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Trees & Nitrogen: Basic Principals

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Described in its most basic form, a tree is a collection of carbon chains with a few other elements attached. There are many elements required for successful tree life. Some elements are needed in much higher proportions than others. What elements a tree requires for life may not be readily available within the environment in which it stands. Within terrestrial environments, usable nitrogen is usually in short supply — if not the most growth-limiting of all essential elements. Nitrogen is one of the key connectors between, and modifiers of, carbon chains.

Nitrogen affects molecular interactions, compound shapes and functions, and chemical symmetry of life-maintaining materials. In ecosystems, usable nitrogen is the most precious of elements — carefully used, relentlessly recycled, and biologically hoarded. If carbon represents the structure of life, nitrogen is the ignition key. Energy bound within organic carbons can only be held and retrieved by utilizing nitrogen.

History of Nitrogen

Trees are roughly 80% water, 19% carbohydrate, and 1% everything else. Figure 1. A major portion of the "everything else" component is nitrogen. Nitrogen has had a long history as a suspect in tree growth. A brief scientific history of nitrogen in trees would include:

1656 — nitrogen is found to be a chief nutrient of trees.
1699 — nitrogen is taken up from soil.
1747 — nitrite is detected in green tree parts.
1804 — nitrogen is found to be essential to trees.
1820 — nitrogen found to be the element in most limited supply.

Nitrogen is an essential component of tree life. Figure 2. Nitrogen is considered a myri-element averaging around 17,000 ppm in living tree tissues, and with only carbon, oxygen, and hydrogen found in greater quantities. Nitrogen has been shown to be essential to tree life in three ways: A) it is required for completing the life cycle of a tree; B) it is an essential part of life sustaining molecules in a tree; and, C) it is a component of essential processes in a tree. Nitrogen is found everywhere in a tree that is growing, living or dying. Nitrogen is commonly supplemented by humans in established landscapes.

Fertilize?

One of the first concerns in discussing nitrogen in tree systems is the practice of supplemental nitrogen enrichment — fertilizer! In natural systems, usable nitrogen is available at low levels through decomposition of organic matter, biological fixation, and/or atmospheric deposition. Nitrogen is carefully conserved and recycled by all organisms on and around a tree.

Recycling materials from decaying organic matter is probably the most important aspect to usable nitrogen supplies, as well as other essential elements. Organic materials contain many nitrogen atoms bound-up with carbon. Long-term soil genesis processes, leakage from living things, and organic matter decomposition represent significant nitrogen resources on a site. Figure 3. A healthy tree can effectively and efficiency capture and control a portion of this nitrogen. Most tree sites have nitrogen available for adequate health and growth, not optimum nor opulent levels.

Human Objectives

In established landscapes, there are management objectives other than "adequate" tree growth. Because of human perceptions and expectations of tree performance, and the ability of trees to respond in specific ways to site resource enrichment, humans manipulate trees and sites to generate goods and services. The messiness and seeming chaos of the littered-strewn, ecologically rich natural soil surface layer is eliminated and replaced by hardscapes, heavy turf, neatly raked piles of organic carcasses and tree embryos, and damaged or limited soil volumes. Natural recycling of elements are short-circuited or stopped. Lack of nitrogen recycling and stringent tree performance objectives require supplemental nitrogen enrichment.

Being cost-effective and biologically correct in supplying nitrogen is important. Biological correctness involves understanding tree / nitrogen interactions. For trees, nitrogen represents a good news / bad news problem. The good news is the atmosphere surrounding trees is at least 78% nitrogen gas (dinitrogen or N2). Every acre of land has a blanket of more than 36,000 tons of nitrogen overhead. The bad news is almost all this nitrogen is tightly bound together and acts as an inert gas with low chemical energy. Atmospheric dinitrogen gas is held in a two atom, triple-bonded molecule. Figure 4. Few living systems have the biological machinery necessary to break apart nitrogen gas. For trees, nitrogen is everywhere, but not a molecule to use.

