Determining Fertilizer Rates and Scheduling Applications in Bareroot Nurseries
by Thomas D. Landis and Charles B. Davey

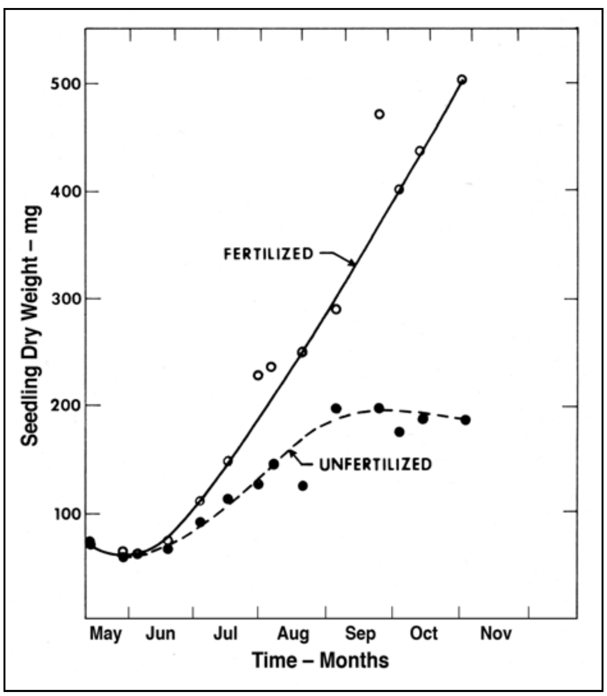
Going through past issues of FNN revealed that it has been quite a while since we talked about fertilization in bareroot nurseries. Sure, there have been the occasional research or proceedings papers (for example, Landis and Fischer 1985), but the last comprehensive discussions of fertilization were in the nursery manuals that are becoming a little dated (for example, Duryea and Landis 1984; Aldhous and Mason 1994). Bareroot nursery production still accounts for the majority of forest nursery production, especially loblolly pine (*Pinus taeda*) —so, it's time to take another look.

Fertilization has been shown to effect both the quantity and quality of seedling growth and, therefore, application of the correct amount of fertilizer at the proper time is critically important to the production of high-quality seedlings. One of the most erroneous maxims of early nursery management was that, because they often grew on sites with low fertility, forest tree seedlings did not require fertilization. On the contrary, one of the primary benefits of growing plants in nurseries is that, with proper fertilization, plantable-sized stock can be obtained many times faster than would occur naturally (Figure 1A). This fact was realized in the earliest forest nurseries where water slurries of animal waste were the first fertilizers (Figure 1B). Early experiments at the Savenac Nursery showed that the "naturally slow growth" of Engelmann spruce (*Picea engelmannii*) could be accelerated through fertilization in the nursery, and also resulted in better outplanting survival (Wahlenberg 1930).

The best nursery soils are selected for their physical properties rather than their inherent fertility, but all nursery soils contain a least small amounts of all the essential mineral nutrients. However, because the entire plants are removed during harvesting, nursery crops can quickly deplete soil fertility. When a crop of 2+0 conifer seedlings was analyzed, they had removed 110 to 440 lbs (50 to 200 kg) nitrogen (N), 9 to 77 lbs (4 to 35 kg) phosphorus (P), and 55 to 231 lbs (25 to 105 kg) of potassium (K) from the soil in each rotation (van den Driessche 1980). This large nutrient requirement is compounded by the fact that only a relatively small percentage of the mineral nutrients in applied fertilizers are actually taken-up by plants. For example, a 1+0 Sitka spruce (*Picea sitchensis*) crop utilized only 13 to16% of the N, 2 to 4% of the P, and 10 to 22% of the K in applied fertilizers (Benzian 1965).

