WQ-43

On-Farm Soil Monitoring for Water Resource Protection

Use this publication to actively monitor changes in soil quality for improved decision making and field management practices.

Farm Assessment for Water Resource Protection

What's Inside **Page**

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Soil and Water Quality

Soil is a living and dynamic resource upon which plant and animal life depends. Improving and protecting the soil reduces erosion, improves water infiltration, increases the efficiency of nutrient and mineral cycles, sequesters carbon from the air which helps build soil organic matter and tilth, and sustains the soil resource for future generations and other species. Improving and protecting soil quality can help support sustainable crop, pasture, and woodland production, and to maintain water supplies. Improving and protecting farm land soils is essential to water quality, as well as other natural resources such as air quality and wildlife habitat. What happens on the land, and in the soil, ultimately impacts water resources.

Soil Monitoring Tracks Changes in Soil Quality

Monitoring is a way of tracking change by measuring an indicator. One type of monitoring you are familiar with is measuring and keeping track of the yield of your crops from year to year. Yield monitors enable farmers to keep track of yield differences within a field, and many farmers make decisions based on yield differences they see in different parts of their field. Monitoring can lead to better decisions.

Monitoring soil resources makes sense for financial, production, and conservation reasons. Taking the time to measure and record changes in the soil provides you with valuable information about your farm's soil quality and health. Monitoring is especially useful to let you know how changes in your field and cropping practices affect the soil.

This publication will present quick-to-learn and easy-to-do methods for monitoring soil quality and health. It can be used to improve planning and decision making, as well as to strengthen field assessments (Field Assessment for Water Quality Protection, WQ-42, also available through Purdue Extension). These methods are based on the USDA Soil Quality Test Kit and work by agronomist Preston Sullivan. The methods were developed and tested during a two-year period on a variety of Indiana farms.

These simple, effective monitoring methods are not intended to replace analytical soil tests. What they will do is give you quick insight into the soil's condition or quality, without using specialized equipment. The equipment you need is probably already on-hand or is inexpensive to obtain.

Remember that no matter how good your memory, important details of changes on your land are easily lost unless you record them. The record sheet on page 11 offers a method to record your monitoring observations.

What and When to Monitor

There are two fundamental approaches to assess soil quality:

- Take measurements annually over time to discover changes or trends in soil quality
- Compare the results to a standard or baseline soil condition such as an undisturbed fence row or more ideally a neighboring natural ecosystem with similar soil type

This publication provides instructions for monitoring five soil quality indicators: water infiltration, aggregate stability, earthworms, soil compaction, and plant and crop residue cover. These indicators are interrelated and can provide insight into how soil and water resources are related. Improvements in one indicator are likely to show positive changes in the others. It is best to monitor as many of the indicators as possible. Many other indicators of soil quality are also suggested. A much longer list is in the USDA Soil Quality publications <http://soils.usda.gov/sqi/soil_quality/assessment/>. The five methods in On-Farm Soil Monitoring for Water Resource Protection were chosen because they are the soil quality indicators and methods that farmers felt were easily learned yet effectively measured soil quality.

Choose as many indicators as you are able to monitor, and then monitor them on at least an annual basis at the same time each year. Late spring and early autumn are often the best times to monitor these soil quality indicators in Indiana. One exception: plant and crop residue cover should be monitored within three weeks after planting as this is often the most critical time that soil is exposed. In addition, it is always a good idea to conduct standard laboratory soil tests for nutrients, organic matter, and other parameters relevant to your soil and nutrient management at least every three years.

Monitoring is useful when performed consistently and carefully recorded. In the case of soil monitoring, it can take several years to see significant changes. Having monitoring records for several consecutive years can be especially useful when correlated with management changes on the land. It is a good idea to have a "control" area such as a natural habitat, or side-by-side row, or field crop comparisons, to compare your results with over time. Monitoring results are most useful when looking at trends over time for each sampling site.

The methods in this publication can be used to:

- Monitor trends and changes in soil quality in the same field over time, especially when linked with changes in your management for these fields
- Make side-by-side comparisons (within the same soil types) of different soil management systems to determine their effects on soil quality
- Compare field results to an undisturbed fence row soil or neighboring natural ecosystem
- Compare problem and non-problem areas within a field

Using the Record Sheet
(The record sheet is on page 11)

The record sheet is arranged to easily record the results from the soil quality indicators. Soil quality monitoring is not of much value unless it is used to assess field management and the assessment leads to practices that improve soil quality. Take the time to first record the general information about the field and sampling areas. This reference information will be important when using your results to compare from year to year. Although comparisons between fields, neighboring farms, and different farming methods can be attempted, keep in mind that the factors of soil type, topography, and weather can play a significant role in the results. This is the reason the most accurate use of your monitoring results will be within field or within soil types.

