

EXPERIMENTS

Leaf it alone: are falling leaves a burden or an economic and ecological windfall?

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ABSTRACT

Students estimate the amount of nitrogen in fallen leaves using field-collected leaves and nitrogen content values from the scientific literature. Students then estimate the cost of replacing the nitrogen content of the leaves with chemical fertilizers should the leaves be raked and removed. The overall experiment is flexible but will generally take three class periods distributed throughout the fall semester. Activities include building and deploying leaf litter traps, collecting and drying leaves, identifying trees, and performing calculations.

KEYWORD DESCRIPTORS

- **Ecological Topic Keywords:** Biogeochemical cycles, nitrogen cycle, human impacts, forest ecology, ecological economics, sustainability
- **Science Methodological Skills Keywords:** Classification, field work, library research, quantitative sampling, random sampling, use of primary literature
- **Pedagogical Methods Keywords:** Guided inquiry, problem-based learning

CLASS TIME

Varies depending on how the experiment is performed and the level of students. However, you should devote approximately 1 hour for the introduction and setup of the leaf litter traps early in the fall and 1.5 hours in late fall after leaves have fallen from the trees. You will need an additional hour of class time if you plan to have students build the litterfall traps, and an additional 20 minutes of class time if students are to find their own literature sources for nitrogen content values.

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OUTSIDE OF CLASS TIME

Varies, however I would recommend an additional 1 hour of time outside of class.

STUDENT PRODUCTS

Students will fill out a worksheet that leads them through data collection and calculations and can address further application questions.

SETTING

Timing and location are essential for this study since you will be capturing leaf fall. Assuming deciduous trees are prevalent on campus, choose an area that is mostly representative of your campus grounds. I would recommend placing litterfall traps out early in the fall at the beginning of the month and then collecting leaf litter at least every 2 weeks. Ideally you will collect leaf litter throughout the fall until few leaves remain on the tree. Additional lab work includes sorting the litter, drying the litter in a drying oven (if available), and then weighing the dried leaves on a balance.

COURSE CONTEXT

This experiment was performed in an introductory, non-majors environmental science lab consisting of approximately 20 students. However, the activity could be adapted for an ecology lab or advanced ecological or environmental course with incorporation of data analysis from NEON field sites.

INSTITUTION

This activity was originally taught at a small, 4-year undergraduate institution.

TRANSFERABILITY

The activity was originally designed for a single lab section. However, it could be adapted to work across multiple lab sections if different areas on campus were sampled. Alternatively, the steps required could be divided and data pooled. Geography and campus terrain may limit the use and accessibility of this experiment.

ACKNOWLEDGEMENTS

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SYNOPSIS OF THE EXPERIMENT

Principal Ecological Question Addressed

- 1) How much nitrogen is cycled back onto the land-surface through leaf-fall; and
- 2) Is it environmentally and economically sustainable to collect leaves from a lawn in the fall?

What Happens

Students sample litterfall by building and/or deploying litterfall traps to estimate the nitrogen content of the fallen leaves and the ecological and economic costs associated with removing leaves from a lawn.

Experiment Objectives

At the end of the unit, students will demonstrate:

1. Random sampling techniques
2. Use of technological resources
 - Google Earth for study area dimensions
 - Google Scholar for finding N content of litter by species
3. An understanding of common tree species and basic tree identification
4. The ability to convert units and perform basic mathematical calculations

Equipment/ Logistics Required

PVC pipe and elbow fittings, window screening, zipties, short sections of rebar for anchoring PVC litterfall traps, paper litter bags, balances, drying oven (optional)

Summary of What is Due

Students complete a [worksheet](#) that leads them through data collection and calculations and can address further application questions.

DETAILED DESCRIPTION OF THE EXPERIMENT

Introduction

The common fall practice of raking up leaves and sending them to the landfill (or alternatively to a compost facility) exports important nutrients that on-site turfgrass, trees, and other plants need for growth and maintenance. Some of the most important nutrients that plants require for growth and maintenance are nitrogen and phosphorus (Chapin et al. 2011). These nutrients are taken up by the deciduous tree during the growing season and used to form new biomass and to harness the sun's energy.

