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Soils & Tree Nitrogen

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Organic forms of nitrogen on any site are usually locked into complex and tightly held compounds. Most of these organic forms of nitrogen are unavailable for tree use. Tree-available and uptakable forms of inorganic nitrogen are primarily ammonium (NH4+) and nitrate (NO3-). Note it is possible for organic nitrogen forms like urea and free amino acids to be taken up by trees to a limited degree. Between unusable organic nitrogen forms and tree-preferred inorganic nitrogen forms, lie many soil organisms (almost exclusively bacteria). These bacteria use whatever nitrogen source is accessible to live and, in the process, transform nitrogen into another form. Figure 1.

Nitrogen transformation steps in soils include a long line of aerobically respiring organisms incorporating nitrogen into their organic bodies. The decay, breakdown, and transformation process (mineralization) yielding tree-usable inorganic nitrogen can be summarized into three steps. Figure 2. Each step takes chemical energy from the materials (oxidation).

1) aminization where proteins are decomposed to simple amine (NH2) containing materials and carbon dioxide (CO2);

2) ammonification where amine containing materials (NH2) and water (H2O) are transformed into ammonium cations (NH4+) and an OH- unit; and,

3) nitrification where ammonium cations (NH4+) and oxygen (4O) are transformed into nitrate anions (NO3-), water H2O, and 2(H+) units.

Final Forms

Each transformation step is performed by a different set of soil bacteria which generate energy for themselves from this process. Note the nitrification process (step 3 above) requires plenty of oxygen (O2) and generates two proton units of acidity. Because of the involvement of specific bacteria in mineralization of nitrogen — soil pH, oxygen content, and temperature all play an important role in determining the amount of inorganic nitrogen made available.

The native nitrogen source used by trees tends to be associated with soil pH. Neutral and high soil pH values favor microorganisms generating nitrate. Acidic pH soil values tend to inhibit nitrate generation by microorganisms and favor ammonium. Nitrate is considered the preferred bulk nitrogen source for trees, especially in more artificial landscapes. Usually any nitrogen source available is quickly moved toward the nitrate form in healthy soils. Ammonium is quickly pushed to nitrate in aerobic soils, but in wet and poorly drained soils, ammonium is a good tree nitrogen source because nitrification is slow. Urea in most soils is pushed to ammonium within 3-5 days. Figure 3.

Problems?

There are some soil treatments which prevent nitrogen transformations by interfering with the activity of specific groups of bacteria. These chemicals have been utilized primarily in agriculture to slow or prevent transformations until crops can utilize available nitrogen. Acid soils (<5.5 pH), poorly drained or flooded soils, and cool temperatures all slow or stop the mineralization processes. Low soil oxygen contents, as in wet, organic, or compacted soils, can lead to a nitrogen conversion termed "denitrification" where nitrates ($NO3^-$) are directly converted into inert nitrogen gas (N2). Figure 4. Small amounts (~0.15%) of nitrite in soil can be released as nitrous oxide gas (N2O).

Soil is filled with tree roots, plus roots from all other plants in an area. In addition, roots are surrounded with millions of soil-living organisms most of which need oxygen. Poor drainage, water saturation, or a flood event when soil is warm (growing season temperatures) can cause all available oxygen to be used-up within a few hours. Microbes act as oxygen sponges, using any available oxygen before tree roots have a chance.

As oxygen is consumed, microbe respiration progresses to using other materials like nitrogen, manganese, iron, sulphur and carbon. Nitrogen is the first major element used for respiration by soil microbes when oxygen is depleted. Nitrogen respiration in warm saturated soils can cause available nitrogen from enrichment to be converted into inert gas within a few days.

Ionic Changes

Once mineralized, and in an usable inorganic form, available nitrogen is prey to other problems in soils. The ammonium cation (NH4+) and nitrate anion (NO3-), by definition, have different electrostatic charges generated in water solutions (represented by the "+" or "-" symbols). Clays and organic material surfaces in soils generate negative charges, collectively called cation exchange sites. Organic material surfaces also generate a limited number of positively charged sites responsible for anion exchange sites.

