soil Respiration

Soil Quality Kit – Guides for Educators

United States Department of Agriculture
Natural Resources Conservation Service

Soil respiration is a measure of carbon dioxide (CO_2) released from the soil from decomposition of soil organic matter (SOM) by soil microbes and respiration from plant roots and soil fauna. It is an important indicator of soil health because it indicates the level of microbial activity, SOM content and its decomposition. In the short term high soil respiration rates are 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 available to crops (e.g., phosphate as PO_4, nitrate-nitrogen as NO_3, and sulfate as SO_4).

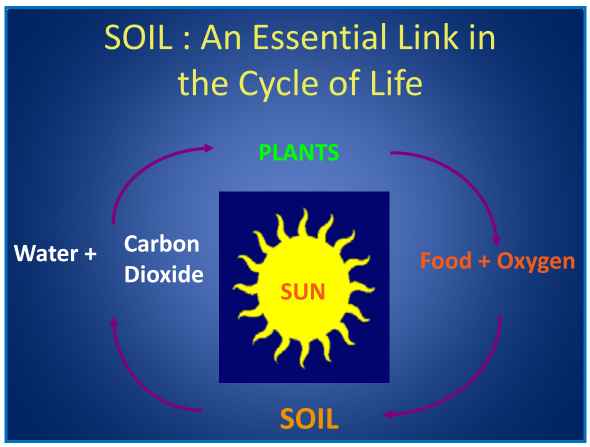

Figure 1. Soil microbial activities and respiration and mineralization of organic matter in soil completes the cycle of life on earth releasing water, oxidized minerals (NO_3, PO_4, etc.) and CO_2 needed by photosynthetic green plants to use the sun's energy to produce food (carbohydrates, etc.) and 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 factors that impact soil respiration, such as climate, cannot be changed. Inherent soil respiration rates depend on 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 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). Ideal soil moisture is near field capacity, or when approximately 60 percent of pore space is filled with water. Respiration declines in dry soils due to the lack of moisture for microbes and other biological activity.

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 (NO_3), instead of oxygen, resulting in loss of nitrogen, as nitrogen gases (N_2 and nitrogen oxides), 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.

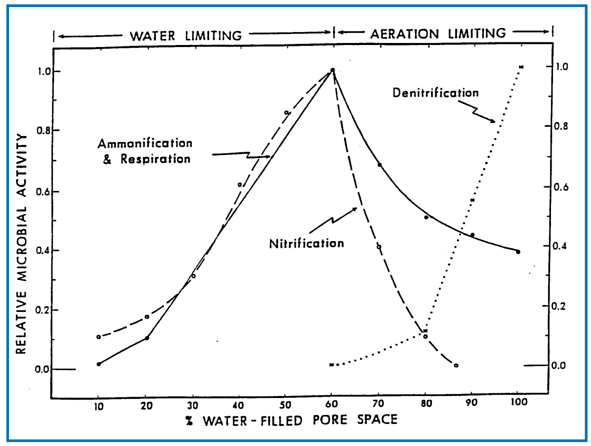

Figure 2. Relative aerobic (respiration, ammonification, nitrification) and anaerobic microbial activity (denitrification) as related to soil water-filled pore space (Parkin et al., 1996).

Soil Respiration Management

Management practices can either increase or decrease SOM. Soil health and long term soil respiration improve with increased SOM. 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 between rows 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 pH or salinity increases. Similarly, sludge or other organic materials with high concentrations of heavy metals, certain pesticides or fungicides, and salts may be toxic to microbial populations decreasing respiration.

Measures to improve SOM and/or soil porosity:

- Minimize soil disturbance and farm equipment 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,
- Leave undisturbed residue on the soil surface rather than incorporating, burning, or removing.

Soil respiration rates respond to management measures such as plant residue or manure addition, tillage, and 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).

Management Practice	Application	Short term Impacts	Long Term Impacts
Solid manure or organic material application	Provide additional carbon and N source for microbes to breakdown and increase biomass production.	Increased respiration when manure begins to breakdown and increased biomass production.	Positive impact on soil structure, fertility and SOM content.
High residue crops or cover crops used in rotation with high C:N ratio	High C:N ratio crops coupled with added N (from any source) increase decomposition and accrual of SOM.	High C:N ratio crop residue tie up nitrogen temporarily in order to break down residue, increased soil moisture, decreased erosion.	Positive impact on long term soil quality, fertility and SOM content.
Tillage such as annual disking, plowing etc.	Stirs the soil providing a temporary increase in oxygen for microbes to break down carbon sources.	Provides a flush of nitrogen, other nutrients and CO_2 release immediately after tillage. Increases erosion rates, decomposition rate of residue, and other carbon sources.	Declines in SOM, soil quality, soil fertility.
Crop residue management	Leave residue on the surface increasing ground cover to protect the soil.	Increased crop residue cover can tie up nitrogen temporarily in order to break down residue, increased soil moisture, decreased erosion and cooler soil temperatures.	Positive impact on long term soil quality, fertility and SOM content.

