

Subject Area

Soil Biology | All Grade Levels

Standards Addressed

National Science Education Standards

Type of Lesson

- Hands-on
- Web based
- Outdoor
- Indoor
- Computer-based
- Experiment
- Small group exercise/discussion critical thinking

Time

Teacher prep time - 45 minutes
Student class time - 1-1.5 hours

Materials Needed

Lipton Rooibos tea bags (93% rooibos)
Lipton Green tea bags (89% green tea)
Permanent, waterproof marker
Spade or spoon
Sticks to indicate the place where the tea is buried
Scale, which should be accurate on 0.01 grams or the TBI flyer, which can be used as a scale and ordered via TBI website
Warm & sunny place for drying the tea bags
Data form to fill in your report (link on pg.3)

Required Software

Excel for calculations
Internet browser to send results to data base

Student Learning Objectives

Students will be able to understand:

- the concept of decomposition
- its relevance for soil fertility & our climate

Students will be able to explain:

- why decomposition is affected by climate conditions
- why different materials have different decomposition rates
- why soil quality is important
- why decomposition differs in different soil orders & in soils of different regions

Keywords

decomposition, soil organic matter, climate change, experiment, carbon cycle

Tea4Science

Summary

The students will use a simple method to measure decay of organic matter (plants) by making use of commercially available tea bags. The method consists of burying Lipton tea bags with Green tea and Rooibos tea, and digging them up after three months. The retrieved bags are dried, cleaned on the outside, and weighed on a balance with a minimum of two decimal places (preferably at least three). Thereafter, weight loss, decomposition rate, and stabilization index will be calculated using the collected data by the teacher or the students (if their age allows) using an Excel sheet. The students can take part in a global citizen science experiment by sending their data to the Tea Bag Index Project (in the period mid-2015 to 2018). The students will learn that (1) there is biological activity in the soils, (2) the intensity of this biological activity depends on environmental conditions, and (3) this biological activity has feedbacks that influence climate change.



Photo: Bas van de Riet

Why is this subject important

With this experiment students learn about decomposition of plant material. Decomposition is a part of the global carbon cycle and tells us about the biological activity in the soil. Decomposition is the decay of organic (plant) matter by soil microorganisms. This process releases nutrients from the organic matter that can be used by the soil organisms and plants. It also releases CO₂, which is an important greenhouse gas and that will be emitted to the atmosphere, which in turn may accelerate global warming. Therefore, this experiment is important in relation to soil quality and has relevance for climate change.

Complementary/Connectivity with Other Subjects

Links can be made with:

- Mathematics by calculating the results
- Sports by having TBI as an outdoor orienteering or geocaching activity
- Botany by learning about plant species and plant material

Where to Find the Materials

Lipton Rooibos tea: <http://www.dutchsupermarket.com/en/lipton-rooibos-tea.html>

Lipton Green tea: <http://www.dutchsupermarket.com/en/lipton-green-tea-sencha.html>

Scale: <http://www.amazon.com/Super-Digital-Electronic-Pocket-Scale/dp/B006G66ZF6>

Participants receive a 10% discount when they mention "TBI10" with their purchase.

Instead of scales the TBI flyer can be ordered (from mid-2015 to 2018, as long as it is available)

via: www.decolab.org/tbi



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Methods/Procedure

The teacher can prepare most of the work or let the students do part of the preparation themselves. Things that can be done also by the student are marked with an S, teacher activities are marked with T. If you want to study the effect of climatic conditions (temperature and moisture) on decomposition, bury the tea bags in contrasting environments (e.g., warm and cold site, or inside in a pot and outside). If you want to study the effect of different land use, bury the tea bags in different ecosystems (e.g., forest, grassland, and cropland). If you want to study the effect of different soil orders, bury your tea bags in different soils [e.g., Histosol (organic soils) and Entisol (soils of floodplains)].

