Macronutrients - Nitrogen: Part 1

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Starting back in 1996, we began writing articles on the 13 essential mineral nutrients that are needed for plant growth. To date, we have covered the 3 secondary macronutrients and 7 micronutrients and now we will finally get to the "Big Three": nitrogen (N), phosphorus (P) and potassium (K). They are called macronutrients because they make-up such a high percentage of the total mineral nutrient content of plants. Together, nitrogen, phosphorus and potassium comprise almost two-thirds of the total mineral nutrients in a plant (Table 1). They also are called "fertilizer elements" because they are the principal mineral nutrients in major fertilizers. In fact, federal law requires that percentage of these elements must be clearly shown on fertilizer labels - nitrogen as % N, phosphorus as % P_2O_5, and potassium as % K_2O.

We will start discussing nitrogen in this issue but, because it is such a complex subject, we have had to divide it into two parts. This first part will discuss the ecological and physiological aspects of nitrogen including availability and how it is taken-up and assimilated by seedlings. The second part, which will be included in the next FNN issue, will look into all aspects of nitrogen management in nurseries including monitoring in soils and tissue, fertilizer types and application methods, and cultural and environmental effects of overfertilization.

Introduction

Nitrogen is the mineral nutrient found in the highest concentration in plant tissue, comprising over one-third of the total mineral nutrient content (Table 1). Nitrogen is almost always the most limiting mineral nutrient affecting crop growth and forest and conservation nursery seedlings are no exception. Nitrogen's importance to nursery culture is confirmed by the fact that there are more articles dealing with nitrogen in the FNN database than any other nutrient: twice as many as P and 6 times as many as K.

Although nitrogen gas (N_2) makes up over three-quarters of the earth's atmosphere, the majority of plants cannot access this nitrogen. One source estimated that 78,000 metric tons of nitrogen gas are in the air above each hectare of land. However, this vast supply of atmospheric nitrogen has to be converted to either ammonium (NH_4^+) or nitrate (NO_3^-) ions before most plants can use it. Some atmospheric nitrogen can be captured in precipitation and carried into the soil, but the majority is fixed by specialized soil bacteria. These microbes are either free-living or form nodules on the roots of legumes plants such as clover or on some non-leguminous plants such as red alder. Nitrogen-fixing bacteria form a symbiotic relationship with their hosts. The host plants benefit by having the atmospheric nitrogen fixed into a usable form, while the bacteria obtain energy from the chemical conversion and a place to live. Man has also learned to convert atmospheric

Table 1 - The three essential macronutrients and their typical concentration in seedling tissue

Element	Symbol	% of Total Mineral Nutrients in Plants	Adequate Range in Tree Seedling Tissue (%)		Where and When Published
			Bareroot	Container	
Nitrogen	N	37.5	1.2 to 2.0	1.3 to 3.5	Summer, 2003 & Winter, 2004
Phosphorus	P	5.0	0.1 to 0.2	0.2 to 0.6	To Do - Summer, 2004
Potassium	K	25.0	0.3 to 0.8	0.7 to 2.5	To Do - Winter, 2005

