How to Determine Fertilizer Rates and Application Timing in Bareroot Forest Nurseries[1]

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Abstract.--The uptake and utilization of N, P, and K is affected by nutrient characteristics, seedling factors and nursery environment. Fertilization plans should be customized to reflect individual nursery characteristics. Fertilizer application rates can be determined through soil testing or by crop use. Timing of fertilizer applications varies between nutrients based on nutrient characteristics and seedling response.

The use of fertilizer in forest tree nurseries is generally considered to be a routine cultural operation and many nursery managers apply fertilizers on traditional calendar dates according to some general guidelines. Fertilizers supply a significant portion of the mineral nutrients needed for seedling growth, particularly of the major "fertilizer elements": nitrogen (N), phosphorus (P), and potassium (K). 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.

FACTORS AFFECTING FERTILIZER NUTRIENT UCILIZATION BY TREE SEEDLINGS

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

Seedling Development

All three fertilizer nutrients are required in relatively large amounts by young seedlings but the 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 1A). N and K, on the other hand, have high early uptake rates which gradually drop off during the growing season; this pattern closely follows the pattern for net seedling growth as represented by the net assimilation rate (Figure 1B). These data suggest that P should be made available to the plant both early and late in the growing season whereas N and K should be supplied during periods of seedling growth.

Species of Seedling

Different tree seedlings have different growth characteristics and therefore require mineral nutrients in different amounts. Rapidlygrowing pioneer species, such as jack pine *(Pinus banksiana)* and quaking aspen *(Populus tremuloides),* require lower amounts of fertility (particularly N) than slower-growing spruces or ash (Stoeckeler and Arneman, 1960). 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 are heavily fertilized to force height growth.

Seedbed Density

The number of seedlings growing per unit area of seedbed has a significant effect on their nutrient uptake. Most nursery workers are familiar with the "dished", chlorotic pattern in seedbeds suffering from N deficiency; this condition exists because seedlings in the interior of the seedbed are under more competition and receive relatively less N than seedlings near the edge (Armson and Sadreika, 1979). This effect of seedbed density varies between species, however, as van den Driessche (1984a) found that Douglas-fir *(Pseudotsuga menziesii)* 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 seedlings per sq.ft. and a field efficiency of 60%, the resultant growing density of 650,000 seedlings per acre would be extremely high, compared to a typical density of 20,000 plants per acre for corn.

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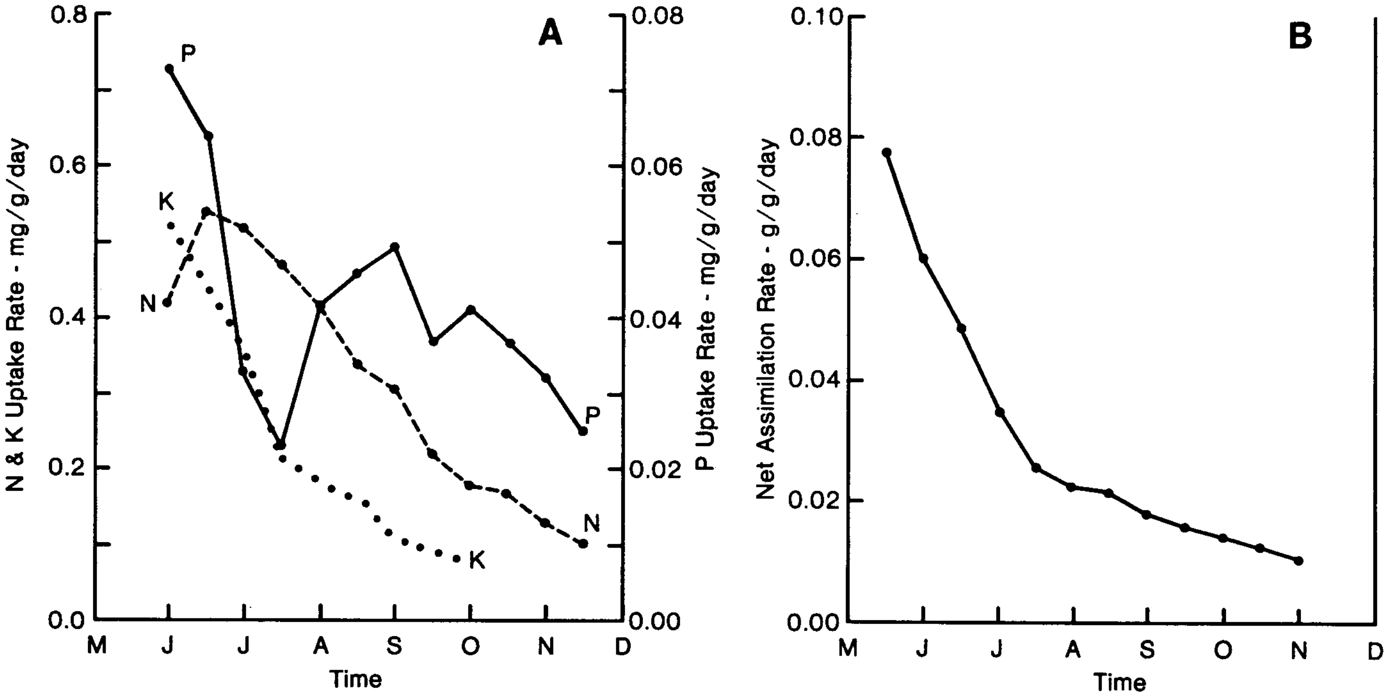

