How to Maximize Efficiency of Fertilizers in a Forest Tree Nursery[1]

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Abstract

The essentiality of nitrogen, phosphorus, and potassium was reviewed. Knowledge of the reaction of these nutrients in soil is a prerequisite to efficient use of nitrogen, phosphorus, and potassium fertilizers in forest nurseries. Notwithstanding economic considerations, biological requirements are strong determinants of nursery fertilization procedures.

INTRODUCTION

In order to maximize the effects of fertilization in a bareroot tree nursery, it must be realized that nutrition like temperature, moisture, light energy, and soil factors, strongly influences plant growth and development. It is necessary to know the characteristics of nutrient elements, their function in the plant, the form in which they are preferentially absorbed by tree species, properties of the chemical compounds that are being applied, and the interaction of fertilizer products with different soils. Although there are six major and six minor elements that are essential for plant growth, the scope of this report is confined to a discussion of those most common in commercial fertilizers, namely nitrogen (N), phosphorus (P), and potassium (K). In order to optimize a tree nursery operation, it is also necessary to apply the fertilizers cost effectively. Fertilizers differ in cost throughout North America depending on the cost of their various components. Application costs will be discussed in the context of bareroot seedling production in the Canadian Prairies.

CHARACTERISTICS OF NUTRIENTS

Nitrogen: Function in Plants

Nitrogen moves readily in plants and is a mobile element in the soil. It is absorbed most commonly as nitrate (NO_3) and ammonium (NH_4^+) ions and less so as urea ($(NR_2)_2CO$). Within the plant, all forms of nitrogen are converted initially to the amide (NH_2) form and later combine with carboxyl groups to form amino acids, the building blocks of proteins (Tisdale and Nelson 1966). Nitrogen is an integral part of the chlorophyll molecule. Adequate N produces vigorous vegetative growth with deep green color whereas stunted chlorotic plants result from a deficiency of N. Deficiency symptoms appear first on older foliage because N is readily translocated to the meristematic region. At suboptimal levels of N, carbohydrates are deposited in vegetative cells but are converted to proteins as N increases. Excess N causes succulence and results in weakening of cell walls. The vegetative phase is prolonged and maturity is delayed, predisposing the crop to frost and insect damage.

Fate of Fertilizer N in Soil

Nitrate - NO_3

Fertilizer N exists in one or more of three forms, namely nitrate, ammonium, and urea. Nitrate nitrogen is mobile in soil and is subject to loss by leaching predominantly because it moves readily with soil water. Nitrate is not strongly held on the soil exchange complex because of its negative charge. Thus, irrigation and the presence of coarse textured soils (a combination common in many bareroot tree nurseries) lead to leaching loss of nitrate from the root zone.

Since nitrate moves readily with soil water, it also moves upwards with capillary water during dry weather and may be deposited in surface or near surface soil horizons following evaporation.

Nitrate is lost also through denitrification by bacterial conversion to ammonium N and eventually to gaseous N (volatilization). Poor

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[1]Paper presented at the Intermountain Nurserymens Association meeting, Fort Collins, CO, August 1315, 1985.

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drainage, impaired soil oxygen, and alkaline conditions contribute to denitrification.

Nitrate N is subject to assimilation by soil microorganisms especially in the presence of organic material with a high carbon:nitrogen ratio such as sawdust. N is released only when the microbial activity declines.

Ammonium - NH_4

The primary reaction of the NH + ion is nitrification whereby ammonium N un ergoes bacterial conversion to nitrate. Warm (30 C), moist (field capacity), and well aerated soils accentuate nitrification. Ammonium N is subject also to immobilization by microorganisms in the presence of organic material of high C:N ratio. Nitrogen is released through mineralization only when microbial activity declines as the energy source of the bacteria is depleted. Therefore, if organic material with a wide C:N ratio such as grain straw or sawdust, is added to nursery seedbeds, sufficient N should be added simultaneously to satisfy bacterial and plant needs.