Each indicator is interrelated with the other indicators. Significant changes in one indicator will normally be reflected in the other indicators. You should attempt to monitor as many of the indicators as possible. It often takes less than twenty minutes to conduct all of the indicator tests for a sample site.

The record sheet allows for up to three different field areas to be recorded, with two sample locations for each area. Use a farm map and other physical markers to locate sampling areas from year to year.

How to obtain additional copies of the record sheet:

You are welcome to photocopy the sheet as many times as you like. You can also obtain additional copies of the record sheet by asking your County Purdue Extension Educator (you can locate your County Extension office by calling toll free 1-888-EXT-INFO). The record sheet is also available online at <http://www.ces.purdue.edu/waterquality> and select the "Field Assessment" link. You will find a link to the Soil Monitoring Record Sheet which you may print.

Video Training for On-Farm Soil Monitoring

To view a training video on the assembling of an on-farm soil monitoring kit and how to test soil monitoring indicators, contact the Ag Communication Media Distribution Center at (765) 494-6794 or go to the Web site at <http://www.ces.purdue.edu/waterquality> and select the "Field Assessment" link. Here you will find a link to On-Farm Soil Monitoring for Water Resource Protection.

On-Farm Soil Monitoring Methods

Preparing to Monitor

Make copies of the record sheet for as many fields as you plan to measure. You can photocopy the inside back cover of this publication, or download the file at <http://www.ces.purdue.edu/waterquality>.

A good time for soil monitoring is within three weeks following spring planting and/or early autumn before soil temperature falls below 50°F and when the soil is not too wet or too dry.

1. Record field ID, crop, dates, and sample location information on the record sheet. Use a farm field map to note sample locations.
2. Record the number of days since the last rainfall and the amount, the general weather pattern for the season/year, and the soil temperature, along with other pertinent field history information.
3. Gather the materials you need, (see Table 1) and bring them to a good spot in the field. This could be a problem spot you are concerned about or an area you feel is representative of the entire field.

Table 1. Materials Required
• Point shovel
• Tape measure at least 25' long
• Wire flag or rod at least 18" long
• Clear pint jar or bottle
• Gallon jug filled with water
• Watch
• Soil temperature gauge
• Pencil and clipboard
• Six inch diameter ring that is five inches tall. (Irrigation pipe or PVC with beveled edges or a coffee can with both ends removed)
• Plastic wrap
• Scrap wood block 8" long
• Hammer or rubber mallet
• Bucket to carry the materials

Indicator #1, Water Infiltration Rate

Start with this test, since it can take the most time to complete.

If the soil is saturated, infiltration may not occur. Wait for two days following substantial rainfall events to allow for drying. Make sure that all vegetation is clipped to the soil within the ring area before inserting the ring. However, do not disturb the soil surface.

1. Clear the sampling area of surface residue, etc. Trim any vegetation as close to the soil surface as possible.
2. Using a hand sledge and block of wood, drive the ring to a depth of 3 inches. The ring should be nearly level for a good test.
3. Now use your finger to gently firm the soil surface ONLY around the inside edges of the ring to prevent seepage of water here. Do not disturb the soil in the rest of the ring area.
4. Line the soil surface inside the ring with a sheet of plastic wrap. This helps prevent disturbance to the soil surface when pouring the water into the ring.
5. Fill a bottle with one pint (2 cups or 463 mL) of water. This will provide exactly 1" of water within a 6" diameter ring. Pour the water into the ring, over the plastic wrap. Another way to do this would be to carefully measure and mark 1 inch within the ring and then pour the water into the ring to this depth.

Use a mallet to drive infiltration ring into the soil.

Pour 1 pint of water into the ring.

6. Remove the plastic wrap by pulling it gently out, leaving the water in the ring.
7. Record the amount of time (in minutes) it takes for the 1” of water to infiltrate. Stop timing when the surface is just glistening.
8. If the soil surface inside the ring is uneven, count the time until half the surface is exposed.
9. Enter the amount of time in minutes on the record sheet.

