapid infiltration rates. Some typical values for steady infiltration rates (After long continuous wetting, the rate of infiltration becomes steady.) for general soil texture groups are shown in Table 2. However, the values in Table 2 can be considerably higher in well aggregated or cracked soils and during initial stages of wetting; these values can be lower if surface crusting occurs (Hillel, 1982). Soil structure greatly influences the movement of water into the soil.

Table 3 shows the infiltration rate in minutes per inch and inches per hour and the associated infiltration class. These classes are the soil permeability classes historically used in Soil Survey. Classes are estimated from soil properties and indicate a steady infiltration rate.

Table 3. Infiltration rates and classes.

Infiltration rate (minutes per inch)	Infiltration rate (inches per hour)	Infiltration class
< 3	> 20	Very rapid
3 to 10	6 to 20	Rapid
10 to 30	2 to 6	Moderately rapid
30 to 100	0.6 to 2	Moderate
100 to 300	0.2 to 0.6	Moderately slow
300 to 1,000	0.06 to 0.2	Slow
1,000 to 40,000	0.0015 to 0.06	Very slow
> 40,000	< 0.0015	Impermeable

References

Donahue, R.L., R.W. Miller, J.C. Shickluna. 1977. Soils: An introduction to soils and plant growth. Prentice Hill, Englewood, New Jersey.

Hillel, D. 1982. Introduction to soil physics. Academic Press, San Diego, CA.

Lowery, B., M.A. Arshad, R. Lal, and W.J. Hickey. 1996. Soil water parameters and soil quality. p.143-157. In: J.W. Doran and A.J. Jones (eds.) Methods for assessing soil quality. Soil Sci. Soc. Am. Spec. Publ. 49. SSSA, Madison, WI.

3. Bulk Density

Introduction

Bulk density is defined as the ratio of oven-dried soil (mass) to its bulk volume, which includes the volume of particles and the pore space between the particles. It is dependent on the densities of the soil particles (sand, silt, clay, and organic matter) and their packing arrangement. Mineral particle densities usually range from 2.5 to 2.8 g/cm^3, while organic particles are usually less than 1.0 g/cm^3. Bulk density is a dynamic property that varies with the structural condition of the soil. This condition can be altered by cultivation; trampling by animals; agricultural machinery; and weather; i.e., raindrop impact (Arshad et al., 1996). Compacted soil layers have high bulk densities, restrict root growth, and inhibit the movement of air and water through the soil.

Interpretations

Soil bulk density can serve as an indicator of compaction and relative restrictions to root growth (See Table 4). Typical soil bulk densities range from 1.0 to 1.7 g/cm^3, and generally increase with depth in the soil profile (Arshad et al., 1996). In soils containing high amounts of swelling clays, bulk densities will vary with the water content, which should be measured at the time of sampling.

Table 4. General relationship of soil bulk density to root growth based on soil texture.

Soil texture	Ideal bulk densities (g/cm^3)	Bulk densities that may affect root growth (g/cm^3)	Bulk densities that restrict root growth (g/cm^3)
sands, loamy sands	< 1.60	1.69	> 1.80
sandy loams, loams	< 1.40	1.63	> 1.80
sandy clay loams, loams, clay loams	< 1.40	1.60	> 1.75
silts, silt loams	< 1.30	1.60	> 1.75
silt loams, silty clay loams	< 1.40	1.55	> 1.65
sandy clays, silty clays, some clay loams (35-45% clay)	< 1.10	1.49	> 1.58
clays (> 45% clay)	< 1.10	1.39	> 1.47

Comments

Bulk density values are also required for converting soil water content in percent by weight (gravimetric) to percent by volume (volumetric):

Volumetric water content (g/cm^3) = soil water content (g/g) x bulk density (g/cm^3)

and to calculate porosity, which is the amount of pore space in the soil:

soil porosity (%) = 1 - (soil bulk density ÷ 2.65).

References

Arshad, M.A., B. Lowery, and B. Grossman. 1996. Physical tests for monitoring soil quality. p.123-142. In: J.W. Doran and A.J. Jones (eds.) Methods for assessing soil quality. Soil Sci. Soc. Am. Spec. Publ. 49. SSSA, Madison, WI.

4. Electrical Conductivity

Introduction

The electrical conductivity (EC) of soil-water mixtures indicates the amount of salts present in the soil. All soils contain some salts, which are essential for plant growth. However, excess salts will hinder plant growth by affecting the soil-water balance. Soils containing excess salts occur both naturally and as a result of soil use and management. Salt-affected soils are largely found in the western arid and semiarid areas of the country, where the annual rainfall is low, allowing salts to accumulate in the soil profile. The electrical conductivity measurement detects the amount of cations or anions (salts) in solution; the greater the amount of anions or cations, the greater the electrical conductivity reading. The ions generally associated with salinity are Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, H^{+} (cations), or NO_3^{-}, SO_4^{-}, Cl^{-}, HCO_3^{-}, OH^{-} (anions).

Interpretations

In general, $EC_{1:1}$ values between 0 and 0.8 dS/m are acceptable for general crop growth. Site specific interpretations for soil quality will depend on specific land use and crop tolerance. Table 5 shows the soil salinity class and general crop and microbial responses for each class.

Table 5. Electrical conductivity measurement and salinity classes for a 1:1 soil:water suspension.

Electrical Conductivity (dS m^{-1} at 25 C)	Salinity class	Crop response	Microbial response
0 - 0.98	Non saline	Almost negligible effects	Few organisms affected
0.98 - 1.71	Very slightly saline	Yields of very sensitive crops restricted	Selected microbial processes altered (nitrification/denitrification)
1.71 - 3.16	Slightly saline	Yields of most crops restricted	Major microbial processes influenced (respiration/ammonification)
3.16 - 6.07	Moderately saline	Only tolerant crops yield satifactorily	Salt tolerant microorganisms predominate (fungi, actinomycetes, some bacteria)
> 6.07	Strongly saline	Only very tolerant crops yield satisfactorily	A select few halophilic organisms are active

Adapted from Soil Survey Staff (1993), Janzen (1993), and Smith and Doran (1996). Conversions from the saturation paste extract to the 1:1 soil:water suspensions were perfomed using the regression equation (y = 2.75 x -0.69) developed by Hogg and Henry (1984).

Table 6 provides general salt tolerance ratings for selected crops. These ratings apply to soils in which chloride (Cl^-) is the predominant anion. The EC of soils containing gypsum will tolerate 1 dS/m higher than those listed in this table (Tanji, 1990). Consult a local Soil Survey to determine if gypsum is present in the soil of interest.

Table 6. Salt tolerance of selected crops (Tanji, 1990).

Crop	Rating	Crop	Rating	Crop	Rating
Alfalfa	MS	Clover, iadino	MS	Loquat	S
Alkali grass, Nuttall	T	Clover, red	MS	Love grass	MS
Alkali sacaton	T	Clover, strawberry	MS	Mango	S
Almond	S	Clover, sweet	MT	Milkvetch, Cicer	MS
Apple	S	Clover, white Dutch	MS	Millet, foxtail	MS
Apricot	S	Corn	MS	Muskmelon	MS
Artichoke	MT	Corn (forage)	MS	Oat grass, tall	MS
Asparagus	T	Corn, sweet	MS	Oats (forage)	MS
Avocado	S	Cotton	T	Okra	S
Barley	T	Cowpea	MT	Olive	MT
Barley (forage)	MT	Cowpea (forage)	MS	Onion	S
Bean	S	Cucumber	MS	Orange	S
Beet, red	MT	Currant	T	Orchard grass	MS
Bentgrass	MS	Dallis grass	MS	Panic grass, blue	MT
Bermuda grass	T	Date palm	T	Papaya	MT
Blackberry	S	Eggplant	MS	Rape	MT
Bluestem, Angleton	MS	Fescue, tall	MT	Parsnip	S
Boysenberry	S	Fescue, meadow	MT	Passion fruit	S
Broad bean	MS	Fig	MT	Pea	S
Broccoli	MS	Flax	MS	Peach	S
Brome, mountain	MT	Foxtail, meadow	MS	Pear	S
Brome, smooth	MS	Gooseberry	S	Pepper	MS
Brussels sprouts	MS	Grama, blue	MS	Persimmon	S
Buffelgrass	MS	Grape	MS	Pineapple	MT
Burnet	MS	Grapefruit	S	Plume, prune	S
Cabbage	MS	Guar	T	Pomegranate	MT
Canary grass, reed	MT	Guayule	T	Potato	MS
Carrot	S	Harding grass	MT	Pummelo	S
Castorbean	MS	Jojoba	T	Pumpkin	MS
Cauliflower	MS	Jujube	MT	Radish	MS
Celery	MS	Kale	MS	Rescue grass	MT
Cherimoya	S	Kaller grass	T	Raspberry	S
Cherry, sweet	S	Kenaf	MT	Rhodes grass	MT
Cherry, sand	S	Kohlrabi	MS	Rice, paddy	S
Clover, alsike	MS	Lemon	S	Rose apple	S
Clover, berseem	MS	Lettuce	MS	Rye	T
Clover, hubam	MT	Lime	S	Rye (forage)	MS

Table 6. Continued.

