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# K-12 Partnership Lesson Plan

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# *When mountains disappear where do they go?*

# *Inorganic carbon cycling in your belly and our ecosystems*

## Overview

## In this lesson, students will learn about the “other” carbon, that is, inorganic carbon and how it is important for understanding how mountains erode over millennia, how farmers utilize it to maintain soil health, and its role in the carbon cycle. This lesson will introduce students to the scale at which ecosystem ecology works. A small lab activity demonstrates the chemical reaction at the heart of this lesson (involving TUMS, hence “inorganic carbon cycling in your belly”). The lesson involves working with a scientific journal article and data from it. The journal article illustrates how scientists quantify how humans affect the ecosystem, more specifically, how the inorganic carbon in the river water tells a story about how humans use the land. Together, we walk through a series of graphs from the paper to arrive at conclusions by synthesizing information from multiple graphs. Then we break into pairs, make predictions, graph more real data from the article, and discuss the results as a group.

**Objectives**

At the conclusion of the lesson, students will be able to:

* Describe the scale as which ecosystem ecology works
* Explain the difference between organic C and inorganic C and their cycles
* Explain what geological weathering is
* Describe the chemical reaction when carbon (C) in TUMS (CaCO3) is added to vinegar and how this related to the environment
* Explain the role of agricultural liming in buffering soil pH
* Synthesize conclusions from a sequence of different graphs
* Make predictions of river alkalinity export based on % crop or % forest area in a watershed

**Length of Lesson**

1 hour

**Grade Levels**

High school

**Standards covered (NGSS)**

Disciplinary Core Ideas:

* **HS-LS2-3**: construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions
* **HS-LS2-7**: design, evaluate , and refine a solution for reducing the impacts of human activities on the environment and biodiversity

Cross Cutting Concepts:

* Cause and effect
* Systems and system models
* Energy and matter in systems
* Stability and change of systems

Science and Engineering Practices

* Developing and using models
* Analyzing and interpreting data
* Engaging in argument from evidence

***Previous Michigan Standards Met:***

* **B3.3b**: describe environmental processes (e.g., the carbon and nitrogen cycles) and their role in processing matter crucial for sustaining life
* **B3**.**4C**: examine the negative impact of human activities

**Materials**

* Powerpoint presentation- be sure to look at the notes below each slide for more information
* TUMS
* Vinegar
* pH test strips (optional)
* 1 erlenmeyer flask
* 1 balloon
* 1 balance (that gives at least 2 decimal places)
* Rulers (1 per group of students)
* Copies of data tables (1 for each group)
* Copies of empty graphs (1 for each group)

**Background**

“Weathering” in geological terms is the breaking down of rocks. This can happen physically or chemically. For example, the freezing and thawing of asphalt that erodes asphalt, producing pot holes, is physical weathering. Over time, acid rain dissolving a statue made of concrete is an example of chemical weathering. Weathering is important for understanding how limestone mountain ranges like the Appalachians or the Himalayas wear away over millennia.

Farmers utilize limestone weathering to improve soil health. Repeated application of nitrogen (N) fertilizer acidifies the soil. Nitrifying bacteria in the soil oxidize ammonia (NH3) to nitrite and nitrate (NO2- and NO3-), some of which will form nitric acid, HNO3,decreasing the soil pH. In order to maximize crop yield, farmers need to maintain soils at a pH the crops prefer. In Michigan, the recommended pH for corn, soy and small grains is typically 6.5. When the pH drops below 6.5 a farmer will add “lime”, which is crushed limestone (calcite, CaCO3) or dolomite (CaMg(CO3)2), to his/her fields. When the lime is weathered by the acids in the soil, the carbon (C) in the lime can have two very different fates: it can be weathered by a strong acid (such as HNO3), become CO2 and go into the atmosphere; or it can be weathered by carbonic acid (H2CO3, a weak acid, formed from a molecule of CO2) where both the C from the lime and the C from the H2CO3 become dissolved bicarbonate (HCO3- or “alkalinity”) ions, and remain sequestered from the atmosphere in groundwater, streams and rivers for hundreds to thousands of years.