If the soil did not become saturated after adding the first inch of water you should add a second inch of water and record the time for infiltration for the most accurate measurement. A repeat test should only be necessary if the top three inches of soil is dry.

Remove plastic wrap after adding water.

Use a watch to monitor the length of time for infiltration.

What does the water infiltration test indicate?

A short infiltration time indicates rapid water movement downward through the soil. A shorter infiltration time means that less rainwater is likely to run off the field and into waterways and lakes. Soil that has a short infiltration time and retains moisture is also more drought-resistant. With the exception of some sandy soils, soils with short infiltration times tend to have good pore space and aggregate stability. If water does not infiltrate or takes an excessive amount of time, then it is likely that the soil is compacted and/or has a lack of diversity and numbers of living soil organisms present. Building soil organic matter will shorten the infiltration time.

Notes: Infiltration rate is influenced by soil moisture and especially by soil type. Coarse, sandy soils allow rapid infiltration; soils with limiting clay layers may allow slow or no infiltration of water. Table 2 shows different infiltration rate classes. Attempt to conduct infiltration when the field is neither totally saturated nor totally dry. Resist comparisons between different soil types. The most accurate comparisons will be annual trends at each sample site.

Table 2: Infiltration rates and classes (based on USDA Soil Quality Test Kit Guide information.) These values represent steady infiltration rates (after long, continuous wetting). These values could be considerably lower during the initial stages of wetting.

Infiltration rate (minutes/inch of water)	Infiltration Class
< 3	Very Rapid
3 to 10	Rapid
10 to 30	Moderately Rapid
30 to 100	Moderate
100 to 300	Moderately Slow
300 to 1,000	Slow
1,000 to 40,000	Very Slow
> 40,000	Impermeable

Indicator #2, Earthworm Count

The optimum soil temperature range for earthworms is between 50°F and 70°F, and when the soil is moist, but not fully saturated.

1. Dig a 1 foot diameter hole to a depth of 1 foot. Try to minimize the number of cuts with the shovel to avoid damage to the earthworms. Carefully place the soil in a bucket or next to the hole.
2. Carefully sift and search through the soil removed from the hole for earthworms, signs of activity, and other soil organisms.
3. Count and record the number of earthworms you find on the record sheet.
4. If interested, you can also note the evidence of other soil organisms in the "Additional Notes" area at the bottom of the record sheet.

What do earthworms indicate?

The more earthworms the better, as they indicate a healthy soil in general. Earthworm activity within the soil improves water infiltration and helps to aerate the soil. Earthworms cycle nutrients by digesting organic matter and soil. Some soil scientists have said that a rule of thumb is if 10 earthworms are found in the soil of the dug hole (1 foot wide by 1 foot deep) then the soil could be considered to be healthy. In our on-farm tests, we found a range from 0 earthworms to as many as 25. Factors of tillage, pesticides and fumigants, and salt-based fertilizers tend to reduce, and sometimes eliminate, earthworms and other beneficial soil organism populations. Adopting practices that promote soil organisms will improve the diversity and numbers of beneficial soil organisms. Not using a moldboard plow, reducing residue particle size by using a straw chopper on the combine, adding animal manure, and growing green manure crops are all good ways of improving conditions for soil organisms.

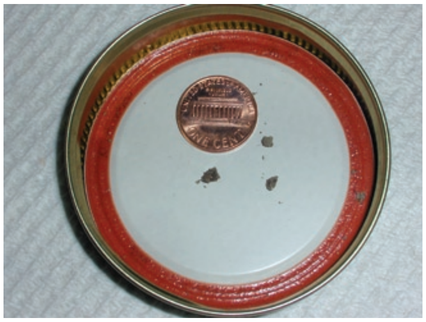
Dig a hole one foot deep and one foot in diameter.

