Chapter 7
Soil Fertility in Forest Nurseries
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Abstract

The soil cation-exchange complex serves as a reservoir of nutrients which are released into the soil solution, where they are accessible to seedlings. Although macronutrients are most readily available in soils of pH 6 to 7, micronutrients are most available in more acid soils; therefore, pH values of 5.0 to 6.0 are recommended for forest nurseries. Under such conditions, available nitrogen is primarily In the ammonium form, and phosphorus can form Insoluble iron and aluminum compounds. Sulfur, potassium, calcium, magnesium, and micronutrients are seldom deficient in forest nurseries because sufficient fertilizer is added as "maintenance" dressings, or supplies from native minerals are adequate. Recommended fertilizer applications for a 2-year nursery rotation range from 112 to 285 kg of nitrogen, 67 to 200 kg of phosphorus, and 75 to 150 kg of potassium per ha. Recommended nutrient levels In both soils and seedlings are tabulated and some effects of nutrients on seedling growth and physiology mentioned.

7.1 Introduction

The primary purpose of forest nurseries is to produce trees to form new forests. Therefore, maintaining adequate fertility in bareroot nursery soils is important to assure production of high-quality planting stock. Gathering the appropriate information on maintaining adequate nursery soil fertility into a single publication has been attempted many times previously [e.g., 1, 9, 58, 71, 77] and undoubtedly will be necessary again as conditions change and new information becomes available. In this chapter, the main factors affecting soil fertility are outlined and the management measures that can alter or maintain fertility described. Particular attention is devoted to fertilizers and their use, and some effects of nutrients on seedling growth and physiology also are included.

7.2 Soil Cation-Exchange Capacity

Soils are derived primarily from minerals but also contain organic matter. The colloidal fractions (< 0.002 mm in diameter) of both mineral soil and soil organic matter are the chemically active portions. The colloidal mineral fraction is constituted of clays consisting of particles (micelles) of silicate and alumina arranged in crystal lattice structures [e.g., 20]. These micelles carry an overall negative charge and so can attract and adsorb positively charged particles (cations) such as hydrogen (H^+) or positively charged metallic ions such as ammonium (NH_4^+), potassium (K^+), calcium (Ca^{++}), and magnesium (Mg^{++}). Colloidal organic matter (humus) also carries negative charges and behaves as micelles do except that it carries many times more negative charges for the same amount of dry weight.

Cations adsorbed to clay micelles and organic matter can be displaced by other cations that are more positively charged or as a result of mass action. The quantity of cations which can be adsorbed or displaced is a measure of the cation exchange capacity (CEC) of the soil. This measurement is important for soil fertility because nutrient cations held on the soil CEC are not leached but are available for plant growth. Although CEC is normally measured at pH 7, nursery soils may have lower pH values and high organic matter contents such that the effective CEC may be lower than the measured CEC.

Nutrients are released from the CEC complex into the soil solution in the form of ions (Table 1), which are absorbed by plants. The proportion of the CEC occupied by bases is referred to as the percent base saturation. The remaining CEC is assumed to be occupied by H^+ ions which confer an acid reaction to the soil; therefore, soils with low percent base saturation tend to be acidic. Low percent base saturation also implies that the supply of nutrient cations for plant growth is low.

CEC is measured in milliequivalents (meq), which relate the combining capacity of soil and nutrient cations. For example, a soil with a CEC of 20 meq could adsorb 20 meq Ca, which

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equals 400 mg Ca (20 x equivalent wt. of Ca, 20.0 g; see Table 1), 20 meq K (782 mg K), or 20 meq Mg (243 mg Mg).

The meq values are normally expressed on the basis of 100 g dry soil. For practical purposes, 1 mg of nutrient/100 g of soil is equivalent to 22 kg/ha (20 lb/acre) furrow slice. Thus, 0.4 meq K/100 g soil would represent

0.4 x 39.1 = 15.64 mg K/100 g
15.64 x 22 = 344 kg K/ha (312 lb K/acre) furrow slice

where 39.1 is the equivalent weight of K (Table 1).

CEC values for a number of nurseries in the Pacific region of Canada and the United States ranged from 8 to 30 meq/100 g soil, and base saturation was usually less than 50% [71]. The OSU Nursery Survey (see chapter 1, this volume) showed the mean CEC of 16 nurseries to be 12.5 meq/100 g (range, 6 to 29 meq/100 g).

Table 1. Ionic forms of macronutrients and their equivalent weights.

Nutrient	Ionic form	Equivalent weight[1]
Potassium	K^+	39.1
Calcium	Ca^{++}	20.0
Magnesium	Mg^{++}	12.2
Nitrogen (nitrate)	NO_3^-	62.0
Nitrogen (ammonium)	NH_4^+	18.0
Sulfur (sulfate)	SO_4^{--}	48.0
Phosphorus (phosphate)	PO_4^{---}	31.7

[1] Equivalent weight is the weight that will combine with (for unlike charges) or replace (for like charges) the weight of some other element. Thus, 39 g of K^+ will replace 20 g of Ca^{++} or combine with 48 g of SO_4^{--}.