Characteristics of Mineral Nutrient Ions

The 13 essential mineral nutrients can be divided into groups based on relative plant demand. We are mainly concerned with the 3 "fertilizer elements" because they are taken-up by plants in such large amounts (Table 1):



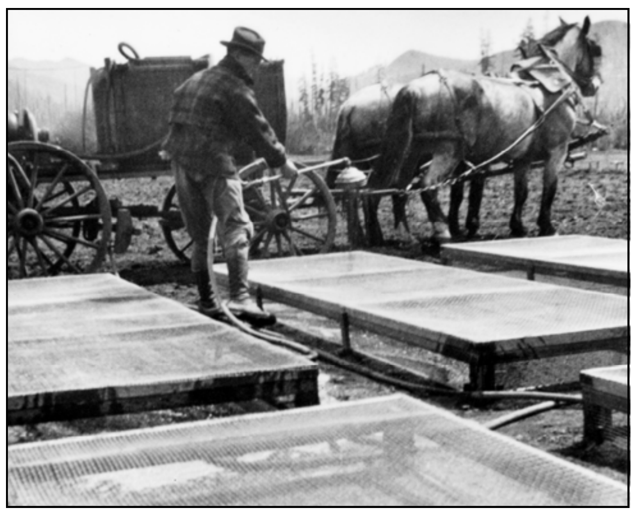


Figure 1 — The tremendous improvement in growth due to fertilization can be seen by this growth comparison for bareroot white spruce seedlings (A). The benefits of fertilization were recognized early where the first fertilizers were water slurries of animal manure (B) (A - modified from Armson and Sadreika 1979).

Table 1 — Characteristics of the three "fertilizer nutrients" (nitrogen, phosphorus, and potassium) that affect fertilizer application and timing

Mineral Nutrient	Ionic Symbol & Charge	Mobility & Leaching Potential	Time of Peak Demand	Fertilizer Application Method and Timing	
				Method	**Timing**
Nitrate-Nitrogen	NO_3^-	High	During rapid growth	Top dressing	4 to 5 times per season
Ammonium-Nitrogen	NH_4^+	Low	During rapid growth	Top dressing	4 to 5 times per season
Phosphorus	$H_2PO_4^-$	Low in soil; high from fertilizers	Early & late in growing season	Incorporation or banding	Pre-sowing
Potassium	K^+	Moderate	All season	Incorporation	Half pre-sowing
				Top dressing	Half mid-season

Nitrogen
Nitrogen (N) is the most important fertilizer nutrient because it fuels plant growth and development, and is taken-up by plants in two different forms. Nitrate (NO_3^-) is a negatively-charged anion and is very mobile in the soil and subject to leaching because anions are not held on the negatively-charged cation exchange (CEC) sites. Ammonium (NH_4^+) ions are positively-charged and so can be bound on the CEC complex that makes them less subject to leaching.

Phosphorus
Plants take-up phosphorus (P) as phosphate ions ($H_2PO_4^-$), but only about 1% of the total P in the soil is in this available form. Most of the soil P is unavailable because it is usually chemically bound in the soil, and so its mobility and leaching potential are low.

Potassium
Potassium (K) occurs in the soil solution as positively-charged cations (K^+) that can be bound on the CEC complex, which makes it moderately susceptible to leaching.

These chemical characteristics, in combination with the time of peak nutrient demand, should be considered for both fertilizer application method and timing (Table 1). N fertilizers should be applied as topdressings at regular intervals throughout the season so that a constant supply of nutrient is available. P is normally applied as a pre-sowing incorporation or banded during sowing to ensure that the immobile P ions are available to the young seedlings. K fertilizers are often applied both as an incorporation at the beginning of the season and again as a top dressing about midseason.

Factors Affecting Fertilizer Nutrient Utilization

The uptake and utilization of mineral nutrients is affected by a variety of factors related to nursery crop characteristics, to the nursery environment, and specific to the individual fertilizer ions.