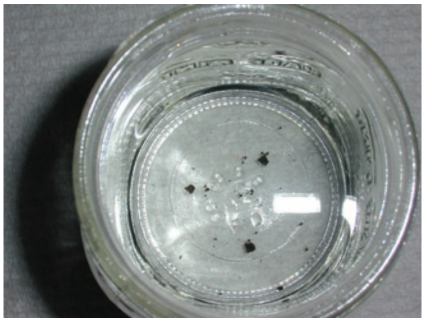
Earthworm counting

Indicator #3, Soil Aggregate Stability

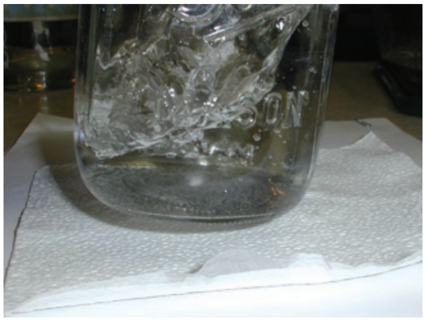
This test uses macro-aggregates. A soil aggregate is a crumb sized group of soil particles that are stuck together. Macro-aggregates are made up of much smaller (less than 0.25mm) micro-aggregates. Each aggregate is separate from other aggregates.

1. Choose three soil macro-aggregates from the top 3" of soil that are each about the size of this "O" (2mm) or slightly larger. Using several aggregates gives a more accurate assessment of the soil stability compared with only one aggregate.
2. Place the aggregates in the clear bottle of water and leave undisturbed for one minute. Check whether the aggregates remain intact.
3. If the aggregates remain intact, gently swirl the bottle several times and observe.
4. If the aggregates are still intact, swirl the bottle vigorously several times and observe the aggregates again.
5. Score aggregate stability as:
   - 1 = aggregates broke apart or dissolved within one minute standing in water
   - 2 = aggregates remained intact in standing water but broke apart after gentle swirling
   - 3 = aggregates remained in tact after gentle swirling
   - 4 = aggregates remained intact after vigorous swirling (make sure the aggregate is not a pebble).
6. Record the score on the record sheet.


1. Select three macro-aggregates from the top three inches of soil.


2. Carefully drop the macro-aggregates into a pint jar of water and observe for one minute.

3. Gently swirl and observe if macro-aggregates remain intact.


4. Vigorously swirl, then observe if macro-aggregates remain intact.


5. Macro-aggregates remain intact following vigorous swirling.


In another test with different soil, these macro-aggregates dissolved.

What does aggregate stability indicate?

The higher the score, the more stable the aggregate. Aggregate stability is the ability of an aggregate to resist disruption from water. Stable aggregates do not break down in the presence of rainfall or water movement. Good aggregate structure provides necessary pore space for water and air exchange within the soil. Unstable aggregates break down when struck by raindrops or water flow. This breakdown releases soil particles that then seal the soil surface, creating surface crusting and clogging of soil pores. Soil with poor aggregate stability can result in soil compaction and increased runoff, soil erosion, and sedimentation of waterways. A well-aggregated soil is loose and crumbles easily through your fingers. A poorly aggregated soil is cloddy and crusted.

Indicator #4, Penetration (Compaction)

1. Use a wire flag, ¼" metal rod, or tile probe marked at 12" to penetrate the soil. Attempt to penetrate up to 12" deep near the dug hole. Do not force the rod – use only slight pressure. Repeat this penetration test in several spots near each sample site.
2. Note the amount of resistance to penetration as:
   0 = No penetration was possible
   1 = Substantial resistance
   2 = Moderate resistance
   3 = Slight resistance
   4 = No resistance, easily penetrated to 12"
3. Record the result on the record sheet along with the depth of penetration in inches (make sure a rock did not impede penetration).
4. Identify and note the depth of compacted layers in the depth column on the record sheet. These compacted layers restrict root growth and water movement.

What does the penetration test indicate?

The higher the score, the more easily the rod or wire flag penetrates the soil. A higher score shows adequate pore space and an absence of compacted layers. If substantial resistance occurred, the soil is probably compacted. Compacted soils or a compacted soil layer will generally result in less water infiltration, poorer root development, and increased rainwater runoff. Compaction can occur from heavy machinery, tillage, as well as from a lack of living soil organisms that help maintain aggregate structure. A diversity of high numbers of soil organisms aerate the soil and create adequate pore space. Their activity prevents compacted layers from forming. Deep-rooting plants such as alfalfa and other cover crops assist in compaction break up over time, as does the freeze-thaw cycle under no-till fields.

Notes: Measuring penetration immediately following tillage can give an inaccurate assessment. In on-farm testing we found compacted layers almost always at 8" deep in soils that had received annual conventional tillage. Soil in fields of two farms that had been under a no-till, no chemicals regime, with cover crops for five years tended to be free from compacted layers. Differences in soil moisture can cause the compaction reading to vary considerably. More soil moisture tends to show less compaction or penetration problems.