7.3 Soil pH

Soil pH, or reaction, is described by the pH scale in which 7 is neutral for soils measured in water. Soils measuring from 5.5 to 6.5 are generally regarded as slightly acid, those from 4.5 to 5.5 as acid, and those less than 4.5 as strongly acid. Values lower than 3.5 are rare. Alkaline soils have pH values above 7.5.

The pH is normally measured in a mixture of 1 part soil to 1 part distilled water: but other ratios (e.g., 1:5) may be used, or 0.1 molar calcium chloride may be used instead of distilled water. However, different methods result in different values. In particular, the calcium chloride method indicates pH values about 0.5 units lower than those obtained in water.

Soil pH affects availability of nutrients to plants and influences the composition of soil flora and fauna, including some crop pathogens. The macronutients nitrogen (N), K, Ca, and Mg are most readily available at soil pH values above 6, but maximum availability of P is restricted to between pH 6 and 7 [20]. The micronutrient metals iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), and cobalt (Co) are most available in soils with pH values below about 5. 5. Most conifers tend to become chlorotic on soils of neutral or alkaline pH because of their inability to obtain adequate Fe and Mn. However, extremely acid soils (pH < 4.5) are infertile because they do not retain nutrient cations such as NH_4^+, K^+, and Ca^{++} to any extent. Incidence of damping-off is reduced when nursery soil pH is maintained in the region of 4.5 to 6.0 [62], and weed problems also are reduced on acid soils (see chapters 18 and 19, this volume).

Ideal values for conifer nursery soils are pH 5 to 6 and those for hardwood nursery soils pH 6 to 7 [65]. Aldhous [1] warns against allowing nursery soil pH to become too high and recommends pH 5 for conifer nurseries, pH 5.5 for hardwoods, and pH 6 for poplars. Growth of several Northwest conifer species is optimal between pH 5 and 5.5 [13].

7.4 Nutrient Form and Availability

7.4.1 Nitrogen

Three forms of N occur in soil: (1) organic N associated with the soil humus, (2) ammonium N (NH_4-N) fixed within the lattice of clays such as vermiculite, and (3) soluble inorganic ammonium and nitrate compounds [20]. As soil organisms slowly break down organic matter, ammonium is released into the soil solution. In the presence of adequate bases, ammonium is nitrified to produce nitrate ions (NO_3^-). Nitrification is probably slow in forest nursery soils because most, but not all, are low in bases. In any case, most conifer seedlings grow well with a predominantly NH_4-N source [43, 49, 69]; Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] can be grown exclusively on NH_4-N [75]. Although the NH_4-N fixed within the clay lattice is relatively unavailable to plants, the NH, + adsorbed within the measurable CEC is available to plants and relatively resistant to leaching; NO_3^-, on the other hand, is readily leached from soil.

The common Kieldahl chemical analysis for N in soils determines all the N present other than nitrate, which is normally excluded. Although this value generally indicates soil N status, it is frequently a poor guide to N fertilizer requirements, which may be better judged from measuring of mineral N in light nursery soils. Effects of fertilizing a sandy loam soil with ammonium nitrate were readily detected by measuring extractable mineral N [74].

7.4.2 Phosphorus and sulfur

Occurring primarily in the earth's surface as insoluble apatite [$Ca_5(PO_4)_3F$ or $Ca_5(PO_4)_3OH$]. P is present in the soil mainly as inorganic phosphates (50 to 70%) and organic P (30 to 50%), which together compose the solid phase. A very small amount of P, in proportion to the solid phase, is present in the liquid phase as orthophosphate ions ($H_2PO_4^-$, HPO_4^{--}, and PO_4^{---}). Though the proportion of orthophosphate ions is influenced by pH, it is thought that plants can take up any one of these ions. These soluble phosphates react with Fe and aluminum (Al) under acid soil conditions to form insoluble $FePO_4 \cdot 2H_2O$ and $AlPO_4 \cdot 2H_2O$ and with Ca to form apatites in neutral and calcareous soils. The P thus becomes fixed in a form that is unavailable to plants.

Phosphorus fertilizers dissolve in water to release orthophosphates which, if not absorbed by plants, are steadily rendered unavailable by the fixation process just described. Soils with more clay tend to fix more of the P supplied by fertilizer than those with less clay, but soils with more organic matter tend to fix less. Organic matter improves P availability because it (1) competes with phosphate ions for binding sites on soil particles. (2) produces organic anions which chelate (form organic compounds with nutrients available to plants) Al, Fe, and Ca, and (3) slowly releases P during decomposition.

In forest soil, trees appear to rely, at least partly, on mycorrhizae for obtaining soil P [30] (see chapter 20, this volume). Even in the nursery, P deficiency has been detected in white spruce *[Picea glauca* (Moench) Voss] after soil fumigation [24]. This lack was attributed to destruction of mycorrhizal fungi essential to P uptake but could be rectified by using adequate P fertilizer.

Heavy use of superphosphate fertilizer has been reported to greatly accentuate Cu deficiency symptoms in Sitka spruce *[Picea sitchensis* (Bong.) Carr.] [13].