In most soils, cation exchange capacity (negative charge bank) is large and greatly affects availability and leachability of charged elements. Anion exchange capacity (positive charge bank) is usually small in its effect. The negatively charged nitrate (NO3-) is electrostatically repelled by soil and organic matter surfaces making tree-available nitrate prone to leaching out of soils with water.

The positively charged ammonium (NH4+) is electrostatically attracted by soil and organic matter surfaces allowing ammonium to remain loosely bound in soil and resistant to leaching. As temperatures increase, more ammonium is converted to nitrate, allowing warm season rains to wash available nitrogen (in nitrate form) away.

Soil Interactions

As water passes through a soil, more leaching of valuable nitrate ions occur. As trees take-up more essential elements, less valuable ions may be left loosely bound near soil charges surrounding tree roots. Cations of essentials elements can be bumped away from negative exchange sites and replaced by acidic elements (such as aluminum (Al), hydrogen protons (H^+), and manganese (Mn)) which would tend to lower soil pH. Leached soils tend to become more acidic and less valuable in supplying essential elements for tree growth over time.

Figure 5 demonstrates how the changing availability of nitrate or ammonium causes significant changes among other tree essential elements. For example, as nitrate availability and concentrations rise, calcium (Ca), cobalt (Co), potassium (K), magnesium (Mg), molybdenum (Mo), and sulfur (S) availability increase while chlorine (Cl), iron (Fe), manganese (Mn), silicon (Si), and zinc (Zn) availability declines. Element interactions with changing nitrogen availability, enrichment, and nitrogen form are difficult to predict accurately. Ecological tuning of enrichment applications must be cautious to minimize undesirable or unexpected outcomes.

Changing pH

Soil pH is affected by the type of inorganic nitrogen present in a soil. High levels of organic materials or ammonium concentrations tend to accelerate a drop in soil pH. Ammonium sources surface-applied to high pH soils, recently limed soils, or soils with free calcium carbonate are transformed into ammonia gas and escape into the atmosphere.

The nitrification process generates two protons (2H+ units -- acidity as measured by pH) for every nitrate transformed from ammonium. High nitrate concentrations initiate an increase in soil pH from OH- and HCO3- excretion by trees through ion transport systems. Internally, tree pH is maintained by organic acid production, while potassium ion transport is used to keep a tree slightly electrostatically negative (more electron dense than environment). Addition of any fixed nitrogen source can disrupt and change soil / tree interactions.

Depletion Zones

As inorganic nitrogen ions are taken-up by a tree, the soil area close to its roots become depleted in nitrate and ammonium. Limited amounts of nitrate can move with water around roots, while ammonium ions remain near exchange sites shifting toward roots. The nitrogen depletion zone increases the difficulty with which trees take-up nitrogen and requires continuous root growth to maintain supplies.

Supply and demand for reduced nitrogen are based upon instantaneous needs with only a small amount in storage. Continuous dosing is a process emulating roots through their elongation growth. A tree attempts to keep nitrogen and phosphorus at steady-state concentration levels. This requires more or less continuous growth to control and capture nitrogen and phosphorus resources, or “hiring” a symbiont to capture resources.

Steady-State Levels

A steady trickle of nitrogen, rather than large bursts of availability, are normal for a tree. Internal growth correlation systems are designed for controlling resource gathering processes. Swamping these sensor systems and sequestering processes for nitrogen in a tree can modify many tree responses to the environment. Some of these responses will have a negative impact on tree health and survival.

Overall tree health, rather than individual measures of growth, should be the targeted goal of nitrogen enrichment. A tree can be made to have dark green foliage and to profusely grow shoots with nitrogen additions, at the expense of other tree parts and processes. From a whole tree perspective, utilizing a simple growth goal or threshold system for gauging enrichment success, while disregarding tree system health and efficient function, can be damaging to trees.

