Forest Nutrient Cycling

Nº. 83

SENIOR

Science

LESSON SUMMARY

Students will be introduced to organic plant matter recycling in forest ecosystems. They will learn about the importance of dead material in forests and the role of decomposer organisms.

TD Friends of the Environment Foundation

FORESTS ONTARIO

Focus on Forests

Activity Information

Grade Level:	Senior
Subject Area:	Science
Estimated Duration:	One day
Materials:	Activity sheet
Setting:	Indoors and Outdoors
Key Vocabulary:	Key nutrients, organic matter, cellulose, lignin, saproxylic organisms
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Background

A forest, as all ecosystems, is partly constituted by living beings consuming nutrients to live. So, as much as Humans need proteins, carbohydrates, lipids and mineral elements to grow up and live, plants, animals, fungi and micro-organisms living in a forest need nutrients to live as well. However, the form of these nutrients and the way forest organisms uptake and use them is very different from us. Let's focus just on plants for now: plants cannot travel looking for food like we can. Everything they use has to come exclusively from the atmosphere and the soil *in-situ*, where their roots fix them. Consequently, the nutrients extracted at one place have to be renewed to allow plants to survive in the long term and more generally to allow the ecosystem to work sustainably. Thankfully, nature "does things well", and annually in forests, amounts of nutrients coming from bedrock weathering and/or decomposition of organic matter such as dead leaves, branches, trunks, roots, animals, and fungi, are released into the soil and the atmosphere. The term "forest nutrient cycling" is used to describe this exchange of elements between the living and non-living components of an ecosystem. Thanks to this cycle, trees in a natural forest grow up autonomously without fertilization unlike annual crops. Let's see a bit further how that works!

Even if each vegetal cell contains more than 10.000 different types of molecule, a tree is basically composed by only a few different kinds of chemical units (organized in thousands of different molecules): the three elements **Carbon** (C), **Hydrogen** (H) and **Oxygen** (O) represent more than 90 % of plants. The rest, equally vital, are Nitrogen (N), Potassium (K), Magnesium (Mg), Calcium (Ca), Phosphorus (P), Sulfur (S) and other oligo-elements. These elements are uptaken either in gaseous form from the atmosphere (Carbon, Hydrogen, and Oxygen) or ions dissolved into water in the soil. The nutrients contained in the soil come from primary mineral weathering (Ca, Mg, K) and organic matter decomposition (N, P) (Fig. 1). In some cases though, when the bedrock is very acid and contain very few nutrients for plants, almost all of the nutrients supply is provided by organic matter recycling.

1. With these elements, plants build molecules, which will constitute tissues organized in organs: roots and rhizomes, trunks, branches, twigs, leaves, flowers and fruits. Among the most famous plant molecules, are glucose, cellulose, hemicelluloses, lignin and pectin.

2. When a tree dies, all its organs will gradually decompose. Because the different plant organs are constituted by different molecules or contain different concentration of a given molecule (the trunk contains proportionally more lignin than the leaves do, for example), some of them can take longer than others to decompose. However the principle of decomposition for all components is quite similar: **big and complex plant molecules are decomposed in elementary components or at least in simpler molecules, available in particular for plant nutrition**. Plant decomposition is a succession of processes that we could describe in several steps. Thousands of organisms, from animals to fungi and bacteria, are involved in these processes.

3. The first step is **mechanical decomposition**: the dead plant organs are mechanically fragmented by animals and climatic events (rain, wind, storm, thunder, etc.). For example, birds and mammals look for food in dead wood, and fragment them into coarse pieces. Earthworms, eat the dead leaves and fragment them into smaller pieces. Then insects, various other arthropods (myriapods, springtails, acarines, etc.) and nematodes transform them into tiny pieces. This first step reduces the size of dead pieces and increases hugely their surface area, which will facilitate and accelerate the chemical decomposition.