Analysis of total soil P is relatively uninformative because only a small fraction of P is available for plant growth. Consequently, several methods for determining available P have been devised which employ a variety of extracting agents (such as sodium bicarbonate and various dilute acids) and give a variety of results, seldom comparable. One suitable method for acid nursery soils is the dilute acid-fluoride procedure (Bray and Kurtz No. 1 solution; see [33], p. 159) which is used in Ontario [7] and British Columbia [71]. A sodium bicarbonate extraction solution (Olsen's method: see [33], p. 164) is widely used for calcareous soils of high pH.

Sulfur (S) occurs mainly in soil organic matter and is absorbed by plants as sulfate. Unlike P, it is not rendered unavailable to plants by reaction with other soil components, and it is usually present in adequate amounts in fertilized nursery soils because many fertilizers contain it in substantial amounts. For example, ammonium sulfate contains 24% S, potassium sulfate 18% S, and calcium superphosphate 12% S. Nevertheless, S can be deficient in nurseries [18]. In fact, incidence of S deficiency may be increasing due to use of fertilizers with low S content as well as reduced industrial SO_2 emissions. The amount of S in a conifer is closely related to the amount of N; the ratio is 1 part S to 14 parts N by weight [66]. Knight [35] recommends ensuring that 1/15 as much S as N is applied to light soils to safeguard against deficiency.

7.4.3 Potassium, calcium, and magnesium

The cations K^+, Ca^{++}, and Mg^{++} are adsorbed on soil cation-exchange sites where they are available to plants. Potassium-containing minerals, which are widespread, weather to release K. Exchangeable Ca and Mg also are derived from weathering of soil minerals, but these are not so ubiquitous. Ca is more readily displaced than K and can become depleted in acid nursery soils. However, even K can be rapidly depleted by leaching in sandy nursery soils with a pH of 5 or less [37].

7.4.4 Micronutrients

The metallic micronutrients Fe, Mn, Cu, and Zn occur as cations in the soil solution at low pH. At high pH they are converted to insoluble oxides and hydroxides which are not available to plants; for example. Douglas-fir seedlings growing in an artificial container soil (pH 6) to which too much Ca (50 meq/100 g) had been added showed Mn deficiency symptoms and contained no detectable foliar Mn. Healthy seedlings growing in a medium with a similar Ca level but at pH 5.5 contained 2 ppm foliar Mn [unpubl. data. 76]. Availability of micronutrients is generally reduced by increasing soil pH, as occurs with liming, although availability of molybdenum (Mo) is increased by raising pH. Boron (B) is generally more available under acid conditions; however, its concentration usually decreases down the soil profile. Therefore, deficiencies may be accentuated in dry weather because surface root activity is curtailed by lack of water [20]. Organic matter can complex metallic cations and render them unavailable to plants or can also produce molecules that chelate micronutrients.

7.5 Recommended Nutrient Levels

Soil and plant analysis can help the nursery manager maintain adequate nutrient levels for satisfactory plant growth (see chapter 8, this volume). These analyses are not always easy to interpret, however, and the quality and growth of stock over the previous few years provide equally important guidance for changes in nursery fertility.

7.5.1 Soils

The soil nutrient levels to be expected in a fertile nursery on the Pacific Coast growing Douglas-fir seedlings (Table 2) can probably be taken as a guide for most nurseries in the Northwest, although the range of values may be large [71]. Analyses from nurseries in other regions [e.g., 73] show levels similar to or somewhat lower than those in Table 2. Note that percentage of Kjeldahl N is largely a function of soil organic matter content and seldom indicates the N available to plants.

Table 2. Expected range In analytical values for Douglas-fir nursery soils (adapted from [71]).

	Range	Analytical method
pH	4.8-5.5	1 soil: l water paste
Organic matter, %	3-5	Wet oxidation
N, %	0.20-0.25	Kjeldahl
P, ppm	100-150	Bray and Kurtz No. 1, dilute acid-fluoride
K,meq/100g	0.20-0.30	
ppm	78-117	
Ca, meq/100 g	3.0-8.0	1 N ammonium acetate leachate at pH 7
ppm	600-1,600	
Mg, meq/100 g	0.7-2.0	
ppm	170-486	
CEC, meq/ 100 g	10-20	

Soil is most conveniently sampled when it is in fallow or after cover cropping so that recommendations for adjusting fertilizer schedules can be prepared before sowing the new crop (see chapter 8, this volume). One of the best ways of using soil analysis is to maintain records for each management unit and interpret them for the effects of different management procedures.

7.5.2 Seedlings

Because nutrient concentrations in conifers vary with season, it is conventional to sample seedlings in late autumn or early winter when nutrient levels are relatively stable. Whole shoots or entire plants commonly are analyzed for 1+0 seedlings, but only needles usually are removed and tested in older stock. Nutrient concentrations in needles are higher than those in stems and roots, but concentrations in 1+0 seedlings are higher than those in 2+0 seedlings. It is convenient to sample whole 1+0 seedlings in mid-October for chemical analysis so that inadequacies in plant nutrient concentrations can be rectified by fertilizing during the second year of growth (see chapter 8, this volume).

