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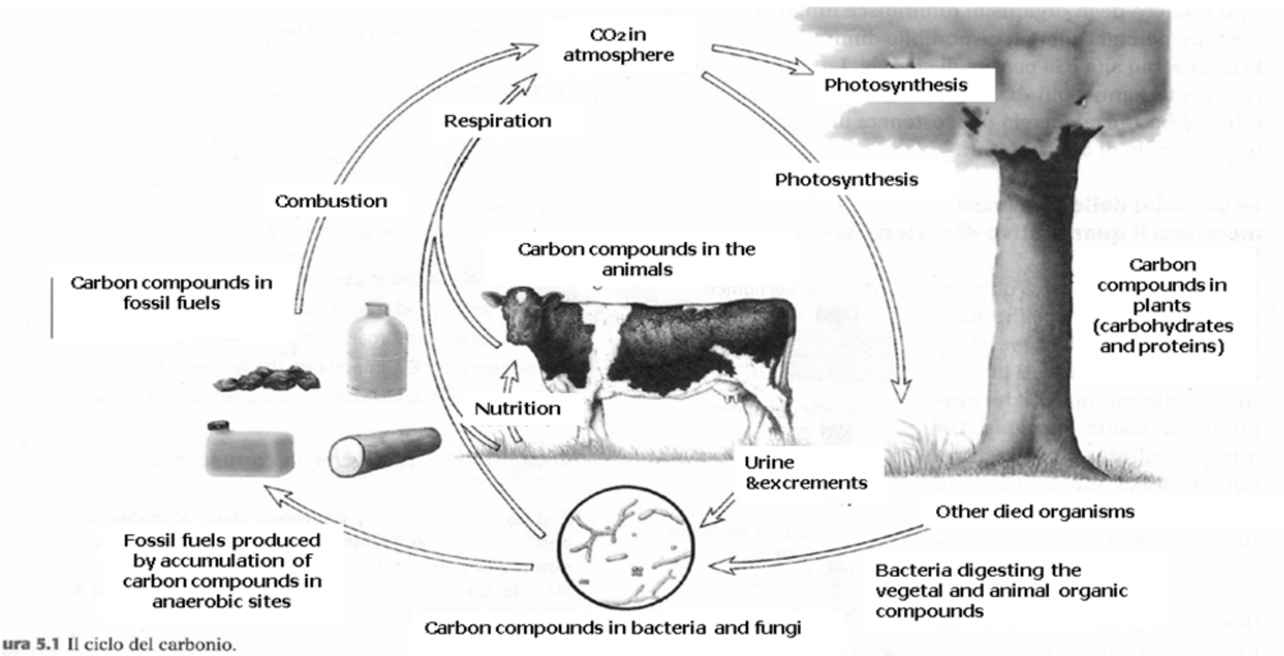
THE SOIL BREATHES

Introduction:

Soils represent a huge carbon storage and play an important role within the carbon cycle. Carbon dioxide is assimilated by the vegetation, is soluble in water and in these ways it passes to the solid form such as carbonates, organic matter in marine and terrestrial ecosystems.
But CO_2 comes also back to atmosphere from soils. Soils in fact are the substrate where living organisms interact with non-living materials, the decomposition and mineralization processes by microorganisms and bacteria take place and other cycles of elements develop between soil and atmosphere.
The CO_2 produced and its diffusion to atmosphere is called "soil respiration".



ura 5.1 Il ciclo del carbonio.

The process of soil respiration is strictly dependent on the organic matter characteristics, the pedoclimatic conditions and the presence of organisms: the transformation of the organic material ranges from 1 to 10 years depending on the vegetal ecosystem (W. Larcher, 1993).
The soil density and humidity have a strong influence on gas diffusion: high porosity and low water content make it easier but the mineralization processes also have optimal temperatures and optimal soil moisture.
In this activity 3 different parameters will be measured: soil respiration, soil moisture and bulk density.

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Preparation time:
20 minutes

Duration of activity:
30 minutes

Application: Earth's science, chemistry, biology.

Time for data analysis and discussion:
20 minutes

Previous knowledge required:
Basic knowledge in chemistry, earth science matters is appreciated.