1. T: For each student, or pair of student/student group, Take an unused Lipton Green tea (EAN 87 22700 05552 5) and Rooibos tea (EAN 87 22700 18843 8) bag. To obtain better estimates of TBI parameters, bury at least four sets of tea bags per site.
2. T: Print data forms for each group of students and make the calculation sheet available on the computer.
3. S: Mark/number the tea bags on the white side of the label with a permanent black marker. The yellow part will most likely disappear. The white part is plastic and writing on it is safe (if your marker is good).
4. S: Before you bury the tea, measure the weight of each tea bag using scales (minimum 0.01 g accuracy) or the TBI flyer. Fill in the weight in the data form.
5. S: Bury the teabags in 8 cm-deep, separate holes while keeping the labels visible above the soil (e.g., in nearby forest, grassland or cropland).
- T: When your class is big enough, it is possible to compare different soil orders (e.g. Histosol (organic soils), Mollisol (common grassland steppe soils), Vertisol (shrinking and swelling soils in Texas), Spodosol (common under coniferous forests), Entisol (soils of floodplains)) within the class and see which soil orders have a fast decomposition or a high stabilization.

6. S: Mark the burial site with a stick (make sure that the stick is not prone to trampling or removal by other people strolling around).
7. S: Fill in the data form: Note the initial weight, date of burial, geographical position, environmental properties (e.g., grassland, forest, agricultural land, which plants are around the burial site), and experimental conditions of the site.
8. S: Recover the tea bags after approximately 90 days (for instance over the summer holiday).
9. S: Remove adhered soil particles and dry at a dry, sunny place for at least 3 days.
10. S: Remove what is left of the label (the yellow/white square) but leave the string and weigh the bags using scales (minimum 0.01 g accuracy) or the TBI flyer.
11. S: Fill in the [dataform](#) on the site containing: Date of recovery, weight after 90 days, and other additional observations.
12. T: Calculate weight loss as percentage of the start weight. Calculate your TBI by using the Excel sheet and compare the calculated parameters. Average per location or soil order and compare (for interpretation of the TBI parameters see: background information).
13. T: If you do your experiment between mid-2015 and 2018, send the results also to tbi@decolab.org, and we will incorporate your data into a bigger dataset. In this way, your activity contributes to a real and bigger experiment.

Common Mistakes/ Troubleshooting Tips

1. The Lipton Rooibos and Green tea bags should be used for the experiment, since other material won't allow for calculation of the right parameters. Do not confuse "Rooibos tea" and "Red tea"; they are two different types. Check the EAN number. Other tea types will only show you that decomposition occurs (i.e., you will observe a weight loss in your tea bags). In case you decide to use another tea brand, you cannot calculate the TBI parameters. Make sure to use bags of non-decompos-

able material, otherwise you lose the bag because it decays and you won't be able to measure the weight loss accurately.

2. When TBI flyer is used as a scale, only use the one provided by us, do not print it yourself from the PDF provided on the website. Instructions on how to use the flyer as a scale are provided on the TBI flyer. The flyer-scale basically functions as a cantilever beam that tips from the table if the part from the table (to which you attach the tea bag) is heavier than the part that is still on the table.
3. The tea bags need to be completely dry before weighing them after the experiment.
4. If the tea bags are broken after being in the soil, it can't be used for calculating the TBI parameters. Therefore, be careful when you dig them up! If only the string was lost and no tea was lost from a hole in the bag, you can still use your bag by tying a new string to the bag (from another tea bag) or by correcting for the loss of the string by adding its weight (0.03 g) to the final weight.
5. Remember to label the tea bag on the white side of the label with a waterproof marker; otherwise the writing will be washed off during the 3-month burial time.
6. When using the TBI flyer for weighing, you will be asked for the flyer type when entering the data. The type number can be found at the bottom right corner of the flyer.
7. Keep it as an aim to have 3 months burial time, but burial lengths can vary between 65 and 100 days, in order to calculate the TBI parameters correctly. If you do not aim to calculate the TBI decomposition parameters, a minimum of 60 days will, in most climates, be sufficient to see differences in decomposition between locations. In case your location has a very hot climate, the burial time can be shorter. In case your location has a very cold climate, the burial time can be longer. More information can be found in Keuskamp et al. (2013).