Figure 1.--(A) Comparison of nutrient uptake rates of N, P, and K, with (B) seedling growth rate during the growing season (modified from Armson, 1960).

Temperature

The effect of temperature on nutrient uptake is not surprising but few people realize how significant it can be. A study by van den Driessche (1984b) shows that seedling growth is severely restricted below 10°C, regardless of the level of P fertilization; this growth reduction is very abrupt which suggests that root function is impaired at low temperatures (Fig. 2). Because this is a general physiological effect rather than a specific ion effect, this temperature restriction probably occurs for all mineral nutrients.

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.

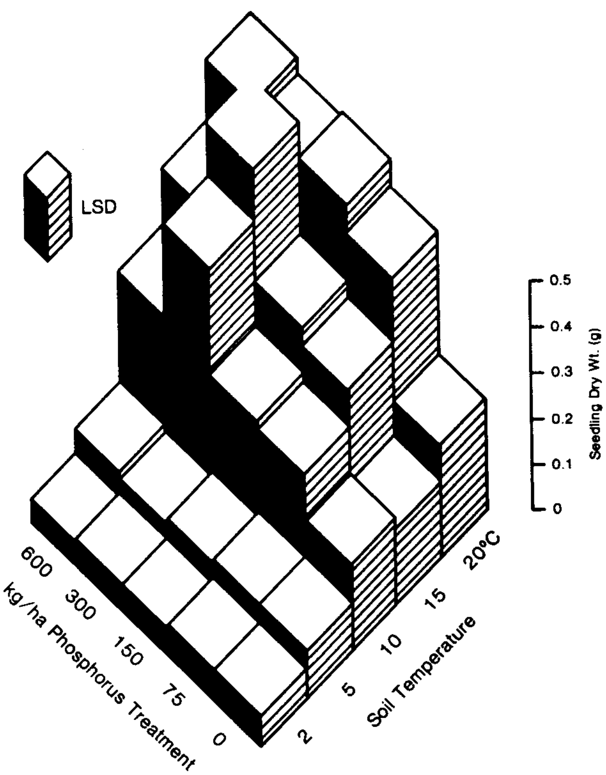

Figure 2.--The effect of soil temperature and phosphorus fertilization rates on Douglas-fir seedling growth (van den Driessche, 1984b).

Table 1.--Characteristics of fertilizer nutrients that influence fertilizer application and timing.

Fertilizer Elements	Nutrient Mobility and Leaching Potential		Time of Peak Nutrient Demand	Fertilizer Application Method	Fertilizer Application Timing
Nitrogen	NO_3^-	High	During rapid growth periods	Top Dressing	At regular intervals (4-5X per season)
	NH_4^-	Medium			
Phosphorus	$P_2O_5^-$	Low	Early and late in growing season	Incorporation or Banding	Pre-sowing
Potassium	K^+	Medium	During rapid growth periods	Incorporation and Top Dressing	Half-presowing and Half-midseason

Characteristics of Individual Fertilizer Ions

Each of the three fertilizer elements acts differently in the soil depending on its electrical charge and other chemical properties. 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 sites (CEC). The phosphate ion ($P_2O_5^-$) is also an anion 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 by a number of other ions in the soil and so its mobility and leaching potential are low. K^+ and ammonium -N (NH_4^+) are positively-charged cations that can be bound on the CEC complex; both ions are moderately subject to leaching (Table 1).