Crop	Rating	Crop	Rating	Crop	Rating
Ryegrass, perennial	MT	Sudan grass	MT	Wheat, semidwarf	T
Safflower	MT	Sugar beet	T	Wheat, durum	T
Salt grass, desert	T	Sugarcane	MS	Wheat, durum (forage)	MT
Sapote, white	S	Sunflower	MS	Wheat (forage)	MT
Sesame	S	Sweet potato	MS	Wheat grass, standard	MT
Sesbania	MS	Tangerine	S	Wheat grass, fairway	T
Sirato	MS	Timothy	MS	Wheat grass, interm.	MT
Sorgham	MT	Tomato	MS	Wheat grass, slender	MT
Soybean	MT	Trefoil, narrowleaf	MT	Wheat grass, tall	T
Sphaerophysa	MS	Triticale	T	Wheat grass, western	MT
Spinach	MS	Turnip	MS	Wild rye, Altai	T
Squash, scallop	MS	Vetch, common	MS	Wild rye, beardless	MT
Squash, zucchini	MT	Watermelon	MS	Wild rye, Canadian	MT
Strawberry	S	Wheat	MT	Wild rye, Russian	T

Rating	EC range for 1:1 soil:water suspension for which yield reductions occur
S = Sensitive	> 0.90 dS/m
MS = Moderately sensitive	> 1.40 dS/m
MT = Moderately tolerant	> 2.50 dS/m
T = Tolerant	> 4.00 dS/m

Excess salts affect plant growth by (1) direct toxicities; e.g., boron; (2) disrupting the ionic balance in the plant; (3) interfering with nutrient uptake; e.g., blossom-end rot of tomatoes due to high salt interference with calcium uptake; and (4) reducing the availability of water by lowering the osmotic potential (Fitter and Hay, 1987). Excess sodium (Na^+), often expressed as *exchangeable sodium percentage* (ESP), can deteriorate soil structure by dispersing soil clays.

Considerations

The electrical conductivity of a solution is affected by temperature. Generally the electrical conductivity of a solution increases with temperature at a rate of approximately 1.9% per 1°C increase (Rhoades, 1993). The conductivities in Table 5 are standardized at 25°C. Most EC meters adjust for deviations from 25°C within a specific temperature range. Therefore, conductivity measurements must be taken within this temperature range (Refer to instructions packaged with the meter.) to avoid under- or overestimating the electrical conductivity.

Generally, the effects of soil moisture on the EC measurement will be negligible when soil water content is at or below field capacity. If water content is above field capacity, adjustments should be made to maintain a 1:1 ratio of soil to water. Another approach would be to air-dry the soil if it is too wet.

When distilled water is not available, tap or rain water can be used. Measure the conductivity of the water source, and subtract the water source EC value from the sample EC value.

The relationship between electrical conductivity and salt concentration is only approximate. General relationships that have been established are (Rhoades, 1996):

1) Total cation (or anion) concentration: meq/L ≅ 10 x EC (dS/m).
2) Total dissolved solids: mg/L ≅ 640 x EC (dS/m).
3) Osmotic pressure: kPa (at 25°C) ≅ 0.36 x EC (dS/m).

Where NO_3^- is the predominant ion in the soil solution, a very useful relationship has been established between the EC (in 1:1 soil to water mixture) readings and soil nitrate (NO_3^-) concentrations (Smith and Doran, 1996).

EC (dS/m) x 140 ≅ mg NO_3^--N/kg of soil

This relationship assumes the complete extractability of NO_3^- in water and that NO_3^- is the major anion in the soil solution.

Conversions

1 dS/m (decisiemens per meter) = 1 mmhos/cm (millimhos per centimeter)
1 dS/m (decisiemens per meter) = 1000 μS/cm (microsiemens per centimeter)
1000 μS/cm (microsiemens per centimeter) = mS/cm (millisiemens per centimeter)

References

Fitter, A.H. and R.K.M. Hay. 1987. Environmental physiology of plants. Academic Press, London.

Hogg, T.J. and J.L. Henry. 1984. Comparison of 1:1 suspensions and extracts with the saturation extract in estimating salinity in Saskatchewan soils. Can. J. Soil Sci. 64:699-704.

Janzen, H.H. 1993. Soluble salts. p. 161-166. In: M.R. Carter (ed.) Soil sampling and methods of analysis. Canadian Society of Soil Science. Lewis Publ., Boca Raton.

Rhoades, J.D. 1993. Electrical conductivity methods for measuring and mapping soil salinity. p. 201-251. In: D.L. Sparks (eds.) Advances in agronomy, Vol. 49. Academic Press, Inc., San Diego, CA.

Rhoades, J.D. 1996. Salinity: Electrical conductivity and total dissolved solids. p.417-435. In: D.L. Sparks (ed.) Methods of soil analysis: Part. 3-chemical methods. Book Series no. 5. SSSA and ASA, Madison, WI.

Smith, J.L. and J.W. Doran. 1996. Measurement and use of pH and electrical conductivity for soil quality analysis. p. 169-185. In: J.W. Doran and A.J. Jones (eds.) Methods for assessing soil quality. Soil Sci. Soc. Am. Spec. Publ. 49. SSSA, Madison, WI.

Soil Survey Staff. 1993. Soil survey manual. United States Department of Agriculture. Hnbk no. 18. U.S. Gov. Printing Office, Washington, DC.

Tanji, K.K. (ed.). 1990. Agricultural salinity assessment and management (Manual No. 71). Prepared by Subcommittee on Salinity Manual of the Committee on Water Quality of the Irrigation and Drainage Division of the American Society of Civil Engineers. American Society of Civil Engineers, New York.

5. Soil pH

Introduction

Soil pH is a measure of the acidity or alkalinity of a soil, which affects the availability of plant nutrients, activity of microorganisms, and the solubility of soil minerals. Major factors affecting soil pH are temperature and rainfall, which control the intensity of leaching and soil mineral weathering. Acidity is generally associated with leached soils; alkalinity generally occurs in drier regions. However, agricultural practices, such as liming or addition of ammonium fertilizers, can alter soil pH. The pH measurement is actually measuring the hydrogen ion activity [H^+] in the soil solution.

Interpretations

In general, pH values between 6 and 7.5 are optimum for general crop growth. Site specific interpretations for soil quality will depend on specific land use and crop tolerance.