Clean Up and Lab Safety

The tea bags will be treated as regular waste after the experiment. Make sure all tea bag material (including the string and label) are picked up from the burial places and put into waste after the experiment. Remember that these tea bags can't be put in a compost since they won't decompose.

Vocabulary

Decomposition - decay of plant material from more complicated structures into more simple ones.

Soil quality - the ability of the soil to function, e.g., to be able to decompose organic matter and release nutrients from it.

Carbon cycle - the route that carbon molecules make from being incorporated into plant tissue, to dead plant material on/in the soil to being released in the air after decomposition and so on.

Climate conditions - general term for weather conditions over a longer period.

Environmental conditions - any condition outside the plant that determines its growth (including weather, soil nutrient level, soil compaction).

TBI parameters - the TBI parameters are a characteristic for how much and how fast organic material is broken down.

Additional soil-related words can be found in: <http://www.soils4teachers.org/glossary>
Handouts and Worksheets

See worksheet(link below), to fill in environmental characteristics and to calculate the TBI decomposition parameters.

www.soils.org/files/s4t/tbi-calc-excel.xlsx

Discussion Questions

1. What is decomposition?

During plant growth, plants capture and fix the greenhouse gas carbon dioxide (CO₂) in various organic structures. When the plant dies, soil organisms such as fungi, bacteria, and soil invertebrates break down the dead plant material (litter) and release part of the stored carbon into the atmosphere as CO₂ (Coleman et al., 2004). During this process of decomposition, the various organic components of the litter are broken down with different rates and to a different extent (Fig. 1).

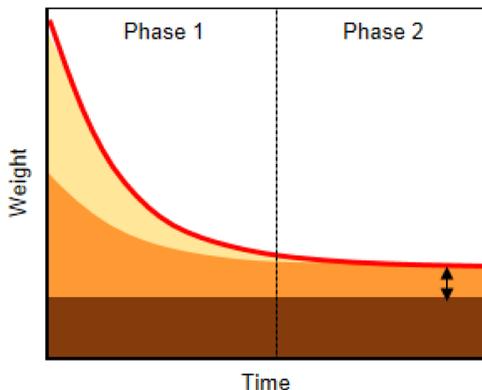


Fig. 1. Schematic of weight loss of the organic matter during decomposition. Red line indicates decomposition. Yellow part is the easily decomposable part of organic matter including sugars. The orange part is the more difficult compounds including cellulose. The brown part is the recalcitrant compounds including lignin.

The easily decomposable material (e.g., sugars) is broken down first. When this material is mostly gone, decomposition is dominated by the decay of more difficult or recalcitrant compounds (e.g., cellulose). Some labile compounds are transformed to more recalcitrant structures (they are stabilized). After some time, decomposition almost comes to a hold as only the very recalcitrant and stabilized components are left (e.g., lignin).

The decomposition process as a whole is often characterized by its initial decomposition rate and the fraction of material left when decomposition rates approach zero. The fraction of the labile fraction that is not decomposed at that moment is referred to as stabilization (Wieder and Lang, 1982). Both the decomposition rate and stabilization depend on the chemical composition of the plant material, the environmental conditions under which it is broken down, and the activity of the organisms breaking it down and the interactions among those (Hobbie, 1996; Cornwell et al., 2008; Cleveland et al., 2014).

2. Who does decomposition?

There are tens of thousands of organisms that are involved in decomposition in 1 gram of soil. They are mainly micro-organisms such as bacteria (40%) and fungi (50%). In common terms we know them as mushrooms (which are only 0.5% of the organisms in the soil), mold, and slime. Soil organisms such as fungi and bacteria do most of the decomposing but few soil animals also have the needed enzymes that would allow them to digest plant litter (Coleman et al., 2004). Worms are one of the exceptions as they are very important decomposers. One square meter of soil can contain up to 1000 earthworms (Coleman et al., 2004). However, these larger organisms cannot pass through the mesh of the tea bags, so that you will only see the influence of micro-organisms.

3. What is organic matter?

What happens with an apple when you throw it away? What about chewing gum? Have you ever found a leaf where you only saw the veins? Are the differences between these different materials? If so, why?

