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Going underground to investigate carbon locked in soils

Featured scientist: Ashley Lang from Indiana University

Research Background:

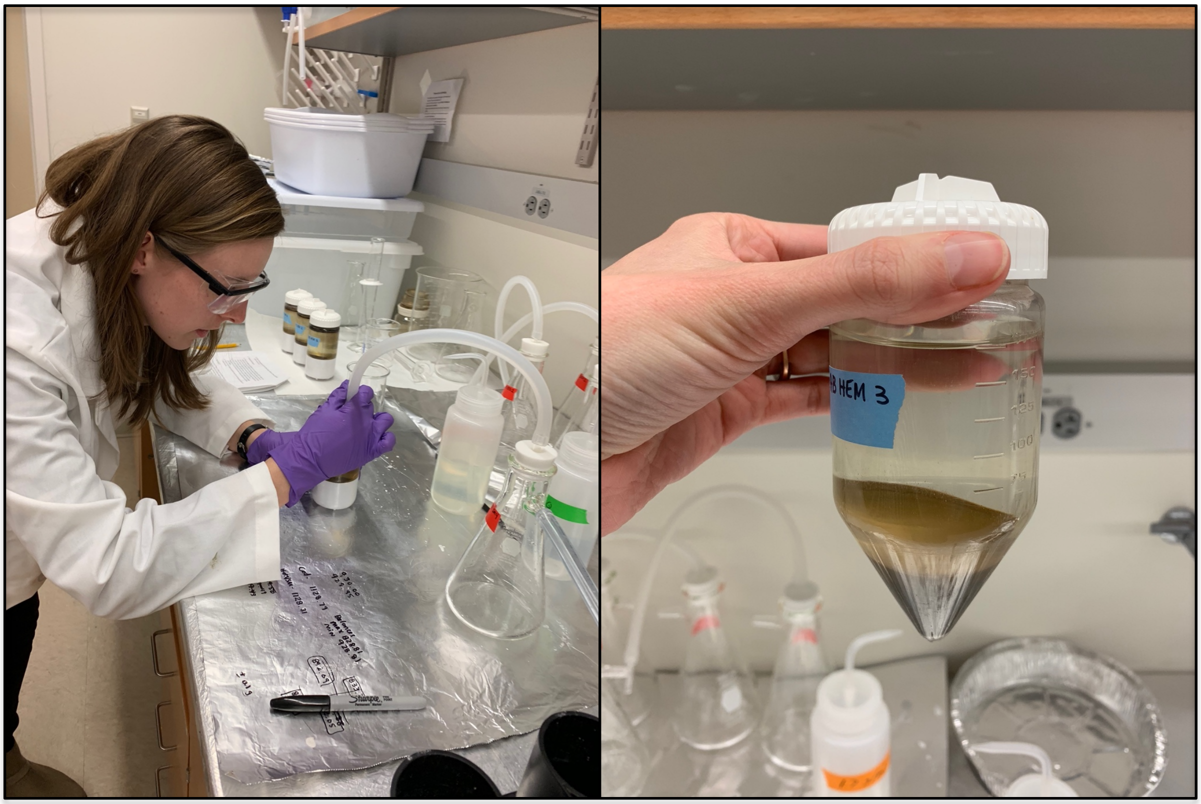
Soil is an important part of the carbon cycle because it traps carbon, keeping it out of the atmosphere and locked underground. At a global level, the amount of carbon stored by soil is more than is found in all of the plants and the atmosphere combined. Carbon trapped underground does not contribute to the rising carbon dioxide concentration in our atmosphere that leads to climate change. For decades, scientists have been researching how much carbon our soils can store to understand its role in slowing the pace of climate change.

Carbon enters the soil when plants and animals die, and their organic matter is decomposed by soil bacteria and fungi. Sometimes it is broken down into very small molecules. These molecules become attached to minerals in the soil, like clay particles. We call this **mineral-associated organic matter (MAOM)**. The carbon is connected to minerals with very strong chemical bonds. Because these bonds are hard to break, the carbon stays in the soil for long periods of time and accumulates on clay minerals.

Some studies have shown that the carbon in MAOM can be trapped in soils for thousands of years! When more of the carbon in the soil is attached to minerals and locked in the soil for longer time periods, the ecosystem is serving an important role in keeping carbon out of the atmosphere.