Come autumn, some of the nutrients contained in a leaf are cycled back to the tree in a process called resorption (Hagen-Thorn et al. 2006). However, nitrogen, phosphorus, and carbon still remain in the senescing leaf, and these nutrients fall to the ground when the leaves undergo abscission (leaf shedding). The concentration of nutrients in the leaves following abscission varies by tree species (Ostrowsky 1997).

Leaves falling on the ground will eventually decompose, slowly freeing up the nutrients contained in the leaf litter which can then be captured by other organisms including bacteria, archaea, fungi, and plants (including the grasses that make up most lawns and the trees that shed their leaves the previous year). Some of the fallen leaf material may be made up of compounds that resist decomposition. Therefore the nutrients contained in these resistant compounds may not be available to other organisms for an extended period of time. Other resistant compounds will become humus. Humus improves the texture and water holding capacity of the soil and is also important for carbon sequestration (Chapin et al. 2011).

In this activity, you will work to determine how much nitrogen is lost from an area on campus if fallen leaves are raked up and removed in the fall. Additionally, you will work to calculate the economic costs of replacing any lost nitrogen with a chemical fertilizer so as to maintain normal growth. Note, however, that any chemical fertilizers applied will not replace other important nutrients that may be lost with the leaves, particularly carbon and micronutrients.

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Materials and Methods

Study Site(s):

Any site with deciduous trees and turfgrass could be studied in this activity. The activity could also be altered slightly to focus on nitrogen cycling in a deciduous forest as opposed to an urban or suburban lawnscapes.

Overview of Data Collection and Analysis Methods:

Week 1:

1. Build elevated litterfall traps out of PVC, window screening and zip ties
2. Deploy litterfall traps

Weeks 2-4:

1. Collect leaves from traps weekly and place in labeled drying bags. Place bags in drying oven or leave at room temperature if drying oven not available. Depending on moisture content, mass, and drying method, drying times will vary.

Once all leaves have fallen and are dry:

1. Sort litter materials into several units
 - a. Leaves- sort by species
 - b. Twigs, fruits, bark
2. Mass the materials within each unit
3. Using the leaves, estimate the total N content (in grams) of the samples by multiplying the mass of each species' leaves by the corresponding N content (%) obtained from Ostrofsky (1997). If a species is not listed in Ostrofsky (1997), use the average N content across all species.
 - a. What is the average N content (grams) per m² for our study area? _____
 - b. What is the variability (standard deviation) in N content across our study area? _____
4. Estimate the cost of replacing the N content of the leaves with fertilizer should the leaves be removed

- a. If the cost of a 12 kg container of 20-0-0 fertilizer (N-P-K; means 20% N by weight) is \$23 at Tractor Supply (<https://www.tractorsupply.com/tsc/product/gordons-liquid-lawn-pasture-fertilizer-20-0-0-with-micronutrients-2-1-2-gal>), what is the cost per gram of N? _____
- b. Our study area is _____ m²
- c. What is the cost to replace N lost if leaves are removed from our study area? _____
- d. Our campus area is _____ m²
- e. What is the estimated cost to replace N lost if leaves are removed from across campus? _____

Questions for Further Thought and Discussion:

1. What are some issues with the way we sampled litterfall? Why don't we just sample all leaves that fall on campus grounds?
2. What are some issues in using our sampled study area to estimate the nitrogen content of leaf fall across campus? How could our estimate be improved?
3. Does the nitrogen content of each species vary from tree to tree and regionally?
4. If leaves are left on the ground or "mulched" using a mower, what happens to the nitrogen and carbon they contain? Besides influencing turfgrass productivity, might this also have an effect on the productivity of the trees in the area?
5. For this experiment we focused on nitrogen, but what else is in litterfall that would hinder turfgrass or forest productivity if removed?
6. Why do people remove leaves from their turfgrass lawns? Where does this material go?
7. Another potentially large source of nutrient loss, in particular nitrogen, can occur through the mowing, collection, and disposal of grass clippings. How would you estimate how much nitrogen or carbon is removed from a turfgrass ecosystem on an annual basis?
8. Ecosystem services are benefits to humans provided by ecosystems. Do turfgrass lawns provide ecosystem services?

