Soil respiration is a measure of carbon dioxide (CO₂) released from the soil from decomposition of soil organic matter by soil microbes and respiration from plant roots and soil fauna. High soil respiration is not always better; it may indicate an unstable system and loss of soil organic matter (SOM) because of excessive tillage, or other factors degrading soil health. It can be measured by simple methods or more sophisticated laboratory methods. The amount of soil respiration is an indicator of nutrients contained in organic matter being converted to forms that are available to crops (e.g., phosphorus as PO₄, nitrogen as NO₃, and sulfur as SO₄). Inherent factors that impact soil respiration, such as climate, cannot be changed. However, soil respiration levels can be managed using measures such as crop residue management, fertilizers, manure application, etc.

Figure 1. Soil microbial activities and respiration and mineralization of organic matter in soil completes the cycle of life on earth releasing water, oxidized minerals (NO₃, PO₄, etc.) and CO₂ needed by photosynthetic green plants to use the energy of the sun to produce food (carbohydrates, etc.) and oxygen required for respiration to complete the cycle (J.W. Doran, M. Sarrantonio, and M.A. Liebig. 1996. Soil Health and Sustainability. Advances in Agronomy, V.56:1-54. Academic Press).

Inherent Factors Affecting Soil Respiration

Inherent soil respiration rates depend on the amount and quality of SOM, temperature, moisture, salinity, pH, and aeration. Biological activity of soil organisms varies seasonally, as well as daily. Microbial respiration more than doubles for every 10°C (18°F) soil temperatures rise up to a maximum of 35 to 40°C (95 to 104°F), beyond which soil temperature is too high, limiting plant growth, microbial activity and soil respiration.

Soil respiration increases with increasing soil moisture up to the level where pores are filled with too much water limiting oxygen availability which interferes with soil organism’s ability to respire (Figure 2). Soil is saturated when 100 percent of pore space is filled with water rather than air. Ideal soil moisture is near field capacity, or when 60 percent of pore space is filled with water. In dry
soils, respiration declines because of the lack of soil moisture.

As soil water-filled pore space exceeds 80 percent, soil respiration declines to a minimum level and most aerobic microorganisms “switch tracks” and use nitrate (NO₃), instead of oxygen, resulting in loss of nitrogen, as nitrogen gases (N₂ and nitrogen oxide), emission of potent greenhouse gases, yield reduction, and increased N fertilizer expense.

Medium textured soils (silt and loam soils) are often favorable to soil respiration because of their good aeration, and high available water capacity. In clay soils, a sizeable amount of SOM is protected from decomposition by clay particles and other aggregates limiting soil respiration and associated mineralization (ammonification) of organic N. Sandy soils are typically low in SOM and have low available water capacity limiting soil respiration and N mineralization.

Figure 2. Relative aerobic (respiration, ammonification, nitrification) and anaerobic microbial activity (denitrification) as related to soil water-filled pore space (Parkin et al., 1996).

Soil Respiration Management

Management practices can either increase or decrease SOM, which enhances soil health and long term soil respiration. Leaving crop residues on the soil surface, use of no-till, use of cover crops, or other practices that add organic matter will increase soil respiration. Crop residues with a low carbon to nitrogen (C:N) ratio (e.g. soybean residue) decompose faster than residues with a high C:N ratio (e.g., wheat straw). High residue producing crops coupled with added N (from any source) increase decomposition and accrual of SOM. Conversely, tillage methods that remove, bury, or burn crop residues diminish SOM content will reduce soil respiration over the long term.

Irrigation in dry conditions and drainage of wet soils can significantly boost soil respiration. Soil respiration tends to be higher in crop rows than in the interrow due to added contributions from plant roots. Compacted areas such as wheel tracks tend to have lower respiration than non-compacted areas because there is less aeration, less drainage, and higher water content.

Managing soil pH and salt content (salinity) is important because they regulate crop growth and nutrient availability and distribution which impact soil organisms responsible for SOM decomposition, and other processes contributing to soil respiration. Fertilizers may stimulate root growth and nourish microbes; however, at high concentrations, some fertilizers can become harmful to microbes responsible for soil respiration because of changes in pH or salinity. Similarly, sludge or other organic materials with high concentrations of heavy metals, certain pesticides or fungicides, may be toxic to microbial populations decreasing respiration.
Measures to improve SOM or soil porosity:

- Minimize soil disturbance and production activities when soils are wet,
- Use designated field roads or rows for equipment traffic,
- Reduce the number of trips across field,
- Subsoil to disrupt existing compacted layers,
- Cropping systems that include combinations of continuous no-till, cover crops, solid manure or compost application, diverse rotations with high residue crops and perennial legumes or grass used in rotation,
- Residue is left on the surface rather than incorporating, burning, or removing crop residues.