Use a wire marking flag or a ¼" metal rod to check for compacted layers.

Note the amount of resistance to penetration.

Record the result on the record sheet along with the depth of penetration in inches.

Indicator #5, Plant and Crop Residue Cover

1. Starting near the dug hole, stretch the tape measure (25, 50, or 100 foot) across the ground, or diagonally across crop rows.
2. Looking down at the tape from directly above it and at each foot mark, count each occurrence of residue or living plant material. Always read from the same side of the tape and count only what is directly next to the foot mark. Count only residue that is at least 3mm in size (larger than this O).
3. Calculate the percentage of soil cover by multiplying the number of residue/living plant material counts as follows: x 4 for a 25 foot tape, x 2 for a 50 foot tape, and x 1 for a 100 foot tape.
4. When using a 25 or 50 foot tape, repeat this procedure three times in different areas of the field, and average the results.
5. Record the percentage of plant and residue cover on the record sheet.

What does plant and residue cover indicate?

The higher the percentage of plant and residue cover the better the soil is protected from adverse factors such as wind, rain, and direct sunlight. A high percentage of ground cover for the longest period of the year usually correlates with lower soil erosion and runoff rates, as well as increased water infiltration. Fields with bare spots or bare soil are at risk of erosion and runoff problems, especially on areas with greater slopes. Even though "conservation tillage" is defined as leaving at least 30% residue cover after planting, achieving that minimum level still leaves 70% of the soil bare. The use of cover crops, double cropping and intercropping, as well as no-till cropping systems will increase the ground cover percentage and extend the period of time that plant and residue cover is present.

Living Plant

Bare Soil

Plant Residue

Additional Soil Quality Testing:

The five soil quality indicators discussed in this publication; water infiltration, earthworms, aggregate stability, penetration test, and plant cover were chosen for their ease of use and relevance to farm soil management. There are many other possible soil indicators you can monitor. Here are several to consider:

Organic matter and humus

In addition to standard soil nutrient testing, consider soil lab tests for percent organic matter and humus content. Appropriate Technology Transfer for Rural Areas (ATTRA) maintains a listing of labs that test for organic matter and humus <http://attra.ncat.org/attra-pub/soil-lab.html>. Soil organic matter is the thread that ties together the biological, chemical, and physical properties of a soil. Most Indiana soils contain between 1 and 6 percent organic matter, though some bog soils can contain as much as 90 percent organic matter. Soil fertility, water infiltration and absorption, soil compaction, soil organisms, susceptibility to erosion, and resistance to insects and disease are all affected by soil organic matter.

Humus and organic matter are often used interchangeably, but they are not the same. Humus is the much more stable fraction of organic matter, and it is highly resistant to further decomposition. Humus enhances the formation of soil aggregates and stores mineral nutrients for use by plants. High levels of humus are required to maintain adequate levels of nitrogen, sulphur, boron and many other minerals, because these minerals cannot bind with clay particles. These mineral nutrients leach out of the soil profile when it rains if they are not attached to humus. The percentage of organic matter and humus content also relates to the ability of the soil to sequester carbon from the atmosphere.

Crop cultivation, harvesting and removal of plant material, erosion, and natural decomposition can all reduce the amount of organic matter in soils. A well known example of the loss of organic matter due to agricultural activities is found in the prairie soils of the Midwest that have lost large amounts of their organic matter content since tillage commenced. However, there are many things you can do to maintain and increase organic matter level through sustainable soils management. See the resources on page 10 for more information.

Soil food web testing

New laboratory procedures now enable landowners to obtain accurate counts of the bacteria, fungi, protozoa, nematodes, and mycorrhizal fungi in their soil. These procedures allow the monitoring of changes in soil microorganism biology to take place. Soil microorganisms are integral to soil quality, and can be adversely affected by tillage, chemicals, and fertilizers. The level of different organisms in your soil can provide important insight into the level of productivity and function of your soil. More information on these procedures and uses of soil biology monitoring are available online at <http://www.soilfoodweb.com/>

The Indiana Soil Quality Card

This is a quick observational assessment of soil quality using a descriptive rating guide. The Indiana Soil Quality Card can be obtained by contacting Scot Haley, Resource Soil Scientist, USDA-Natural Resources Conservation Service 317-290-3200 (Ext 379), E-mail: <scot.haley@in.nrcs.usda.gov>. Examples of Soil Quality Cards for other states are online at <http://soils.usda.gov/sqi/soil_quality/assessment/cardguide.html>.