4. The second step, **chemical decomposition**, involves mainly bacteria, fungi and insects. **These organisms have special skills: a whole range of enzymes which allow them to assimilate and metabolize complex plant molecules** such as cellulose, hemicelluloses and lignin. Enzymes will attack chemical links of big molecules and transform them into simple sugars, which are used by these organisms (bacteria, fungi and insects) in their metabolism as a source of energy. Some molecules such as cellulose are quite easily decomposed and transformed into glucose. Energy metabolism of the sugar glucose triggers a production of carbon dioxide and water vapor, released by the organism, such as the mineral elements bound with the cellulose fibers. **These elements go either into the atmosphere or the soil water and will then quickly become available again for plant nutrition** (Fig.2 and Fig.3). This relatively quick process, is referred to as primary mineralization. However, some plant molecules, such as lignin and tannins, have structures and components more complicated to decompose and take more time. A part of these molecules stays for a long time in an intermediate level of decomposition before becoming completely decomposed. They form a material called "humus", composed by a soluble fraction (mainly humic and fulvic acids) and a solid fraction (humins). Humins molecules come from organic matter partly digested, dead micro-organisms residues or soluble acids polymerization (molecules become more complex). Humus is a very important part of soils used for plant nutrition and nutrient storage in the ecosystem (Fig. 3).

   In most cases, humus amalgamates with a mineral fraction of soil to form a complex called "clay-humic complex" (calcium in soil is needed for this agglomeration). This complex has the property to fix cations, atoms missing an electron. Yet, mineral nutrients uptaken by plants from soil are in the ion form, cations or anions, solved into water (mycorhizal fungi, associated with plant roots, are very valuable partners in ion extraction by plants). The soil water containing ions is called "soil solution". Humus acts as a pantry for plants: when soil water can't absorb all the mineral ions released by organic matter decomposition, the surplus binds to the clay-humic complex, waiting to be released into the soil solution as soon as room is available for them. A small part on this humus is decomposed every year (around 1 %) into mineral elements, constituting the "secondary decomposition" and completing the cycle.

5. We could eventually mention a third step: nutrients redistribution all over the stand, vertically (in-depth) and horizontally (at the surface). Earthworms and micro-mammals play a key role in burying organic matter deeper in the soil. Birds, mammals, insects and fungi move it over long distances.

6. Depending on the ecosystem, organic matter decomposition process can be unequally quick and efficient, conditioning forest soil aspect and availability of nutrients for plants. Nutrient cycling is influenced by abiotic and biotic factors, such as :

Abiotic

- Climate: the warmer and more humid the weather is, the quicker the cycle is. Length of the vegetative season plays a role as well, as decomposer organisms activity is stronger during this period.
- Bedrock's nature: usually, soils formed on acidic bedrocks have a poor biological activity and few decomposer organisms, this slowing the organic matter recycling.

Biotic

- Species diversity: each insect, fungus and bacteria has specific enzymes that can only decompose specific plant molecules. Some of them can decompose cellulose, others lignin, etc. That's why a strong diversity of species in a forest is a key factor for a complete and quick organic decomposition.
- Chemical composition of leaves, mainly Nitrogen and Carbon proportions. Because the decomposers need Nitrogen to decompose carbohydrate molecules, the lowest the Carbon/Nitrogen (C/N) rate is, the quicker the decomposition goes.

Species diversity and humus type are closely interlinked: a rich humus (with a low C/N ratio) is a key condition for a high soil biodiversity, while a high soil biodiversity allows a quick nutrient recycling and then a rich humus.