References

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Helpful Links

National Ecological Observatory Network litterfall and fine woody debris protocol and procedure:

<http://data.neonscience.org/api/v0/documents/NEON.DOC.001710vE>

National Ecological Observatory Network: <https://www.neonscience.org/>

Tools for Assessment of Student Learning Outcomes:

Performance is based on the completion of the provided [worksheet](#). The worksheet is graded for completeness and accuracy.

NOTES TO FACULTY

Challenges to Anticipate and Solve

1. As with any activity at an introductory level that requires performing calculations, students need plenty of encouragement. The activity as written has a few more steps included to help students work through the calculations on their own. This activity was designed for non-science majors so you may be able to shorten these steps to challenge your group of students.
2. I have not provided dimensions for the leaf litter traps intentionally. You will want to build them to suit your site and budget. The National Ecological Observatory Network (NEON) uses 0.5 m² elevated litter plots that are 70 cm X 70 cm squares and elevated 0.8 m above the ground surface (National Ecological Observatory Network 2017). You do need to make sure that you or the students cut the window screening so that it is large enough to form a deep basket. Otherwise, captured leaves can easily blow out of the trap. It also helps to routinely collect litter and to gently place baseball sized rocks in the mesh basket.
3. Our leaf litter traps were placed in a very busy area on campus. While we did not have any issues with theft or tampering over several months, this may be an issue. I recommend again checking the traps frequently and also having a few spare traps ready to go in case your traps disappear. Additionally, I had the students produce laminated signs to accompany the traps to accomplish 3 things: 1) practice their written communication skills for a general audience; 2) educate the community about our study; and 3) hopefully reduce tampering.

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Comments on Introducing the Experiment to Your Students:

Introduce students to the topic of nutrients, litterfall, and lawn maintenance (Approx. 20 minutes)

1. Ask students and discuss: What happens if leaf and other litter is removed from a lawn
2. Discuss the importance of nutrients and organic material for soil health
 - a. This module is focused heavily on nitrogen, but could expand to look at other nutrients as well
3. Discuss how the nutrients removed in leaf litter (and other materials to be discussed later) are commonly replaced with fertilizer applications
4. Discuss potential issues associated with fertilizer application
 - a. Issues include:
 - i. Costs of fertilizers
 - ii. Potential for runoff
 - iii. Issues associated with the production of fertilizers

Comments on the Data Collection and Analysis Methods:

Below is an annotated description of the activity from section 3 with comments and answers provided whenever possible in italics.

Week 1:

1. *(Optional) Build elevated litterfall traps out of PVC, window screening and zipties (Approx. 70 minutes)*
 - a. *Break students up into 4 groups and rotate through the following stations*
 - i. *Station 1: Cutting of PVC*
 - ii. *Station 2: Cutting of window screening*
 - iii. *Station 3: Assembly of units*
 - iv. *Station 4: Production of educational signage*
 - b. *Alternatively, you could prebuild the litterfall traps and skip this step*
2. Deploy litterfall traps *(time varies- see options below)*

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- a. *Litterfall traps are deployed in a number of different configurations depending on sampling area, plot size, time, and level of the class. This is a great opportunity to discuss the pros and cons of random versus stratified sampling and how each approach could be employed. I recommend directly measuring the sampling area and dividing up into plots. You can then select which plots to sample from using a random or stratified method.*

Weeks 2-4 (may take longer than 4 weeks depending on weather, location, and tree species):

1. Collect leaves from traps weekly and place in labeled drying bags. *This could be done as a class or by the instructor or TA. Place bags in drying oven or leave at room temperature if drying oven not available. Depending on moisture content, mass, and drying method, drying times will vary.*

Once all leaves have fallen and are dry:

1. Once dry, sort litter materials into several units (30 minutes)
 - a. Leaves- sort by species (*note: this will be easier with fresh leaves, however it is generally not too challenging with dried leaves and takes up less time to do it all at once during this class period*)
 - b. Twigs, fruits, bark
2. Mass the materials within each unit (10 minutes)
 - a. Using the leaves, estimate the total N content (in grams) of the samples by multiplying the mass of each species' leaves by the corresponding N content (%) obtained from Ostrofsky (1997). If a species is not listed in Ostrofsky (1997), use the average N content across all species. *Depending on time and level of class, students could be asked to find the Ostrofsky (1997) article and locate the relevant information in the document (located in Table 1 of Ostrofsky (1997)), or could be provided with the resource or relevant N concentrations. Alternatively you could directly measure N content if you have the capability and time.*
 - b. What is the average N content (grams) per m² for our study area? _____