These 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 top-dressings at regular intervals throughout the season so that a constant supply, of nutrient is available. P is normally applied as a presowing incorporation or banded during sowing to insure 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.

WAYS TO ESTABLISH A FERTILIZER APPLICATION PLAN

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

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 a 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.

2. Recommendations - This category includes both advice from consultants and recommendations from technical articles and nursery manuals. Nursery consultants are able to visit individual nurseries and learn specifics about soil factors, crop characteristics, and climatic conditions and develop a customized fertilizer program. On the other hand, consultants are expensive and can be addictive - a nursery manager could become overly dependent on outside assistance. Nursery manuals and technical articles usually give "generic" fertilizer recommendations and the nursery manager must be able to modify these recommendations to fit his own conditions and species.

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 species of seedling, and also should be conducted over several rotations so that all sources of variation can be sampled. Nursery managers should seek the assistance of a statistician or nursery specialist in the planning stages and during the interpretation of nursery fertilization trials.

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 in the lab; these extracting solutions supposedly remove the same amount of nutrient that would be available to the tree

seedling. P availability is particularly hard to measure and testing labs across the country use a variety of different extracting solutions which give different P availability values. 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 and may not be applicable to other species of seedlings. Soil testing can also be an expensive operation, especially if the recommended number of samples is taken, so nursery managers should make sure that the cost of the test includes interpretation and recommended fertilizer treatments. Consultants can be very helpful in the interpretation of test results and their fee is usually very worthwhile.

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.

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 (Table 2). 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.

Table 2.--Soil Test Nutrient Targets for Nurseries of the Inland West

Fertilizer Element	Units	Target
Nitrogen (N)		
Total N	%	0.10 to 0.20
Nitrate -N	ppm	25 to 50
Phosphorus (P)[1]		
Available P	ppm	20 to 50
Available P_2O_5	lbs/ac	92 to 230
Potassium (K)		
Available K	ppm	100 to 150
Available K_2O	lbs/ac	240 to 360

[1] Using Olsen's sodium bicarbonate procedure

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

Replacement Applications of N

N 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 45-178 lbs/ac (50-200 kg/ac) of N during a rotation. The actual amount of N that a tree seedling crop requires is dependent on species, seedbed density, climate and soil type. Fertilizer nutrient recovery is also relatively low ranging from 13-16% N for a 1+0 crop to perhaps 50% during the 2+0 year (van den Driessche, 1984c). N recommendations vary but some examples from recent nursery manuals are provided in Table 3.

Table 3.--Recommended Nitrogen (N) Application Rates Per Year

Source	Units	Seedlings 1+0	Seedlings 2+0	Transplants X+1
Armson and Sadreika (1979)	lbs/ac	50-200	60-200	40-150
	kg/ha	56-224	67-224	45-168
Aldhous (1975)	lbs/ac	28-100	28-100	45-90
	kg/ha	25-75	25-75	50-100
van den Driessche (1984c)	lbs/ac	0-107	100-147	80-160
	kg/ha	0-120	112-165	90-180
Stoeckeler and Slabaugh (1965)	lbs/ac	40-80	40-80	40-80
	kg/ha	36-71	36-71	36-71

SNA should also be used at the end of the growing season to monitor the actual amount of N that the seedlings are able to take up and this information can then be used to fine-tune fertilizer applications during the following season. SNA can also be used for trouble shooting during the season if nutrient deficiency symptoms such as chlorosis or dished beds 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% (Table 4) which are very broad; each nursery should strive to accumulate enough data to develop standards for their own species.

Table 4.--Standard Values for Mineral Nutrient Concentrations in Conifer Needle Tissue (Landis, 1985)

Mineral Nutrient	Units % dry wt	Adequate Range [1]
Macronutrients		
N	%	1.20 to 2.00
P	%	0.10 to 0.20
K	%	0.30 to 0.80
Ca	%	0.20 to 0.50
Mg	%	0.10 to 0.15
S	%	0.10 to 0.20
Micronutrients		
Fe	ppm	50 to 100
Mn	ppm	100 to 5000
Zn	ppm	10 to 125
Cu	ppm	4 to 12
Mo	ppm	0.05 to 0.25
B	ppm	10 to 100
Cl	ppm	10 to 3000

[1] Macronutrient values are from Youngberg (1984) and micronutrient values from Powers (1974)

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) (Table 2). The ppm units can be converted to amount of fertilizer per acre using the process provided in Table 5. This process uses a standard weight of 4,000,000 lbs for an acre-foot of loam soil (or 2,000,000 lbs/6 in. rooting depth) which is a reasonable approximation and allows the nursery manager to compute the actual amount of fertilizer required to maintain the soil fertility at the desired levels.