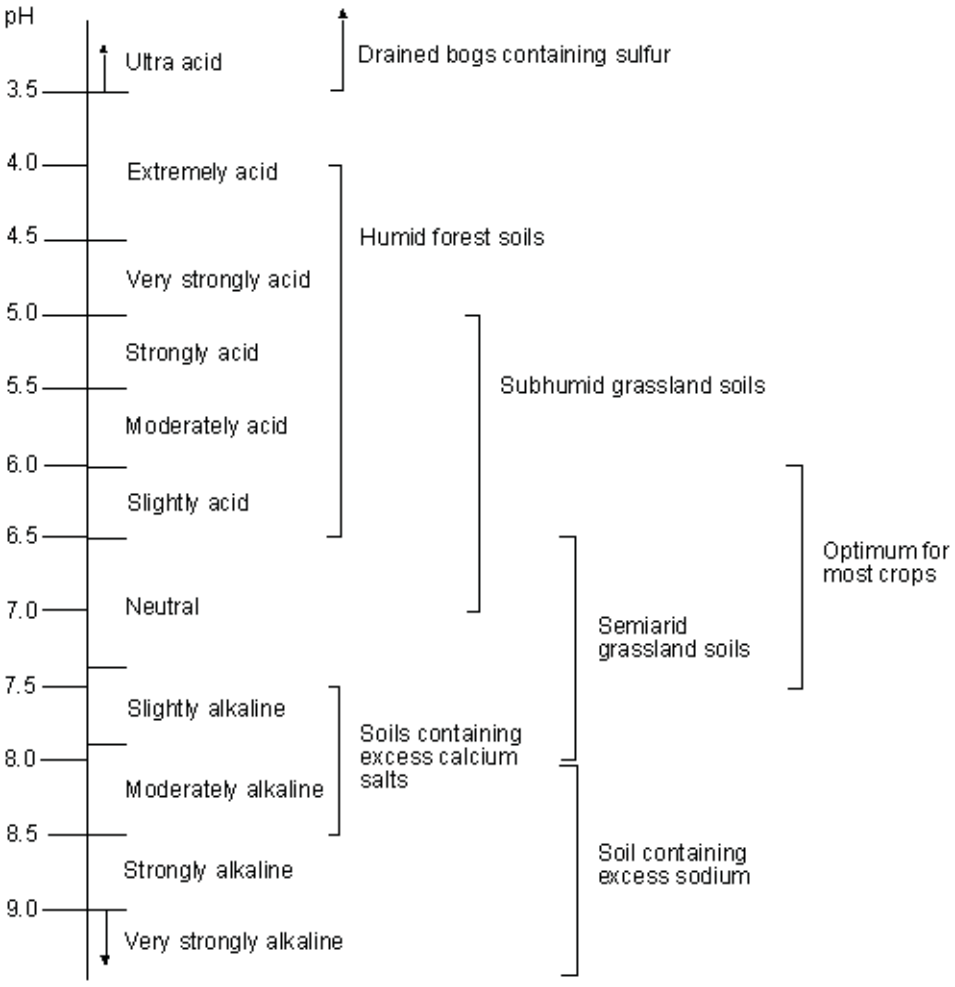


Figure 1. Soil pH, ranges for pH classes, and associated soil conditions. Adapted from the National Soil Survey Manual (1993) and Troeh and Thompson (1993).

Table 7. Suitable soil pH ranges for selected crops (Whittaker et al., 1959).

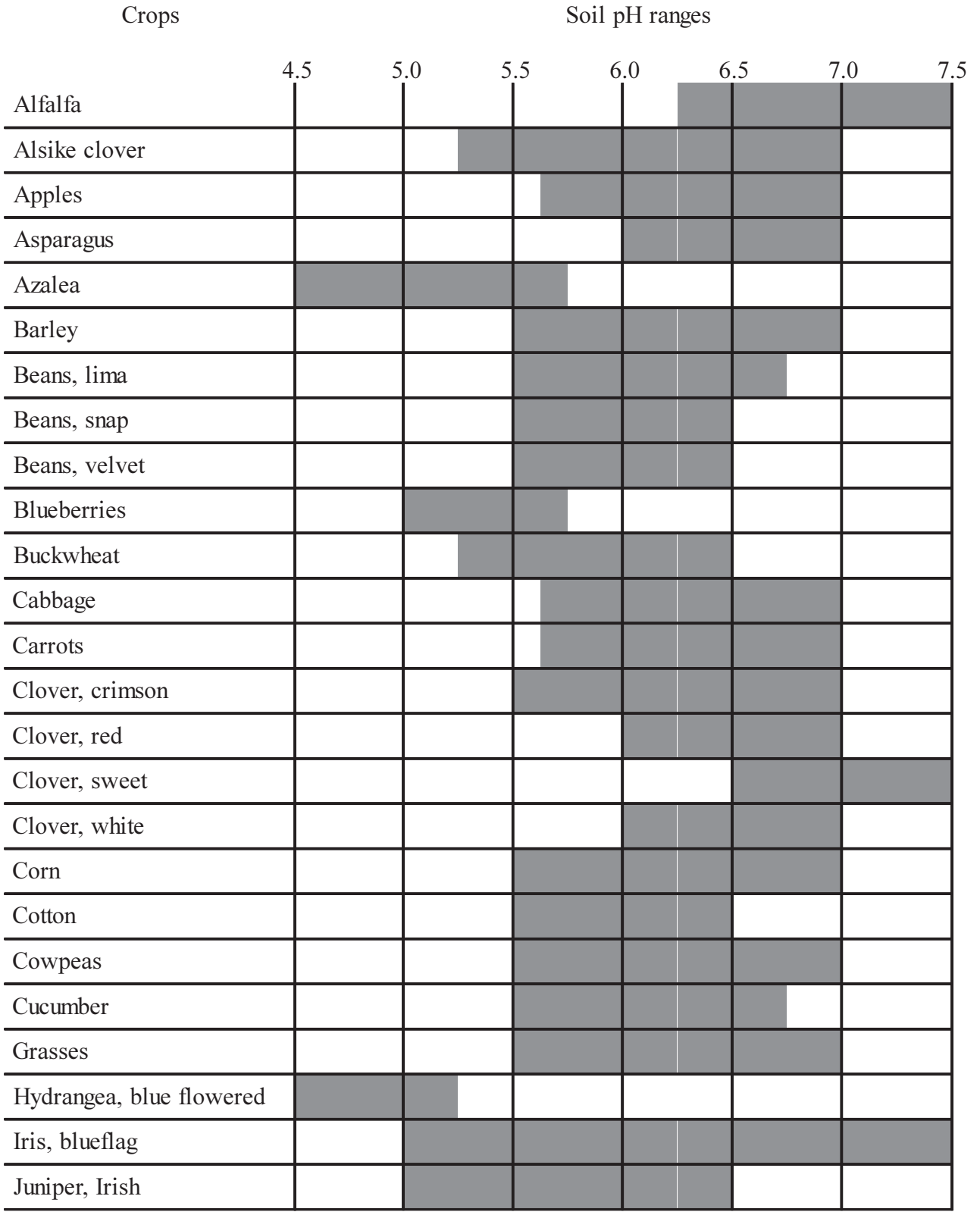
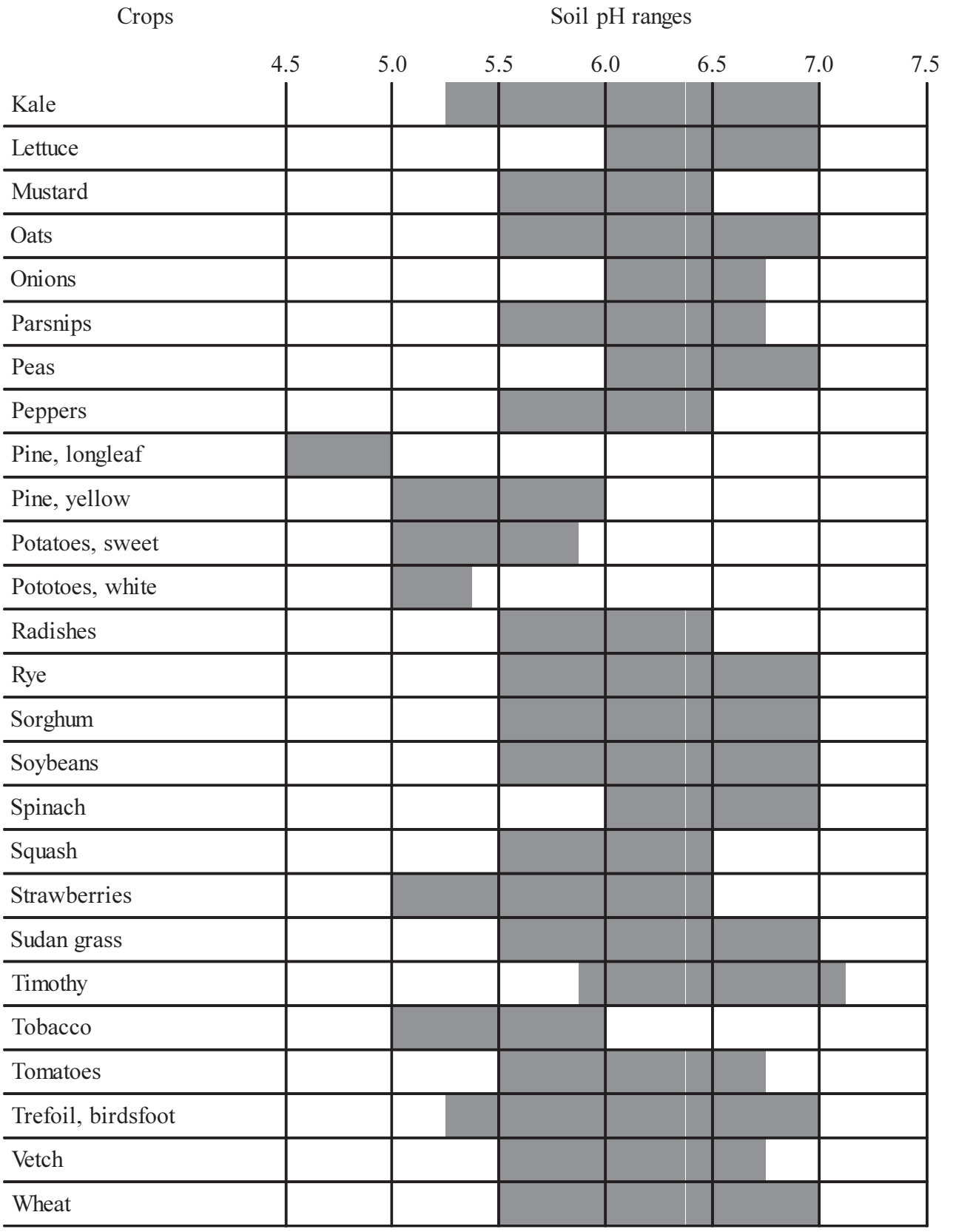


Table 7. Continued.