High / Low

The amount of inorganic nitrogen present in soil has a direct effect on tree health and growth. At decreasing concentrations, beginning well before visual symptoms are present (because of internal recycling and reallocation of nitrogen), is nitrogen deficiency. At high nitrogen concentrations, toxicity and physiological disfunction can be problems. There is an intermediate zone of moderate nitrogen concentrations where tree health and growth is "adequate" for sustained growth. This adequate zone is the target for management activities. The adequate zone is narrower and toxic zone more easily reached with supplemental ammonium nitrogen sources, as compared to nitrate sources. Figure 6.

Soil Systems

Trees do impact (passive) and change (active) their own rhizospheres with organic additions. These materials are comprised of everything within a tree (because everything can leak out), and everything outwardly shed from a tree. Microflora and fauna of the rhizosphere are fed, housed, and killed by tree materials and exudates. All the microorganisms of soil help cycle and recycle elements and life co-factors needed by a tree. Some microorganisms are invited to infect roots in order to present a larger tree rooting area at a smaller cost to the tree.

Mulch and composted organic matter have strong roles to play with nitrogen availability around tree roots. A thin, tree / wood derived, well aerated and mixed, composted organic layer over the rooting area, covered by a thin, course textured, organic mulch layer, can be helpful in recycling nitrogen. Use of tree litter and other organic components provide food-stocks for soil organisms which breakdown and recycle essential materials. Slowly decaying organic materials, like bark, should be used only in small proportions and only for the top mulch layer. Inorganic and dense materials should be avoided. Supplemental nitrogen enrichment can be broadcast over the top of a mulch / compost area.

Ecological Management

Supplemental nitrogen enrichment, loss of organic matter, detrimental soil changes, and landscape maintenance chemicals can disrupt a tree / soil ecological community. Carefully tuning nutrition within a tree by nitrogen enrichment, and through nitrogen sources within composted organic matter, can provide the many advantages of a healthy soil. Abusive soil management practices can leave trees open to deficiencies, toxicities, and pest attack.

Citation:

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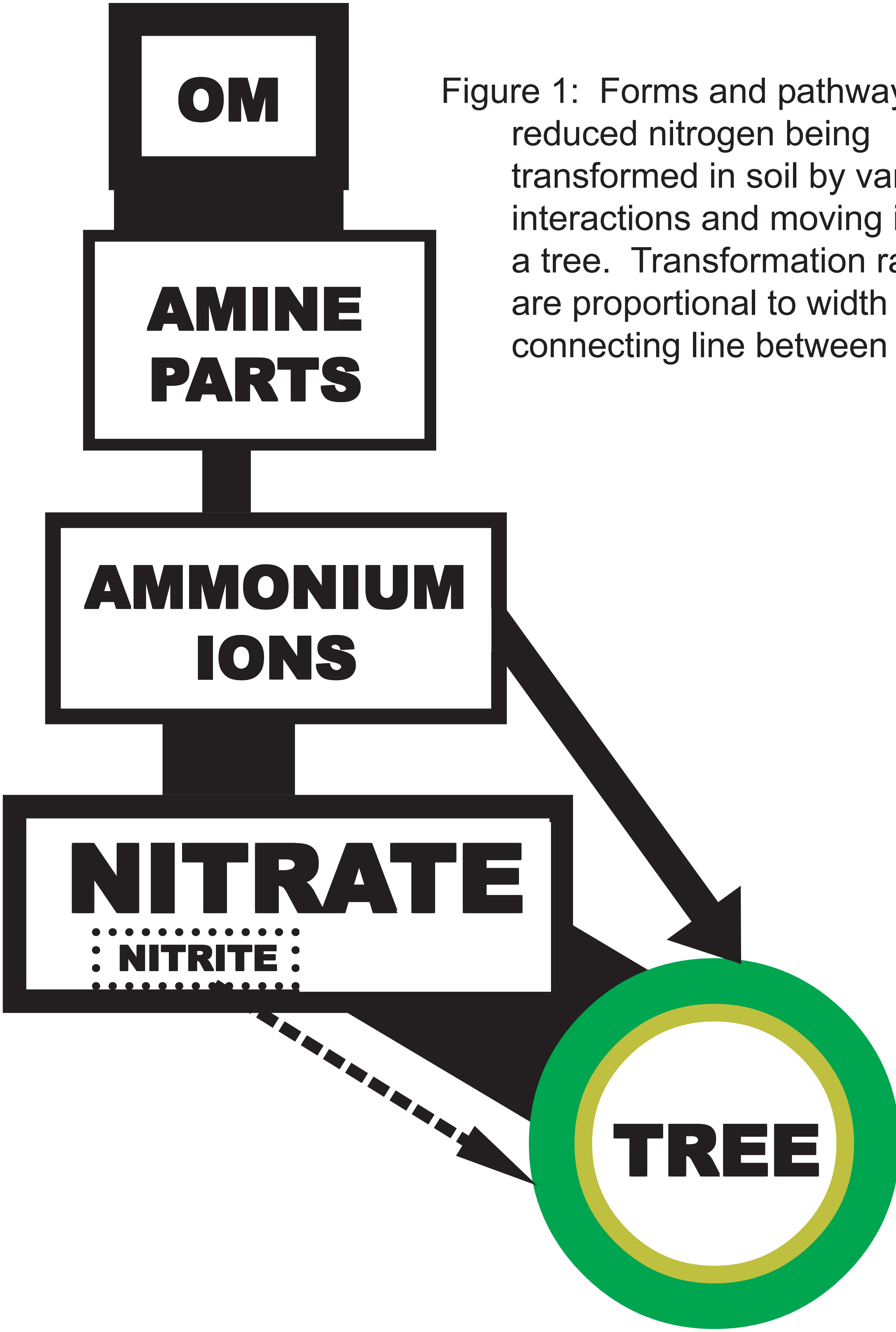

Figure 1: Forms and pathways of reduced nitrogen being transformed in soil by various interactions and moving into a tree. Transformation rates are proportional to width of connecting line between boxes.

