Lesson Plan: Organic Acid Leaching Demo

Introduction:

In this lab, students are shown that organic matter is made up of three different types of compounds, each with varying levels of resistance to decomposition. This has an impact on nutrient availability for plants. This is a more advanced soil science lab that involves a greater level of detail in soil chemistry. Due to the complexity and detail, it may not be suited for many high school science classroom settings; however, it may provide an interesting chemistry lab for an advanced science course!

Prescribed learning outcomes (PLO) are content standards for the provincial education system; they are the prescribed curriculum. The "Organic Acid Leaching Demo" lesson plan will help students to achieve the following BC PLOs[1]:

- Science 10 – Processes of Science (A1-A6); Physical Science: Chemical Reactions and Radioactivity (C1, C2, C4)
- Earth Science 11 – Surface Processes and the Hydrosphere (F1)
- Chemistry 11 – Skills and Processes of Chemistry (A1-A3); The Nature of Matter (B1, B5); Mole Concept (C2); Chemical Reactions (D1-D5)
- Chemistry 12 – Reaction Kinetics (A1, A2); Nature of Acids and Bases (D3); Applications of Acid-Base Reactions (F1)
- Geography 12 – Themes and Skills (A2-A4)
- Science 8, 9, 10 – Processes of Science (A1-A6)
- Earth Science 11 – Surface Processes and the Hydrosphere (F3)
- Geology 12 - Surface Processes and the Hydrosphere (F1, F2)

Learning Objectives:

- Name and compare the 3 different forms of organic acids in soil organic matter in terms of their solubility
- Experiment with the solubility of soil organic matter components in varying acidities, using rainwater (slightly acidic, pH 5.6), acid rain (acidic, pH 1.5-3.0), and over-liming (alkaline, pH 7.5-8.0) as examples of real world leaching situations
- See the connections between the different organic acids, nutrient availability, and carbon sequestration

Materials:

- 3 funnels/tubes (clear)
- Filter paper
- 3 collection beakers (clear)
- Funnel/tube rack
- 1 cup of moist, dark soil (with high organic matter)
- Solutions of pH 3.0, 5.6, and 7.5

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[1] Please consult the appropriate Integrated Resource Package (IRP) to identify the PLOs. A catalogue of the BC Curriculum Documents (including IRPs) can be found here: http://www.bced.gov.bc.ca/irp/all.php?lang=en#

Activity Description:

Place the filters in the funnels (with collection beakers below the funnels), and put a couple tablespoons of moist soil into each filter. Make sure the soil used is quite dark in colour; soil rich in organic matter will give clearer results. Moisten soil with extractant solutions of different pH values, so that one soil is treated with a pH of 3.0, one with pH 5.6, and one with pH 7.0. Leave for at least 1 min. Then add enough of the extractant solutions for some to drip through the filter paper. Leave for another 5 min. Compare colour of the extracts in the collection beakers; the colours should get darker with increasing pH of extractants.

The solutions of various pH represent different real-world solvents:

pH 3.0 = acid rain
pH 5.6 = rain
pH 7.5 = excess of lime applications in agricultural soil

Humic substances are compounds produced through the decomposition of organic matter. They are complex substances of high molecular weight, which are resistant to further decomposition (due to their complexity). They tend to be dark in colour and are chemically characterized by ring-type (a.k.a. "aromatic") structures. Humic substances make up 60-80% of total soil organic matter (SOM), and are where carbon can be sequestered in the soil. There are three general groups of humic substances with varying degrees of complexity of chemical structure:

1) Humins → particles with large molecular weight, relatively small specific surface area, a relatively low number of carboxyl groups, and are inactive. Insoluble in both acid and alkali.

2) Humic acids → smaller in size then humins and have more carboxyl groups than humins. Soluble in alkali, but insoluble in acid.