Nutrient Availability

Soil pH affects the availability of nutrients to plants or crops (Figure 2). Nutrient availability is affected by changes in the solubility of soil minerals. Most minerals are more soluble in acid soils than in neutral or slightly basic soils. The greatest availability for most nutrients is between pH 6 and 7 (Figure 2). Where nutrients are shown interlocking in Figure 2, those nutrients at that pH combine to form insoluble compounds, reducing their availability. Soil pH also affects the activity of beneficial microorganisms, which affects nutrient availability. In general, fungi function at a wide pH range, but bacteria and actinomycetes function better at intermediate and higher pH.

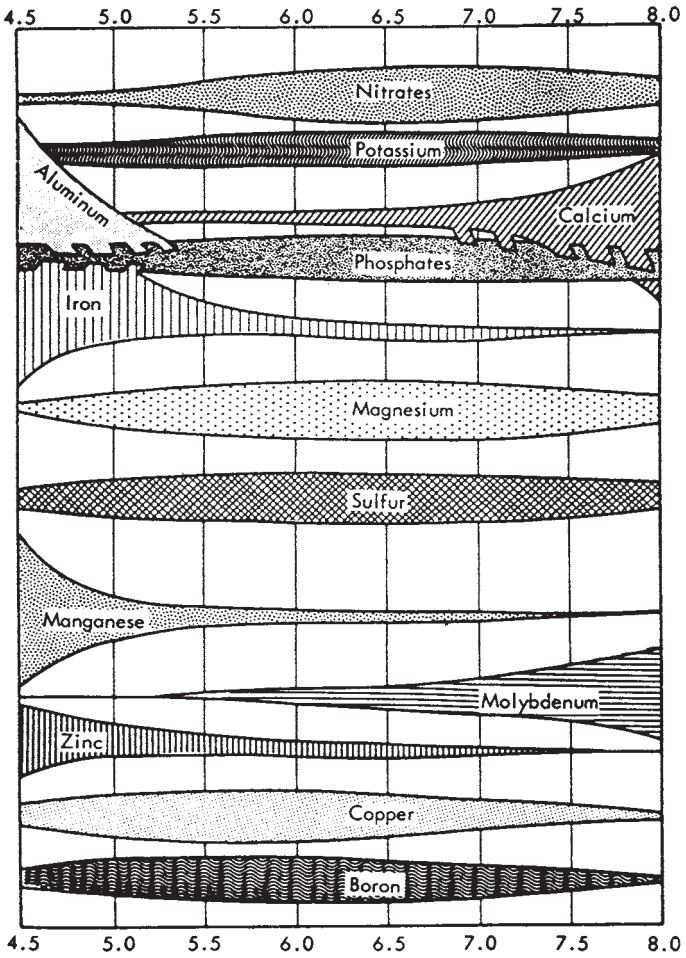


Figure 2. Nutrient availability based on pH of mineral soils (Soils Handbook, Kentucky Agr. Exp. Stn. Misc. 383, 1970, p.28).

Comments

The presence of salts affects soil pH by decreasing the reading by 0.2 to 0.3 pH units (Thomas, 1996). To mask the effects of salts, a 0.01 M $CaCl_2$ solution has been commonly used instead of distilled water.

Declining pH is a sign of inefficient N use where ammonia based fertilizers are used (see Smith and Doran, 1996).

References

Brady, N.C. 1990. The nature and properties of soils. 10th ed. Macmillan Publ., New York.

Smith, J.L. and J.W. Doran. 1996. Measurement and use of pH and electrical conductivity for soil quality analysis. p. 169-185. In: J.W. Doran and A.J. Jones (eds.) Methods for assessing soil quality. Soil Sci. Soc. Am. Spec. Publ. 49. SSSA, Madison, WI.

Soil Survey Staff. 1993. Soil survey manual. United States Department of Agriculture. Hnbk no. 18. U.S. Gov. Printing Office, Washington, DC.

Thomas, G.W. 1996. Soil pH and soil acidity. p.475-489. In: D.L. Sparks (ed.) Methods of soil analysis: Part 3-chemical methods. Book Series no. 5. SSSA and ASA, Madison, WI.

Treoh, F.R. and L.M. Thompson. 1993. Soils and soil fertility. 5th ed. Oxford Univ. Press, New York.

Whittaker, C.W., M.S. Anderson, and R.F. Reitemeier. 1959. Liming soils, an aid to better farming. USDA Farmers Bul. 2124.

6. Soil Nitrate

Introduction

Soil nitrate (NO_3^-) is a form of inorganic nitrogen (N) that is available for use by plants. It forms from the mineralization (by microorganisms) of organic forms of N (i.e., soil organic matter, crop residue, and manure) in the soil. The rate of N mineralization is dependent on the amount of soil organic N, water content, temperature, pH, and aeration. Crop needs are met by soil-derived mineral-N and by fertilizer-N. Efficient management of soil N requires knowledge of crop needs for N and the amount of soil-derived N. Nitrate is mobile in soil, so it can be leached with percolating water below the root zone. All soils lose a small amount of nitrate to groundwater, including soils under natural vegetation. When amounts leach that are greater than what occurs naturally, we need to be concerned. Nitrate is not a contaminant until it leaches below the root zone or is transported off-site in surface runoff. When leached to groundwater, there is a human and animal health risk. In surface water systems, nitrate can contribute to euthrophication.

Interpretations

The amount of residual nitrate-N in the soil at any one time is a function of the rate at which microorganisms decompose soil organic matter (Figure 3). This rate is dependent on temperature, moisture, aeration, type of organic residues, pH, and other factors (Dahnke and Johnson, 1990). Also, once soil nitrate has formed, it is subject to leaching, fixation, denitrification, and plant uptake (Figure 3). Therefore, it is difficult to interpret the nitrate-N content in terms of how much and when N will be available to meet crop needs. However, residual nitrate-N tests can be useful in determining fertilizer-N needs of crops in certain regions during specific times of the year and at specific crop growth stages (Dahnke and Johnson, 1996). **For interpretations of residual nitrate-N tests for crop needs, consult local or regional calibrations.**

Any amount of nitrate in the soil that is not used by the crop may potentially be leached from the root zone and become an environmental liability. Nitrate is not adsorbed on to soil particles unless they have a positive charge. Therefore, nitrate can readily move with percolating water out of the root zone and into groundwater or into surface waters through subsurface flow (Figure 3). Acidic soils of the humid tropics contain a significant amount of positively charged soil particles which can hold nitrate and keep it from leaching.

Nitrogen Cycling

In general, soil nitrate levels will change significantly during the course of the year and from week to week. Soil nitrogen is continuously cycling, moving from one form to another (Figure 3). It is derived primarily from atmospheric nitrogen gas (N_2). Soil microorganisms fix N_2 to produce organic nitrogen, which becomes part of the soil organic matter. The decomposition of organic matter converts some organic nitrogen into mineral nitrogen (mineralization). Ammonium (NH_4^+) produced by mineralization (an intermediate step) can be converted to nitrate by specific microorganisms (nitrification). The nitrate formed is then available for uptake by plants or microorganisms and is converted to organic forms of nitrogen (immobilization). Under water logged or anaerobic conditions, nitrate may be substituted for oxygen and ultimately released to the atmo

sphere as elemental nitrogen or nitrous oxide gas (N_2 or N_2O) [denitrification]. Each N transformation depends on the activity and abundance of a specific population of microorganisms that require different sets of optimal environmental conditions.