FIG 1 - SOURCES OF MAIN NUTRIENTS UPTAKEN BY TREES

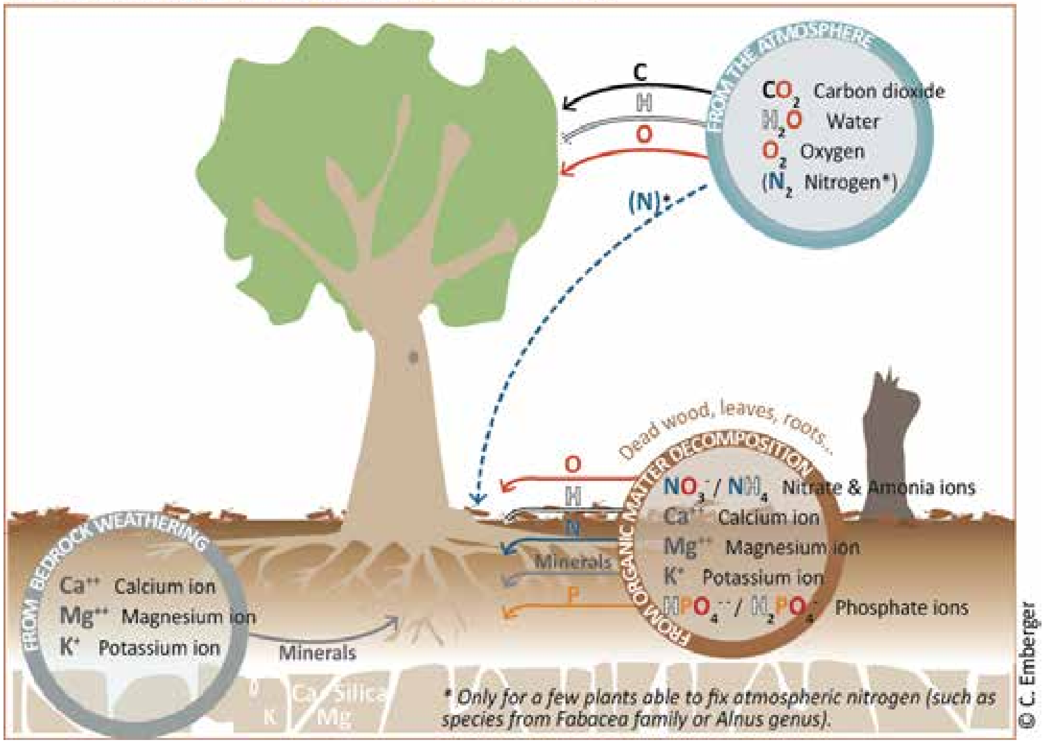


FIG 2 - A EXAMPLE OF CELLULOSE MINERALIZATION BY BEETLE LARVA

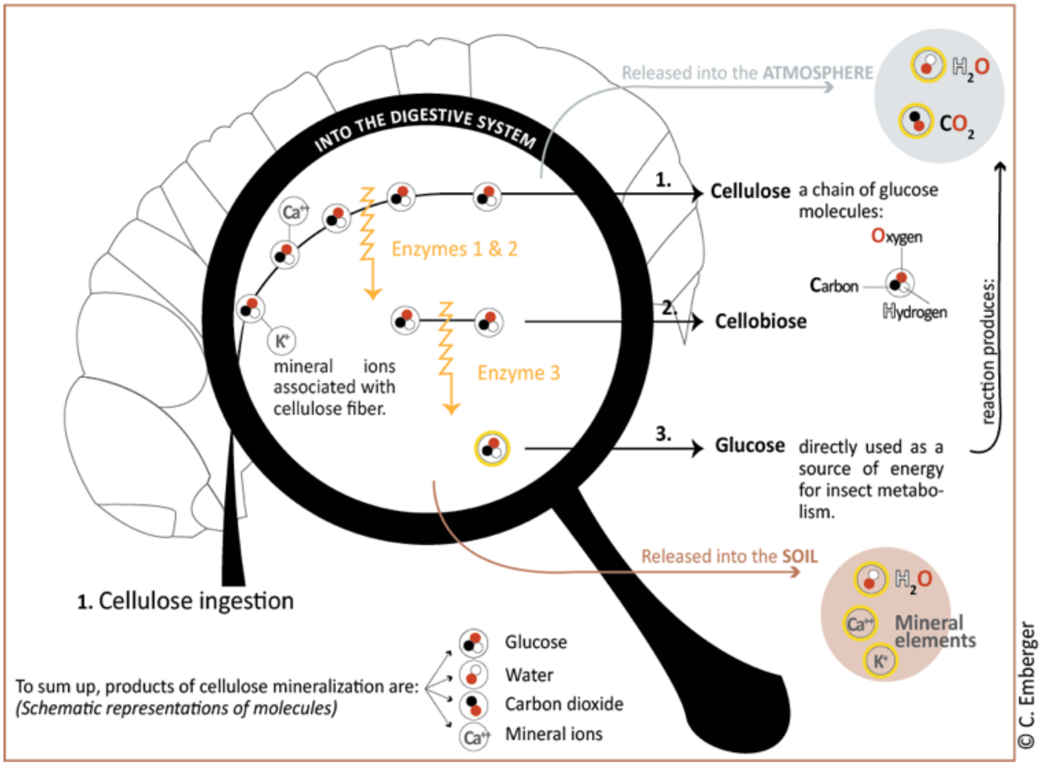
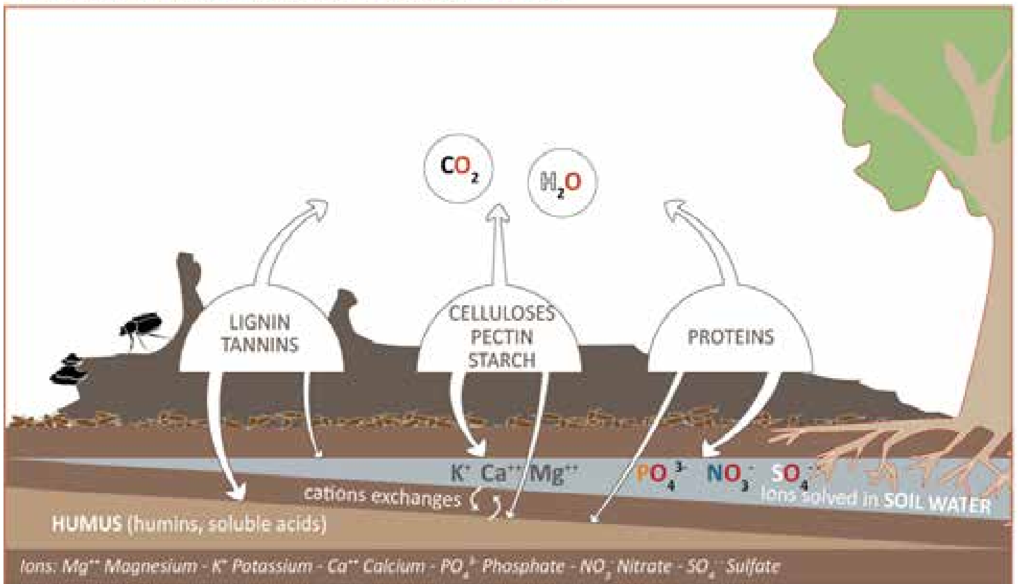