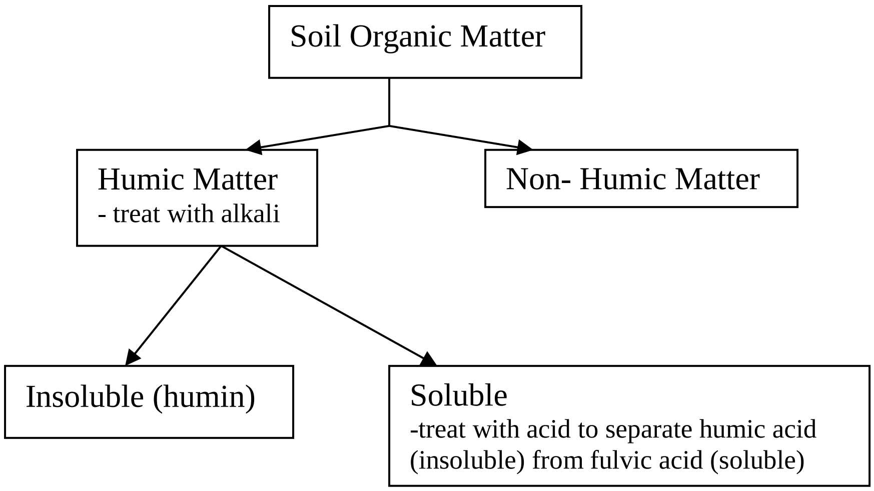
3) Fulvic acids → the smallest in size among humic substances, and have a large number of carboxyl groups per unit mass (which means they contain more functional groups of an acidic nature). For this reason they are the most active among humic substances. Soluble in both acid and alkali. Good chelators of metals.

A useful graphic outlining the differences in humic substances can be found here:
http://karnet.up.wroc.pl/~weber/kwasy2.htm

Fulvic acids have a smaller molecular size and are the least complex in structure compared to humic acid and humin. Because they are less complex, it is easier for extractants to interact with and alter the chemical structure of the fulvic acid (through protonation of aromatic rings to form water-soluble ions). These alterations create water-soluble ions from the fulvic acid, which allows fulvic acids to leach into solution. Fulvic acids are lighter in colour than their humic acid and humin counterparts.

Humic acids and humin are more complex in structure, and are both resistant to extraction by acids. ***Humic acids*** can be leached by alkaline extractants because neutralization of the acid by the extractant converts acidic components into neutral, water-soluble ions. ***Humin***, however, is the most complex and is insoluble in both alkaline and acidic conditions.

The flowchart below outlines the susceptibility of the three different humic substances to different extractants:



The colours of the extractants in this lab should get darker with increasing pH, as the alkaline solutions draw out more humic acid which is darker in colour. Acidic solutions, however, only increase solubility of fulvic acid, resulting in lighter colouration of the extract (as fulvic acid is lighter in colour). (Recall: humin is not extracted in this demo, as it is insoluble.)

Photo: Dru Yates

Figure 12. The funnels set up, with increasing pH of extractant from left to right.

In nature, acidic conditions are better suited to fungal activity than bacterial activity. This results in the solution of fulvic acid, and a decrease in the production of humic substances (resulting in lower C storage). Under excess lime, the alkalinity typically favours bacterial activity. Bacterial decomposition in the soil is typically more rapid than fungal activity, and so it results in the production of more humic acid and humin. This increases C retention and largely decreases nutrient availability. However, the alkalinity also increases the susceptibility of humic acid to break down and release C, because alkalinity makes the humic acid more soluble.

The complex nature of humic acids and humin make them more resistant to microbial activity and extraction. They provide longer term storage of carbon (C), nutrients, and metals. This improves the capacity of the soil to store C, but limits nutrient availability in the short-term.

Fulvic acids, on the other hand, are less complex and, therefore, less resistant to microbial activity and extraction. With more microbial activity, more CO_2 is released, but nutrients become available. In particular, more metals are chelated and made available in the soil as the fulvic acids in solution interact with the metals in the soil.