Nutrient concentrations vary with growing conditions of the crop, and from year to year, but certain ranges can be expected (Table 3). Seedlings with concentrations below the lower limit of the 50% range may be inadequately supplied with nutrients, and those with levels close to the minima almost certainly require appropriate fertilizing. Micronutrient levels in whole 1+0 Douglas-fir seedlings whose roots had been thoroughly washed ranged from 30 to 101 ppm B, 108 to 180 ppm Mn, and 47 to 66 ppm Zn [71]. In 1+0 white spruce, Mn ranged from 328 to 1,456 ppm [70]. The higher values were associated with applying chelated micronutrients to the seedlings.

Nutrient levels expected in needles of adequately supplied 2 + 0 Douglas-fir (Table 4) are probably a guide to levels that can be expected in most other conifer species grown in Northwest nurseries. The deficiency level of K in white spruce needles was 0.13 to 0.21% [31]. The Mn level ranged from 636 to 2,852 ppm in 2+0 white spruce foliage in a nursery experiment where Mn chelate was used [70]. The deficiency level of S for Sitka spruce needles was about 0.08% and the sufficiency level about 0.16% [18]. The deficiency level of Cu in Sitka spruce was 2.5 ppm and in Douglas-fir 4 ppm [60].

Interpreting foliar nutrient concentrations can be complicated by effects of environmental factors and interactions between nutrients. However, in healthy plants the ratios between the different nutrients are fairly constant. Work with Douglas-fir, Sitka spruce, and western hemlock *[Tsuga heterophylla* (Raf.) Sarg.] seedlings shows that if the percentage of N is set at 100, the proportions of the other nutrients are, approximately, 16P, 60K, 5Ca, 5Mg, 9S, and 0.7Fe under favorable nutrient conditions [32]. These proportions can serve as a guide to nutrient imbalance within the seedling.

Table 3. Means and ranges of morphological and nutrient-concentration values for samples of 40 (80 white spruce) 1+0 seedlings of five species collected on October 15, 1968 to 1978.

Measurement	Mean	Minimum	Maximum	50% range[1]
Coastal Douglas-fir (233 observations)				
Seedling dry wt., g	0.48	0.08	1.36	....
Shoot length, cm	9.93	3.60	19.22	....
Shoot: root ratio	0.50	0.29	1.05	....
N, %	1.61	0.74	2.55	1.41-1.81
P, %	0.20	0.11	0.45	0.17-0.23
K, %	0.85	0.43	1.32	0.74-0.95
Ca. %	0.30	0.01	0.61	0.22-0.38
Mg, %	0.11	0.06	0.22	0.10-0.13
Interior Douglas-fir (70 observations)				
Seedling dry wt., g	0.29	0.07	0.81	....
Shoot length, cm	6.34	3.50	12.80	....
Shoot: root ratio	0.56	0.30	1.15	....
N, %	1.93	1.34	2.79	1.73-2.13
P, %	0.25	0.18	0.41	0.22-0.28
K, %	0.84	0.63	1.44	0.74-0.95
Ca, %	0.31	0.05	0.67	0.22-0.40
Mg, %	0.12	0.07	0.17	0.10-0.13
Sitka spruce (44 observations)				
Seedling dry wt., g	0.23	0.08	0.47	....
Shoot length, cm	5.68	3.40	11.90	....
Shoot: root ratio	0.51	0.25	1.03	....
N, %	2.03	1.06	2.62	1.80-2.26
P, %	0.25	0.16	0.37	0.18-0.33
K, %	1.15	0.74	1.42	1.05-1.25
Ca, %	0.51	0.32	0.71	0.45-0.57
Mg, %	0.16	0.11	0.25	0.14-0.18
White spruce (234 observations)				
Seedling dry wt., g	0.18	0.03	0.60	....
Shoot length, cm	3.90	1.70	9.20	....
Shoot: root ratio	0.57	0.24	0.97	....
N, %	2.59	0.24	3.50	2.28-2.91
P, %	0.32	0.22	0.42	0.30-0.35
K, %	0.90	0.52	1.26	0.83-0.98
Ca, %	0.49	0.12	0.87	0.39-0.59
Mg, %	0.15	0.10	0.22	0.14-0.17
Lodgepole pine (53 observations)				
Seedling dry wt., g	0.58	0.15	1.58	....
Shoot length, cm	6.55	2.70	14.60	....
Shoot: root ratio	0.42	0.30	0.62	....
N, %	1.99	1.38	2.66	1.76-2.22
P, %	0.25	0.17	0.33	0.22-0.28
K, %	0.95	0.73	1.24	0.86-1.03
Ca, %	0.32	0.19	0.52	0.27-0.37
Mg, %	0.13	0.10	0.17	0.12-0.14

[1] Range in mineral nutrient concentrations for 50% of observations; range calculated as mean ± 0.68 standard deviation.

7.5.3 Deficiency symptoms

Inadequate mineral nutrition usually results in reduced seedling growth before any characteristic deficiency symptoms become evident. Visual symptoms of macronutrient deficiencies have been described by Purnell [52], Sucoff [61], Stone [59], Benzian [13], Baule and Fricker [11], and Armson and Sadreika [9]. Morrison's [46] summary (Table 5) shows that, in many instances, symptoms are rather similar for deficiencies of different nutrients. Thus, determining the particular nutrient causing the deficiency is seldom possible without supporting evidence, such as tissue analysis or alleviation of symptoms by nutrient addition.