As agriculture has intensified in the US Corn Belt, nitrogen fertilizer application has increased. Two scientists from Yale University hypothesized that this increase in N fertilizer use would also mean a decrease in soil pH and an increase in lime application. To test this, they looked at US Geological Survey records for water chemistry and water volume near the mouth of the Mississippi River starting in 1953. The water chemistry and volume for this location represents an integration of land use effects on the water over the Mississippi River basin, which includes most of the Corn Belt. They found that there was a slight increase in discharge (volume of water) over this time period. They explained this by pointing to an increase in rainfall and an expansion of agricultural land use in the basin over this time period. If you convert a forest to a row crop field, the agriculture can alter the hydrology of the watershed by: 1) not having crops on the land during the winter to help hold moisture in the soil with their roots and 2) tile drainage increases the fraction of precipitation that will drain to streams and rivers as opposed to percolating into groundwater where it moves more slowly into streams and rivers.

You might expect that an increase in water volume would lead to a dilution of the water chemistry. But they found the concentration of HCO3- was also slightly positive over this time period. If you put together the volume of water and the concentration of HCO3- to calculate the total HCO3- mass exported to the Gulf of Mexico, there was a clear positive relationship over time. They also found that the more land in a watershed that is in agriculture the more HCO3- it exports in its rivers. This data show 1) a measurable increase in HCO3- in step with agricultural intensification and expansion over time, which suggests that more lime is being used in the basin, and 2) a significant fraction of the C in lime applied to fields ends up as HCO3-, meaning it was weathered by carbonic acid and sequestered a molecule of CO2 for every molecule of CaCO3.

### Activities of the session

1. Use powerpoint (with extensive notes provided) to introduce inorganic carbon (slides 1-7)
2. Vinegar and TUMS demo (slide 7)
   1. Ask a volunteer “scientist” or have the students do the exercise in groups
   2. Make a table on the board with 2 columns: Before and After and 2 rows, Mass and pH. Ask the class to predict how pH and mass will change before and after you add the TUMS to the acid
   3. Ask volunteer to verify for the audience the ingredients in TUMS (calcium carbonate) and vinegar (acetic acid)
   4. Pour ~100 mL of vinegar into a 200 mL Erlenmeyer flask
   5. Test pH of vinegard. Record “before” pH.
   6. Add ~10 TUMS into a balloon
   7. Attach the balloon opening to the mouth of the flask. DO NOT let TUMS drop into the vinegar yet
   8. Weigh the flask with vinegar, balloon, and TUMS. Record “before” mass.
   9. Keeping the balloon on the flask, allow the TUMS to fall into the flask. As the TUMS dissolve, they produce CO2 gas which will/should blow up the balloon a little. While this is happening talk to the students to brainstorm what is happening in the flask. Do they see bubbles in the vinegar? Are the TUMS changing shape, disappearing? Where are they going? What is blowing up the balloon? What do they predict pH will be? What do they predict mass to be? We are witnessing the transformation of C from a solid (TUMS) into a gas (CO2).
   10. Once the TUMS have fully dissolved (you can speed this up by grinding up the tums beforehand with a mortar and pestle), ask class to predict (again) how the mass has changed. Some students might predict that the mass is now lighter since the C is now a gas, but the law of conservation of mass tells us that it should weight the same if it is a closed system. Weigh the flask again (with balloon attached). Record “after” mass. Has the mass changed? In theory, it should not have changed at all (even though the C transformed into gas, it is still C and weighs the same whether a solid or gas--conservation of mass). In reality, the mass probably decreased slightly. How could this happen? The flask and balloon are probably not a completely closed system—the balloon is allowing some gas to escape.
   11. Take the balloon off and measure the pH of the solution. Record the “after” pH. Discuss (or have the students balance) the equation:

CaCO3(s) + 2CH3COOH(aq) ==> H2O(l) + CO2(g) + Ca(CH3COO)2(aq)

* 1. The same chemistry happening in your tummy is happening with mountain weathering and in ag soils, just in different forms.