FIG 3 - MAIN PLANT'S MOLECULES DECOMPOSITION



Most of cellulosic and proteins molecules are quickly decomposed and used for nutrition by decomposers (glucose cf. Fig. 2, nitrogen...) and plants (ions released and solved into soil solution). A little part though will constitute a fraction of humus (mainly solved acids). On the contrary, only a little part of lignin is directly decomposed in basic molecules available for living organisms. As a first step, the major part of lignin is only roughly and partially decomposed, leaving important residues (humin) and solved acids. These more or less complex molecules, forming humus, will eventually very slowly be decomposed in basic molecules.

Activity

In the field

1. Introduce the nutrient cycling concept in a field trip in a mixed forest. Make the students observe and describe trees in different steps of decomposition: living trees, dead wood, fresh litter, humus, etc.
2. Stop by a dead tree. Make them observe it, and using the tree decomposition scale (See Annex. 1), ask them to determine the main decomposition step. Observe as well the diversity of decomposition step in that dead tree. Observe coarse weathering caused by birds and mammals, and finer weathering caused by fungi (white/brown rot). Make them think about what happens when a tree dies, how the material is transformed and where it goes.

In classroom

3. Back in class, present the nutrient cycling (using the "background") and explain further processes of decomposition and recycling.
4. How does forest management impact that nutrient cycling? Divide the class into two groups. The first one is given a first scenario: You are a forest landowner in Ontario. You own a coniferous forest growing in a nutrient-poor soil. Each 30 years you clear cut all your forest in order to sell the wood. The second group is given another scenario: You are a forest landowner in Ontario, owning the same type of forest in nutrient-poor soils. Each 30 years you cut down about the third of your trees to sell the wood but maintain some old and dead tree. Ask them the following question: considering nutrient cycling processes, how can you expect your wood production to evolve in a short term? Long term? Why?
5. Explain to the students that dead wood and biodiversity are closely interlinked: biodiversity is essential for wood decomposition and nutrients recycling while dead wood is vital for numerous organisms: animals, plants, fungi and bacteria. It constitutes a habitat for some of them (woodpeekers, all animals living in tree cavities for example), and a source of food for others (some insects, fungi…). These organisms, depending of dead wood for living, are called "saproxylic" organisms and represent about 25 % of total forest biodiversity. Make the student draw a diagram explaining the relationship between biodiversity and dead wood.
6. Have a class discussion around that question: what reasonable management recommendations could we make about dead plant material maintain in a sustainable management perspective, regarding to nutrient cycling?