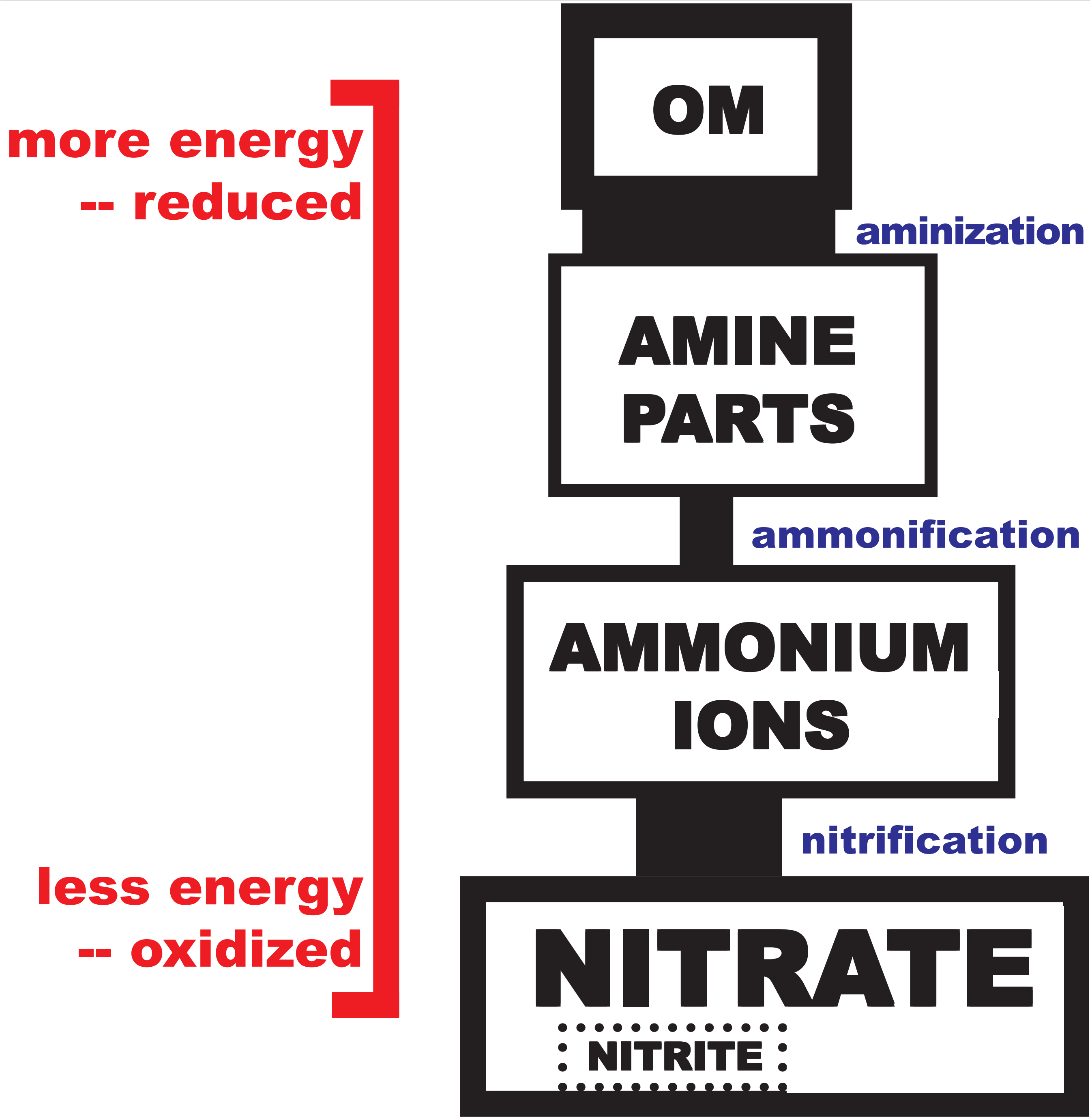

Figure 2: Forms and pathways of reduced nitrogen being tranformed by predominantly bacteria in soil from more energy dense materials in decaying organic matter (OM) to a less energy dense material (oxidized) -- nitrate.