Soil respiration reflects the response to management measures such as plant residue or manure addition, tillage, nitrogen applications as shown in Table 1. Temporary increases in soil respiration induced by certain management practices and have negative impact on SOM and long term soil respiration.

**Table 1. Interpreting management impacts on soil respiration and soil organic matter (SOM).**

<table>
<thead>
<tr>
<th>Management Practice</th>
<th>Application</th>
<th>Short term Impacts</th>
<th>Long Term Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid manure or organic material application</td>
<td>Provide additional carbon source for microbes to breakdown.</td>
<td>Increased respiration when manure begins to breakdown.</td>
<td>Positive impact on soil structure, fertility and SOM content.</td>
</tr>
<tr>
<td>High residue crops or cover crops used in rotation with high C:N ratio</td>
<td>High C:N ratio crops coupled with added N (from any source) increase decomposition and accrual of SOM.</td>
<td>High C:N ratio crop residue tie up nitrogen temporarily in order to break down residue, increased soil moisture, decreased erosion.</td>
<td>Positive impact on long term soil quality, fertility and SOM content.</td>
</tr>
<tr>
<td>Tillage such as annual disking, plowing etc.</td>
<td>Stirs the soil providing a temporary increase in oxygen available for microbes to break down carbon sources.</td>
<td>Provides a flush of nitrogen, other nutrients and CO₂ release immediately after tillage. Increases erosion rates, decomposition rate of residue, and other carbon sources.</td>
<td>Declines in SOM, soil quality, soil fertility.</td>
</tr>
<tr>
<td>Crop residue management</td>
<td>Leave residue on the surface increasing ground cover to protect the soil.</td>
<td>Increased crop residue cover can tie up nitrogen temporarily in order to break down residue, increased soil moisture, decreased erosion and cooler soil temperatures.</td>
<td>Positive impact on long term soil quality, fertility and SOM content.</td>
</tr>
<tr>
<td>Nitrogen fertilizer application</td>
<td>Provides nitrogen (energy) source for microbes to break down high C:N ratio.</td>
<td>Temporary increase in respiration due to increased rate of breakdown of organic</td>
<td>When managed correctly has an overall positive impact on SOM and soil.</td>
</tr>
</tbody>
</table>
Soil respiration reflects the capacity of soil to sustain plant growth, soil fauna, and microorganisms. It indicates the level of microbial activity and SOM content and its decomposition. Soil respiration can be used to estimate nutrient cycling in the soil and the soil’s ability to sustain plant growth.

Excessive respiration and SOM decomposition usually occurs after tillage due to destruction of soil aggregates and increased soil aeration. This depletes SOM, limits nutrient availability, and reduces yields.

Low soil respiration rates indicate that there is little or no SOM or aerobic microbial activity in the soil. It may also signify that soil conditions (soil temperature, moisture, aeration, available N) are limiting biological activity and SOM decomposition. With low soil respiration, nutrients are not released from SOM to feed plants and soil organisms. Reduced soil respiration occurs when soils are

<table>
<thead>
<tr>
<th>Residue (e.g. corn stalks, wheat straw) quicker</th>
<th>Materials</th>
<th>Quality by increasing production levels, and residue amounts.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle or farm equipment traffic</td>
<td>Compacts soil decreasing pore space, water movement, oxygen for microbes, and N loss from denitrification.</td>
<td>Decreases respiration, yields, water infiltration and increases runoff.</td>
</tr>
</tbody>
</table>

What management measures that impact respiration are being used on the field(s) being evaluated, and what impact will they have on respiration?

______________________________________________________________________________________

______________________________________________________________________________________

______________________________________________________________________________________

Do you expect these management measures to have a positive or negative impact on long term respiration rates? Why or why not?

______________________________________________________________________________________

______________________________________________________________________________________

______________________________________________________________________________________

Problems Related to Respiration and Relationship of Respiration to Soil Function

Soil respiration reflects the capacity of soil to sustain plant growth, soil fauna, and microorganisms. It indicates the level of microbial activity and SOM content and its decomposition. Soil respiration can be used to estimate nutrient cycling in the soil and the soil’s ability to sustain plant growth.

Excessive respiration and SOM decomposition usually occurs after tillage due to destruction of soil aggregates and increased soil aeration. This depletes SOM, limits nutrient availability, and reduces yields.

Low soil respiration rates indicate that there is little or no SOM or aerobic microbial activity in the soil. It may also signify that soil conditions (soil temperature, moisture, aeration, available N) are limiting biological activity and SOM decomposition. With low soil respiration, nutrients are not released from SOM to feed plants and soil organisms. Reduced soil respiration occurs when soils are
flooded or saturated, and nitrogen is lost through denitrification and sulfur lost through volatilization.