Table 5. Visual deficiency symptoms in conifers (adapted from [46]).

Nutrient	Deficiency symptoms
N	General chlorosis and stunting of needles increasing with severity of deficiency; in most severe cases, needles short, stiff, yellow-green to yellow; in some cases, purple tipping followed by necrosis of needles at end of growing season.
P	Youngest needles green or yellow-green; older needles distinctly purple-tinged; purple deepens with severity of deficiency; in very severe cases in seedlings, all needles purple.
K	Symptoms vary: usually needles short, chlorotic, with some green near base; in some severe cases, purpling and necrosis with top dieback, or little or no chlorosis of needles but purpling, browning, or necrosis.
Ca	General chlorosis followed by necrosis of needles, especially at branch tips; in severe cases, death of terminal bud and top dieback; resin exudation.
Mg	Yellow tipping of current needles followed in severe cases by tip necrosis.
S	General chlorosis of foliage followed in severe cases by necrosis.
Fe	More or less diffuse chlorosis confined in milder cases to new needles; in more severe cases, bright yellow discoloration with no bud development.
Mn	Needles slightly chlorotic; in severe cases, some necrosis of needles.
B	Tip dieback late in growing season with associated chlorotic-to-necrotic foliage, intergrading to dieback of leading shoot with characteristic crooking.
Zn	Extreme stunting of trees with shortening of branches; needles yellow, short, crowded together on twig, sometimes bronze-tipped; older needles shed early, with resultant tufting of foliage; in severe cases, trees rosetted with top dieback.
Cu	Needles twisted spirally, yellowed or bronzed; "tip-burn" or necrosis of needle tips evident; in severe cases, young shoots twisted or bent.
Mo	Chlorosis of leaves followed by necrosis of tissue, beginning at tip and eventually covering whole leaf.

Table 4. Nutrient concentrations[1] expected in dry needles of 2 + 0 Douglas-fir in October.

	Nutrient concentrations											
Level	N	P	K	Ca	Mg	S	SO_4	Fe	Mn	B	Cu	Zn
	~ ~ ~ ~ ~ ~ ~ % ~ ~ ~ ~ ~ ~ ~						~ ~ ~ ~ ~ ~ ~ ppm ~ ~ ~ ~ ~ ~ ~					
Adequate	1.8	0.18	0.8	0.20	0.12	0.18	80	……	390-1,294	9-39	5.1-7.7	17-63
Low	1.2	0.14	……	……	……	……	……	39-51	……	……	……	……
Very low	1.0	0.09	……	……	……	……	……	……	……	5	2.4-5.1	……

[1] A variety of sources has been used; these are cited in [72]. P concentrations have been revised downward from that paper. Micronutrient values are from [59].

7.6 Fertility Management

Managing nursery soils is something of an art because specifications for many soil and crop characteristics cannot be precise. Location, climate, soil, weather, and many other factors make each nursery unique. Though guidelines and limits can be provided, much depends upon the individual nursery manager, who can keep adequate records of cultural treatments, particularly soil amendments, and conduct regular analyses of soils and crops. By being aware of how soil fertility factors are changing and how stock is growing in the nursery and performing after outplanting, the nursery manager can develop prescriptions to maintain adequate soil fertility.

7.6.1 Controlling soil pH

Raising soil pH can be relatively easy, but reducing it is much more difficult. Thus, any attempts to increase nursery soil pH should be careful and conservative. Fertilizers modify soil pH, with most of the commonly used N and P sources tending to acidify the soil. This effect is usually small and can readily be offset by an occasional small amendment of dolomitic limestone. The considerable ability of soils to resist change in pH is due to the buffer capacity resulting mainly from the reserve acidity of the cation exchange complex. The pH is detected in the soil solution, but this is in equilibrium with the cation exchange complex. Greater proportions of clay or organic matter in the soil provide a larger cation exchange complex and so buffer the soil solution against pH change. High buffer capacity implies stable soil pH.

Soil pH can be reduced with S, aluminum sulfate [$Al_2(SO_4)_3$], and sulfuric acid (H_2SO_4). But these substances are toxic to conifer seedlings at high concentrations and should therefore be applied as long before sowing as possible. Adding more than 1,680 kg/ha (1,500 lb/acre) of S to Ontario nurseries reduced survival of red pine (*Pinus resinosa* Ait.) in the seedbed, though average seedling dry weight increased up to at least 2,520 kg/ha (2,250 lb/acre) of S [47]. Experience in Ontario nurseries has shown that 560 kg/ha (500 lb/acre) of S reduces soil pH 0.5 units over the range pH 5. 5 to 7.0 [9].