Ashley is working to understand how much stable carbon there is in soils, and the role of climate. Microbes work faster in warmer and wetter conditions, which results in quicker decomposition. Ashley thought this rapid decomposition would cause organic matter to be broken down into smaller particles sooner. Therefore, she thought that in warmer or wetter environments, more soil carbon would attach to minerals and become stable MAOM. In colder or drier environments, she expected this process to happen more slowly, leading to a smaller amount of MAOM in the soil.

To test these ideas, Ashley used soil samples from forests with different climates throughout the Eastern United States. Soil samples were collected from New Hampshire to Alabama by teams of researchers using the same sampling protocol. The samples were mailed to Ashley's lab at Indiana University for analysis. Ashley measured the amount of MAOM in each soil sample by taking advantage of a key feature: MOAM is heavy! Ashley submerged each soil sample in a saltwater solution, and the parts that floated were discarded, while the parts that sunk to the bottom were classified as MAOM. She then rinsed the salt off and measured the amount of carbon in the MAOM with an instrument called an elemental analyzer. She compared this number to the amount of carbon in the whole soil sample to calculate what percentage of the total soil carbon was attached to minerals.



(Left) Ashley in the lab, using a saltwater solution to isolate mineral-associated organic matter (MAOM) from soil samples. (Right) MAOM at the bottom of a test tube in a salt solution.

Scientific Question: How does an ecosystem's climate affect the percentage of soil carbon stored as mineral-associated organic matter (MAOM)?

What is the hypothesis? Find the hypothesis in the Research Background and underline it. A hypothesis is a proposed explanation for an observation, which can then be tested with experimentation or other types of studies.

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Scientific Data:

Use the data below to answer the scientific question:

Site	Mean Annual Temperature (C)	Mean Annual Precipitation (mm)	Mean Percent of Carbon in MAOM	Standard Deviation (Mean Percent of Carbon in MAOM)
New Hampshire	6.2	1325	76.7	8.1
Alabama 1	17.6	1372	83.2	3.5
Alabama 2	18.1	1386	85.2	5.8
Massachusetts	7.4	1199	77.7	6.6
Tennessee	14.4	1340	77.2	9.5
Maryland	13.6	1075	84.3	7.1
Wisconsin	4.8	797	78.6	9.4

What data will you graph to answer the question?