Primary *sources* of nitrates:

- addition of fertilizers containing nitrate,
- microbial conversion of ammonium fertilizers to nitrate-N,
- microbial conversion of organic N (i.e., soil organic matter and manures) to nitrate-N.

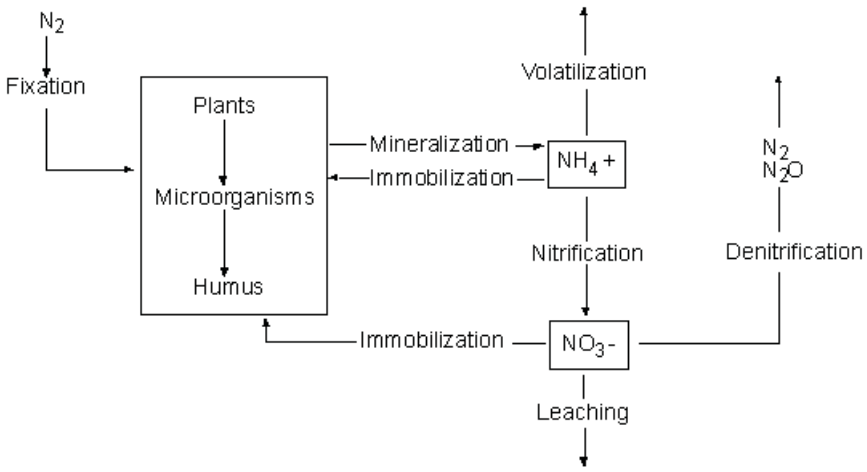


Figure 3. Generalized soil nitrogen cycle.

Primary *fates* of nitrates:

- utilization by microorganisms or plant roots (immobilization)
- leached below the root zone
- moved off-site in surface runoff
- microbial conversion of nitrate-N to nitrogen gas

Comments

The nitrate/nitrite test strips can determine both nitrate and nitrite concentrations (two test pads on each test strip). Nitrite levels in soils are usually not detectable (in a transition state); therefore, its measurement is not warranted. The nitrate test pad on the test strip measures the sum of both nitrate-N and nitrite-N present in the sample. If nitrite is detected in the sample, the amount can be subtracted from the nitrate reading to get the actual amount of nitrate-N in the sample.

Spring soil nitrate-N tests can be used to assess the effectiveness of soil and cropping management practices in providing sufficient N for optimal crop yields. For example, for corn in the Midwest, values of 20-25 ppm nitrate-N in top foot (30 cm) of soil are needed (14-16 ppm is the threshold for soils receiving manure or having alfalfa or soybeans as the previous crop) [Allan et al., 1996; page 196].

References

Allan, D.L. and R. Killorn. 1996. Assessing soil nitrogen, phosphorus, and potassium for crop nutrition and environmental risk. p.187-201. In: J.W. Doran and A.J. Jones (eds.) Methods for assessing soil quality. Soil Sci. Soc. Am. Spec. Publ. 49. SSSA, Madison, WI.

Dahnke, W.C. and G.V. Johnson. 1990. Testing soils for available nitrogen. p.127-139. In: R.L. Westerman (ed.) Soil testing and plant analysis. 3rd ed. SSSA Book Series 3. SSSA, Madison, WI.

7. Aggregate Stability

Introduction

Aggregate stability is a measure of the vulnerability of soil aggregates to external destructive forces (Hillel, 1982). An aggregate consists of several soil particles bound together. The destructive force in this test is flowing water. Aggregates that stand up to the forces of water are called water stable aggregates (WSA). In general, the greater the percentage of stable aggregates, the less erodible the soil will be. Soil aggregates are a product of the soil microbial community, the soil organic and mineral components, the nature of the above-ground plant community, and ecosystem history. They are important in the movement and storage of soil water and in soil aeration, erosion, root development, and microbial community activity (Tate, 1995). Breakdown of aggregates is the first step to crust development and surface sealing, which impedes water infiltration and increases erosion. Soil aggregation can change over a period of time, such as in a season or year. Aggregates can form, disintegrate, and reform periodically (Hillel, 1982).

Interpretations

The percentage of water stable aggregates indicates the amount resistant to disturbance by flowing water. **In general, greater amounts of stable aggregates are better for soil quality**.

Aggregates improve soil quality by:

- protecting soil organic matter entrapped in the aggregates from exposure to air and microbial decomposition,
- decreasing soil erodibility,
- improving water and air movement (Aggregates increase the amount of large pore spaces.),
- improving the physical environment for root growth,
- improving soil organism habitat.

Aggregate stability is affected by the amount and type of the following soil constituents (Kemper, 1966):

Soil Organic Matter content:

Aggregate stability generally increases with organic matter content (Table 1). The effect is more pronounced in soils containing small amounts of clay. Generally, increases in organic matter above 2% do not increase aggregate stability appreciably.

Soil Clay content:

Aggregate stability is affected by the amount and type of clay in the soil and generally increases with clay content (Table 1). This effect decreases at higher clay contents (Table 1). In general, high surface-area clays (i.e., montmorillonite) tend to cause greater aggregation than low surface-area clays (i.e., kaolinite).

Aluminum and Iron Oxide content:

Aggregate stability generally increases with free iron oxide content. In general, free aluminum oxides do not appreciably increase aggregate stability.

Calcium Carbonate content:

The calcium carbonate content generally does not appreciably affect aggregate stability.

Exchangeable Sodium content:

Aggregate stability decreases with increasing amounts of exchangeable sodium. In general, water stable aggregates are nonexistent in soils with greater than 20% exchangeable Na^+.

Table 8 contains suitable values for aggregate stability based on soil organic matter and clay content. A suitable range of values could be developed for a soil using the aggregate stability values for the organic matter content and clay content as end members to the range. For example, for a soil with 2% organic matter and 10% clay, the suitable aggregate stability range (taken from Table 8) would be 65 to 75% water stable aggregates.

Table 8. Suitable values for % water stable aggregates based on clay and organic matter content (Kemper, 1966). Water stable aggregates for % clay should be read independently of % organic matter in this table.

Organic Matter (%)	Water Stable Aggregates (%)		Clay (%)	Water Stable Aggregates (%)
0.4	53		5	60
0.8	66		10	65
1.2	70		20	70
2	75		30	74
4	77		40	78
8	81		60	82
12	85		80	86

Aggregate stability values are based on 519 soil samples from the arid, semiarid, and subhumid regions of the United States and Canada. The majority of the samples were from cultivated areas, but a large number were taken from virgin or replanted grasslands (Kemper, 1966).

Soil aggregates are divided into two general groups based on aggregate size (diameter):

- **Microaggregates** (less than 250 μm) consist of primary soil particles and smaller microaggregates bound together. Binding agents include:
  - humified organic matter (organic polymers)
  - polyvalent metals or cations
  - roots and fungal hyphae
  - polysaccharides
  - plant and microbial debris (encrusted)
  - iron and aluminum amorphous oxides
- **Macroaggregates** (> 250 μm) consist of microaggregates bound together. Major binding agents are:
  - fungal hyphae
  - fibrous roots
  - polysaccharides

iron and aluminum oxides (soils that contain more than 10% iron and aluminum oxides)

The size of the water stable aggregates measured in the soil quality kit are macroaggregates.

Macroaggregates form readily under the following conditins:

- under pasture or forage grasses (dense, fibrous root mass),
- where organic residues have been added,
- where large amounts of microaggregates (< 250 μm diameter) are present.

Differences between micro- and macroaggregates include the following:

- Macroaggregates are more sensitive to changes in management than microaggregates and thus, are considered a better indicator of changes in soil quality. Macroaggregate stability depends on management because of the transient nature of the binding agents.
- Macroaggregates form more rapidly than microaggregates.
- Carbon is more stable in microaggregates than in macroaggregates.
- Microaggregates are more water stable than macroaggregates.
- When the proportion of macro- to microaggregates increases, soil quality increases.

Considerations and Comments

The temperature of the water used to sieve the soils should be maintained within the range of 22 to 25°C (71.5 to 77°F). At higher water temperatures, aggregate stability tends to decrease.

To make observational estimations of aggregate stability or relative comparisons, weighing and drying of the aggregates are not necessary.

When dry aggregates are wetted up too quickly at atmospheric pressure, disintegration and slaking can result. Upon rapid wetting, capillary water entering the pores causes air entrapped inside the aggregate pores to increase in pressure causing them to rupture (Kemper and Rosenau, 1986).