Sulfur and slaked lime [$Ca(OH)_2$] were applied to silt loam soils at two coastal nurseries in spring to obtain plots with different soil pH [68]. Douglas-fir sown during the same spring showed little adverse effect from these S applications. Sulfur applied at 4,480 kg/ha (4,000 lb/acre) decreased pH by about 1 unit from the control in June and 1.4 units in September (Table 6). Slaked lime applied at 4,480 kg/ha (4,000 lb/acre) increased pH by about 1.1 units in June and about 1.0 in September. Between September and June of the following year, no further major changes in pH occurred.

Organic materials are safe acidifying agents whose effects often become appreciable only after several years of continuing application (see chapter 9, this volume). Hop waste (from a brewery) was effective in reducing pH of a calcareous silt loam (pH 7.8 to 8.0) at a nursery in the East Kootenay region of British Columbia. A dressing 2.5 cm (1 in.) thick, worked into the soil, reduced pH 1.2 units after 2 years; a similar dressing of commercial peat decreased pH 1.0 unit.

Table 6. Average changes in soil pH obtained with S and slaked lime [$Ca(OH)_2$] at two coastal nurseries.

Treatment	March application, kg/ha	Soil pH ~ ~Year 1~ ~ June	Sept.	~ ~Year 2~ ~ June
Control	0	5.6	5.4	5.5
S	1,680	4.9	4.5	4.7
	4,480	4.5	4.0	3.9
Ca(OHi7	1,680	6.3	5.9	5.9
	4,480	6.7	6.3	6.3

Ground limestone or dolomitic limestone (which contains Mg as well as Ca) is equally good for raising soil pH. The effectiveness of a unit quantity of limestone in changing pH is influenced by both soil texture and soil organic matter content (Table 7). Both clay and organic matter increase the soil's buffer capacity, making it more difficult to either raise or lower the existing pH.

Most nurseries in the Northwest irrigate heavily, and the pH and dissolved salt content of irrigation water can influence soil pH. Water with high pH, containing cations and especially bicarbonates, tends to raise soil pH. Acid injection into the irrigation system is possible [8] when water sufficiently low in bicarbonates is not available.

Table 7. Ground limestone (1,000 kg/ha) required to raise existing soil pH to one of three chosen pH values In soils of different textures (adapted from [1]).

	Intended pH for soil-texture class														
	Sands, loamy sands			Sandy loams			Silty loams, silt loams, loams, sandy clay loams			Clay loams, silty clay loams, clay			Soils in previous class, but high inorganic matter[1]		
Existing pH, by soil analysis	5.0	5.5	6.0	5.0	5.5	6.0	5.0	5.5	6.0	5.0	5.5	6.0	5.0	5.5	6.0
3.0	5.0[2]	6.3	7.5	6.0	7.7	9.0	8.2	10.2	12.2	10.0	12.5	15.0	11.9	14.9	18.0
3.2	4.5	5.8	7.0	5.5	7.0	8.5	7.3	9.4	11.4	9.0	11.5	14.0	10.8	13.7	17.0
3.4	4.0	5.3	6.5	4.9	6.4	7.9	6.5	8.5	10.5	8.0	10.5	13.0	9.5	12.6	15.6
3.6	3.5	4.8	6.0	4.3	5.8	7.3	5.6	7.8	9.8	7.0	9.5	12.0	8.4	11.3	14.3
3.8	3.0	4.3	5.5	3.6	5.1	6.7	4.9	6.9	8.9	6.0	8.5	11.0	7.2	10.2	13.2
4.0	2.5	3.8	5.0	3.0	4.5	6.0	4.1	6.2	8.2	5.0	7.5	10.0	6.0	8.9	11.9
4.2	2.0	3.3	4.5	2.5	4.0	5.5	3.3	5.3	7.3	4.0	6.5	9.0	4.8	7.8	10.8
4.4	1.5	2.8	4.0	1.9	3.4	4.9	2.5	4.5	6.5	3.0	5.5	8.0	3.6	6.5	9.5
4.6	1.0	2.2	3.5	1.3	2.8	4.3	1.6	3.6	5.6	2.0	4.5	7.0	2.4	5.4	8.4
4.8	0.5	1.8	3.0	0.6	2.1	3.6	0.9	2.9	4.9	1.0	3.5	6.0	1.3	4.1	7.2
5.0	…..	1.3	2.5	…..	1.5	3.0	…..	2.0	4.1	…..	2.5	5.0	…..	3.0	6.0
5.2	…..	0.8	2.0	…..	1.0	2.5	…..	1.3	3.3	…..	1.5	4.0	…..	1.8	4.8
5.4	…..	0.3	1.5	…..	0.4	1.9	…..	0.4	2.5	…..	0.5	3.0	…..	0.6	3.6
5.6	…..	…..	1.0	…..	…..	1.3	…..	…..	1.6	…..	…..	2.0	…..	…..	2.4
5.8	…..	…..	0.5	…..	…..	0.6	…..	…..	0.9	…..	…..	1.0	…..	…..	1.3

[1] If the soil contains more than 10% organic matter, use the next higher soil-texture class.

[2] To convert to tons/acre, multiply by 0.398.

