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Soil Quality Institute

Soil Quality Test Kit Guide

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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 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/sqihome.shtml**.

Soil Quality Institute Staff

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

Figure 2.2

- 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).

[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

Figure 2.3

- 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.
- 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%.

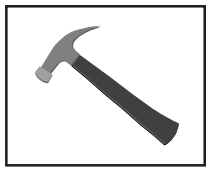
Figure 2.6

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)

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)**.

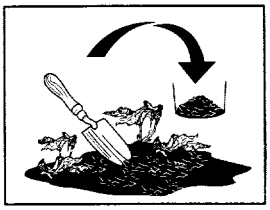
Solvita Soil Life kits can be obtained from Woods End Research, Mt. Vernon, ME; solvita@woodsend.org.

Figure 1b

Figure 2b

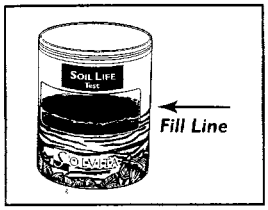
[1]Trade names are used solely to provide specific information. Mention of a trade name does not constitute a guarantee of the product by the U.S. Department of Agriculture nor does it imply endorsement by the Department or the Natural Resources Conservation Service over comparable products that are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

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

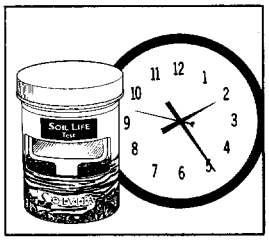


RUNNING THE SOLVITA™ TEST

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.

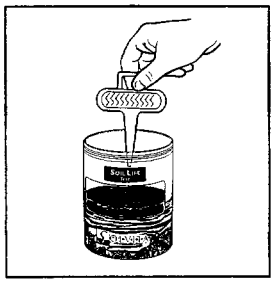


2. **IDEAL SOIL MOISTURE:** The soil should be at the ideal growing condition moisture before it is sampled. If the sample is very dry or very wet, it is best to wait until favorable conditions return. This may mean watering a dry soil and waiting 1-2 days again before sampling. If too wet, make a small 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.

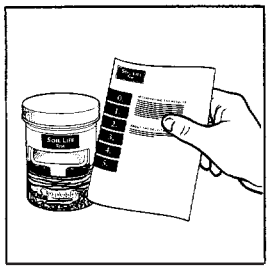


3. **PUT SAMPLE INTO JAR:** Put the loose mix of soil into the jar just to the fill line. As you fill, tap the bottom of the jar sharply on a counter; this helps assure the correct density. Fill only to the indicated line. Record the time on the lid.

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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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:

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

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.