Independent variable(s): ____

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Dependent variable(s): ____

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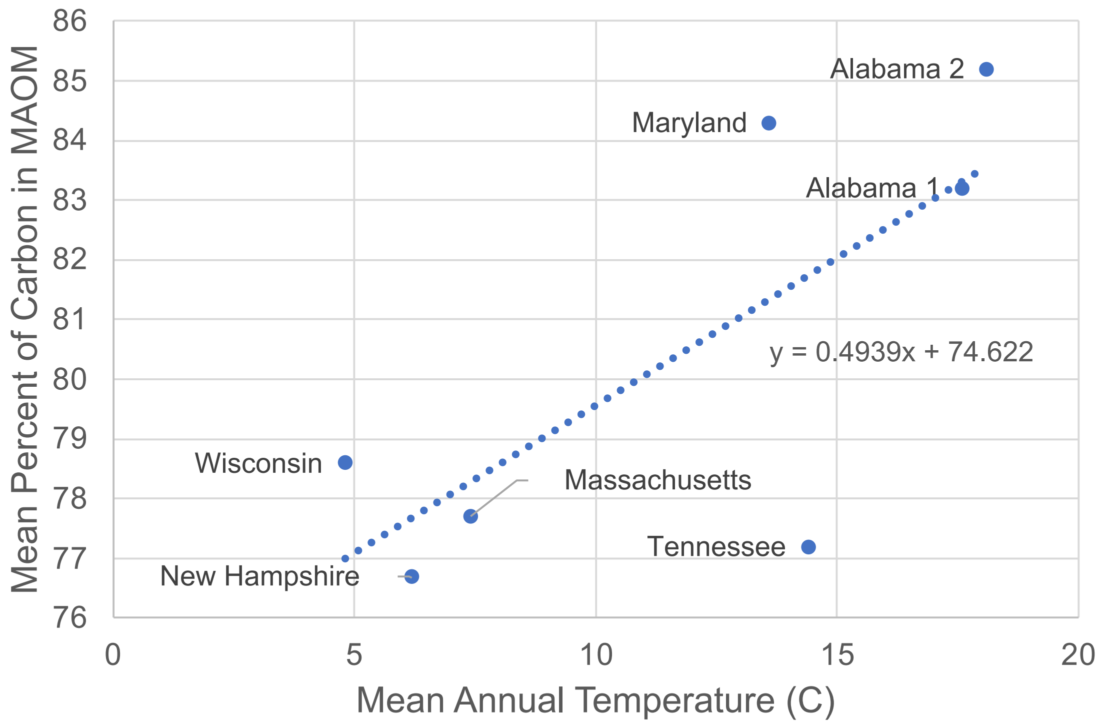
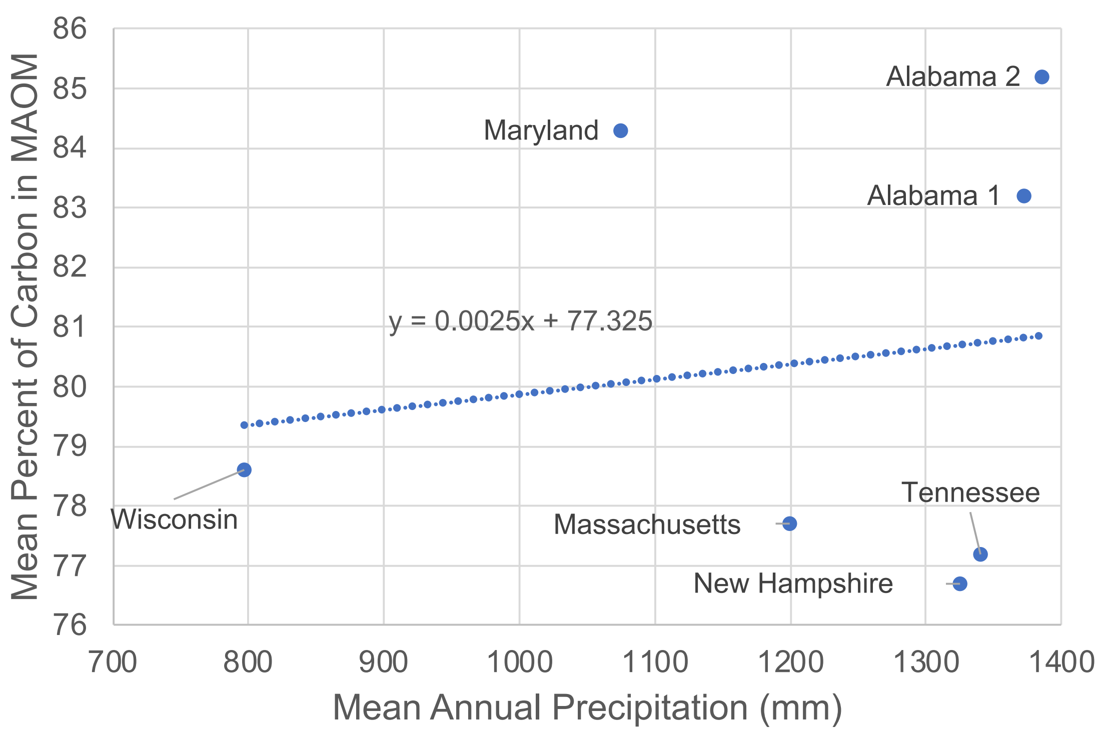
Below are graphs of the data: Identify any changes, trends, or differences you see in your graphs. Draw arrows pointing out what you see, and write one sentence describing what you see next to each arrow.





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Teacher Note: In the Teacher Guide, we have added regression lines and equations for the lines of best fit, but these do not appear in the student versions.

Interpret the data:

Make a claim that answers the scientific question, how does an ecosystem's climate affect the proportion of the total soil carbon stored as mineral-associated organic matter (MAOM)?

In warmer ecosystems, a higher percentage of the carbon in soil is attached to minerals than in colder ecosystems. The amount of precipitation in an ecosystem does not seem to affect the amount of carbon attached to soil minerals.