7.6.2 Organic matter

Organic matter consists of three principal components—(1) plant, animal, and microbial residues in various stages of decomposition, (2) humus, and (3) live microorganisms [27]—and affects soil in various ways (see chapter 9, this volume). It increases the CEC, buffer capacity, and water retention; provides a substrate for microbial activity, which can influence soil crumb structure; supplies some nutrients; appears to play an important part in P nutrition, both by supplying P and by rendering other sources of P more available to plants; and interacts with micronutrients to increase their availability.

Organic materials added to nursery soils are decomposed by microorganisms that respire. Their respiration causes a large portion of the organic matter to be lost by oxidation. Thus, fresh organic matter must continually be added if a particular level of soil organic matter is to be maintained.

In the past, large additions of peat, forest duff, or compost were considered essential for maintaining nursery soil fertility [53, 58]. Long-term experiments comparing the relative merits of organic composts and mineral fertilizers conducted over 15 years in two English nurseries [17] and 20 years in one Scottish nursery [40] generally showed that mineral fertilizers alone produced as much or more seedling growth as added organic matter. Related studies of mycorrhizal development showed no consistent differences between Sitka spruce and Scots pine (*Pinus sylvestris* L.) treated with organic compost and mineral fertilizer [41]. The English nurseries had sandy loam soils, and the soil organic carbon (C) decreased in one of them from 0.7 to 0.6% with no organic matter added. The Scottish nursery apparently started with 17% organic C and still contained about 7% C after 20 years with no organic matter added; even this latter level is high by comparison with Northwest nurseries. But interestingly, the low organic matter content in the English nurseries did not prevent production of satisfactory crops. Apparently, high organic matter content of nursery soils is not essential if adequate, and sufficiently frequent, applications of inorganic fertilizers are made. It would be unwise, however, to allow the level to fall too low because of the other benefits of adequate soil organic matter.

Economics also must be considered. In the Northwest, it should be possible to maintain an organic matter content of about 4% in nursery soil [27]; costs outweigh advantages somewhere near 5%, but advantages make the expenditure worthwhile at 2 to 3%. The organic matter content of 21 Northwest nurseries varied from 2 to 6% (average 3.7%), and the range for different management areas within nurseries was greater (0.9 to 12.0%) (OSU Nursery Survey). Thus, an organic matter level of about 4% is a practical goal for most nurseries in this region.

Various forms of organic amendments are added to nursery soils, but the additional C may increase the C:N ratio sufficiently to reduce the amount of N available to the crop. For example, dry softwood sawdust can immobilize about 6 kg (12 lb) of N per ton and dry hardwood sawdust about 12 kg (25 lb) of N per ton [2]. Thus, supplemental N fertilization may be necessary when certain organic amendments are made.

Cover cropping, which seldom or never increases the level of soil organic matter or soil N [27, 54]. may, however, benefit the soil by conserving nutrients otherwise lost by leaching and improving soil physical and biological properties (see chapter 10, this volume).

7.6.3 Fertilization

Fertilizers can be organic (such as compost or manure) or inorganic (the various salts of nutrient elements now widely used in forest nurseries). The concentrations of nutrient elements in organic fertilizers are usually low; for example, composts may contain 2 to 4% N and 0.2 to 1.8% P [13] and farmyard manure about 1.1 to 1.5% N [4]. Inorganic fertilizers, on the other hand, are manufactured to definite nutrient specifications, referred to as "the analysis," and may contain high nutrient concentrations. For example, urea fertilizer contains 45% N. The properties and behaviors of fertilizers are described in various publications [e.g., 9, 23, 44].

According to an ancient but awkward convention, concentration in the analysis appears as **percentage** of N but as **percentage of the oxide** of P, K, Ca, and Mg; this means that a fertilizer specified as 21-0-0 contains 21 % N, but one specified as 0-20-0 contains 20% P_2O_5. Although the fertilizer analysis usually states only the percentages of N, P_2O_5, and K_2O, other nutrient elements also may be present. For instance, calcium superphosphate (0-20-0) contains Ca and S as well as P (Table 8). Because nearly all work is done in terms of nutrients and not nutrient oxides, it is convenient to convert nutrient oxide values to nutrient values. To convert (1) P_2O_5 to P, multiply by 0.437; (2) K_2O to K, multiply by 0.830; (3) CaO to Ca, multiply by 0.714; and (4) MgO to Mg, multiply by 0.60.

Increased absorption of P occurs in the presence of N. In fact, the greatest stimulation of absorption takes place when N is intimately mixed with P [45]. Thus, ammonium phosphate fertilizers are very effective sources of P, particularly when banded below the seed before sowing. Because chloride damage to conifers can result from applying potassium chloride [14], potassium sulfate may be a safer K source, particularly for spruce.

Soil pH can be changed by adding mineral fertilizers. Ammonium and urea salts, and even ammonia solutions, make the soil more acid. Ammonium sulfate is particularly effective in reducing soil pH. Nitrate fertilizers containing a base [KNO_3 or $Ca(NO_3)_2$] increase soil pH. Phosphate fertilizers either have no effect on soil pH or increase it, unless they contain ammonium, in which case they reduce it. Potassium sulfate and chloride have negligible effects on soil pH.