Organic matter in the soil originates primarily from dead plant remains (litter) and the microbial biomass on this litter. It consists of many different compounds with varying structure, content, and recalcitrance (Kögel-Knabner, 2002). The dead plant material consists of aboveground (e.g., leaves) as well as belowground (roots) structures and everything the

plant loses or leaks (roots leak a lot of substances). Organic material in the soil includes the elements carbon (C) (50%), oxygen (O) (40%), nitrogen (N) (3 %), and small amounts of phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg), and micronutrients are also present. People generally classify organic material into three different categories based on rate of decay (von Lützow et al., 2008): (i) labile or active (decays within 1 to 2 years, e.g., apples and the pulp in between the veins of the leaf); (ii) intermediate (10 to 100 years, e.g., the stalk of the apple, a branch); and (iii) slow (100 to >1000 years, e.g., banana and orange peels, chewing gum).

When you throw away an apple it starts to decompose, it has a lot of sugars (that's why they are so nice to eat) and these will be decomposed fast. A chewing gum is a synthetic rubber product, a polymer, and therefore will not decompose. It most likely will stick to the surface that it has been disposed on and it will gradually wear off into microscopic tiny pieces.

4. Why does Green tea break down faster than Rooibos tea?

Because Green tea and Rooibos tea are made from different materials that differ in the degree to which decomposers are able to handle them. Green tea is leaf material and consists of more easily degradable material compared with Rooibos tea, which is woody (Keuskamp et al., 2013).

5. Discuss why decomposition occurs at different speed in different environments?

Factors that slow down the activity of decomposers include cold, acidity, and drought. These conditions slow down decomposition. Warm and moist conditions are more suitable for most decomposers; thus, they become more active. These conditions will speed up decomposition. Think of what conditions you find favorable to be active. Could you run a marathon when it is too cold or too hot, or too dry or too wet?

6. Discuss what soil quality is, and how it affects decomposition.

Soil quality is the collective term to give a general description of soils and it is based on soil chemical, physical, and biological properties including nutrient content, aggregate stability, soil organic matter content, and richness and number of earthworms. Soil quality is thus defined as its suitability for use by humans (Larson and Pierce, 1991). A high-quality soil makes plants grow fast and healthy, it maintains or enhances water and air quality and supports human health when, e.g., soil erosion is low and, thus, unhealthy levels of dust are not generated (Doran et al., 1994; Karlen et al., 1997).

7. How can humans affect decomposition? How will that affect our climate?

Any activity that affects decomposer activity affects decomposition. For example, human-induced global warming may enhance decomposition rates, fertilization of agricultural fields by humans may increase decomposition rates, trampling by cattle decreases decomposition rates by making the soil more compact and less favorable for decomposing microorganisms, and drainage of fields affects decomposition rates. In peaty areas, the latter may also cause soil subsidence.

8. What would happen if there were no decomposition at all?

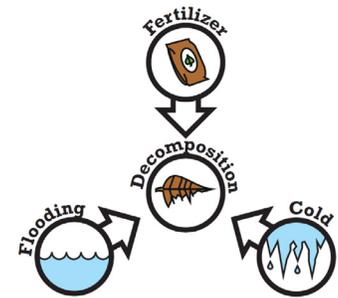
Without decomposition, organic matter will increase and accumulate in the soils. This would also mean that the nutrients in this organic material will not be made available to plants again. Plants would eventually die because they do not have enough food.

Evaluation/Assessment

1. What is decomposition?

See answer above. A good video on carbon cycle can be watched here <http://epa.gov/climatestudents/basics/today/carbon-dioxide.html>, after which the students can practice drawing the carbon cycle and indicating where the decomposition occurs.

2. In the picture below, discuss why decomposition occurs at different rates/speed in different environments.



Extra nutrients—will increase decomposition, microorganisms/soil organisms have more resources to also degrade the more recalcitrant material.

Flooding—will decrease decomposition. Microorganisms also need to breathe.

Cold—will decrease decomposition. It costs a lot of energy to decompose material when it is cold; thus, microorganisms are less active when it is cold.