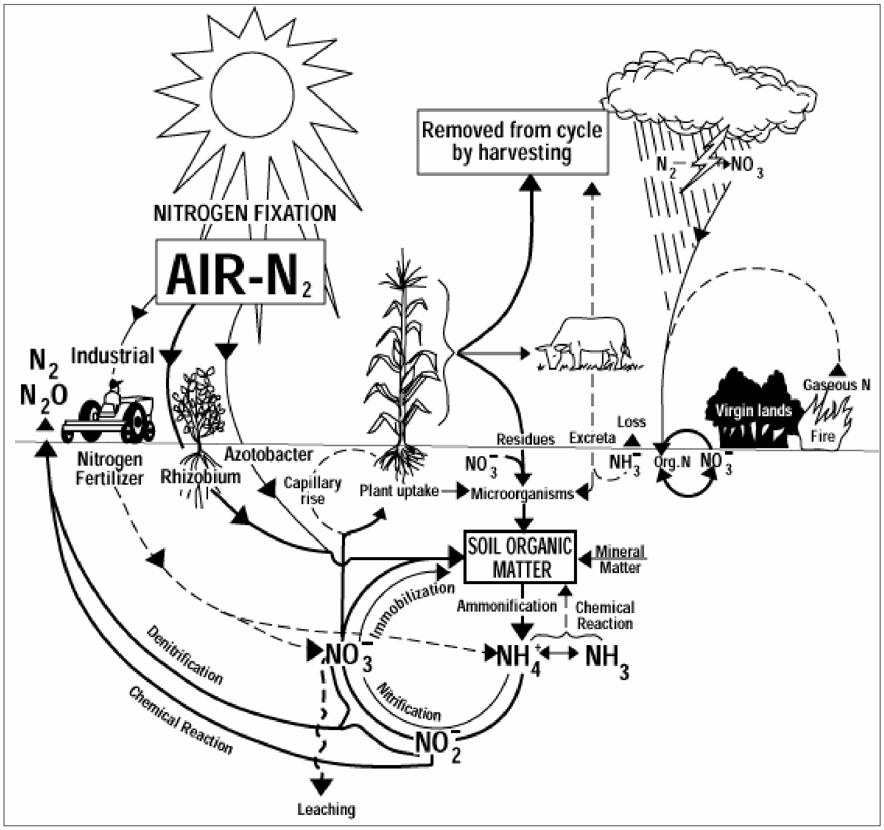


Figure 1 - All Nitrogen Originates as an Atmospheric Gas which is Fixed by Microorganisms or in Fertilizers, and Then Cycles Through Nature By Natural and Man-Made Processes (from Brown and Johnson)

nitrogen into fertilizers by the Haber process in which gaseous nitrogen and hydrogen is synthesized into ammonia at high pressure and temperature. Once fixed, nitrogen is cycled through the natural world by man-made and natural process (Figure 1).

Role in Plant Nutrition

Nitrogen is vital to every physiological process that takes place within living plants. It is a constituent of all 20 amino acids, which are the building blocks of proteins. Proteins have both structural and physiological functions in plants. Some proteins are part of the structure of cell walls and membranes while others are enzymes, which means that nitrogen is involved in virtually every biochemical and synthesis reaction that occurs in plants. Nitrogen is also part of the molecular structure of nucleic acids, the building blocks for DNA, which carries the genetic blueprint of every organism on earth. Then, if that's not enough, the molecular structure of chlorophyll contains 4 nitrogen atoms (Figure 2). An adequate supply of nitrogen promotes high photosynthetic activity, evidenced by the dark green color of well-fertilized plants. To sum it all up, nitrogen is an integral part of the physical structure of plants, all enzyme systems within plants, the genetic makeup of plants, and the process of photosynthesis. There is no structure or function within a green plant that can be completed in the absence of nitrogen. In order for a plant to be able to exist, support its own weight, grow, reproduce, defend itself and photosynthesize, it needs nitrogen. Without nitrogen, life as we know it could not exist.

Nitrogen is needed in highest concentrations in plant parts that are actively growing, namely young leaves, flowers, and root tips. When nitrogen is limiting, cell division and expansion slows and so it is no wonder nitrogen fertilization is used to control plant growth in nurseries. New cell construction requires duplication of genetic material, construction of cell walls and membranes, and activation of enzyme systems, all of which require nitrogen. When the nitrogen supply decreases, nitrogen is mobilized from mature foliage and translocated to areas of new growth. Because chlorophyll production also drops off when nitrogen is limiting, older leaves and needles turn yellow and, in severe cases, actually senesce. If the deficiency persists, chlorophyll production slows which decreases photosynthesis. At the same time, production of the many nitrogen-containing building blocks are reduced and the result is a smaller, slower growing plant.

Plants seem to have evolved so that accessing nitrogen is first priority among all physiological processes. In nature, this is a survival mechanism but, when excess nitrogen fertilizer is supplied in nurseries, plants continue to take it up with disastrous consequences. Overfertilized nursery plants divert energy, carbohydrates, water and other mineral nutrients to the assimilation of nitrogen, throwing all physiological systems out of balance. These and other adverse effects of excess nitrogen fertilization will be discussed in Part 2.

Availability in the soil and growing media. Nitrogen is available in soils from nitrogen fixation, the decomposition of organic matter or, from the addition of fertilizers (Figure 1). Although some nitrogen is made slowly available as plant residues and soil microorganisms decompose, the majority of nitrogen in nurseries is supplied by fertilizers in one of three forms: urea ($NH_{3)}$, ammonium (NH_4^+), and nitrate (NO_3^-) (Table 2).

Urea does not last long in the soil because it is water soluble and, if not lost to leaching, is quickly converted to ammonium by specialized soil bacteria (Table 2). Under warm and moist conditions, this conversion is very rapid. There are also many types of ammonium fertilizers and, since the ions are positively-charged, they are adsorbed on the cation exchange sites of clays and organic matter. However, ammonium ions not immediately used by plants are converted by another species of soil bacteria into nitrate ions.