The ammonium ion is absorbed more strongly than nitrate by soil colloids owing to its positive charge and therefore is less prone to leaching by percolating water. Its retention in soil is fostered by high cation exchange capacity, and by soil conditions that are unfavorable for nitrification, e.g., low temperature, excess soil moisture. However, conditions (waterlogging and oxygen deficiency) that favor denitrification should be avoided.

In alkaline soil, the ammonium ion is converted to gaseous ammonia and is subject to loss through volatilization. Deep placement, i.e. well within the root zone, adequate mixing, and avoidance of hot, windy conditions during application of ammonium fertilizers will minimize N loss. Ammonium fertilizers increase acidity generally because nitrification is an acid-forming process.

Urea - $(NH_2)_2CO$

In soil, urea reacts with water, i.e., hydrolyzes, to form initially ammonium carbonate and subsequently free ammonia, ammonium ions, and carbonate ions. The initial hydrolysis is aided by the enzyme urease and because it is rapid, seedlings may be damaged by the ammonia released. Nitrogen loss through volatilization is minimized by deep placement. However, fate of the ammonium ion, once formed, will be controlled by plant uptake and factors that affect nitrification and immobilization as explained earlier. The immediate effect of urea fertilizer is to increase soil pH but as nitrification progresses, pH is reduced.

Nitrogen Forms and Seedling Growth

Among conifers, the preferred form of N varies with tree species. In Saskatchewan, 3-0 jack pine (Pinus banksiana) produced best growth in terms of height and dry weight with either ammonium sulphate or calcium nitrate (Edwards 1981). White spruce (Picea glauca) on the other hand grew best with ammonium N. In British Columbia, Douglas-fir (Pseudotsuga menziesii) grew best with the ammonium form of N (van den Driessche 1984).

It should be pointed out that soil properties play an important role in maximizing the efficiency of applied N. Since ammonium fertilizers are acid forming, they promote uptake of N in soils in which soil pH is unsuitably high. Ammonium sulphate, for example, is prescribed repeatedly in Western Canada for circum-neutral soil in bareroot nurseries.

Nitrate fertilizers, excluding ammonium nitrate, are not acid forming but could raise soil pH. Use of nitrates of sodium, potassium and calcium may result in alkaline conditions; mobile nitrate ions are readily absorbed by plants leaving an excess of basic cations.

Phosphurus: Function in Plants

Phosphorus is absorbed in lower amounts than either N or K, but it is essential for the initiation of primordial growth and seed formation and the stimulation of root growth. It acts as an energy carrier, being part of the high energy phosphate bonds that are essential in the processes of photosynthesis and respiration (Tisdale and Nelson 1966). Phosphorus deficiency leads to severe stunting, and depending on the plant species, leaves could be deep green or the lower (older) leaves and needles may become deeply bronzed or reddish-purple. Sometimes there are no symptoms of P deficiency besides severe reduction in growth. It is a mobile element in plants and normally deficiency symptoms develop earliest on lower (older) tissue.

Fate of Phosphorus in Soil

Availability of P in soil depends on pH and on the presence of other ions, but efficiency- of P utilization by plants is low (20X). Plants absorb P mostly as orthophosphate ions, H_2P0_4 and HPO ^{2}. In acid medium, H PO is favored but the^{4}presence of aluminum, iron and manganese in very acid soil results in fixation or precipitation of P as insoluble phosphates. As soil pH rise above pH 5.0, H PO declines in favor of HPO but above pH 7.0,^{4} the presence of calcium and^{4}magnesium will result in precipitation of insoluble phosphates (Tisdale and Nelson 1966). In general, soil pH of 5.0 - 6.0 is ideal for conifers whereas pH of 6.0 - 7.0 is preferable for hardwoods.

The above fixation or loss in availability may be minimized by proper placement. Broadcast placement followed by intimate mixing with the soil leads to increased fixation, assuming the above factors (pH, metal ions) are present. The recommended alternative is band placement whereby the fertilizer is set in localized bands beside and below the seed.