Making N Usable

Living tree systems must utilize fixed or reduced nitrogen (energized N) for incorporation into amino acids, nucleic acids, and proteins. Reduced nitrogen has been energized and made chemically reactive by addition of electrons. Reduced nitrogen is electron-dense and viable as a biological building component or a reaction coupler inside a tree. Reduction, fixation, or a change in oxidation states, is essential for nitrogen use by a tree.

For example, nitrate (NO3-) is a common nitrogen containing anion in soil and is often enriched on sites. The nitrogen portion of nitrate must go through four major changes in form, each with an associated energy addition (increasing electron density), before the nitrogen can be used within a tree. In this case, oxidation state values must be forced from a +5 in NO3- (low energy, fairly benign nitrate anion) to -3 in NH4+ (a small, high energy, potentially toxic ammonium cation), an eight electron input difference.

Natural Fix

Nitrogen used by living systems does have its ultimate source in the huge ocean of atmospheric nitrogen. But, nitrogen must be "fixed" or "reduced" into biologically usable forms in one of several ways. Most nitrogen is made usable to trees through a biological fixation process (termed "<u>nitrogen</u>

fixation") which must occur under near anaerobic conditions. Biological fixation of nitrogen is engineered by many soil organisms, summarized into three primary groups:

-- free-living nitrogen fixing bacteria and algae (both aerobes and anaerobes);
-- symbiotic nitrogen fixing organisms (Rhizobia, Actinomycetes, cyanobacteria); and,
-- nodule forming nitrogen fixing bacteria (Rhizobia spp.). Note Rhizobia is the generic term for all species of nitrogen fixing bacteria in legume nodules.

Specific tree associated biological fixation example include alder (Alnus spp.) nitrogen fixing actinomycetes, and some tree legumes and their Rhizobium bacteria. Both these tree systems sequester nitrogen fixation activities in localized root areas where oxygen can be kept at bay. Biological fixation of nitrogen is energy expensive and can amount up to 20% of tree energy production through photosynthesis.

Total Fixed

The final biological fixation product from atmospheric nitrogen gas is usually ammonium ions (NH_4^+) processed by an enzyme called nitrogenase. Nitrogenase is a slow processing (~5 N_2 per second) enzyme which uses a large amount of energy (16 ATPs) to generate two ammonium ions and dihydrogen gas (H_2). Twelve carbons are required for every dinitrogen (N_2) fixed. Additional means of natural nitrogen fixation includes lightning generated materials and high altitude photochemical transformations. The total natural nitrogen fixation is composed of 90% biological fixation, 9% lightning fixed, and 1% phytochemical fixation.

Human Made

Artificial fixation by humans also generates significant sources of reduced nitrogen used by living things. The equivalent of roughly 15% of the total amount of natural nitrogen fixation is generated by industrial fixation. Additionally, in our modern world, atmospheric and water pollution problems provide some fixed nitrogen sources. Any advantage of this pollution-source nitrogen is usually off-set by dose, timing, pH, and toxicity problems. Figure 5.

Industrial fixation uses energy-expensive high temperatures (400°F) and high pressures (200 atms) to crack atmospheric nitrogen (N_2) into ammonia (NH_3). Ammonia in water yields ammonium ions ($NH_3 + H_2O = NH_4^+$). A total of 38 cubic feet of nitrogen gas is needed to fix one pound of reduced nitrogen. It is biologically interesting how living systems fix nitrogen in oxygen-filled, ambient temperature, and atmospheric pressure with only biological catalysts. One way of thinking about nitrogen energy relations is to consider transforming ammonium nitrate (NH_4-NO_3) quickly back into dinitrogen gas (N_2). This nitrogen compound is the basis for a number of explosives.

Organic N

Usable nitrogen is a rare commodity for trees. Mineral soil and soil parent materials contain little nitrogen. While animals consume plants and other animals for their reduced nitrogen, trees must collect usable nitrogen from the environment. Much of soil nitrogen is held within living bodies of bacteria, fungi, animals, and plants, all of which try to defend their nitrogen stash. A large amount of nitrogen, in various usable stages or forms, is found in decaying organic materials within soil.