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- c. What is the variability (standard deviation) in N content across our study area? _____
 - i. *Make sure to account for the area of your plot, then take the average of the plots.*
3. Estimate the cost of replacing the N content of the leaves with fertilizer should the leaves be removed (could take place during class or outside of class as homework; Approx. 30 minutes)
 - a. If the cost of a 12 kg container of 20-0-0 fertilizer (N-P-K; means 20% N by weight) is \$23 at Tractor Supply (<https://www.tractorsupply.com/tsc/product/gordons-liquid-lawn-pasture-fertilizer-20-0-0-with-micronutrients-2-1-2-gal>), what is the cost per gram of N? _____
 - i. *Answer: \$ 0.0095 /g N*
 1. *Rounding up means each gram of N costs a penny*
 - b. Our study area is _____ m²
 - i. *Could be directly measured or estimated using Google Earth*
 - c. What is the cost to replace N lost if leaves are removed from our study area?
 - i. *Answer: Multiply the cost of N in \$/g N from above by the study area*
 - d. Our campus area is _____ m²
 - i. *Could be estimated from Google Earth or campus documentation*
 - e. What is the cost to replace N lost if leaves are removed from across campus?
 - i. *Note and discuss the major assumption here in this estimate- that litterfall and nutrient contents are homogeneous across campus*

Comments on Questions for Further Thought:

1. What are some issues with the way we sampled litterfall? Why don't we just sample all leaves that fall on campus grounds?

- *Unless you have a very small campus or a lot of time and resources, you will need to collect samples. It is important to acknowledge however, that our data for the campus area are estimates as they may not necessarily represent the conditions across campus. This strategy adds error but saves time and resources. The sampling strategy you choose is always going to be a balance between these aspects.*
2. What are some issues in using our sampled study area to estimate the nitrogen content of leaf fall across campus? How could our estimate be improved?
 - *This question relates to the previous question. The important thing to convey is that there is undoubtedly variability in leaf fall and nitrogen content across campus. The more samples you can collect, the better your estimate will be.*
 3. Does the nitrogen content of each species vary from tree to tree and regionally?
 - *Again, this question gets at the variability in our samples and across campus. Ideally, we would be able to measure the actual nitrogen content of our leaf-litter samples to account for some of this variability. If you have the capacity to do this in your lab or in a colleague's lab, that would be ideal as nutrient content will vary from leaf to leaf depending on the environmental conditions at the tree and leaf scales. In particular the size, location, and orientation of the leaf can impact the amount of nitrogen due to variations in pigment content and exposure to nutrient leaching processes such as throughfall. Additionally, soil conditions and fertilization of the campus grounds may lead to elevated nutrient concentrations in the leaves and/or altered decomposition rates.*
 4. If leaves are left on the ground or "mulched" using a mower, what happens to the nitrogen and carbon they contain? Besides influencing turfgrass productivity, might this also have an effect on the productivity of the trees in the area?
 - *This question is designed to connect with the material at the beginning of the activity. Essentially, the mulching process will speed up decomposition and return the nutrients to the soil where they can then be taken up by other organisms. Some of the nutrients may leach from the soil into waterways or be lost in gaseous forms.*
 5. For this experiment we focused on nitrogen, but what else is in litterfall that would hinder turfgrass or forest productivity if removed?
 - *Nitrogen, phosphorus, carbon, potassium, sulfur, magnesium, calcium, and many other nutrients are contained in the leaf*

matter. Therefore their removal can reduce the fertility of the soil and the growth of the plants in the area.