Cost: EGM-1 from PPsystem, Hitchin, UK is provided by the Research Center.
Other devices can be used in alternative. About 30€ for Colorimetric Gas Detection Tubes (method taken by USDA Soil kit manual) or a portable Gas Analyzer for CO_2

Measuring Soil Respiration:

Materials:
EGM-1 with Soil Respiration Chamber
or any other Infra Red Gas Analyzer equipped with its own Soil respiration chamber.

In alternative:

- Cylindrical chamber made of PVC ring
  (10 cm diameter and 15 cm height)
- lid to fit the diameter of the chamber with rubber stoppers
- 1 plastic tube
- hand sledge and wood block
- 1 meterstick
- stopwatch or timer
- Colorimetric Gas Detection tube
- 2 needles and one 150 ml syringe

- Soil thermometer
- 1 block note, pen

Procedure: EGM-1 is an Infra Red Gas Analyzer to measure carbon dioxide efflux from the soil.

It is equipped with a H_2O filter (it excludes water vapor -IR gas absorber- from the flux of air) and it is connected to the cylindrical chamber (H=15cm; Ø=10cm) placed on soil just before the measure starts. Place the chamber on the soil and press it by hand to avoid external air entrance into the chamber, the gas efflux is pumped and measured automatically by the gas analyzer. The air is constantly mixed by an inner automatic fan to obtain a representative flux of gases. The instrument measures the concentration of CO_2 and it stops the measurement after 120 seconds or a difference of 60 ppm from the initial value.
The instrument measures <u>carbon dioxide concentration</u> (ppm) and <u>efflux of carbon dioxide from soil</u> (g/m^2hr).

1) Take a patch of soil from the garden or the forest, 10cm deep. Try to keep the sample intact, keeping it compact or, if you can, run the experiment outside, select one or more sites with different characteristics
2) remove the litter and cut the vegetation from the spot (approx. Ø=150mm) to avoid measuring leaf respiration.
3) use the EGM-1 following the instructions: place the chamber on the soil and wait till the measurement is finished. Repeat the measurements and do the same in the other spots . (one measurement takes 120 seconds).
4) Record the values on a notebook.

<u>Alternative method for soil respiration (by USDA, elaborated):</u>

1) Clear the soil surface of vegetation and litter. Drive the ring into the soil using the hand sledge and a wood block to a depth of about 10 cm. If the soil is stony and the ring cannot go deep enough , insert it until you feel resistance from the rocks. 2) Measure the height of the ring to the top of the ring in centimeters (take 4 measurements and make the average) 3) Cover the ring with the lid and wait **exactly** 30 minutes.	

4) While waiting prepare the apparatus to measure the CO2:

a. connect one needle to one end of the plastic tube (picture)
b. open both the ends of the Colorimetric Gas Detection tube
c. connect the Colorimetric Gas Detection tube to the other end of the plastic tube
d. take the second plastic tube and connect it to the free end of the Colorimetric Gas Detection tube (the arrow should point away from the needle)
e. connect the second tube to the syringe

5) At the 30th minute, insert the needle into the rubber stopper and the second needle into the second stopper to allow the air flow into the head space during the gas sampling. The second needle should be inserted just before the head space is sampled.

6) Slowly take 100 cc of air by the syringe (1 cc = 1 mL).

7) If the reading is less than 0.5% on the Colorimetric Gas Detection tube , take four additional 100 cc sample of the head space through the same Colorimetric Gas Detection 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.

8) Record the % of CO_2 on the Colorimetric Gas Detection tube: read on the "n=1" column if 100 cc was sampled or on the "n=5" column

if 500 cc was sampled. The % of CO_2 should be an estimate of the highest point that the purple color can be easily detected. 9) Take the soil temperature close to the ring at the time of sampling Remove the lid after finishing with the measurements.	