The organic matter pool of nitrogen in soil is valuable to all living things in the area. This biological (ecological) pool of nitrogen represents a bank account of "life" capital that can be used in growing trees. If this pool becomes depleted, for any of a number of reasons, short-term (acute) or long-term (chronic) shortages will develop and impact tree growth and health.

N Competition

Almost all organisms must take already energized (fixed/reduced) nitrogen from the environment. Unfortunately, the environment is a highly competitive place. All life forms need the rare usable forms of nitrogen, all for the same reasons. Different organisms have different strategies for collecting usable nitrogen. Nitrogen is not made nor destroyed, just recycled from organism to organism. Each time nitrogen passes through a living organism, another organism tries to grab it before the nitrogen is completely oxidized and returned to the atmosphere as an inert gas ($N2$).

Nitrogen nutrition in trees involve the tree and site in an elaborate exchange of materials. Almost 60% of all nitrogen gathered by a tree is recycled internally. Once in a reduced form, nitrogen is used and maintained in its reduced form. Only upon organ death, such as with absorbing root turn-over or in shed tissues, will some valuable nitrogen escape. Quick catastrophic accidents, such as an untimely freeze killing leaves preventing a tree from withdrawing nitrogen supplies from damaged parts to be shed, can be a serious drain on the whole tree resource levels.

Passages

Usable / reduced / energized nitrogen is available for capture by a tree when an organism dies and decays, excretes nitrogen containing wastes, or sheds materials and parts. The organic matter breakdown and nitrogen release process can be a long and drawn-out set of steps in which nitrogen passes from one living system to another.

For example, nitrogen in a decaying tree root can be captured by a detritus feeding insect — then passed to a bacteria — then moved to another bacteria upon the first bacteria's death, and on to a fungi — to a soil arthropod — back to an insect — to a mammal — and finally back to a living tree root again. Healthy ecological systems have a closely conserved nitrogen recycling network.

Terms of Loss

Nitrogen is kept close to living things because of its value in manufacturing the stuff of life, and its expense in preparation. As living cells die, there is a time period when nitrogen is available to whomever can capture it effectively. Nitrogen can be <u>immobilized</u> in organic matter and living organisms for a while, and not directly available to other organisms. But as life declines away, nitrogen can become available for short periods.

As organic materials are consumed and decay, nitrogen finally may pass through, by <u>mineralization</u>, into inorganic forms like ammonium ($NH4+$) or nitrate ($NO3-$). The pool of inorganic nitrogen compounds in a soil is usually quite small and is the target of many organisms seeking nitrogen. It is enrichment of the inorganic and organic soil pools of usable nitrogen to which people make additions with nitrogen containing fertilizers.

Stressed Out Trees

It is clear trees can be enriched with nitrogen products any time of the day or night, any season of the year, and with any type of preexisting conditions. A tree's defensive system is formidable, and with plenty of carbon in storage, can usually handle site disruptions, internal resource changes, and pest attacks brought about by nitrogen enrichment. This does not mean random large dumping of reduced nitrogen is best for a tree, for a particular management objectives, or for the tree health care provider. Nitrogen additions can mask or overshadow other types of poor management practices. Nitrogen additions can change the balance of power between a tree, pest, and environment. Nitrogen additions can be used to initiate other problems requiring further treatment.

What is actually best for a tree can be different than what myth, tradition, and standard practices might suggest. In the past, ownership objectives and monetary income were top priorities for managers. Tree health was always a distant third under some management priorities. Nitrogen enrichment regimes can be purposely designed to damage and kill trees in established landscapes, especially if a tree is under stress and strain from other major environmental impacts. These types of purposeful designs are not formed out of maliciousness, but from ignorance and greed.