Being negatively-charged, nitrate ions do not adsorb to the cation exchange sites and, if not taken-up by plants, will rapidly leach out of the soil profile (Table 2). Other soil microbes, given enough time and the right soil conditions, can covert nitrate back into organic forms or back into nitrogen gas (Figure 1). Excess nitrate is especially utilized by soil bacteria under conditions of low soil oxygen such as water logging. These bacteria use nitrate as a source of oxygen for respiration, thereby causing the production of nitrogenous gases, which are subsequently lost to the atmosphere (Figure 1).

It should be obvious by now that the nitrogen cycle in nurseries is a very “leaky” system. In fact, most applied nitrogen fertilizer is not absorbed by plants at all but lost to leaching or volatilization. Heavy fertilization only drives this process faster.

Uptake by plants. Roots of higher plants take up inorganic nitrogen as nitrate and ammonium ions which have different charges (Figure 3). Organic fertilizers must also be broken down into these ionic forms before uptake can occur. Because the mode of uptake differs for each ion, their effect on overall plant growth rate as well as the relative growth rate of roots vs. shoots is pronounced. As we have just discussed, reducing the amount of nitrogen fertilizer can be used to slow plant growth. However, cutting back on total nitrogen can lead to nutrient imbalances and impair important physiological and biochemical processes. A more sensible approach is to regulate seedling growth rates by applying fertilizers containing nitrate instead of ammonium-based fertilizers.

Ammonium, and especially its equilibrium partner ammonia, are toxic at quite low concentrations. When they are taken-up by roots, plants immediately detoxify them by forming amino acids, amides, and related compounds. This process requires stored energy and carbohydrates which supply the carbon skeletons. Once assimilated, these organic nitrogen compounds are translocated through the xylem to the shoots for further utilization.

Table 2—Characteristics of the different forms of nitrogen in nurseries

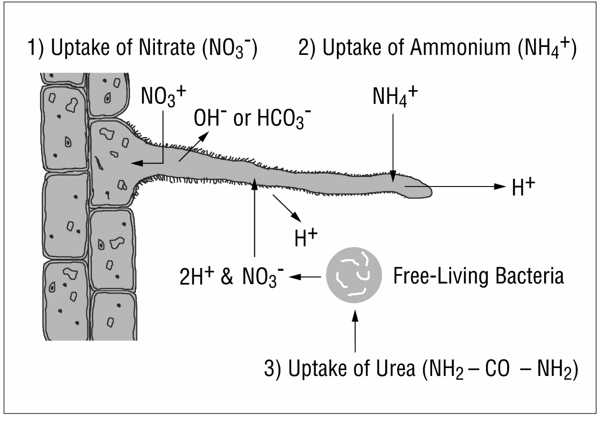
Name	Chemical Symbol & Ionic Charge	Leaching Potential	Remarks
Urea	**NH_3**	**High**	**Soil bacteria must convert urea to ammonium before uptake by plants**
Ammonium	**NH_4^+**	**Low**	**Held on cation exchange sites. Must be converted in roots after uptake**
Nitrate	**NO_3^-**	**High**	**Can be taken-up by plants and translocated without conversion**
Organic	**Several forms with no charge**	**Low**	**All organic fertilizers must be converted to ammonium ions before uptake**

Under high ammonium fertilization, the build-up of amino acids, amides, etc. essentially "drive" a plant to grow. Therefore, crops grown exclusively with ammonium fertilizers may deplete their carbohydrate resources to dangerously low levels, resulting in soft, succulent plant tissue. Roots may have their carbohydrate reserves depleted to the point where their growth and disease resistance is compromised. These conditions are most common during periods of low light and short days, when net carbohydrate synthesis rates are low. Warm conditions aggravate the situation further so greenhouse growers should be particularly careful using ammonium fertilizers for winter crops or during period of extended cloudy weather.

Nitrate, on the other hand, is not toxic and is mobile in the xylem on its own. This facilitates its transport to anywhere within the plant where nitrogen may be needed. Excess nitrate is stored in vacuoles in either root or shoot tissue. Nitrate cannot be used directly, however, but must be converted back to ammonia. This is a multi-step process requiring several enzymes, cofactors such as molybdenum, energy and time. Because nitrate does not have to be utilized immediately upon entry into the plant, it does not drive growth and carbohydrate depletion to the same degree as ammonium. And, because nitrate reduction takes place in growing plant tissue, carbohydrates in roots are not depleted.