Although P fertilizer applications should be computed using the calculations in Table 5, many fertilizer specialists recommend that a starter dose of P be incorporated into the seedbed or banded at the time of sowing regardless of the soil test level. The root system of the newly germinated seedling is very restricted whereas the demand for P is high during seed germination and early seedling growth; these starter applications help insure that a supply of P is readily accessible. van den Driessche (1984c) 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. Unfortunately, most of the standard seed drills used in forest tree nurseries are not equipped for banding although the conversion should not be difficult. An opportunity also exists to use the commercial mycorrhizal applicator manufactured by Whitfield as a band fertilizator applicator; this applicator costs approximately $4500 and is compatible with most nursery seeders (R. A. Whitfield Forestry Manufacturing Co., Mableton, GA).

Table 5.--Determining Fertilizer Application Rates from Soil Test Results[1]

1. **Determine amount of nutrient needed**

   Target P Level = 35 ppm
   \- Soil Test Level = 18 ppm
   Need to add as fertilizer = 17 ppm

2. **Convert ppm to lbs/ac**

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

   Given: One acre of soil 6" deep (plow-slice) weights 2×10^6 lbs

   $$\frac{17 \text{ lbs}}{1{,}000{,}000 \text{ lbs}} = \frac{X}{2{,}000{,}000 \text{ lbs}}$$

   X = 34 lbs/ac P

3. **Convert from P to P_2O_5**

   34 lbs/ac x 2.3 = 78.2 lbs/ac P_2O_5

4. **Convert to weight of bulk fertilizer**

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

   $$\frac{78 \text{ lbs/ac } P_2O_5}{0.46} = 169.6 \text{ lbs of 0-46-0 per acre}$$

[1] This same procedure can be used to determine K application rates by substituting 1.2 for 2.3 to convert from K to K_2O in Step 3, and using the appropriate bulk fertilizer conversion in Step 4.

K 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. Nursery managers should utilize soil tests, however, to determine the K availability at their own specific nurseries.

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. General guidelines for the normal range of P and K are given in Table 4; these should be useful until each nursery is able to develop their own standards.

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 - This nutrient is normally applied in a series of small applications over the growing season (Table 6). Because all N fertilizers 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 watered-in immediately. The first application of N is usually delayed until after the seedlings have become established because of concern about stimulating damping-off fungi and the possibility of 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 light-textured soils.

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, of course, 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 the nutrient uptake is actually occurring. Because of climatic and edaphic variation, each nursery must develop its own degree day system but an example of the degree day schedule used for Ontario nurseries is given in Table 7.

Table 6.--Application Timing of N Top Dressings (Aldhous, 1975 and others)

Crop	Season	Number of Fertilizer Applications: Initial	Subsequent
Seedlings	1+0	5-7 weeks after germination or when primary needles appear	At 3-4 week intervals [1]
	2+0	As early as possible	At 3-4 week intervals [1]
Transplants	X+1	At least 1 month after transplanting	At 4-5 week intervals [1]

[1] Repeat applications may be necessary after heavy rains.

Table 7.--Cumulative Degree Days (1°C basis)[1] can be used to Schedule N Fertilizer Applications (Armson and Sadreika, 1979)

Application No.	Southern Ontario: Jack and Scots Pine	Southern Ontario: Others	Northern Ontario: Jack Pine	Northern Ontario: Others
1	55	55	55	55
2	440	220	330	165
3	1100	440	660	330
4	1650	1100	1320	495
5	--	1650	1760	660
6	--	2310	--	990
7	--	--	--	1430
8	--	--	--	1870

[1] Although not specified, these values are presumably air temperatures.