What Is Best

There are some management practices and nitrogen additions which are best for a tree. For many tree health care professionals, there is a growing recognition of what is best for a tree, is best for a tree owner, AND the professional. Survival of mythological practices and concepts remain a constant reminder of the value of professional development and growth. The tree / site resources and clients require professional tree health care providers to continue their education about tree nutrition and nitrogen interactions.

Citation:

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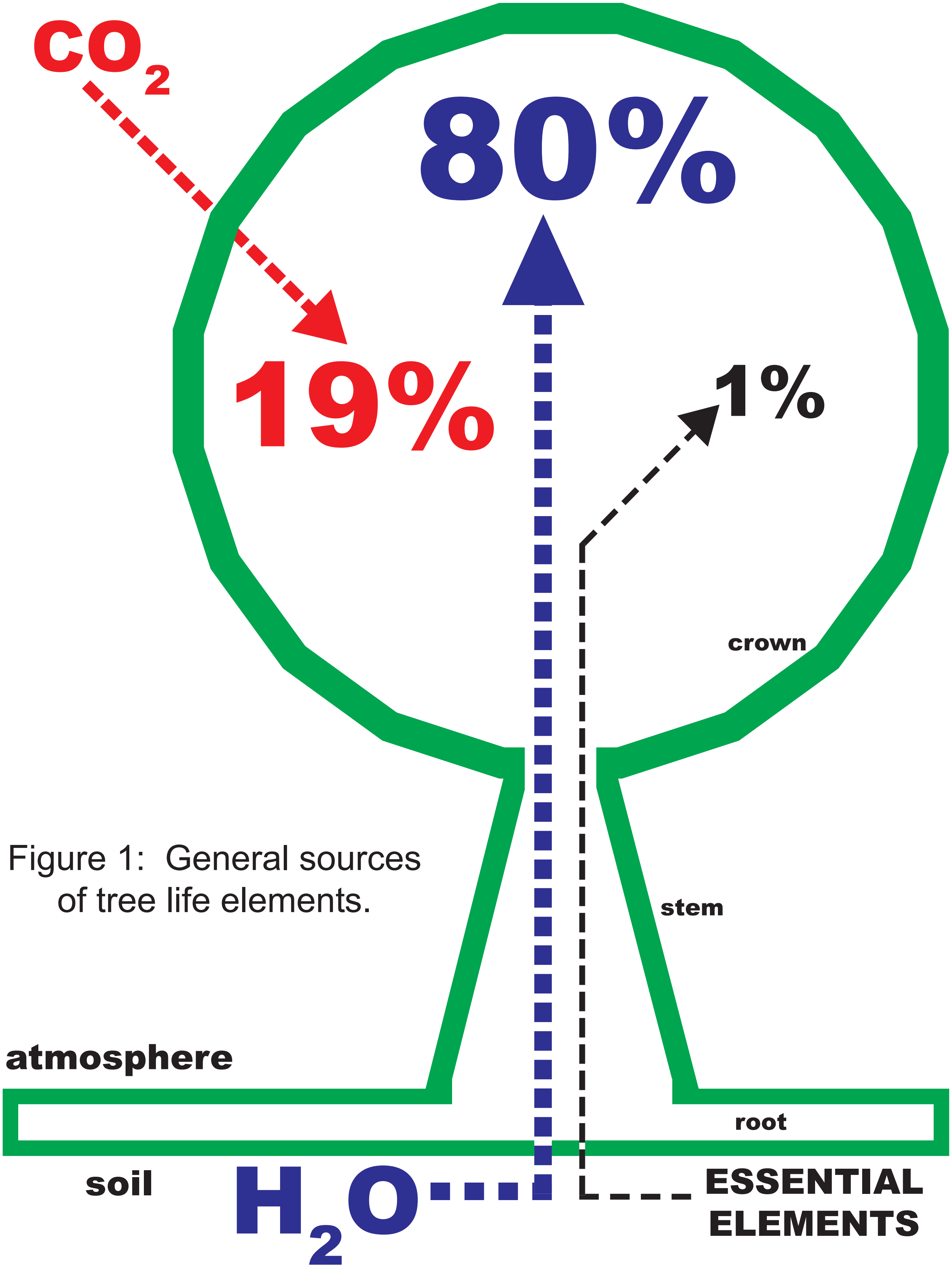