References

Angers, D.A. and G.R. Mehuys. 1993. Aggregate stability to water. p. 651-658. In: M.R. Carter (ed.) Soil sampling and methods of analysis. Canadian Soc. Soil Sci., Lewis Publ., Boca Raton.

Arshad, M.A., B. Lowery, and B. Grossman. 1996. Physical tests for monitoring soil quality. p.123-142. In: J.W. Doran and A.J. Jones (eds.) Methods for assessing soil quality. Soil Sci. Soc. Am. Spec. Publ. 49. SSSA, Madison, WI.

Hillel, D. 1982. Introduction to soil physics. 2nd ed. Academic Press, San Diego, CA.

Kemper, W.D. 1966. Aggregate stability of soils from western United States and Canada. USDA Tech. Bull. no. 1355. U.S. Gov. Print. Office, Washington, D.C.

Kemper, W.D. and R.C. Rosenau. 1986. Aggregate stability and size distribution. p. 425-442. In: A. Klute (ed.) Methods of soil analysis: Part I, physical and mineralogical methods. American Society of Agronomy, Madison, WI.

Tate, R.L. 1995. Soil microbiology. John Wiley & Sons, New York.

Tisdall, J.M. and J.M. Oades. 1982. Organic matter and water-stable aggregates in soils. J. Soil Sci. 33:141-163.

8. Soil Slaking

Introduction

Slaking is the process of fragmentation that occurs when aggregates are suddenly immersed in water (Chan and Mullins, 1994). Slaking occurs because the aggregates are not strong enough to withstand the stresses of rapid water uptake. At fast rates of wetting, internal stresses arise from differential swelling and air entrapment in the soil aggregate (Kay, 1998). These stresses may be released through the creation of an increasingly extensive network of failure zones in the soil fragments or aggregates. The differences between tests of aggregate stability and slaking are the type of stress applied and the size of aggregates or soil fragments used. The slake test is a qualitative and simpler test to perform. The two tests may not necessarily yield the same results.

Interpretations

The slake test in the kit yields a stability rating of 0 to 6 (Herrick, 1998). Soil fragments or aggregates which fall into classes 0 to 3 are relatively unstable. Class 4 indicates some stability, but very little strength. Classes 5 and 6 represent relatively stable soil fragments or aggregates. Soil strength relates to the ability of the soil to resist loss of its structure.

Stability ratings of soil surface crust fragments are interpreted differently. Soil crust formation in agricultural systems reduces the capacity of the soil to function (i.e., soil crusts can reduce air and water movement into the soil and can inhibit seedling germination). In general, weakly formed or unstable crusts are better than very strong or stable crusts, which have a greater potential to lower soil quality. The subsurface fragments or aggregates directly beneath the crust are tested to provide an indication of the potential for future slaking and crusting of the soil (potential of crust formation).

Slaking is affected by:

- the soil water content,
- rate of wetting,
- texture,
- clay mineralogy, and
- organic matter content.

Slaking is more severe when the soil is initially dry than when it is moist. For loamy soils, the pressure of entrapped air has been shown to be more important. For clayey soils, differential swelling was shown as the more important process (Chan and Mullins, 1994). In general, organic matter can influence both the rate of wetting and the resistance to stress generated during wetting (Kay, 1998). The stability of aggregates is strongly dependant on the rate of wetting; therefore, aggregate stability declines as the rate of wetting increases.

References

Chan, K.Y. and C.E. Mullins. 1994. Slaking characteristics of some Australian and British soils. European J. of Soil Sci. 45:273-283.

Herrick, J.E. 1998. Manual for monitoring and assessing rangeland health. USDA-ARS.

Kay, B.D. 1998. Soil structure and organic carbon: A review. p.169-197. In: R. Lal, J.M. Kimble, R.F. Follett, and B.A. Stewart (ed.) Soil processes and the carbon cycle. CRC Press, Boca Raton.

9. Earthworms

Introduction

Earthworm populations may vary with site characteristics (food availability and soil conditions), season, and species. Populations are highly variable in space and time, which can range from less than 10 to greater than 10,000 individuals per square meter (Curry, 1998). However, not all areas or soils support earthworms. Either they were not introduced, or environmental conditions are not favorable. Earthworms generally increase soil microbial activity and soil chemical fertility and enhance soil physical properties.

Interpretations

About 10 earthworms per square foot of soil (100 worms/m^2) is generally considered a good population in agricultural systems. Populations generally do not exceed 20 per square foot of soil (200 worms/m^2) in cultivated systems (Edwards, 1983). In grassland systems, populations can generally range up to about 50 per square foot of soil (500 worms/m^2) [Edwards, 1983]. The hand digging method does not capture certain deep-burrowing or fast moving earthworm species. However, hand digging is one of the best methods available.

Earthworms improve soil quality by:

- increasing the availability of nutrients. (Available plant nutrients (N, P, & K) tend to be higher in fresh earthworm casts than in the bulk soil.) [Edwards et al., 1995];
- accelerating the decomposition of organic matter by incorporating litter into the soil and activating both mineralization and humification processes;
- improving soil physical properties, such as aggregation and soil porosity;
- suppressing certain pests or disease organisms; and
- enhancing beneficial microorganisms.

Earthworms and soil aggregation processes:

- Fresh earthworm casts are often highly dispersed, nearly saturated masses of soil, which are unstable and susceptible to erosion (Edwards et al., 1995). As earthworm casts age, they can become more stable. The organic matter content, wet-dry cycles, and fungal hyphae and other microbial products help to stabilize casts over time and improve the aggregation of soil.
- In general, the more sensitive the soil is to physical disturbance, the more effective casting is for stable aggregation but less effective for tensile strength (Schrader and Zhang, 1997).

Factors affecting earthworm populations include the following (Curry, 1998):

Tillage

- Tillage generally kills about 25% of the earthworm population. The indirect effects of tillage affects the remaining population. These indirect effects include increases in surface temperature, decreased soil moisture regimes, reduced litter input, and more rapid oxidation (decomposition) of crop residues.
- Earthworm populations are often greater under no-till than under conventional tillage. Large populations of both surface-dwelling and deep-burrowing earthworms are often

associated with improved soil physical conditions. Higher infiltration rates often occur in no-till than in conventional tillage systems due to (in part) the large number of macropores from earthworm activity.

Temperature

The optimum temperature range for earthworms is between 10 and 20°C. The upper lethal range is 25 to 35°C. Few species can tolerate temperatures below 0°C. Many species have behavioral and/or physiological adaptations that enable them to survive unfavorable conditions.

Soil Properties

- Medium textured soils are more favorable for earthworms than sandy or clayey soils.
- Depth of aeration in soils affects the deep-burrowing species.
- Soil pH affects earthworm populations. Earthworms are usually absent in soils with pH less than 3.5 and are scarce in soils with pH between 3.5 and 4.5. The majority of the earthworms live in soils with pH between 5.0 and 7.4.
- Quality and amount of food (organic matter) affect earthworm distribution and abundance.

Food Source

Litter, or organic, residue on the soil surface is the primary food source for earthworms in most ecosystems. However, dead roots and root exudates can also be important food sources. If the physical and chemical environments are not limiting, the quality and quantity of litter input frequently determines earthworm abundance.

Soil Disturbance

- Earthworm populations are generally higher in undisturbed soil systems.
- Population size depends on the severity and frequency of soil disturbance.
- If the soil disturbance is not repeated, earthworm populations can recover fairly rapidly (within a few years).

Soil Moisture

Soil moisture restrictions generally determine earthworm distributions and their activity.

Agrochemicals

- Pesticides, especially insecticides, can affect earthworm populations. The majority of triazine herbicides (i.e., atrazine, simazine, and cyanizine) are slightly toxic. Carbamate-based fungicides (i.e., carbendazim, benomyl, and thiophanate-methyl) are very toxic. Organophosphates (i.e., phorate, isozophos, chlorpyrifos, and ethoprophos) and most of the carbamate-based insecticides (i.e., carbaryl, carbofuran, methomy, and methiocarb) are toxic. Most of the nematicides (i.e., D-D, metham-sodium, and methyl bromide) have been reported to be toxic to earthworms (Edwards et al., 1995).
- Regular use of ammonium sulfate and anhydrous ammonia and sulfate coated urea has been shown to decrease earthworm populations (Edwards et al., 1995).

References

Curry, J.P. 1998. Factors affecting earthworm abundance in soils. p.37-64. In: C.A. Edwards (ed.) Earthworm ecology. CRC Press, Boca Raton.