1. Return to powerpoint to discuss the importance of inorganic carbon in Michigan
2. Introduce study described in powerpoint
3. Guide students through interpreting the graphs in the powerpoint
4. Make predictions about why alkalinity in the Mississippi has increased.
5. Graphing exercise
   1. Have students break into pairs
   2. Hand out the two blank graphs (not the data yet), colored pencils (2 different colors per group) and rulers (1 per group)
   3. Explain that these graphs are for smaller watershed within the Miss. R. Dr. Raymond looked at satellite imagery for these watersheds and calculated the percent area that is in crops vs. forest. For low % crop assume high % forest and vice versa. On the x axis is % cropland or % forest, and the y axis is HCO3 export.
   4. Draw a line showing your predictions for the cropland graph. (help the students work through how to represent a prediction on a graph. Perhaps draw on the board a positive/growth relationship, a negative/declining relationship, a zero change (flat line) relationship. Look at the % cropland graph first. For a watershed that is low % cropland (and we assume high % forest) would you expect high or low HCO3 export? (low, no lime applied to fields, no tillage or tile drains.) For a watershed that is high % cropland would you expect high or low HCO3 export? (high export, applying N and needs lime, and tilling and installing tile drains). Should graph some sort of positive line, you do not have enough information here to predict the slope of the line, and that’s ok, it’s more about getting the positive relationship.) Have the students use one color to draw a single prediction line, color in the key on the graph appropriately.
   5. Draw a line showing your predictions for the forest graph. Tell students that forests are not getting N fertilizer or lime, and are not getting plowed or tile drained to help them conclude that at high % forest they should expect low HCO3 export and vice versa. So this graph should have a negative line prediction. Students can use the same prediction color on this chart, color in the key.
   6. Now hand out the data sheets and have the students work together to graph the data points, using their second colored pencil. Remind them that each row, each data point is an individual watershed. Have them follow the steps on the slide above.
   7. When they are finished, have the students come together to share their graphs with the group and discuss what they mean. (the more cropland in a watershed the more HCO3 export).
   8. See results on slide 20
6. Exit analysis: Please write 3-4 sentences explaining how the increase in agriculture in the Mississippi River basin since the 1950s affected alkalinity export/drainage/discharge from the river. or: how eating TUMS is like adding lime to your field. or: why C sinks are important. Optional: Draw a picture to help explain what you wrote.

**Resources**

* Excerpt from documentary about the Rogers City Limestone Quarry in Michigan: <https://www.youtube.com/watch?v=h2wAl04oGkw>
* Figure: streams and rivers as integrators and hotspots <http://environment.yale.edu/raymond-lab/projects/integrators-hotspots/>
* Figure: the carbon cycle from a river’s perspective http://www.nature.com/nature/journal/v436/n7050/fig\_tab/436469a\_F1.html

**Extensions and Modifications**

This lesson could be used as a jumping off point for experiments involving the BEST plots. Students could make predictions about the pH of the fertilized vs. un-fertilized plots, then they could collect soil cores and measure pH. They could discuss reasons why they did or did not observe the expected pattern in soil pH (different plants growing in the fertilized vs. un-fertilized plots and switchgrass vs. prairie plots, if more biomass is taking up the fertilizer N, there is potentially less left for microbes to nitrify; time of year of sampling). Students could graph results with error bars and do a t-test to compare results from the different treatments.

You could emphasize more of the geology story behind the limestone:

* limestone formation by ancient tropical coral reefs, perhaps include the biology of reef formation;
* tectonic plates—how did these tropical reefs get to their current higher latitudes?
* glaciation—how the expansion and retreat of glaciers several times ground up the sediments so that in southwest MI we do not have solid layers of intact limestone and coral fossils (like at the quarry in Rogers City) we have deep “glacial till” sediments a sandy mixture including ground up limestone. Much of the limestone that was at the surface has weathered away (especially in agricultural fields), more can be found about 1.5 m below the surface.
* how dolomite is formed: http://en.wikipedia.org/wiki/Dolomite

This lesson could be adapted to dig more into the chemistry. It could be used to talk about dilution and concentrations—particularly the graphs from the journal article. You could also talk more about the real world implications of the chemistry (climate change and C sinks and C sources). You could use this to talk about isotopes. Scientists use δ13C to figure out the source of their CO2 gas samples: CO2 from biological respiration is very depleted in δ13C (about -25 per mill) while “ancient” C (marine fossil limestone) is not depleted (about 0 per mill). Usually samples come out somewhere in between these two signatures, representing a mixture of both sources (or “end members”). Scientists use mixing models to interpret the fraction resulting from the different sources.

**Assessment**

Save 5 minutes at the end of class, have students write on the back of one of the handouts 3-4 sentences describing

* what happens to the carbon in lime when it is added to a crop field? or
* what is a carbon sink and why are they important? or
* how is eating TUMS like adding lime to your field?
* Optional: draw a picture to help explain what you wrote.

Note this lesson was developed by Bonnie McGill, if you have questions please contact her at mcgillbo@msu.edu.