3. How is decomposition linked with climate change?

When plant material decomposes it releases the greenhouse gas carbon dioxide (CO₂) into the atmosphere. Carbon dioxide is a gas that causes global warming. When it is warmer, decomposition will increase, releasing more carbon dioxide into the air. It is therefore very important to understand the relation between decomposition and temperature.

4. How many years does it take for the following items to decompose?

Newspaper (6 weeks), apple core (2 months), orange peels (6 months), banana peel (3 to 4 weeks), cigarette butts (10 to 12 years), plastic bottle (450 years), aluminum can (200 to 500 years), plastic bag (20 to 1000 years), glass (1 to 2 million years). Most plastic things don't really decompose, but they are broken down into microscopic, small particles.

Background Information

Why is this subject important - Decay of organic matter, decomposition, is the breakdown of plant and other organic material. Decomposition is a critical process for life on Earth. Through decomposition, food becomes available for plants and soil organisms that they use in their growth and maintenance. When plant material decomposes, it loses weight and releases the greenhouse gas carbon dioxide (CO₂) into the atmosphere. In cold environments, breakdown is slower than in warm environments, meaning more carbon is stored in the soil and less CO₂ is released. The speed of decomposition of plant material is determined by:

- Environmental conditions (moisture content, acidity, nutrient content).
- The chemical composition of the material that needs to be broken down (wood vs sugars).
- The presence of decomposers (organisms that are involved in the break down, like mites, worms, fungi, bacteria. Different organism groups specialize in different materials and make them available for others).

The amount of CO₂ in the air is the balance of what plants take up and what decomposition releases. As CO₂ causes the atmosphere to warm, changes in decomposition can affect the climate. Especially because the soil contains an enormous amount of carbon. In order to understand global CO₂ emissions from soils, it is important to know more about decomposition in different kinds of soils. Such an insight would enable scientists to improve climate models that calculate current and future CO₂ fluxes. Efforts have already been taken to map global soil and climate conditions; however, an index for decomposition rate is still missing. Many people have tried to estimate decomposition and the relation between decomposition and environment, but in order to understand global decomposition, we need more information on the relation between decomposition and climate from around the world. As previous methods to measure decomposition required a lot of work, predictions on the relations between soil and decomposition are often imprecise. Using tea bags to measure decomposition is much easier compared with previous methods where the bags needed to be made manually.

By burying two types of tea with different decomposition rates, we obtain information on how much and how fast plant material is broken down. By calculating the decomposition rate constant k , the speed of the decomposition can be investigated. Values for k vary approximately between 0.01 and 0.04, being the highest in the warmest climate and lowest in the coldest climate (Keuskamp et al., 2013). The stabilization factor, S , gives us an estimate of how much of the organic matter will be staying in the soil, without being decomposed. In our studies, S values ranged between 0.05 and 0.6, decreasing when temperature and precipitation gets higher (Keuskamp et al., 2013).

The grade level can be decreased by making it to an outdoor activity where the tea bags can be found through a search route, e.g., make a route on geocaching. The teacher has buried the tea 3 months before the activity. The main aim is then to learn that decomposition happens (i.e., that it causes plant material to disappear). By seeing the difference in weight between new and buried tea bags the children will see it. The type of tea bag does then not matter so much, as long as the bag itself is plastic. We would, however, highly appreciate if the teacher would take the effort to find the real tea and provide us with a new data point.

During the hike/search route, the questions can be put on a paper displayed at certain locations and children have to answer them while walking.

For instance:

1. Rank the following items in their speed of decay.

Newspaper (6 weeks), apple core (2 months), orange peels (6 months), banana peel (3 to 4 weeks), cigarette butts (10 to 12 years), plastic bottle (450 years), aluminum can (200 to 500 years), plastic bag (20 to 1000 years), glass (1 to 2 million years)

2. Collect a leaf in different stages of decay.

3. A mushroom is an organism that eats organic material. Which part of the mushroom "eats"?

- a. Cap
- b. Roots which for mushrooms are called Hyphae (right answer)
- c. The seeds of a mushroom which are called spores

4. What gas is released by decay?

- a. Oxygen
- b. Hydrogen
- c. Carbon dioxide (right answer)

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5. What is a good quality soil?