The USDA Soil Quality Test Kit

A detailed and more involved field test kit is available through the USDA Soil Quality Lab titled *Soil Quality Test Kit.* This kit was originally designed for use by Natural Resources Conservation Service and other conservation professionals, but can be used by others. Doing all of the test methods may take between four to six hours to complete for each sample site. Download the instructions packet at <http://soils.usda.gov/sqi/soil_quality/assessment/> or call 334-844-4741 for more information.

Soil Monitoring Record Sheet (use one record sheet for each field each time you monitor)

Field ID ________ **Date/year** ________ **Soil moisture** ❑ wet ❑ moist ❑ dry **Soil temperature** ________

Soil type(s) ________ **Tillage frequency & type** ________

Date manure applied ________ **Date of other organic matter application** ________

Fertilizer type & amount ________

Pesticide names and amounts ________

Crop rotation (Circle current or most recent crop) ________

Field Area	Location identifiers (distance from landmarks or GPS locations)	Water Infiltration rate (minutes)	Earth-worm Count #/hole	Aggregate Stability Score[a]	Penetration (Compaction) Score[b]	Depth (inches)	Plant & Residue Cover (%)
Example	100 steps NW from SE corner	10 min 20sec	10	3	3	8″	85
Area I	1						
	2						
Area II	1						
	2						
Area III	1						
	2						
Average							
Baseline I[c]							
Baseline II							

[a] aggregate stability score: 1 = aggregate broke apart within one minute standing in water, 2 = aggregate remained intact in standing water but broke apart after gentle swirling, 3 = aggregate remained intact after gentle swirling, 4 = aggregate remained intact after vigorous swirling.

[b] compaction score: 0 = No penetration, 1 = Substantial resistance, 2 = Moderate resistance, 3 = Slight resistance, 4 = No resistance, easily penetrated to 12".

[c] Baseline refers to a natural site where habitat disturbance is low such as woods, meadow, undisturbed fence row, etc. This can be a useful baseline comparison within the same soil types as field samples.

* *This worksheet is based on information from USDA-Soil Quality Institute's Soil Quality Test Kit Guide, and Early Warning Biological Monitoring-Croplands by Preston Sullivan and The Allan Savory Center for Holistic Management.*

Notes:

Soil Quality and Soil Management Resources

Purdue Extension publications. For copies, call 1-888-EXT-INFO or go online at <http://www.ces.purdue.edu/extmedia>.

- Conservation Tillage and Water Quality, WQ-20
- Earthworms and Crop Management, AY-279
- Estimating Corn & Soybean Residue Cover AY-269
- Role of Micronutrients in Efficient Crop Production, AY-239
- Soil Compaction in Indiana, AY-221
- Soil Sampling for P, K, and Lime Recommendations. AY-281
- Winter Cover Crops: Their Value and Management, AY-247
- What Soil Erosion Means to Land Productivity, AY-246

Other soil quality publications

- Building Soils for Better Crops, 2nd ed. Magdoff, F., and H. van Es. 2000. Sustainable Agriculture Network. Handbook Series Book 4. Beltsville, MD. An excellent handbook for the farm. Phone: 802-656-0484. $19.95.
- Soil Biology Primer, by Elaine Ingham, Andrew Moldenke, and Clive Edwards. A landmark publication providing clear education about soil biology from Soil and Water Conservation Society. Phone: 515-289-2331. $13.00.

Publications available on the Web

- Sustainable Soil Management, by Preston Sullivan. 2001. An extensive publication with in-depth practical recommendations from Appropriate Technology Transfer for Rural Areas publication found online at <http://attra.ncat.org/attra-pub/soilmgmt.html> Or call toll free 1-800-346-9140.
- Drought Resistant Soils, by Preston Sullivan, 2000. Describes how to minimize the impact of drought. From Appropriate Technology Transfer for Rural Areas, <http://attra.ncat.org/attra-pub/drought.html>. Or call toll free 1-800-346-9140.
- NRCS Soil Quality Web Site <http://soils.usda.gov/sqi/>. Look for the Soil Quality Information Series Fact Sheets at this Web site, including: Organic Matter, Aggregate Stability, Infiltration, Available Water Capacity, Compaction, and Soil Biodiversity. Or call 334-844-4741.

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WQ-43

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12/03