Soil-fertilizer contact may be minimized also by pelleting or aggregating the fertilizer. This is advisable with materials of high water solubility. (Slow-release fertilizers are coated with slowly soluble compounds to retard reaction of the fertilizers with soil water.) This is especially useful in areas of high precipitation). Enhanced utilization of phosphate fertilizers may be achieved also by combining them with organic matter (peat, farm manure, etc.) to extend their availability.

Potassium: Function in Plants

Potassium unlike N and P is not synthesized into other compounds. It is absorbed as the ion K^+ and is essential for protein synthesis and in production and translocation of carbohydrates. It is related to N metabolism; K deficient plants are high in soluble N suggesting blockage in the synthesis of protein from amino acids (Tisdale and Nelson 1966). It is a mobile element; deficiency symptoms occur first on lower leaves as marginal or tip burn and in some cases as chlorosis. It also functions in the promotion of growth of meristematic tissue, strengthens cell walls and is essential to stomatal movement and control of turgor (Tisdale and Nelson 1966).

Fate of Potassium in Soil

Potassium in soil exists primarily as an unavailable (fixed) form that is in equilibrium with smaller amounts of a slowly available and readily available forms. As plants absorb readily available (i.e. water soluble and exchangeable) K, the amount absorbed is replaced from both the slowly available and unavailable forms in a reversible process and a dynamic equilibrium is maintained.. Most (90-98%) of the K in soils is in the unavailable form and held by secondary clay minerals (expanding type).

When K fertilizers are applied to the soil, the element may be readily absorbed from solution, or absorbed by clays as exchangeable K. Some of the unused K reverts to the slowly available form and finally supplements the large unavailable pool. Plant uptake causes K to move slowly in the opposite direction and replenish the easily available fraction.

Potassium is subject to leaching in soil but its retention in slowly available and unavailable forms for eventual release to plants helps to minimize losses. Long term application of K fertilizers reduces the K-fixing power of the soil and increases the easily available (exchangeable) fraction. The degree of retention against leaching loss will depend on soil texture and, consequently, the exchange capacity. Many bareroot nurseries have coarse textured soils with low exchange capacity and are irrigated; such soils are more prone to leaching losses of K. Leaching loss of K increases as soil acidity increases (Krause 1965) and below pH 5.0, **it is** advisable to apply lime to increase the degree of base saturation and lower the risk of K loss. On neutral and alkaline nursery soils in Saskatchewan leaching loss of K was miniscule compared to that of calcium, magnesium, and NO_3-N (Edwards 1977).

Timing and Placement of Fertilizers

Efficiency of utilization of fertilizers can be increased by proper timing and placement. For production of conifer seedlings in bareroot nurseries, P and K are applied as basal dressings during preparation of the seedbed prior to seeding whereas **N** is applied as a top dressing in multiple doses and at two to three week intervals throughout the growing season. Nitrogen fertilizers especially NO_3 are subject to leaching loss in coarse textured soil and may cause salt injury to young seedlings. Following application, all fertilizer material should be brushed off the foliage and watered lightly into the soil. Multiple applications of N are warranted also because rate of growth and nutrient uptake vary through the season (Armson 1963). A more precise approach to multiple dosage is application of the fertilizer according to the accumulation of heat units. Armson (1962) recommended the use of 36^0F (2^0 C) as the base temperature for white spruce in Ontario.

Although many nurseries use broadcast application of P, ideal placement is banding because of its relative immobility in soil, propensity for fixation and its low degree of recovery by plants. Banding of the fertilizer (beside and below the seed) causes less mixing with the soil and lowers the risk of fixation (Tisdale and Nelson 1966). The practice requires specialized equipment and this may account for its unpopularity in tree nurseries so far. (The technique has been applied successfully in agriculture.)

Potassium is mobile in soil and may be applied as multiple top dressings. The practice is followed in some nurseries but the primary drawback is the risk of foliar burn to seedlings. Broadcast application followed by disking prior to seeding is the practice at many nurseries in the prairie region. However in locations with soils of high K-fixing capacity, band placement is advisable.