Affects on pH. Plants grown on either ammonium or nitrate fertilizers change the pH of their soil or growing medium, specifically the zone immediately adjacent to the roots. Nitrate fertilizers cause soils and growing media to become more alkaline whereas organic nitrogen, urea or ammonium fertilizers make them more acidic. These changes in pH are due to a couple of reasons. First, the nitrification of organic, urea, and ammonium fertilizers produces hydrogen ions (H^+). Secondly, hydrogen ions are excreted by the roots upon ammonium uptake, and hydroxyl ions (OH^-) upon nitrate uptake (Figure 3). Consequences of this can be positive or negative depending on the cultural context. Growers have used the acidifying effect of ammonium fertilization to reduce the upward pH drift associated with high alkalinity water sources.

Figure 3 - Although three forms of nitrogen are available to plant roots, only ammonium and nitrate ions are taken-up. Note that, because hydrogen and hydroxyl are released by this process, the pH of the soil will be affected.



Influences on Plant Growth and Development

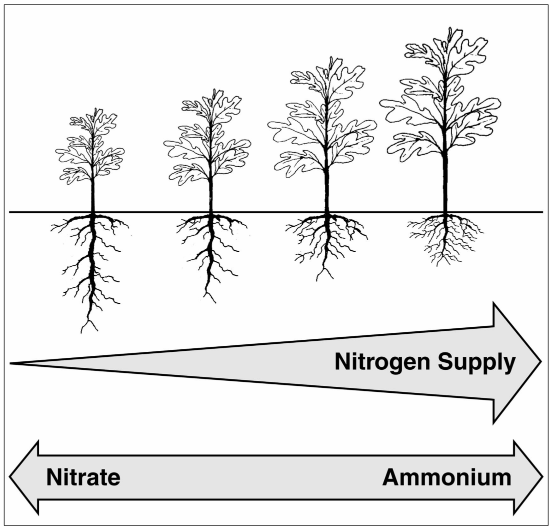
Growers use nitrogen fertilization to control the amount and type of tissue in their crops. When all other conditions are favorable, the amount and type of nitrogen fertilizer can be used to accelerate or slow down seedling growth. Not only the total growth rate, but the ratio of shoot growth to root growth can be affected by the type and amount of nitrogen fertilization (Figure 4).

Seedling Growth Phases. High nitrogen fertilization favors rapid shoot growth and produces leaves and needles which are larger and thinner. On the other hand, relatively low nitrogen levels lead to slower growth, smaller and thicker leaves, and a higher root:shoot ratio. The type of nitrogen fertilizer is also important. Ammonium-based fertilizers force more shoot expansion relative to root growth whereas nitrate fertilizers tend to favor stem and root growth (Figure 4).

Establishment Phase - Growers usually keep nitrogen levels low (for example, 50 ppm) when seedling are just getting established. This is because small plants cannot utilize high levels of nitrogen but also minimizes chances for damping-off because excess N stimulates fungal pathogens. Ammonium fertilizers are preferred because it takes young plants several weeks to develop the nitrate reductase enzyme.

Rapid Growth Phase - Once the crop is established, however, nitrogen levels are increased two to four times (typically to 100 to 200 ppm) and fertilizers with a higher proportion of ammonium are favored. The type of fertilizer and nitrogen rate must be adjusted for species differences, however. Naturally slower-growing species may need to be "pushed" with nitrogen levels up to 300 ppm whereas fast growers are kept at the 50 ppm rate. The cultural objective during this Phase is to maximize shoot growth, and seedling height increases rapidly during this period. However, this accelerated growth produces many cells with relatively weaker cell walls and this succulent growth is more subject to physical injury and other stresses. Even moderate

Figure 4 - Because nitrogen is so critical to seedling physiology, nitrogen fertilization can be use to speed-up or slow-down seedling growth as well as control their shoot-to-root ratio.



moisture stress or unusually high temperatures can physically damage ("burn") succulent foliage.

Hardening Phase - Growers typically lower nitrogen fertilization and change to nitrate fertilizers during the Hardening Phase as one of the cultural changes to induce dormancy and hardiness. Lower nitrogen rates are necessary as a first step in inducing dormancy and developing cold hardiness. Slower cell division produces thicker cell walls which are more resistant to physical stresses. Slowing the shoot growth rate is also the first step to inducing budset which is the start of the dormancy and hardening process. Calcium nitrate is a popular hardening fertilizer because the nitrate slows down cell division and the calcium helps build stronger cell walls.

Conclusions and Recommendations - Part 1

Well, that concludes the first part of our discussion of nitrogen as a essential plant nutrient and we think that you'll agree that it's a complicated and fascinating subject. Nitrogen is absolutely critical for controlling the amount and type of seedling growth in modern nurseries. Balanced against its cultural importance is the responsibility to minimize the environmental effects of overfertilization. We'll discuss nitrogen management in detail in the next issue of FNN.

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