**Measuring Soil Respiration**

**Materials Needed to Measure Respiration**

- Solvita® sample jar for correct volume of soil or 3-inch diameter aluminum cylinder and lid (Figure 3)
- Foil-pack containing a special gel paddle (Figure 3)
- Solvita® color key (Figure 4) for reading results
- Solvita® interpretation guide to estimate differences in soil quality, respiration, and potential N release
- Aluminum foil or cap when aluminum cylinder is used
- Solvita® soil life respiration test (paddles)
- Soil thermometer or controlled room temperature

**Considerations** – When mixing soil, respiration temporarily increases, due to aeration similar to tillage by increasing the amount of oxygen available to break down organic matter quicker. This procedure also reduces the effect of root respiration. However, it is very effective to compare relative differences in soil quality, respiration, and nitrogen (N) release of one site to another.

An alternative to mixing soil is to use an intact soil core in the 3-inch diameter aluminum cylinder, from the infiltration/bulk density test. An intact core better reflects respiration for no-till applications, while a mixed sample will better reflect respiration either immediately after tillage (flush) or post tillage (at least 1 day or longer after mixing). To get an accurate comparison of different management systems several soil samples representing different management systems can be compared.

**Step by Step Procedure**

1. **Soil Sampling (Field):** Soil respiration is highly variable both spatially and seasonally, and is strongly affected by organic matter, manure applications, oxygen levels, soil moisture, salinity and soil temperature. Soil is sampled in a fresh condition just before the test is performed. At least 10 small samples should be gathered randomly from an area that represents the soil type and management history with a probe from the surface 0-6 inch depth and placed in the small plastic bucket. Repeat this for each sampling area.
2. **Mixing (Field):** Mix soil in the bucket just well enough to be homogeneous and remove roots, residue, large stones and residues from the sample and place in a labeled plastic zip bag.

3. **Add Water If Needed (Field or Classroom):** The sample should have ideal moisture (near field capacity) for growing conditions. If field conditions are dry it is best to add water 24 hours prior to sampling. If needed water can be added to the sample prior to starting the test in the classroom.

4. **Put Sample Into Solvita® Jar (Classroom):** Shortly after sampling put moist mix of soil up to fill line in the Solvita® jar. As you fill, tap the bottom of the jar on a hard surface to ensure there are no voids.

5. **Insert color gel paddle into soil with the gel facing out next to the clear side of the jar. Be careful not to jostle or tip the jar. Screw the lid on very tightly, and record the time on the lid. Keep the jar in the classroom at controlled temperature 68-75° F and out of the sunlight for 24 hours.**

6. **Read the gel color after 24 hours and record the results on Table 3.**

7. **Answer the discussion questions and complete the interpretations section of Table 3. Refer to Solvita® soil test instructions for additional information and interpretations.**

*Mention of commercial products does not constitute an official endorsement by the U.S. Department of Agriculture.*

### Interpretations

Record soil respiration rates and complete Table 3. The Solvita® respiration test reflects the health of the soil based on the level of CO₂ respiration. Respiration levels reflect the quality of soil, soil organic matter content, and can be used to approximate quantity of nitrogen released per year in an average climate (refer to Table 1). The rate of CO₂ release is expressed as CO₂-C lbs/acre-3"/day (or kg/ha-7.6cm /d).

High soil respiration rates are indicative of high biological activity (refer to Table 2). This can be a good sign of a healthy soil that readily breaks down organic residues and cycles of nutrients for crop growth. As soil respiration improves from management measures such as diverse crop rotations, and residue management the Solvita® response may go from an inactive condition (#1 blue-gray) to a very active state (#3-4 green-yellow). In some cases, heavily manured soils or soils high in organic content can attain a very high rate (#5 yellow). This can be detrimental when decomposition of stable organic matter occurs. It is generally desirable to have at least green color #3. It typically takes several years for a soil to improve from a low biological status to a more active one. With proper residue management, diverse crop rotations, organic matter additions and avoidance of destructive tillage practices, the time to reach a more optimum condition is shortened.
## Table 2. Basic soil biological quality.