Moisture
Soil moisture levels can affect mineral nutrient uptake in several different ways. Nutrient uptake due to mass flow occurs when ions dissolved in the soil solution move with the soil water towards the roots during transpirational uptake. Nutrient absorption is greatest when soil moisture is at field capacity which gives the ideal balance of both water and air. Low soil water content reduces nutrient uptake directly because the resultant low

hydraulic conductivity restricts water movement whereas saturated soils reduce nutrient uptake indirectly because the anaerobic conditions adversely affect root and microbial activity.

Plant species and source

Different crops have different growth characteristics and therefore different fertilizer requirements. Rapidly-growing pioneer species, such as jack pine (*Pinus banksiana*) and quaking aspen (*Populus tremuloides*), require lower amounts of fertility (particularly N) than slower-growing spruces (*Picea*) or ash (*Fraxinus*) (Stoeckeler and Arneman 1960). Davey (1994) concluded that broadleaved species require significantly more fertilization than conifers, especially N and calcium (Ca). Some nursery managers do not add any supplemental fertilizer to the seedbeds of aspen or western larch (*Larix occidentalis*) in an effort to control height growth whereas spruces or true firs (*Abies*) are heavily fertilized to force height growth. High elevation and interior sources of wide-ranging species such as ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) must be given higher fertilizer levels than low elevation and coastal sources.

Crop age

All 3 fertilizer nutrients are required in relatively large amounts by young plants but actual uptake patterns vary. The amount of P stored in the seed is quite limited and therefore supplies of this nutrient are required almost immediately after germination. Armson (1960) studied the uptake patterns of N, P, and K and found that P was rapidly taken up early in the 1+0 growing season and again later in the year (Figure 2). N and K, on the other hand, have high early uptake rates which gradually drop off during the growing season. These data suggest that P should be made available to the plant early and late in the growing season whereas N and K should be supplied during periods of rapid seedling growth.

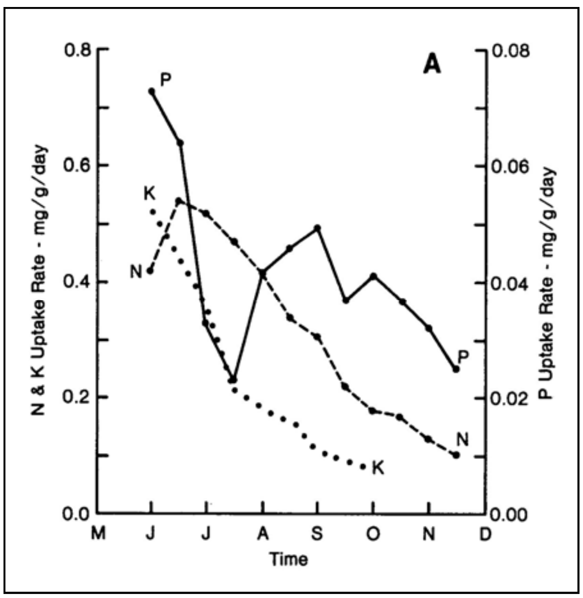


Figure 2 — Nutrient uptake rates of nitrogen (N) and potassium (K) are high relative to seedling size and peak early and then decrease through the growing season, whereas the relative uptake of phosphorus (P) has peaks both early and late in the season (modified from Armson, 1960).

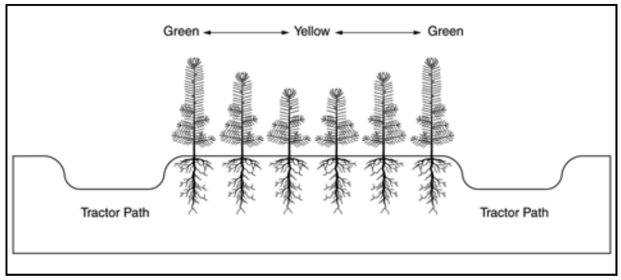


Figure 3 — Plants utilize more nitrogen than any other mineral nutrient which results a characteristic deficiency symptom where plants on the interior are more stunted and chlorotic than those on the outside.