10) Calculation:

Soil respiration (SR) is the amount of gas that comes out from a given area of soil and in a given time interval

Pressure Factor (PF) is considered =1

Temperature Factor (TF) is expressed in °K = (T (°C) + 273,15) / 273,15

Δ t = time interval expressed in hour 30 min=0,5 hr

Volume above the soil:
chamber's area · chamber's height (measured with the meterstick)=
$(10^2/4 \cdot \pi \text{ cm}^2) \cdot \ldots \text{ cm} = V (\text{cm}^3)$ to be converted in m^3

we need to express the % of CO2 in g per volume:
n= m / M
Molar mass = 44,01 g
Considering CO_2 as an ideal gas:
1mol occupies a volume of $24{,}47 \cdot 10^{-3}$ m^3

The grams of CO_2 per volume:

$m / V = \% \, CO_2 \cdot (44{,}01 / 24{,}47 \cdot 10^{-3})$

SR =

$PF \cdot [(T + 273{,}15) / 273{,}15] \cdot [(\%CO_2 - 0.035) \cdot (44{,}01 \, \mathbf{g} / 24{,}47 \cdot 10^{-3} \mathbf{m^3})]$
$\cdot$ Volume above soil $\mathbf{m^3}$ / [Chamber Area $\mathbf{m^2}$ $\cdot$ (Δ t **hr**)]

SR= PF · TF · CO_2 (g/m^3) · V (m^3) / A (m^2) · 0,5 (hr) => **g / m² hr**

Soil samples after the measurements can be analyzed for the estimation of roots and other macro-biomass or other chemical characteristics.

11) Data elaboration and discussions:
- identifying the factors that produce and promote the efflux of CO_2 from soil (comparing soils with different biomass; or different for compaction or texture).
- take the concentration of atmospheric CO_2 using the syringe and the Colorimetric detector tube or using the automatic gas analyzer without the soil respiration chamber. Compare the amount of CO2 from soil and the concentration of the gas in atmosphere
- verify if the soil respiration changes with soil moisture (comparing samples with different soil moisture)

Measuring Soil Moisture:

Materials

- 1 plastic bag
- 1 dish to dry the sample
- oven or microwave to dry the sample
- 1 garden trowel
- 1 precision state (?)

Procedure: :

The water content is measured by the gravimetric method. It will require 10 minutes for preparing the samples and weighing them. Time for drying the samples depends on the method.

1) Take about 300 g of soil from 4 samples (holes) from the first 10 cm of depth since they are richest in biomass and roots.
2) Take a subsample from all the soil taken previously.
Determine the FRESH WEIGHT.
3) Put the subsample in the oven (24 hours at 105°C) or in the microwave (3 cycles of 4 minutes at max power) or air-dry them. This will however take longer.
4) Determine the DRY WEIGHT
5) Soil Water Content (SWC) is expressed as the difference between the fresh weight (FW) and the dry weight (DW) in relation to the dry weight of the soil sample.

SWC= (FW-DW)/DW.

Measuring bulk density:

Materials :

- 2 plastic bags
- 1 liter or more of water
- 1 graduated cylinder
- 1 garden trowel
- 1 precision state
- 1 dish to dry the sample
- oven or microwave to dry the sample

Procedure

Bulk density is a parameter that can give an idea of the compaction that influence also the efflux of gas in the soil.

1) Make a hole about 10·10·10 cm^3 in the first 10 cm of soil depth and put all the soil into the plastic bag. If it's stony, remove the stones.
2) Take a thin plastic bag can be modeled easily inside the hole and return all the stones inside the bag.
3) fill the graduated cylinder with water and pour it in the bag inside the hole measuring the quantity of water necessary to fill it. Since 1ml of water from the graduated cylinder is 1 cm^3, you have a direct measure of the volume of the hole.
4) Once back in the laboratory, weigh the soil taken from the hole (Fresh Weight) and dry it (see above: soil moisture point 3)
5) Take its Dry Weight.
6) The **bulk density (BD)** will be the ratio between the content of soil (DW) and its volume (V).
7) BD= DW/V (g/cm^3)

Presentation of Results:

You can use this table for each soil type and carry on comparisons.