<table>
<thead>
<tr>
<th>Color/Colorimetric Number</th>
<th>Soil Respiration Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Blue-Gray</td>
<td>Very Low Soil Activity</td>
</tr>
<tr>
<td>2 Gray-Green</td>
<td>Moderately Low Soil Activity</td>
</tr>
<tr>
<td>3 Green</td>
<td>Medium Soil Activity</td>
</tr>
<tr>
<td>4 Green-Yellow</td>
<td>Ideal Soil Activity</td>
</tr>
<tr>
<td>5 Yellow</td>
<td>Unusually High Soil Activity</td>
</tr>
</tbody>
</table>

### Soil Respiration Activity

- **Very Low Soil Activity**: Associated with dry sandy soils, and little or no organic matter.
- **Moderately Low Soil Activity**: Soil is marginal in terms of biological activity and organic matter.
- **Medium Soil Activity**: Soil is in a moderately balanced condition and has been receiving organic matter additions.
- **Ideal Soil Activity**: Soil is well supplied with organic matter and has an active population of microorganisms.
- **Unusually High Soil Activity**: High/Excessive organic matter additions.

### Approximate Level of CO₂ – Respiration

<table>
<thead>
<tr>
<th>Approximate Quantity of CO₂ Release per Week (lbs CO₂/kg soil/wk)</th>
<th>Approximate Level of CO₂ – Respiration</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;300 mg CO₂/kg soil/wk</td>
<td>&lt;9.5 lbs CO₂-C/acre-3”/d</td>
</tr>
<tr>
<td>300-500 mg CO₂/kg soil/wk</td>
<td>9.5 - 16 lbs CO₂-C/acre-3”/d</td>
</tr>
<tr>
<td>500-1000 mg CO₂/kg soil/wk</td>
<td>16-32 lbs CO₂-C/acre-3”/d</td>
</tr>
<tr>
<td>1,000-2,000 mg CO₂/kg soil/wk</td>
<td>32-64 lbs CO₂-C/acre-3”/d</td>
</tr>
<tr>
<td>&gt;2,000 mg CO₂/kg soil/wk</td>
<td>&gt;64 lbs CO₂-C/acre-3”/d</td>
</tr>
</tbody>
</table>

### Approximately Quantity of Nitrogen (N) Release per Year (average climate)

<table>
<thead>
<tr>
<th>Approximate Quantity of Nitrogen (N) Release per Year (lbs/ac/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;7 lbs/acre</td>
</tr>
<tr>
<td>10-20 lbs/acre</td>
</tr>
<tr>
<td>20-40 lbs/acre</td>
</tr>
<tr>
<td>30-80 lbs/acre</td>
</tr>
<tr>
<td>&gt;64 lbs CO₂-C/acre-3”/d</td>
</tr>
</tbody>
</table>

* Source: Doran, J. (2001) USDA-ARS Soil Quality Institute correlation of Solvita® and field soil respiration. Calculations based on a 3-inch soil core (7.6 cm).

## Table 2. Soil respiration levels and interpretations.

<table>
<thead>
<tr>
<th>Sample Site</th>
<th>Median 24-hr Soil or Room Temp.</th>
<th>Time-frame</th>
<th>Start Time</th>
<th>End Time</th>
<th>Gel Color &amp; Colorimetric Number</th>
<th>Soil Activity Rating (Table 1)</th>
<th>Avg. Respiration Level lbs CO₂-C/acre-3”/d</th>
<th>Quantity of Nitrogen Released (lbs/ac/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example 1</td>
<td>77F (25C)</td>
<td>4/30-5/1/12</td>
<td>8 AM</td>
<td>8:15 AM</td>
<td>GryGreen – 2.5</td>
<td>Moderately Low to Medium</td>
<td>16 lbs</td>
<td>20 lbs</td>
</tr>
</tbody>
</table>
Were the results of the test what you expected? Why or why not?
______________________________________________________________________________________
______________________________________________________________________________________
______________________________________________________________________________________

Do you expect SOM levels to decline, improve, or stay the same? Why?
______________________________________________________________________________________
______________________________________________________________________________________
______________________________________________________________________________________

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**Glossary**

**Soil Microbes** – Soil organisms such as bacteria, fungi, protozoa, and algae that are responsible for soil respiration and many important soil processes such as nutrient cycling. (The number of soil organisms in a heaping tablespoon of fertile soil can exceed 9 billion, 1.5 times the human population of the earth.)

**Respiration** – Carbon dioxide (CO₂) is released from soil from several sources: decomposition of SOM by soil microbes, and respiration from plant roots and soil fauna. It can be measured by simple methods or more sophisticated laboratory methods.

**Mineralization** – Organic matter decomposition which releases nutrients in a plant available form (e.g., phosphorus, nitrogen, and sulfur), that occurs during respiration.

**Ammonification** – Production of ammonium (NH₄) from SOM decomposition.

**Denitrification** – Anaerobic conversion and loss of nitrate nitrogen to nitrite and NO, N₂O, and N₂ gases.

**Nitrification** – An aerobic microbial process converting soil ammonium N to plant available nitrate (or nitrite, NO, and N₂O when pH, EC, or oxygen levels impair aerobic activity).