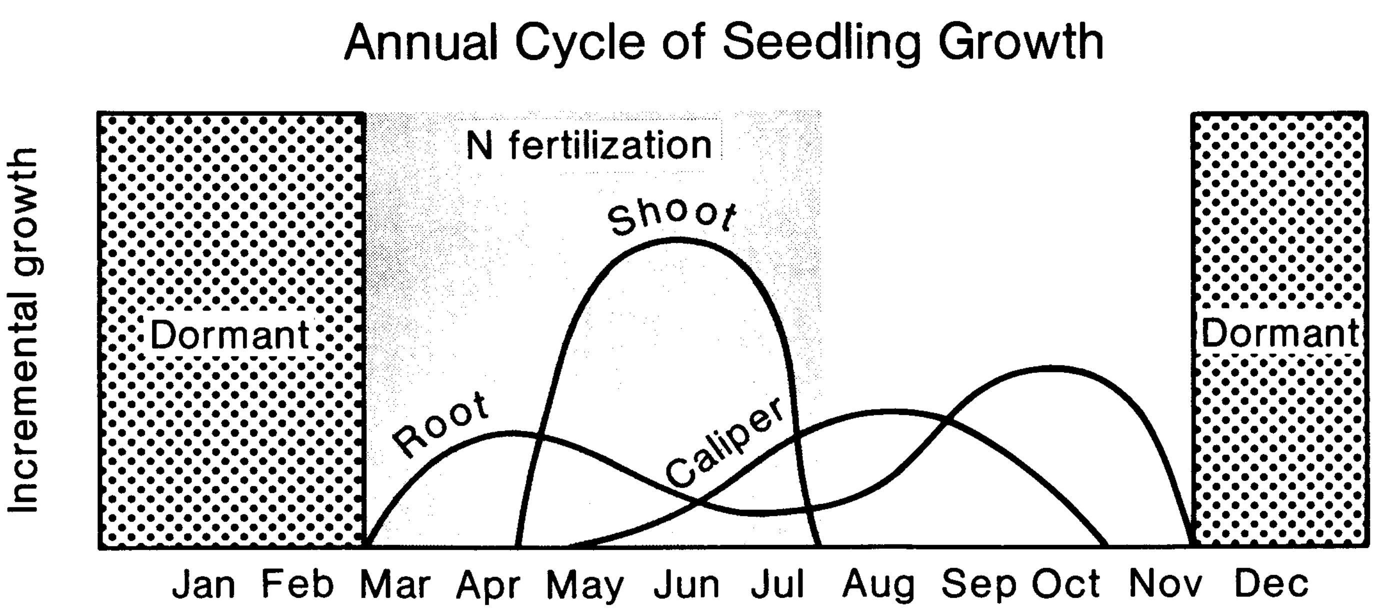

Figure 3.-- Nitrogen (N) fertilization should be scheduled early in the growing season during the period of rapid growth.

If a degree day schedule is not available, the next best procedure is to schedule N fertilizer applications based on seedling growth curves. Plots of growth increments (Fig. 3) show the times when growth generally occurs and so fertilizer applications can be scheduled at regular intervals during this period. This approach insures that the fertilizer is available during the time of maximum seedling growth rather than later in the year when the fertilizer would be wasted or could adversely affect the onset of dormancy or frost hardiness.

Phosphorus - P applications 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 presowing applications are effective because of the immobility of P in the soil. Fallow year applications are applied to the cover or green manure crop so that the P can 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 at the time of sowing to minimize the potential for chemical immobilization. P uptake is temperature dependent (Fig. 2) and so it is important that adequate supplies are available during the early spring. Mycorrhizae are very important in the P nutrition of tree seedlings and 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 presowing 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.

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 should develop a fertilization plan which is 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 5 of these procedures to produce a balanced fertilization plan. These plans are not permanently fixed, however, and managers must be flexible enough to accommodate new information into their fertilization plans.

Fertilizer application rates can be determined by soil testing or crop use. Both P and K are applied based on soil test results: the amount of nutrient that is required to bring the soil level up to a target level is calculated and then maintenance applications of fertilizer are used to make up the deficiency. Because there is no practical soil test for available N in nursery soils, replacement applications of N fertilizer are generally applied to replace the N used by the seedlings during the year.

The timing of fertilizer applications is also different for each of the fertilizer elements. N is normally applied as a series of top dressings during the growing season. Degree days or seedling growth curves can be used to synchronize N applications with periods of active seedling growth. P is normally applied during the fallow year, incorporated into the seedbed prior to sowing, or banded during sowing so that adequate P is available during the early part of the growing season. K fertilizer applications may be applied either as a presowing incorporation, a top dressing, or both, depending on leaching potential.

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