Figure 1: General sources of tree life elements.

element	symbol	average in tree (parts-per-million)	relative proportion in trees
group 1: (mega-)			
carbon	C	450,000 ppm	1,000,000
oxygen	O	450,000 ppm	1,000,000
hydrogen	H	60,000 ppm	133,000
group 2: (myri-)			
nitrogen	**N**	**17,000 ppm**	**38,000**
potassium	K	12,500 ppm	28,000
calcium	Ca	10,000 ppm	22,000
group 3: (kilo-)			
magnesium	Mg	2,500 ppm	5,500
phosphorus	P	2,250 ppm	5,000
sulfur	S	1,500 ppm	3,300
group 4: (hecto-)			
chlorine	Cl	250 ppm	550
group 5: (deka-)			
iron	Fe	75 ppm	170
manganese	Mn	45 ppm	100
zinc	Zn	38 ppm	85
boron	B	30 ppm	65
copper	Cu	20 ppm	45
group 6: (deci-)			
silicon	Si	0.7 ppm	1.5
molybdenum	Mo	0.5 ppm	1.1
nickel	Ni	0.4 ppm	0.9
cobalt	Co	0.2 ppm	0.4

Figure 2: List of tree essential elements divided into concentration groups (average concentration within trees), and relative proportion in trees with carbon and oxygen levels set at one million.