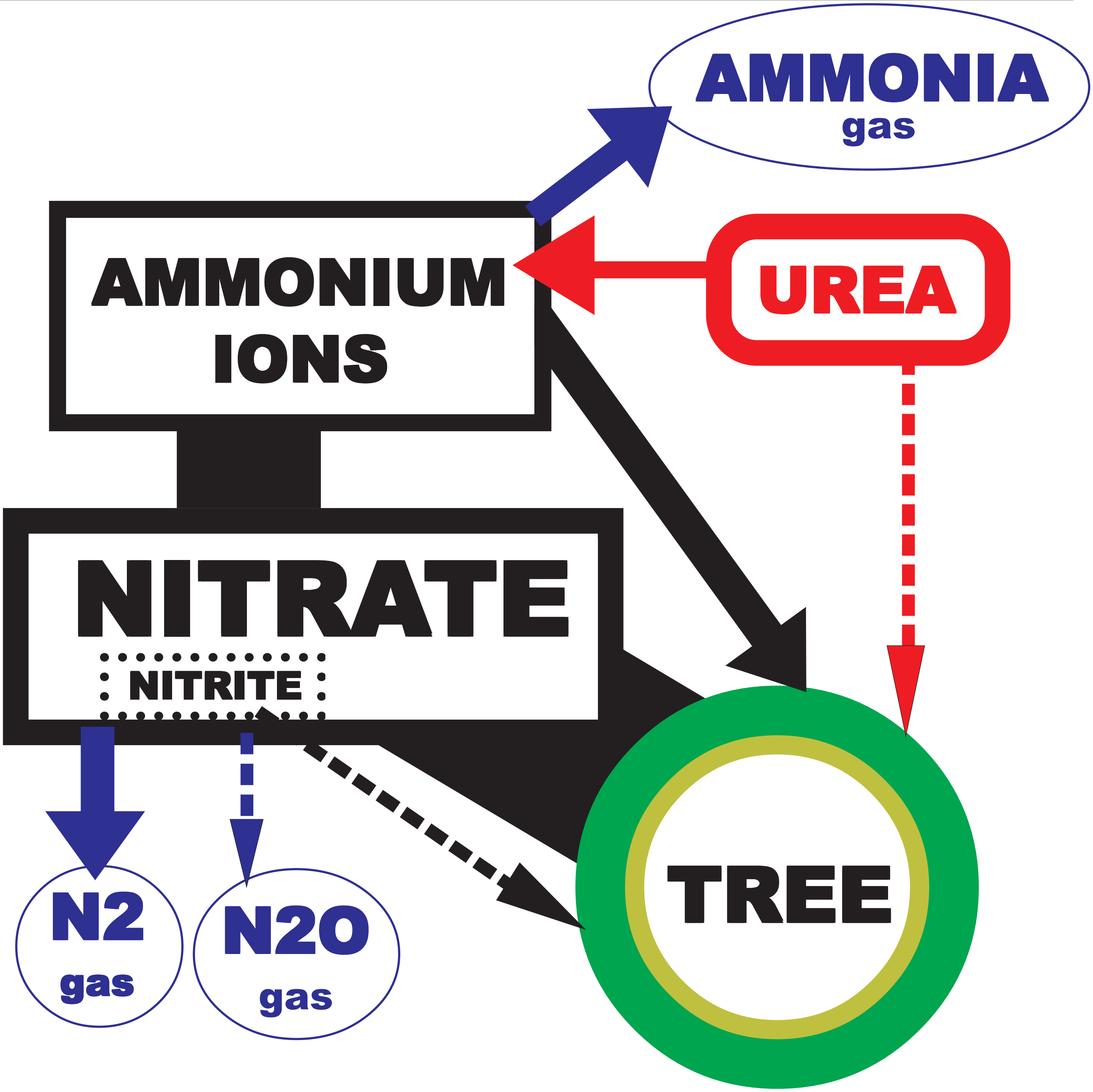

Figure 3: Possible pathways of reduced nitrogen in soil transformed from urea fertilizer and moved into a tree or lost to the atmosphere.