Seedbed density

The number of plants growing per unit area of seedbed has a significant effect on their nutrient uptake. Experienced nursery workers are familiar with the "dished", chlorotic pattern in seedbeds suffering from N deficiency (Figure 3); this condition occurs because plants in the interior of the seedbed are under more competition and receive relatively less N than those in the outside rows (Armson and Sadreika 1979). This effect of seedbed density varies between species, however, as van den Driessche (1984a) found that Douglas-fir and Sitka spruce (*Picea sitchensis*) were more sensitive than lodgepole pine (*Pinus contorta*). Many nursery managers do not appreciate the very high growing density of tree seedlings compared to agricultural crops. If we assume a seedbed density of 25 plants per square .foot and a field efficiency of 60%, the resultant growing density of 650,000 plants per acre would be extremely high, compared to a typical density of 20,000 plants per acre for corn.

Temperature

The effect of temperature on nutrient uptake is not surprising but few people realize how significant it can be. van den Driessche (1984b) found that seedling growth is severely restricted below 50 ^{o}F (10 ^{o}C), regardless of the level of P fertilization; this growth reduction is very abrupt, which suggests that root function is impaired at low temperatures (Figure 4). Because this is a general

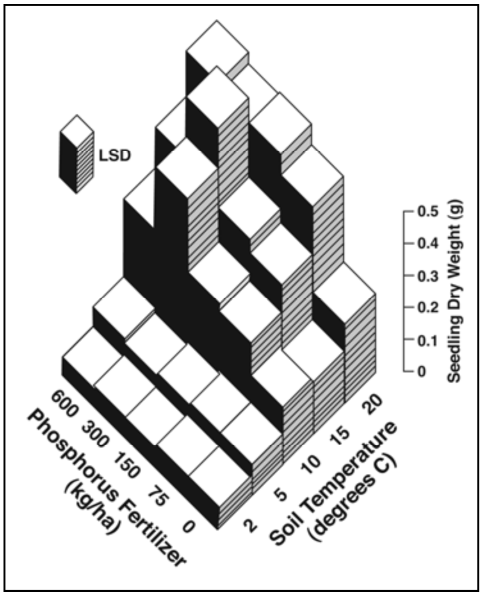


Figure 4 — Soil temperatures below 50 °F (10 °C) have a significant effect on phosphorus upake and resultant growth of Douglas-fir seedlings (van den Driessche 1984).

physiological effect rather than a specific ion effect, this temperature restriction probably occurs for all mineral nutrients.

Ways to Establish a Fertilization Plan

Every bareroot nursery needs a fertilization plan — a systematic, documented approach describing fertilizer application practices. Each plan will be different and will reflect the characteristics of the individual nursery and their specific crops. Most fertilization plans are established using one or more of the following approaches:

1. Personal experience

This is probably the most common and certainly the most traditional way to set up a fertilization program. As in any farming operation, nursery managers can build up real expertise based on their experiences over the years. In addition to keen powers of observation, nursery workers should have a basic understanding of fertilizer action and soil science in order to learn what works best at their own nursery. The real limitation to this method, however, is the time required to accumulate this experience. Because of the multi-year rotations inherent in tree production, a person must remain at the nursery long enough to witness several different rotations and experience a range of weather and crop variation over a period of many years.

2. Recommendations

This category includes both advice from consultants and recommendations from technical articles and nursery manuals. Nursery consultants are able to visit a variety of different nurseries and learn specifics about soil factors, crop characteristics, and climatic conditions, which helps them to develop customized fertilizer programs. On the other hand, consultants are expensive and nursery managers could become overly dependent on outside assistance. Nursery manuals and technical articles usually give "generic" fertilizer recommendations and the nursery managers must be able to modify these recommendations to fit their own soil and weather conditions and plant species requirements.