Nitrogen fertilizer or manure application	Provides nitrogen (energy) source for microbes to break down high C:N ratio residue (e.g. corn stalks, wheat straw) quicker.	Temporary increase in respiration due to increased rate of breakdown of organic materials.	When managed correctly has an overall positive impact on SOM and soil quality by increasing production levels, and residue amounts.
Vehicle or farm equipment traffic	Compacts soil decreasing pore space, water movement, oxygen for microbes, and N loss from denitrification.	Decreases respiration, yields, water infiltration and increases runoff.	Production declines, increased soil erosion and runoff, decreased soil quality, compacted soils and reduced microbial activity.

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

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

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Problems Related to Soil Respiration and Relationship 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 soil microbial activity. 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 <u>3-inch diameter aluminum cylinder</u> and lid (Figure 3)

____ Foil-pack containing a special gel paddle (Figure 3)

____ Solvita® 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

Figure 3. Solvita® sample jar and gel paddle.

Figure 4. Solvita® Color Key.

Considerations – When mixing soil, <u>respiration temporarily increases,</u> due to aeration similar to tillage by increasing the amount of oxygen available to break down organic matter quicker. This procedure also does not reflect root respiration. However, it is very effective to compare relative differences in soil quality, respiration, and nitrogen (N) release of one site versus another.

<u>An alternative to mixing soil is to use an intact soil core in the 3-inch diameter aluminum cylinder,</u> 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. <u>Soil Sampling (Field):</u> Soil respiration is variable both spatially and seasonally, and is strongly affected by organic matter, manure applications, oxygen levels, soil moisture, salinity (EC) 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 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 plastic bucket just well enough to be homogeneous and remove roots, residue, large stones and residues from 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 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 jar. Screw the lid on very tightly, and record the time on the lid. Keep the jar in the classroom at a controlled temperature of 68-75° F and out of sunlight for 24 hours.

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

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

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Interpretations

Record soil respiration rates and complete Table 3. Respiration levels reflect soil health based on the level of CO_2 respiration. Rates are impacted by 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 2). The rate of CO_2 released is expressed as CO_2-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 nutrients needed for crop growth. Solvita® response may go from an inactive condition (0-1 blue-gray) to a very active state (3.5-4.0 green-yellow) as soil respiration increases from desirable management measures such as diverse crop rotations, and no-till. 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.

Color/Colorimetric Number				
0 - 1 Blue-Gray	1.0 - 2.5 Gray-Green	2.5 - 3.5 Green	3.5 - 4.0 Green-Yellow	4 - 5 Yellow
Soil Respiration Activity				
Very Low Soil Activity	Moderately Low Soil Activity	Medium Soil Activity	Ideal Soil Activity	Unusually High Soil Activity
Associated with dry sandy soils, and little or no organic matter	Soil is marginal in terms of biological activity and organic matter	Soil is in a moderately balanced condition and has been receiving organic matter additions	Soil is well supplies with organic matter and has an active population of microorganisms	High/Excessive organic matter additions
***Approximate Level of CO_2 – Respiration**				
<300 mg CO_2/kg soil/wk	300-500 mg CO_2/kg soil/wk	500-1000 mg CO_2/kg soil/wk	1,000-2,000 mg CO_2/kg soil/wk	>2,000 mg CO_2/kg soil/wk
< 9.5 lbs CO_2-C/acre-3"/d	9.5 - 16 lbs CO_2-C/acre-3"/d	16-32 lbs CO_2-C/acre-3"/d	32-64 lbs CO_2-C/acre-3"/d	>64 lbs CO_2-C/acre-3"/d
Approximate quantity of nitrogen (N) release per year (average climate)				
<10 lbs/acre	10-20 lbs/acre	20-40 lbs/acre	40-80 lbs/acre	80- >160 lbs/acre

* 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 3. Soil respiration levels and interpretations.

Sample Site	Median 24-hr Soil or Room Temp.	Time-frame	Start Time	End Time	Gel Color & Colorimetric Number	Soil Activity Rating (Table 1)	Avg. respiration level lbs CO_2-C/acre-3"/d	Quantity of Nitrogen Released (lbs/ac/yr)
Example 1	77F (25C)	4/30-5/1/12	8 AM	8:15 AM	GryGreen – 2.5	Moderately Low to Medium	16 lbs	20 lbs

Were soil respiration levels what you expected? Why or why not?

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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 table spoon of fertile soil can exceed 9 billion, or 1.5 times the human population.)

Respiration – Release of carbon dioxide (CO_2) 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 releasing nutrients in a plant available form (e.g., phosphorus, nitrogen, and sulfur), that occurs during respiration.

Ammonification – Production of ammonium (NH_4) from SOM decomposition.

Denitrification – Anaerobic conversion and loss of nitrate nitrogen to nitrite and NO, N_2O, and N_2 gases.

Nitrification – An aerobic microbial process converting soil ammonium N to plant available nitrate (or nitrite, NO, and N_2O when pH, EC, or oxygen levels impair aerobic activity).

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