Edwards, C.A. 1983. Earthworm ecology in cultivated systems. p.123-137. In: J.E. Satchell (ed.) Earthworm ecology: From Darwin to vermiculture. Chapman and Hill, London.

Edwards, C.A., P.J. Bohlen, D.R. Linden, and S. Subler. 1995. Earthworms in agroecosystems. p.185-206. In: P.F. Hendrix (ed.) Earthworm ecology and biogeography. Lewis, Boca Raton.

Schrader, S. and J. Zhang. 1997. Earthworm casting: stabilization or destabilization of soil structure. Soil Biol. Biochem. 29:469-475.

10. Soil Physical Observations and Estimations

Topsoil Depth

Topsoil depth is important for water storage and nutrient supply for plant growth. Generally, removal of the topsoil will result in loss of soil fertility, water-holding capacity, soil organic carbon content, and productivity. Measurements of topsoil depth over time provide a good estimate of soil loss (erosion).

Interpretations

Change in topsoil thickness is usually a result of wind erosion, water erosion, deposition of material, or land leveling. Eroded soils will commonly have a reduced Ap horizon (plow layer) or topsoil thickness. Natural erosion occurs in the absence of human disturbances. However, it is the accelerated erosion caused by plowing, burning, overgrazing, and other management practices that remove the protective vegetative cover and results in loss of soil quality.

Root Growth

Depth of soil to a layer that would restrict root growth strongly affects crop production. Factors that influence rooting depth include high salt content and depth to bedrock, stone layer, hard pan, frozen layer, and water table (Arshad et al., 1996).

When continuous pores are present in the soil, roots will grow through these pores as a result of the low mechanical impedance. The distribution of roots in the soil profile is a function of soil depth, thickness, and mechanical resistance of the root-impeding soil layers (Bennie, 1996).

Interpretations

Roots growing through restrictive soil layers undergo morphological changes, particularly root stunting and thickening (Bennie, 1996). Impeded roots are generally shorter, thicker, and more irregularly shaped. The shorter root system will exploit a smaller soil volume for plant nutrients and water, causing the plant to maintain a higher than normal uptake rate of nutrients and water per unit of root length. Also, more photosynthetic energy is needed to sustain root length increases that do occur. All of these factors can result in plant stress, which may eventually result in reduced crop growth and productivity.

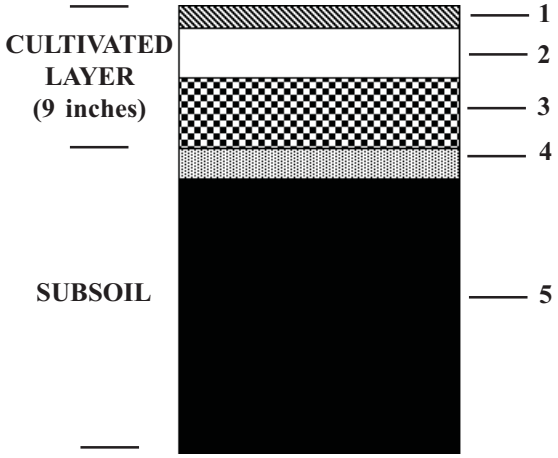
Penetration Resistance

Penetration resistance is a measure of the ease with which an object can be pushed into the soil (Bradford, 1986). It gives an indication of root-impeding layers in the soil and can be used in comparing relative strengths among similar soil types. It can also be used for determining hardpans, zones of compaction, or dense soil layers.

Interpretations

Soil compaction that results in severely restricted root growth is caused mainly by trampling of animals, use of farm and tillage equipment, and vehicular traffic. The type of root system will

determine the ability of a root to penetrate the soil. Figure 4 shows typical locations of compaction zones in cultivated soils.



Zone 1: Surface crusting, which may impede seedling emergence and water infiltration.
Zone 2: Low impedance zone for roots; loosened by tillage.
Zone 3: Plowed or deeply loosened cultivated soil that has been recompacted by vehicular traffic.
Zone 4: Subsoil compaction by wheel traffic and tillage implement-soil interactions during tillage.
Zone 5: May contain high mechanical impedance due to inherent factors, such as duripans, fragipans, ortstein layers, petrocalcic layers, etc., which may occur near the surface if topsoil is not present.

Figure 4. General position of soil compaction zones in cultivated systems (Bennie, 1996)

Penetration resistance depends strongly on the soil water content: the dryer the soil, the greater the resistance to penetration. Therefore, the water content of the soil should be noted when taking a measurement. Penetration resistance is best determined when the soil is at field capacity, which is a uniform condition that can be reproduced from season to season.

Soil Structure

Soil structure is the arrangement and organization of particles in the soil. It is strongly affected by changes in climate, biological activity, and soil management practices. Soil structure affects the retention and transmission of water and air in the soil as well as the mechanical properties of the soil. Observing and describing soil structure in the field is subjective and qualitative.

Interpretations

For plant growth it is desirable to have a physical condition in which the soil is an optimally loose, friable, and porous assemblage of aggregates permitting free movement of water and air, easy cultivation and planting, and unobstructed germination and root growth (Hillel, 1982). The soil structure index is a general quality placement that indicates the closeness to the condition described above. In general, the higher the index value the better the soil's capacity to transmit water and air and to promote root growth and development.

Soil processes involved in the development of soil structure are as follows (Rowell, 1994):

- drying and wetting, which cause shrinking and swelling, creating cracks and channels;
- freezing and thawing, which creates spaces as ice is formed;
- the action of roots (removal of water, release of exudates (organic materials), and formation of root channels);
- the action of soil animals (moving soil material around, creating burrows, and bringing soil

mineral and organic materials into close association); and

- the action of microorganisms (breaking down plant and animal residues and creating soil organic matter and humus as a binding material).

Soil Texture

Soil texture refers to the distribution of sand, silt, and clay sized mineral particles in the soil. Texture is one of the most stable attributes of the soil, being modified only slightly by cultivation and other practices that cause mixing of the different soil layers.

Interpretations

This test is routinely used by soil scientists and provides reliable estimates of soil texture. The textural class places the soil in one area of the triangular diagram based on the distribution of sand, silt and clay in the soil (Figure 5). Texture is an important characteristic, because it influences fertility and helps determine water intake rates, water storage in the soil, ease of tillage, and amounts of aeration. For example, clay soils will retain more water and nutrients than a sandy soil.

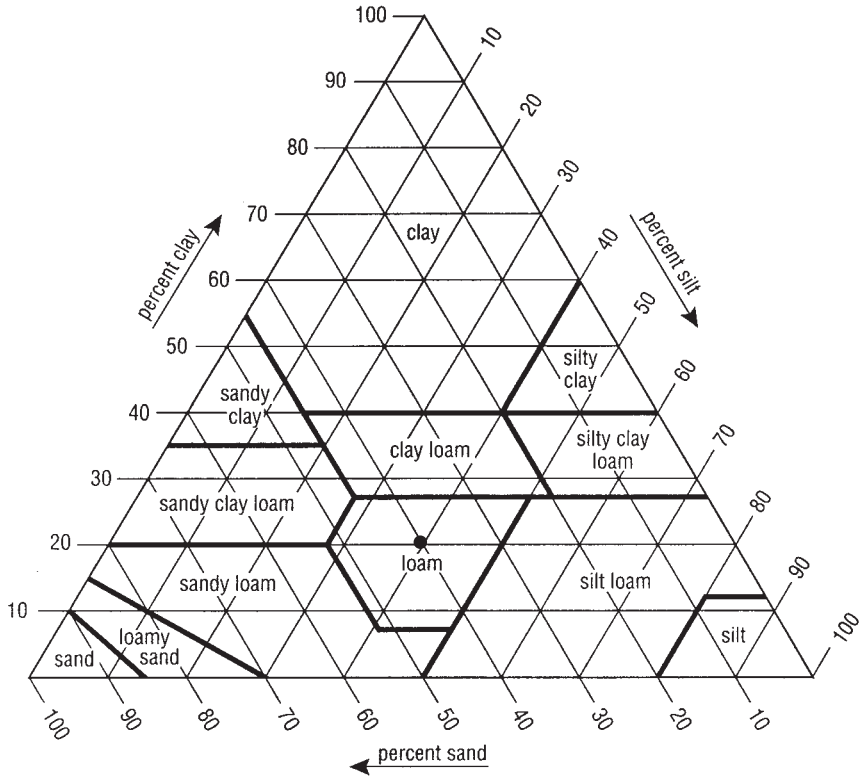


Figure 5. Soil textural triangle showing the percentages of clay, silt, and sand in the textural classes.