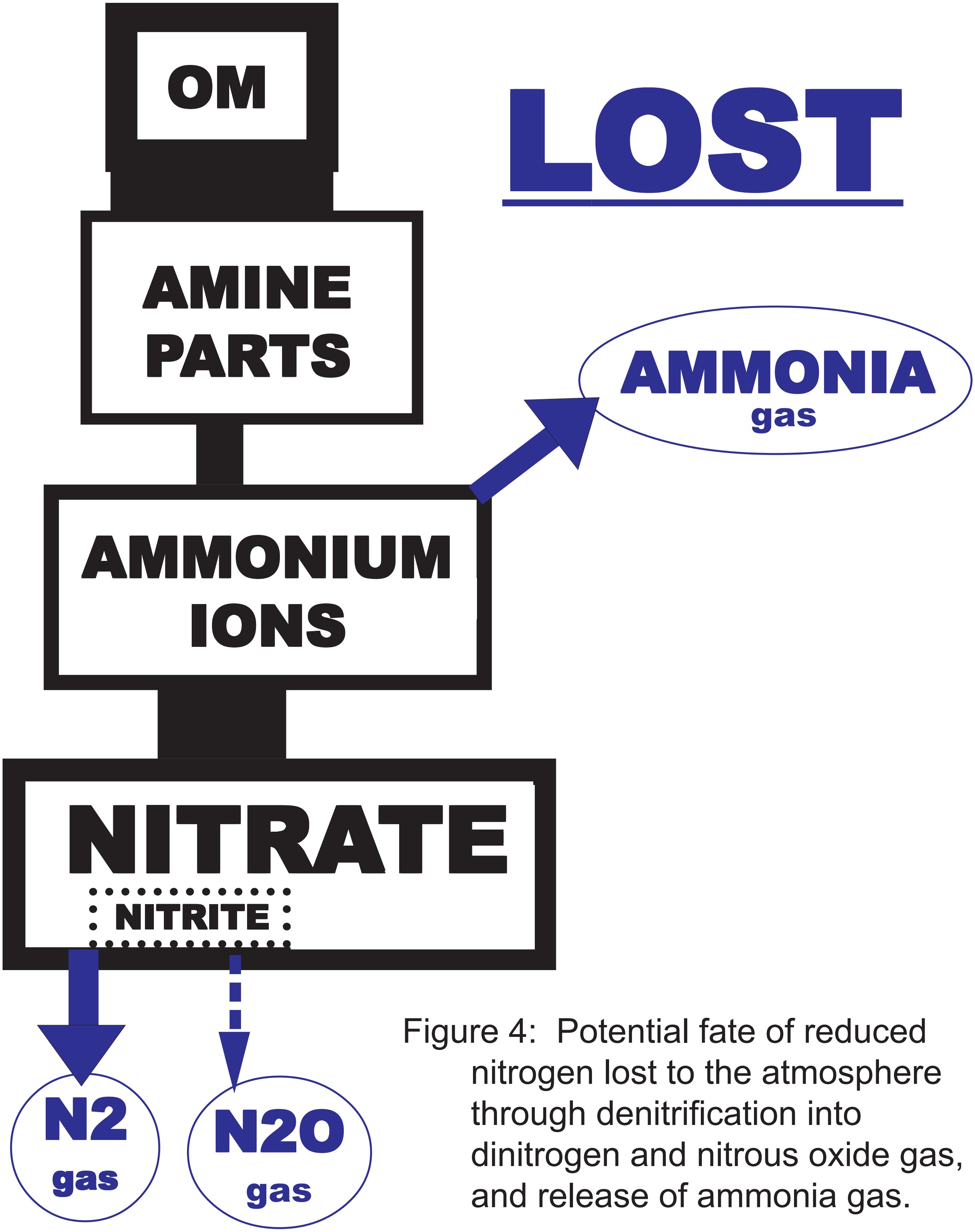

Figure 4: Potential fate of reduced nitrogen lost to the atmosphere through denitrification into dinitrogen and nitrous oxide gas, and release of ammonia gas.

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tree essential element	nitrogen ion added to soil NITRATE	nitrogen ion added to soil AMMONIUM
B	--	--
Ca	S	A
Cl	A	S
Co	S	S
Cu	--	--
Fe	A	S
K	S	S
Mg	S	A
Mn	A	S
Mo	S	A
Ni	--	--
P	--	--
S	S	S
Si	A	A
Zn	A	A

Figure 5: Tree essential element availability interactions for nitrate and ammonium. (listed by chemical symbol).

"A" = antagonistic where addition of nitrogen decreases availability of another element.
"S" = synergistic where addition of nitrogen increases availablility of another element.
"--" = no apparent change in element availability.