Soil that has decomposition, is not compacted, has not too many nutrients, and does not smell bad. Soil that is of good quality can sustain soil functions so that plants can grow well, maintain or enhance water and air quality and support human health and habitation.

6. Circle which plant is Rooibos and which is green tea.

(Rooibos: 1st from the left first row, Green: 3rd from the left first row)



Photo credits (L to R: 1-http://en.wikipedia.org/wiki/Rooibos#mediaviewer/File:Rooibos_%28Aspalathus_linearis%29.jpg, 2-Taru Lehtinen, 3-<http://www.getwellnatural.com/images/view.aspx?productId=112>, 4- Hans Göransson, 5-Taru Lehtinen, 6-Hans Göransson)

7. Organisms that are doing the decay are extremely small and extremely big. How many kinds of soil organisms are there in 1 gram of soil?

- 100 to 500
- 5,000 to 10,000 (correct answer)
- 25,000 to 50,000

8. Which one of the following organisms is NOT involved in decay (they are all involved):

Mite, earthworm, insects, bacteria, fungus, ants, human.

The grade level can be upgraded to a higher level by letting the group do small experiments in which they test the effect of changed environmental conditions. For instance, the effect of temperature can be tested by putting a (clear) plastic ring of a soda bottle around the tea bag burial place and compare it to one set buried without the plastic ring. The plastic ring will increase temperature of the soil inside the ring. Other environmental conditions that can be altered are: 1) acidity: apply vinegar locally; 2) soil moisture: place a fume above the place of burial that doubles the amount of rain falling on the place where the tea bags are buried; 3) apply fertilizer; 4) compacted versus uncompacted soil; 5) compare soils with a lot of organic material (Histosol (organic soils)) and soils without organic material (Aridisol (soils of deserts)); 6) any other environmental characteristics that come up in the interest of the students.

The grade level can also be upgraded by measuring more complex soil and environmental characteristics including:

- Soil moisture (weigh a tablespoon of soil before and after 1 week of drying, then calculate moisture content% = $\frac{[(\text{weight of wet soil} - \text{weight of dry soil}) / \text{weight of wet soil}] \times 100\}$)
- Soil texture (follow guidelines in <http://cmase.pbworks.com/f/Soil+Texture+By+Feel.pdf>)
- Precipitation (make a rain gauge: <http://www.metoffice.gov.uk/education/kids/things-to-do/weather-station/rain-gauge>)

The grade level can also be upgraded by including a control experiment for degradation of nylon bags during burial. For this, empty tea bags should be buried together with the normal ones. Following the protocol, the empty tea bags are also weighed after drying. The results will then facilitate a discussion on what happens to artificial polymers, i.e., plastic in the environment.

Potential Careers

Soil scientists

Soil and climate modelers

Global soil map

Environmental centers

Policy makers

Farmers could assess soil health of their fields by using this method

References

The material is based on a scientific article that has been published from the same authors:

Keuskamp, J.A., B.J.J. Dingemans, T. Lehtinen, J.M. Sarneel., and M.M. Hefting. 2013. Tea Bag Index: A novel approach to collecting uniform decomposition data across ecosystems. *Methods in Ecology and Evolution* 4(11):1070-1075.

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Additional Resources

Project web page: www.decolab.org/tbi/

Facebook: www.facebook.com/teabagindex

Twitter: twitter.com/TeaBagIndex

Carbon cycle: epa.gov/climatestudents/basics/today/carbon-dioxide.html

Decomposition: en.wikipedia.org/wiki/Decomposition

Soil fertility: www.soils4teachers.org/fertility

Soil orders according to U.S. Soil Taxonomy: www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/edu/?cid=nrcs142p2_053588

www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_051232.pdf

Soils 4 Teachers: www.soils4teachers.org

Know Soil, Know Life: www.soils4teachers.org/know-soil-know-life

Soil texture determination by feel: cmase.pbworks.com/f/Soil+Texture+By+Feel.pdf

How to measure precipitation: www.wikihow.com/Measure-Rain

How to measure soil moisture: www.ext.colostate.edu/drought/soilmoist.html

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