What evidence was used to write your claim? Reference specific parts of the table or graph(s).

For temperature, the trend of the line of best fit is strongly positive, and there seem to be two clusters of points: one in the bottom left is made up of the coldest three sites, and one in the top right is made up of the warmest three sites. For precipitation, there are many sites with similar amounts of annual precipitation that have very different amounts of soil carbon in the MAOM.

Explain your reasoning and why the evidence supports your claim. Connect the data back to what you learned about the role of soil in the carbon cycle.

The positive trend line for the temperature of an ecosystem shows that as the mean annual temperature increases, the percentage of the carbon in soil attached to minerals goes up. This means that ecosystems in warmer climates lock more carbon underground in protected forms that can't be released to the atmosphere. Therefore, warmer ecosystems might be better than colder ones for helping store carbon in soil and slowing the pace of climate change because the bacteria and fungi are more quickly decomposing organic matter and allowing it to become attached to minerals where it is warmer.

However, it does not appear that the amount of precipitation in an ecosystem affects the amount of carbon attached to minerals. The line of best fit is fairly flat, telling us that precipitation is not the best variable to predict the amount of soil carbon in MAOM. Therefore, the decomposition of organic matter by bacteria and fungi does not seem to be affected by precipitation as much as it is by temperature.

Teacher Note: These data can also be used to stimulate a class discussion of correlation vs. causation. In this dataset, we see a positive correlation between temperature and amount of MAOM in soil, and a weak positive correlation between precipitation and amount of MAOM in soil. However, a positive correlation does not necessarily mean that temperature is causing the increased MAOM, or that it is the only factor. In addition to temperature, many other features of these forest ecosystems are likely different, including the species of trees that are present, the amount of soil bacteria and fungi, and the types of minerals in the soil. Scientists need to continue to explore how temperature directly affects soil carbon.

Another discussion may center around why temperature seems to matter more than precipitation for the process of MAOM formation in soil. One possible reason is that the range of temperatures in these sites is more dramatic than the range of annual precipitation. (Note: students may ponder how this can be true even though the raw values of the temperature range are less—across the sites, there is a difference in mean annual temperature of about 13 degrees Celsius, and for precipitation, there is a difference of about 600 mm). Therefore, precipitation matters less because all of the sites are sufficiently wet to foster microbial activity, but temperature matters more because some of the sites are much colder than others and cannot support fast decomposition rates.

Your next steps as a scientist:

Science is an ongoing process. What new question(s) should be investigated to build on Ashley's research? How do your questions build on the research that has already been done?

Ashley is also testing the effect of soil mineral composition on the amount of carbon in MAOM. Soil minerals are generally classified as sand, silt, and clay, and only the smallest particles (clay) form these bonds with organic molecules to form MAOM. Therefore, I expect more MAOM where the soil has a higher percentage of clay-sized particles.

Teacher Note: Student responses may vary, and they will probably generate a wide diversity of questions about this system. You can have a class discussion where you jot down all the questions on the board. Be prepared to ask your students to clarify or justify another student's response. Do students see any ways to improve any of their questions? Are some questions untestable?

Remember, if your class wants to send their questions about the study system to Ashley, the scientist studying soil carbon, they can email them to datanuggetsk16@gmail.com.

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What future data should be collected to answer your question?

Independent variable(s): amount of clay in soil

Dependent variable(s): percent of carbon in MAOM

For each variable, explain why you included it and how it could be measured.

Clay content in soil can be estimated with a relatively low-tech method based on the settling time of the different soil particle sizes (lesson plan instructions here). You can place a soil sample in a jar or graduated cylinder full of water, shake the container, and measure the height of the settled material at the base of the container after a set number of minutes for sand, silt, and clay. The Y axis in this case is the same as before because we are asking whether a different property of the ecosystem (soil conditions rather than climate) might be more useful for explaining how much of the soil carbon is attached to minerals.

What hypothesis are you testing in your experiment? A hypothesis is a proposed explanation for an observation, which can then be tested with experimentation or other types of studies.

The amount of clay in the soil is an important predictor of the amount of mineral-associated carbon. More clay should result in more carbon attached to clay minerals.