Date, time:	
SITE:	SOIL COVER:

NUMBER OF MEASUREMENT	SOIL TEMPERATURE (°C)	CO_2 (ppm)	CO_2 FLOW ($g/m^2/hr$)	SOIL WATER CONTENT (%)	BULK DENSITY (g/cm^3)
1					
2					
3					
4					
5					
MEAN VALUE					
Standard Deviation					

Sample results already obtained by your students in the form of tables, graphs or diagrams:

15 Jan 2009	**CO_2 (ppm)**	**SR (g CO_2/m^2 hr)**
Grass cover	447.2	**0.73**
worked soil	473	**3.64**

Table1. Soil respiration and CO_2 concentration in the grass covered area and in the area that has been arranged for planting. EGM-1 has been used.

Fig.1 Students preparing the vegetable garden

Table 1 (data elaborated by the students) shows a high value of soil respiration at the moment of the preparation for planting. The disturbing action changes the soil characteristics such as porosity. It exposes underground fractions to the atmosphere and oxidation reactions and mineralization processes become faster. The CO_2 production increases and also the soil efflux is easier; this result stimulates hypothesis and discussions about agriculture techniques in relation to the carbon stock.

DATE	Soil cover	CO2 ppm	S.D.	SR g CO2/m2hr	S.D.	RH%	S.D.	T(°C)	S.D.
28\11\09	grasses	482.5	24.82	2.33	1.45	17.9%	0	10.75	0.5
16\01\10	grasses	411.2	6.13	0.38	0.16	42.5%	0.06	3	0
10\02\10	grasses	397.5	27.86	0.58	0.57	33%	0.1	3.75	0.5
23\02\10	grasses	432.5	13.82	0.97	0.19	17.6%	0	8	0
13\03\10	grasses	467.5	55.65	0.83	0.63	18.1%	0	3	0

Table 2. CO_2 concentration, Soil Respiration, Soil Moisture and Temperature in samples of soil in a garden covered by grasses.

In undisturbed conditions the soil respiration increases with the soil temperature.
In fact meteorological parameters like air temperature control the biomass and the enzymatic activity in the soil. Precipitation determines the soil moisture.

Discussion of results:

What factors produce the CO_2 in the soil and influence its efflux to atmosphere?

Which may be the limiting factors for CO_2 efflux?

Reflect about land management and land cover. Which ecosystem is most 'active' in soil respiration?

What do you think about agricultural soils?

A second part of the experiments description may be added as a guide or an aid to other teachers who would want to do the experiments in their schools. This can include the following:

1. **Suggested further experiments:**

   Number of roots in the soil samples used for the soil respiration measurements:

   Material:
   1 sieve (<1 mm)
   soil corer
   meter stick
   Water
   small dishes to weigh the roots

   Procedure:
   1) take a soil core 0-10 cm deep and 10-20 cm using the soil corer.
   2) Take their VOLUME (measure the diameter of the soil corer and the length of the soil core).
   3) take the SOIL FRESH WEIGHT.
   4) Put the sample in a fine sieve and under running water, wash it taking care to keep all the roots.
   5) Count the number of roots.

   The number of roots per unit volume of soil is an indicator of root distribution in soil.

   6) weigh the ROOTS DRY WEIGHT (put them in the oven for 24 hours at 80°C) or dry at air but it takes longer time.

   The mass of the roots determines the total amount of roots.

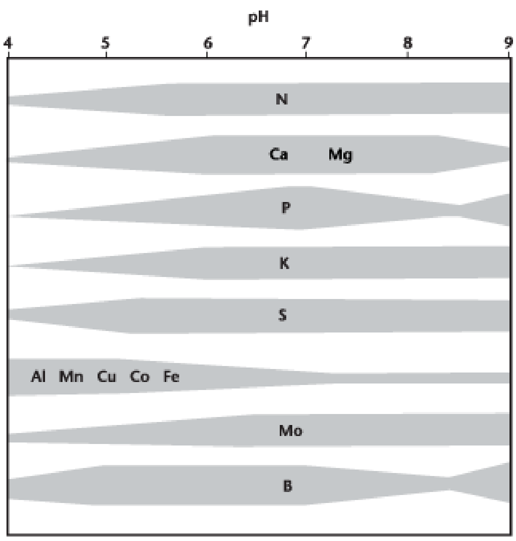
7) Take the Root Length: it can be estimated by the Newman's method or measured using graph paper on a subsample of washed roots.
   Newman's method:
Spread the roots with the mimimum overlap possible, over a regular grid of indeterminate dimensions, but of known regular grid units (e.g. 1 cm). Where necessary, tease the root material apart or cut it into small pieces to avoid overlap. Placing the samples on the grid in a shallow layer of water (in a dish) aids separation of the roots. Count the total number of intersections (N) between the roots and the horizontal (H) and vertical (V) grid lines. Assign a count of 1 to a root crossing a line, a root ending touching a line and a curved root portion touching a line. Curved root portions which lie on or along a grid line are assigned a count of 2. (Tennant 1975). The relationship between the root length and the number of root intersections with the grid lines is given by:

Root length (cm)= $\pi \cdot N \cdot$ grid unit (cm) / 4

Calculate the Root Length Density: Root length / Soil Volume
Evaluation of pH of the soil sample:

The pH indicates if the solution or substance is acid, neutral or basic and depends on the amount of ions H^+ over OH^- . The pH determines the nutrients and ions availability.

pH value	class
4 - 4.5	Extremely acidic
4.5 - 5	Very strongly acidic
5 - 5.5	Strongly acidic
5.5 - 6	Moderately acidic
6 - 6.5	Slightly acidic
6.5 - 7	Very slightly acidic
7 -7.5	Sligtly alkaline
7.5 - 8	
8 - 8.5	Moderately alkaline
8.5 - 9	Strongly alkaline
9 - 9.5	
9.5 - 10	Very strongly alkaline

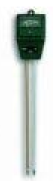


Material:
soil
1 glass pot

1 glass stick to stir
Distilled water
precision state
pH meter (paper or electrodes)

Procedure

1) take a 10g representative sample of soil.
2) use a 50ml beaker or pot where you'll add 10g of soil and 25 g of distilled water (ratio: 1:2.5)
3) stir and let stand for overnight, if you don't want to wait, have a first reading after the soil particles have deposited
4) Stir again, wait the soil particles have deposited on the bottom
5) Measure the soil pH

2. Suggested readings (literature or links):

- Soil Quality Test Kit Guide. United States Department of Agriculture Agricultural Research Service. Natural Resources Conservation Service. Soil Quality Institute. August 1999.
- CarboEurope-GHG Concerted Action. Synthesis of the European GreenHouse Gas Budget. Report 3/2004 Specific Study 2Greenhouse Gas Emissions from European Croplands.
- Larcher W. (1993). ökologie der Pflanzen. ©E. Ulmer Verlag – Stuttgart.
- Giordano A. (1998) Soil and soil conservation with focus on remote sensing. Florence, Studio Editoriale Fiorentino, Firenze.
- Sjoerd W. Duiker (2002). Diagnosing soil compaction using a penetrometer (soil compaction tester).
- Smit A.L., Bengough A.G., Engels C., Van Noordwijk M., Pellerin S., Van de Geijn A.. (2000) Root Methods A handbook. Springer.
- Agronomy Facts 63. Produced by Information and Communication Technologies in the College
- of Agricultural Sciences.© The Pennsylvania State University.
- VISUAL SOIL ASSESSMENT Based on methodology developed by Graham Shepherd1 adapted by J. Benites
- Shepherd, T. G. 2000: Visual Soil Assessment. Volume 1. Field guide for cropping and pastoral grazing on flat to rolling country. Horizons.mw & Landcare Research, Palmerston North. 84p
- Web sites:
- http://soils.usda.gov/sqi/assessment/files/test_kit_complete.pdf
- http://www.soilsensor.com/soiltypes.aspx
- www.cartage.org.lb
- http://soil.gsfc.nasa.gov/pvg/prop1.htm
- http://en.wikipedia.org/wiki/Hydrometer

- http://nesoil.com/properties/horizons/sld012.htm
- http://soils.missouri.edu/tutorial/page2.asp#d
- http://edafologia.ugr.es/
- http://www.classroomearth.org/node/180
- http://www.fao.org/
- http://www.woodrow.org/

3. Some tips or notes on things what one should pay attention to when preparing the experiment:

To measure the soil respiration you can use a Gas Analyzer connected to the cylinder (soil chamber) by a plastic tube.
Note the ppm of CO_2 at the beginning of the measurement and the ppm at the end of the measurement.

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