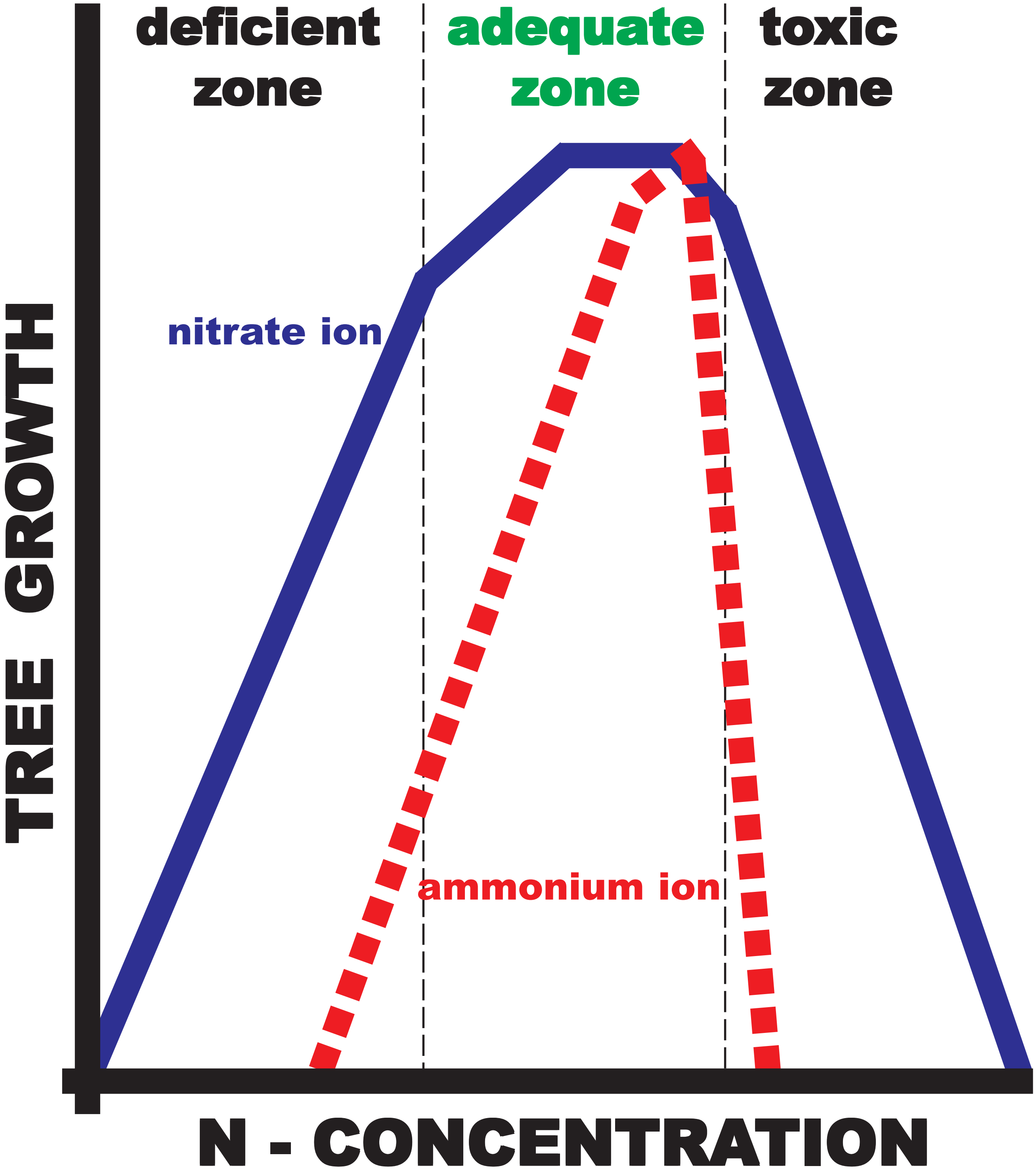

Figure 6: Nitrogen concentrations and availability for tree growth following an essential element growth curve from deficiency to toxicity. Note ammonium cation curve (dotted line) shows a much narrower space between deficiency and toxicity than does nitrate.