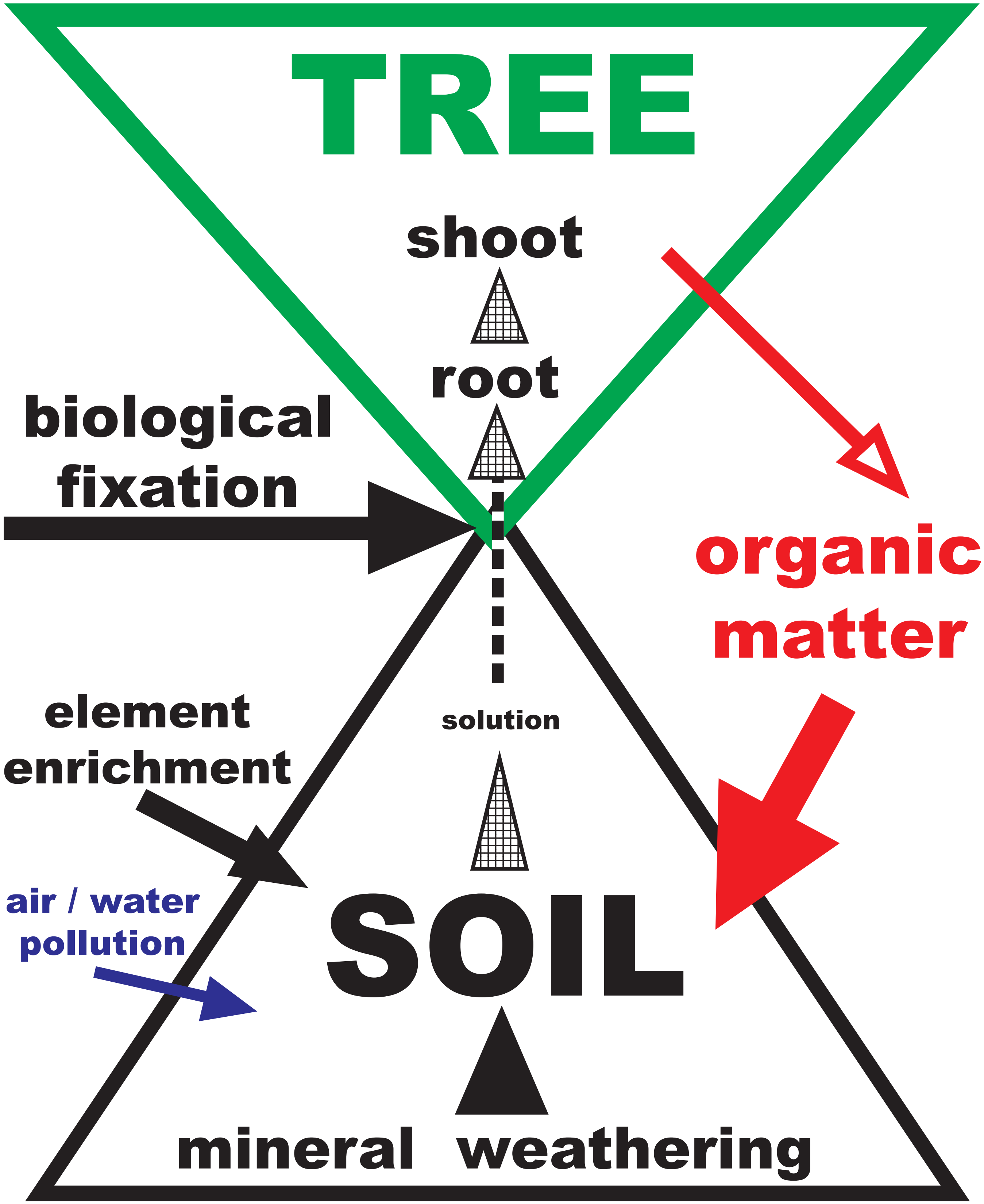

Figure 3: The primary sources of reduced (energized) nitrogen in a soil / tree association.

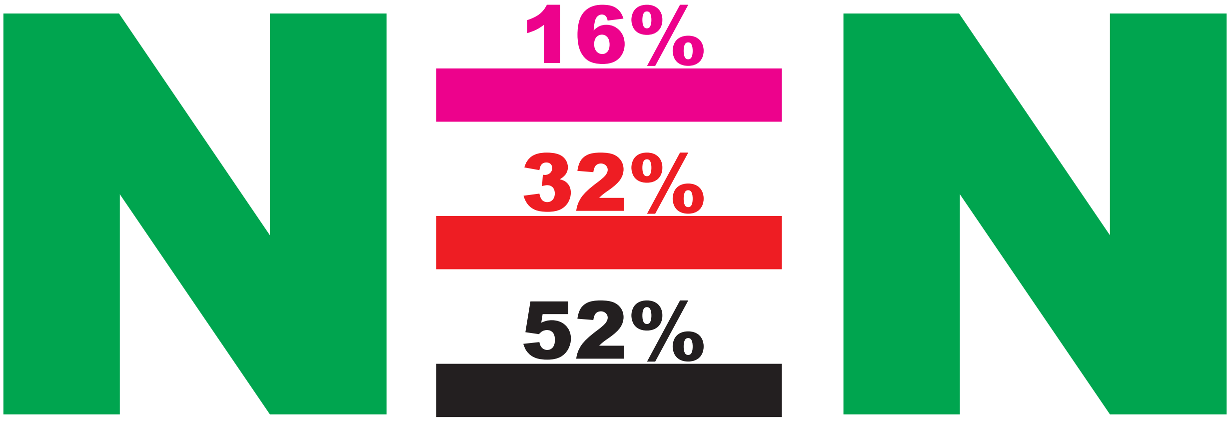

Figure 4: Atmospheric dinitrogen gas (i.e. low energy, almost inert, tightly bound) listed with the relative energy required to break each bond.

REDUCED NITROGEN SOURCES

Natural Fixation

Biological Fixed	90%
Lightning Fixed	9%
Photo-Chemical Fixed	1%
(sub-total	100%)

Artificial Fixation

Industrial Fixed	15%
Pollution Delivered	0.5%

GRAND TOTAL 115.5%

Figure 5: Sources of reduced nitrogen within tree ecosystems.