3. Nursery fertilizer trials

Undoubtedly, the best way to develop a fertilization program is to conduct a series of fertilizer trials right in the nursery so that specific crop responses can be measured. Ideally, trials should be performed on each major soil type and plant species, and also should be conducted over several rotations so that all sources of variation can be sampled. That's "ideally", which doesn't usually apply because most nurseries are just too busy with day-to-day operations. Still, fertilizer trials can lead to valuable insights into how the fertilizer-soil-water-plant complex really works under specific nursery conditions.
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4. Soil testing

Most tree nurseries have had soil tests performed at one time or another but many managers are not comfortable with their own interpretation of the test values. Soil tests are a good way to monitor soil fertility and fertilizer response but they have certain limitations. Most tests report in terms of "available" nutrients but these values vary with the extracting solution used by the lab. These extracting solutions supposedly remove the same amount of nutrient that would be available to the tree seedling during one growing season. P availability is particularly hard to measure and testing labs across the country use a variety of different extracting solutions which give different values on P "availability". Although any agricultural soil testing lab can perform soil tests, most are not familiar enough with tree seedlings to provide relevant interpretation of the results. Most published soil fertility standards for tree seedlings have usually developed from fertility trials with one of the major commercial species such as Douglas-fir or loblolly pine and may not be applicable to other species of seedlings.

5. Seedling nutrient analysis (SNA)

As with soil tests, SNA is expensive but can be invaluable because it is the only real way to determine if the nutrients applied as a fertilizer are ever taken up by the seedling. Interpretation of the test results can be difficult and many of the published standards are ranges of values that may not be sensitive enough to detect a problem with one particular species. Assistance with interpretation is often required and again consultants can be helpful (Landis and others 2005).

Calculation of Fertilizer Application Rates

The amount of fertilizer that should be applied to a nursery seedbed can be determined by soil test results or crop use. "Maintenance" fertilizer applications maintain soil fertility at some target level and are based on soil tests and/or SNA. "Replacement" applications replace the nutrients used by the seedling crop during the year. P and K are usually applied as maintenance applications using target values for the nutrients. Soil N exists in many organic and inorganic forms in nursery soils and there is no widely-accepted test for available N; therefore, N fertilizers are normally applied as replacement applications.

The type of fertilizer to apply is very important and single element fertilizers (for example, ammonium sulfate [21-0-0]) are generally recommended so that fertilizer amendments can be directed at a specific nutrient element. Complete fertilizers (for example, 15-15-15) should not normally be used because there is usually no need to supply N-P-K at the same time (Table 1). Complete fertilizers are also more expensive than most single element fertilizers. Ammonium phosphates (for example, 18-46-0) are exceptions because these multi-nutrient fertilizers are sometimes applied as pre-sowing incorporations or in bands during sowing. As we mentioned, diammonium phosphate can also be applied as a mid-season topdressing.

Replacement applications of N

Nitrogen applications are generally applied based on estimates of crop use because there is no acceptable soil test for available N. van den Driessche (1980) reported that 2+0 conifer crops use from 45 to 178 lbs/ac (50 to 200 kg/ac) of N during a rotation, so these values can be used as replacement application rates. The actual

Table 2 — An example of how to convert parts per million (ppm) from soil test results to application rates in pounds per acre (lbs/ac)

1. Determine amount of nutrient needed

Target phosphorus (P) level: 35 ppm
Subtract soil test P level: -18 ppm
Need to add as fertilizer: 17 ppm

2. Convert from ppm to lbs/ac

$$17 \text{ ppm} = \frac{17 \text{ parts}}{1{,}000{,}000 \text{ parts}} = \frac{17 \text{ parts}}{1{,}000{,}000 \text{ lbs}}$$

Given: One acre-foot of loam soil weighs 4,000,000 lbs, therefore a 9-inch rooting depth weighs 3,000,000 lbs:

$$\frac{17 \text{ lbs}}{1{,}000{,}000 \text{ lbs}} = \frac{X}{3{,}000{,}000 \text{ lbs}}$$