Mineral Particles Soil is composed of mineral particles that vary in size. There are three general classifications (or soil separates) of mineral particles:

- *sand* particles - 2.0 mm (very coarse) to .05 mm (very fine);
- *silt* particles - .05 mm to .002 mm;
- *clay* particles - smaller than .002 mm.

Twelve Soil Textural Classes. Definitions of the 12 textural classes are based on the relative proportion, or weight, of these three particle classifications. Sandy soil, for example, has a greater proportion of sand particles than silt or clay. In reading the textural triangle (Figure 5), any two particle size percentages will locate the textural class. For example, a soil containing 20% clay and 40% sand is located in the *loam* textural class (Figure 5).

References

Arshad, M.A., B. Lowery, and B. Grossman. 1996. Physical tests for monitoring soil quality. p.123-142. In: J.W. Doran and A.J. Jones (eds.) Methods for assessing soil quality. Soil Sci. Soc. Am. Spec. Publ. 49. SSSA, Madison, WI.

Bennie, A.T.P. 1996. Growth and mechanical impedance. p.453-470. In: Y. Waisel, A. Eshel, and U. Kafkafi (eds.) Plant roots: The hidden half. 2nd ed. Mercel Dekker, Inc., New York.

Bradford, J.M. 1986. Penetrability. p.463-478. In: A. Klute (ed.) Methods of soil analysis. Part 1 Physical and mineralogical methods. Agronomy No. 9. Am. Soc. Agron., Madison, WI.

Hillel, D. 1982. Introduction to soil physics. 2nd ed. Academic Press, London.

Rowell, D.L. 1994. Soil science: Methods & applications. Longman Scientific & Technical, Singapore.

11. Water Quality

The quality of water is relative to the purpose for which the water is used; therefore, specific use conditions will determine the suitability of a water body (James et al., 1982).

Water Electrical Conductivity

Introduction

Water salinity levels, as measured by electrical conductivity, can be used to assess irrigation water quality. Other water quality concerns about saline waters include possible physiological effects on humans and animals and mineral taste. Also, high concentrations of certain mineral salts can cause corrosion damage in water systems. The measurement of electrical conductivity is an indicator of the total dissolved solids (TDS) in water. The relationship of EC to TDS will vary depending upon the distribution of major constituent elements present in the water.

Interpretations

Tables 9 and 10 contain safe salinity limits for human and livestock drinking water. Table 11 contains general guidelines for salinity in irrigation waters. For aquatic plant growth, salinity levels should be kept as close to natural conditions as possible (US EPA, 1973).

Table 9. Safe limits for drinking water (US EPA) and average salinity levels for river waters of the world (James et al., 1982)

Water	EC[2] (dS/m 25°C)	Total Dissolved Solids (mg/L)
Drinking water		
SMCL[1]	0.78	500
Livestock and poultry		
US EPA recommendation	4.7	3000
Average salinity levels in river waters		
North America	0.23	146
Europe	0.28	182
Australia	0.09	59
World	0.19	120

[1] SMCL = secondary maximum contaminant levels are unenforceable Federal guidelines regarding taste, odor, color, and other non-aesthetic effects in drinking water.
[2] EC estimated from total dissolved solids (TDS); EC = TDS/640

Table 10. Use of saline waters for livestock and poultry (US EPA, 1973)		
Comment	EC[1] (dS/m 25°C)	Total Dissolved Solids (mg/L)
Relatively low level of salinity. Excellent for all classes of livestock and poultry.	< 1.6	< 1,000
Very satisfactory for all classes of livestock and poultry. May cause temporary and mild diarrhea in livestock not accustomed to them or watery droppings in poultry.	1.6 - 4.7	1,000 - 3,000
Satisfactory for livestock, but may cause temporary diarrhea or be refused first by animals not accustomed to them. Poor waters for poultry, often causing watery feces, increased mortality, and decreased growth, especially in turkeys.	4.7 - 7.8	3,000 - 5,000
Can be used with reasonable safety for dairy and beef cattle, for sheep, swine, and horses. Avoid use for pregnant or lactating animals. Unfit for poultry and probably for swine.	7.8 - 10.9	5,000 - 7,000
Considerable risk in using for pregnant or lactating cows, horses, or sheep, or the young of these animals. In general, use should be avoided although older ruminants, horses, poultry, and swine may subsist on them under certain conditions.	10.9 - 15.6	7,000 - 10,000
Risks are too great and are not recommended for use under any conditions.	> 15.6	> 10,000

[1] EC estimated from total dissolved solids (TDS); EC = TDS/640

Table 11. General purpose guidelines for salinity in irrigation water for arid and semi-arid regions (US EPA, 1973).		
Classification	EC dS/m	TDS mg/L
Water for which no effects are usually noticed	0.75	500
Water that can have detrimental effects on sensitive crops	0.75-1.50	500-1,000
Water that can have adverse effects on many crops: requires careful management	1.50-3.00	1,000-2,000
Water that can be used for tolerant plants on permeable soils with careful management	3.0-7.50	2,000-5,000

Water Nitrate and Nitrite Levels

Introduction

Nitrate in water is of concern in regards to human and animal health and to environmental quality of ground and surface waters. Nitrate in drinking water can cause methemoglobinemia ("blue baby syndrome") in infants under six months of age and can have toxic effects in livestock and poultry. The toxicity occurs with the conversion of nitrate to nitrite after it has been consumed. Nitrite has a more rapid and pronounced toxicity effect than nitrate in drinking water. Fortunately, nitrite concentrations in water sources are usually very low. Nitrate in surface waters can cause accelerated growth of algae and aquatic plants, causing depletion of dissolved oxygen and general degradation of the water body (eutrophication). Eutrophication jeopardizes the use of water for recreation, sport and commercial fishing, agriculture, industry, and municipal supply. Also, nitrates can adversely impact aquatic ecosystems. Nitrate entering surface and groundwater is from non-point sources; both urban and agricultural runoff and leachate are recognized as contributors.

Interpretations

The levels of N required to induce eutrophication will vary depending on the nitrogen to phosphorous ratio. Excesses of either or both N and P can lead to eutrophication. Excessive growth of algae has been shown to occur when total phosphorus (mostly phosphate) levels exceed 0.10 ppm. Table 12 shows commonly used values for total nitrogen (mostly nitrate or ammonia). Eutrophication is defined as an increase in the nutrient status of natural waters that causes accelerated growth of algae or water plants, depletion of dissolved oxygen, increased turbidity, and general degradation of water quality (Pierzynski et al., 1994).

Table 12. Human, animal, and environmental limits of nitrate and nitrite in water (Pierzynski et al., 1994; US EPA, 1973).

Description	Limit or threshold
US EPA maximum contaminant level for nitrate-N in public drinking water	10 mg NO_3-N L^{-1}
US EPA maximum contaminant level for nitrite-N in public drinking water	1 mg NO_2-N L^{-1}
Recommended safe level for livestock and poultry drinking water	40 mg NO_3-N + NO_2-N L^{-1}
Recommended safe level for Nitrite-N alone in livestock and poultry drinking water	10 mg NO_2-N L^{-1}
Threshold for eutrophication in fresh water environments	0.5-1.0 mg N L^{-1}
Threshold for eutrophication in marine environments	> 0.6 mg N L^{-1}

Comments

The nitrate/nitrite test strips can determine both nitrate and nitrite concentrations (two test pads on each test strip). The nitrate test pad on the test strip measures the sum of both nitrate-N and nitrite-N present in the sample. If nitrite is detected in the sample, the amount can be subtracted from the nitrate reading to get the actual amount of nitrate-N in the sample. However, nitrite is rarely found in drinking waters at levels above 0.1 mg L^{-1} (Manahan, 1993).

1 ppm (parts per million) = 1 mg L^{-1} (milligram per liter)

References

James, D.W., R.J. Hanks, and J.J. Jurinak. 1982. Modern irrigated soils. John Wiley & Sons, New York.

Manahan, S.E. 1993. Fundamentals of environmental chemistry. Lewis Publ., Ann Arbor, MI.

Pierzynski, G.M., J.T. Sims, and G.F. Vance. 1994. Soils and environmental quality. Lewis Publ., Boca Raton, FL.

US EPA. 1973. Water quality criteria 1972. PB-236 199/6BE. National Academy of Sciences - National Academy of Engineers. US Environmental Protection Agency, Washington, DC.