Both N and K fertilizers lend themselves to liquid application (fertigation) because of their high solubility. The practice has been followed in only one of the prairie nurseries. Degree of nutrient availability is similar compared to solid application but more practical questions have to be considered by the nurserymen. Is soil texture very coarse? Is frequent irrigation between fertilization events required because of hot weather? What is the strategy to be followed during extensive periods of rainy weather when the fields are due to be fertilized? A safe approach is to rely on solid material to supply the basic amount of nutrients. Supplemental amounts may then be supplied by liquid application. The effect of the latter may not be prolonged but it is useful as a quick boost where this is necessary, e.g. inclement weather.

Fertilizers Commonly Used in Nurseries

In bareroot nurseries, the most commonly used sources of N exclusively are ammonium sulfate (21-0-0) and ammonium nitrate (34-0-0). Phosphorus exclusively is supplied by ordinary superphosphate (0-20-0) and concentrated (triple) superphosphate (0-45-0). Popular combinations of N and P are the ammonium phosphates, specifically monoammonium phosphate (11-48-0 and 11-55-0), diammonium pnosphate (21-54-0), and ammonium phosphate-sulfate (16-20-0). The most common sources of K are potassium sulfate (0-0-50) and potassium chloride (0-0-62).

Rationale for the use of specific fertilizers is developed with biology and economics in mind and, depending on the circumstances, there may be trade-offs between both areas. Thus a price list (Table 1) may be important but long term viability of the nursery is of greater consequence. As a N source, ammonium nitrate is less acid than where soil pH is within acceptable limits. Ammonium sulfate is useful as an acidifying agent (along with elemental sulphur) where soil pH exceeds acceptable limits.

The ammonium phosphates by combining two elements help to lower handling and shipping costs per unit of nutrient. The high nutrient concentration of compounds such as diammonium phosphate adds to their attractiveness. The superphosphates are neutral (to soil pH) and the high P concentration adds to handling efficiency. The drawback with concentrated superphosphate is its uncertain availability and like other phosphate products
(in Western Canada) is expensive (Table 1). Among phosphate sources monoammonium phosphate (11-55-0) was shown to be most effective for Douglas-fir (van den Driessche 1984). Monoammonium phosphate (11-48-0) was also found to be effective for white spruce (Edwards 1981).

The choice of potassium source should be governed by the prevailing salinity level in the soil and irrigation water and the ease with which the soil can be leached. Normally, in western Canadian nurseries if electrical conductivity of the soil exceeds 1.0 mS/cm and that of irrigation water exceeds 0.75 mS/cm, potassium sulfate is preferred. Potassium chloride has a greater salt index and therefore a greater potential for salinity problems and chloride toxicity.

Table 1: Cost (Can.$)[1] of selected fertilizers in western Canada in 1985

Formulation	Fertilizer $/tonne[2]	N $/kg	P $/kg	K $/kg
21-0-0	217	1.03	---	---
34-0-0	263	0.77	---	---
46-0-0	300	0.65	---	---
11-51-0	425	3.86	1.89	---
16-20-0	318	1.99	3.61	---
0-20-0	390	---	4.43	---
0-45-0	600	---	3.03	---
0-0-50	356	---	---	0.86
0-0-62	175	---	---	0.34

[1] Canadian $1.00 is equivalent to U.S. $0.70 approximately

[2] Includes transportation charges and represent random sampling over three prairie provinces.

SUMMARY

The major elements N, P and K are essential to proper plant growth and play a most important role in the constitution of chemical fertilizers that are commonly applied in tree nurseries. In order to use the fertilizers most efficiently, it is necessary to know how each element reacts with the soil following application and the factors that affect their uptake by plants. These considerations will determine optimum timing and placement of the fertilizer. Cost and availability of fertilizers affect selection of specific materials but biological concerns ought to be given priority.

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