X = 51 lbs/ac of P

3. Convert from the elemental to the oxide form (P to P_2O_5 or K to K_2O)

51 lbs/ac x 2.3 = 117.3 lbs of P_2O_5

4. Convert to weight of bulk fertilizer

Concentrated superphosphate (0-46-0) contains 46% P_2O_5

$$\frac{117.3 \text{ lbs/ac } P_2O_5}{0.46} = 255 \text{ lbs of 0-46-0 per acre}$$

amount of N that a tree seedling crop requires is dependent on species, seedbed density, climate, and soil type. As a general rule, the N demands of broadleaved species can be about 50% greater than conifers (Davey 1994). N-fixing species often require only a starter dose of N to establish the plants but crop growth rates and SNA are the best guides (Davey 2002). Tissue tests at the end of the growing season should be used to fine-tune fertilizer applications during the following season. Late summer foliar tests allow time to apply additional nitrogen to bring levels to ideal levels before lifting.

SNA can also be used for trouble shooting during the season if nutrient deficiency symptoms such as chlorosis or dished beds (Figure 3) become evident. When collecting samples be sure to collect both symptomatic and normal seedlings so that comparisons can be made. Target values for N in conifer needle tissue range from 1.20 to 2.00%, so each nursery should strive to accumulate enough data to develop standards for their own situation (Landis and others 2005).

Maintenance applications of P and K
Soil test targets for P and K are usually given in parts per million (ppm) or pounds per acre (lbs/ac). The ppm units can be converted to amount of fertilizer per acre using the process provided in Table 2. Note that these calculations only supply the bare minimum amount of fertilizer and actual availability is dependent on soil texture. Sandy soils may require 10% more, loams 20% more, and some clays up to 40% more fertilizer. Again, use foliar tests for confirmation.

Many fertilizer specialists recommend that P be incorporated into the seedbed or banded at the time of sowing regardless of the soil test level. Root systems of newly germinated seedlings are very restricted whereas demand for P is high during germination and early seedling growth; these “starter” applications help ensure that a supply of P is readily accessible. For example, van den Driessche (1984a) recommends applying ammonium phosphate (11-55-0) at a rate of 27 lbs/ac (30 kg/ha) in a band 3 to 5 inches below the drill row and reports a substantial increase in growth for spruce seedlings. If top dressing is required during the season, use diammonium phosphate which is more soluble than other fertilizers.

Potassium fertilization is not normally required in western nurseries because most western soils contain an abundance of K-bearing minerals, particularly in the Great Plains and Intermountain areas. On sandy soils, particularly in the southeastern states, a late-season topdressing of potassium is frequently needed. Nursery managers should utilize soil tests, to determine the K availability at their own specific nurseries and convert ppm recommendations to application rates (Table 2). SNA should also be used to monitor P and K fertilizer uptake at the end of each growing season or for trouble shooting during the season.

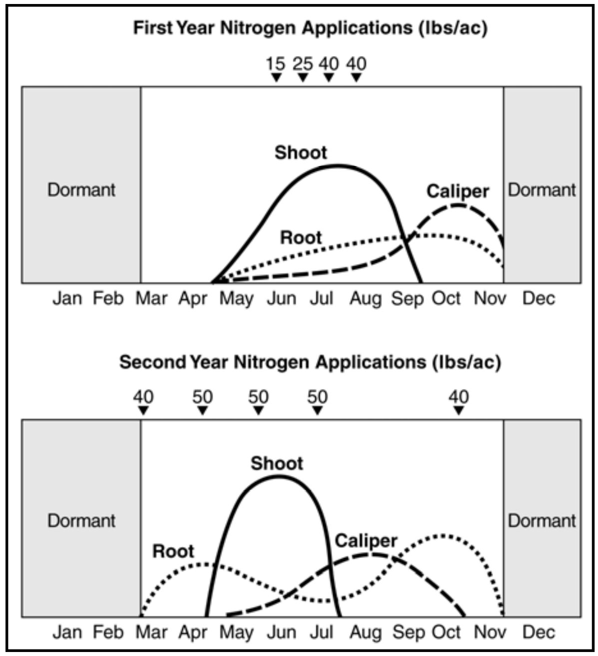

Figure 5 — Nitrogen fertilizer applications should be scheduled around plant growth cycles. In the first year, the first applications are delayed to prevent damping-off disease, but applications should precede bud break for established crops to allow time for the fertilizer to dissolve and move into the root zone.