6. Why do people remove leaves from their turfgrass lawns? Where does this material go?
 - *This is really an open-ended question that gets at cultural norms.*
7. Another potentially large source of nutrient loss, in particular nitrogen, can occur through the mowing, collection, and disposal of grass clippings. How would you estimate how much nitrogen or carbon is removed from a turfgrass ecosystem on an annual basis?
 - *The removal of grass clippings represents a huge loss of nitrogen and other nutrients from an area. This question is designed to reinforce this point but also to force students to work through the experimental design process with a slightly different question.*
8. Ecosystem services are benefits to humans provided by ecosystems. Do turfgrass lawns provide ecosystem services?
 - *This question is designed so that students can start thinking about urban and suburban spaces in a different light. We typically think of heavily disturbed or designed sites such as lawns as “bad” and native grasslands as “good”. While they may be less diverse than natural areas, turfgrass lawns can provide substantial ecosystem services if designed and maintained properly. For example, turfgrass can help to reduce the urban heat island effect, reduce stormwater flows (assuming soil is not too compacted), and provide aesthetic benefits. It can also serve as habit and food for insects and birds.*

Comments on the Assessment of Student Learning Outcomes:

As a reminder, the following items are the learning outcomes for the activity.

- At the end of the unit, students will demonstrate:
 1. Random sampling techniques
 2. Use of technological resources
 - Google Earth for study area dimensions
 - Google scholar for finding N content of litter by species

3. An understanding of common tree species and basic tree identification
4. The ability to convert units and perform basic mathematical calculations

The worksheet effectively tracks success on objectives 1-4. However, because students work in groups for this activity, students may be able to successfully complete the worksheet and presentation without actually demonstrating the learning outcomes. Participation is therefore essential to assess throughout the activity. If participation is not assessed on a regular basis for the course, it may be beneficial to include participation in the assessment for this activity.

Comments on Formative Evaluation of this Experiment:

The experiment requires substantial hands-on work, with many opportunities for evaluating progress. Opportunities include during the experimental planning process, completing the worksheet calculations, and building formulas in a spreadsheet. These activities also take place over an extended period of time and therefore offer opportunities for frequent formative evaluations. I find activities like an exit ticket with a muddiest point useful.

Comments on Translating the Activity to Other Institutional Scales or Locations:

- (1) The experiment could be expanded to multiple locations across campus
- (2) The activity requires deciduous trees and the appropriate timing to capture leaf fall.
- (3) The activity is accessible as long as the campus locations for collecting leaf fall are accessible.
- (4) As currently designed, this activity could be used with a younger audience but I would recommend simplifying the activity to help with the calculations.

Comments on Extending the Activity for More Advanced Data Courses:

After assessing the nitrogen dynamics of your site, you could have students contrast their data with leaf fall data in a mature forest. Data is obtainable from several mature forests that are routinely sampled for a variety of different ecological metrics in the U.S. as a part of the National Science Foundation's (NSF) National Ecological Observatory Network (NEON). You could discuss how

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your study area is relatively sparsely populated by trees compared to a typical forest (assuming this is the case), and then ask for students to predict the magnitude of nitrogen deposited in litter in a dense forest. You could then:

- 1) Discuss why it would be important to understand the amount of nutrients that are falling each year in a forest
- 2) Briefly discuss NEON, showing the NEON site map and some of the variables measured at the sites
- 3) Briefly discuss the NEON sites of interest. It is great to use nearby sites, but check to make sure data is available at your site of interest.
- 4) Have students access data from the NEON data portal or provide students with a spreadsheet file or for a more advanced class you could perform analyses in R/RStudio. You will need to access the “Litterfall and fine woody debris sampling” and “Litter chemical properties” data products for your chosen sites. The following resources will be helpful for you and the students for this activity extension:
 - a. National Ecological Observatory Network Data Portal:
<https://data.neonscience.org/home>
 - b. National Ecological Observatory Network field sites and map:
<https://www.neonscience.org/about-neon-field-sites>
 - c. National Ecological Observatory Network litterfall mass data product and collection documentation:
<https://data.neonscience.org/data-products/DP1.10033.001>
 - d. National Ecological Observatory Network litterfall chemical properties data product and collection documentation:
<https://data.neonscience.org/data-products/DP1.10031.001>

The downloaded data will include a zip file for each site on each date. So, limiting the number of sites and date range at the beginning of the search will be helpful. If also using the litter chemistry data, make sure that both litter mass and litter chemical properties data are available for each site and sampling date. Within a particular zip file will be a spreadsheet with mass or litter chemistry data. The filename includes the phrase “ltr_massdata.” for litter mass data and “.ltr_litterCarbonNitrogen.” for carbon and nitrogen litter content data. To focus on leaf litter mass, students will need to sort or filter the data for records with the label “Leaves” in the “functionalGroup” column and use the data from the “dryMass” column.

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