Fertilizer Application Timing

Once the total annual fertilizer application rate has been calculated, the problem of when to apply the fertilizer and the rate per application must be decided. Because of the different characteristics of these three fertilizer nutrients (Table 1), they will be discussed separately.

Nitrogen
N is normally applied in a series of 4 to 6 applications over the growing season (Figure 5). Because many commonly-used N fertilizers (for example: urea, ammonium sulfate) are water soluble, they are applied as top dressings with standard fertilizer spreaders. N fertilizers can burn succulent seedling foliage and so the fertilizer should be brushed from the foliage or be watered-in immediately. The first application of N is usually delayed until after seedlings have become established because of concerns about stimulating damping-off fungi and fertilizer burn. During the 2+0 year, however, N

fertilizers should be applied as early as possible so that the nutrients are available prior to the first flush of spring growth. Because N is so soluble in the soil, repeat applications may be necessary after heavy spring rains particularly in coarse-textured soils. Some progressive nurseries are applying all their N as a liquid top-dressing which ensures quick uptake and reduces chances for foliar burning (see Fertigation section).

One of the most scientific ways of determining the proper time for N applications is the degree day system which uses accumulated heat units. The degree day approach is attractive because the fertilizer applications are synchronized with seedling growth, which is also tightly linked to temperature. Either ambient or soil temperature can be used as a degree-day basis although soil temperatures are more stable and more accurately reflect the environment where nutrient uptake is actually occurring. Because of climatic and edaphic variation, each nursery must develop its own degree day system; one used by Ontario nurseries can be found in Armson and Sadreika (1979).

Phosphorus
P can be applied during the fallow year or prior to sowing so that the nutrient is available early in the growing season (Table 1); these pre-sowing applications are effective because P is immobile in soil. Fallow year applications applied to cover or green manure crops ensure that P will be fixed into the organic matter and slowly released in subsequent growing seasons. Many soil scientists feel that P is best applied immediately before or during sowing to minimize the potential for chemical immobilization. Again, P uptake is temperature dependent (Figure 4) and so it is important that adequate supplies are available during the early spring. Mycorrhizal fungi are very important in the P nutrition of tree seedlings but many young seedlings do not become mycorrhizal until late in the 1+0 season, especially in fumigated seedbeds. This early mycorrhizal deficiency is further justification for pre-sowing P applications. Banding P fertilizers below the seed is especially effective and is discussed in the section on P application rates.

Potassium
K is moderately mobile in the soil and is required during periods of active growth and can therefore be applied as either a top dressing or incorporated (Table 1). Leaching losses are more serious in sandy soils with a low CEC so frequent top dressings would be more appropriate under these conditions. Probably the most practical procedure would be to apply half the annual amount as a presowing incorporation and the other half as a midseason top dressing. The need for late season K applications can be determined through tissue testing.

Conclusions and Recommendations

The utilization of fertilizer nutrients by tree seedlings is affected by many factors including seedling development, species of seedling, seedbed density, soil temperature, and soil moisture. The characteristics of the individual fertilizer elements (N, P, and K) also affects their availability and utilization in nursery soils.

All bareroot nurseries could benefit from a fertilization plan — a systematic, documented approach to fertilizer use. Fertilization plans must be developed specifically for individual nurseries to reflect unique climatic and edaphic characteristics and the response of individual seedling species. These plans can be developed using several different procedures: personal experience, recommendations, nursery fertilizer trials, soil testing and seedling nutrient analysis. Ideally, nursery managers will use a combination of all five of these procedures to produce a balanced fertilization plan, and accommodate new information as it becomes available.

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New Western Nursery Specialist

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