7.6.3.1 Nutrient elements

Fertilization of nursery soils is necessary to replace lost nutrients. Conifer seedlings, removed complete with root systems and, often, soil, contain substantial quantities of mineral nutrients when they leave the nursery. Weeding nursery beds by hand represents a further loss of nutrients. By contrast, in agriculture, frequently only the seed or part of the root is removed; the remainder of the plant is left to decompose and return its nutrients to the soil. About 1/3 of the nursery field is uncropped paths and headlands, however, and the crop is usually removed once every 2 years, not annually.

Amounts of nutrients removed vary from 50 to 200 kg N, 4 to 35 kg P, and 25 to 105 kg K in 2+0 conifer crops [73]. However, simply replacing these amounts of nutrients in the form of inorganic fertilizers is inadequate because fertilizer recovery is relatively low. Measurements made on 1+0 Sitka spruce crops show that only 13 to 16% N, 2 to 4% P, 10 to 22% K, and 2 to 4% Mg were recovered from added fertilizers [16]. Although recoveries by larger 2+0 seedlings may be greater, they are unlikely to exceed 50%. Thus, amounts of nutrients applied in fertilizers during a rotation tend to be much in excess of the quantities removed in the crop, as is evident from a summary of fertilizer recommendations from North America, Britain, and Germany [73]. The average quantities of nutrients applied per hectare and per rotation in 19 nurseries in the Northwest were 224 kg N, 126 kg P, 103 kg K, 9 kg Mg, 136 kg S, and 557 kg of ground limestone (OSU Nursery Survey), but the quantities applied at individual nurseries varied immensely (Table 9). In most cases, the total amounts shown as top dressings were applied as several smaller doses during the growing season.

Nitrogen.—Most conifers respond rapidly to N fertilizer. In general, the earlier N is applied, the better. Early May-sown seedlings usually benefit from a top dressing of N fertilizer in late June, and rising 2 + 0 stock can be fertilized from March onwards. Seedlings sown in sandy soils of low N status may benefit from ammonium phosphate (11-55-0) banded into the soil before sowing. On the other hand, on heavier soils and where damping-off occurs, N fertilization may not be advisable during the first year of growth; excessive use of N fertilizer on 1 + 0 Douglas-fir seedlings almost invariably accentuates damping-off [56]. Mortality in 1 +0 Douglas-fir seedbeds was found to be lower with ammonium nitrate than with ammonium sulfate [68].

Several applications of 22 to 44 kg/ha (20 to 40 lb/acre) of N should be made during the second growing season as a top dressing (Table 10). Crops should be watered immediately after dry, soluble, N fertilizers have been applied to wash fertilizer off to prevent foliage damage (fertilizer "bum"). The key to efficient N fertilization of conifers seems to be little and often. In general, N should not be applied to seedlings after July; otherwise dormancy may be delayed, During the second or subsequent years of growth, N fertilizer can be applied after buds are set and there is no chance of inducing flushing; this would normally be in late September or October.

Phosphorus.—Growth responses to P fertilizers are seldom detected if maintenance dressings of 67 to 13 5 kg/ha (60 to 120 lb/acre) of P are applied each rotation. However, such responses may be evident [56], particularly when a new nursery is being developed on previously unfertilized land.

Phosphorus fertilizers must be incorporated into the soil close to seedling roots. Thus, they are applied and cultivated

Table 8. Some common fertilizers, their analysis, and factors for determining nutrient amounts for application.

Fertilizer	Analysis	Nutrient	%	Factor[1]	Nutrient	%	Factor	Nutrient	%	Factor
Ammonium sulfate $(NH_4)_2SO_4$	21-0-0	N	21	4.76	S	24	4.17	…..	…..	…..
Ammonium nitrate NH_4NO_3	33-0-0	N	33	3.03	…..	…..	…..	…..	…..	…..
Urea $CO(NH_2)_2$	45-0-0	N	45	2.22	…..	…..	…..	…..	…..	…..
Sulfur-coated urea	32-0-0	N	32	3.13	S	22	4.55	…..	…..	…..
Calcium nitrate $Ca(NO_3)_2$	16-0-0	N	16	6.25	Ca	24	4.17	…..	…..	…..
Ammonium phosphate $NH_4H_2PO_4$	11-55-0	N	11	9.09	P	24	4.17	…..	…..	…..
Diammonium phosphate $(NH_4)_2PO_4$	21-55-0	N	21	4.76	P	24	4.17	…..	…..	…..
Calcium superphosphate $CaH_4(PO_4) + 2CaSP_4 \cdot 2H_2O$	0-20-0	P	8.7	11.5	Ca	20	5	S	11	9.09
Triple superphosphate $Ca(H_2PO_4)_2$	0-45-0	P	19.6	5.1	Ca	14	7.15	…..	…..	…..
Phosphoric acid H_3PO_4	0-52-0	P	22.7	4.4	…..	…..	…..	…..	…..	…..
Potassium sulfate K_2SO_4	0-0-50	K	41	2.44	S	17	5.89	…..	…..	…..
Potassium chloride KCl	0-0-62	K	51	1.96	Cl	46	2.17	…..	…..	…..
Sul-Po-Mag®	0-0-22	K	18	5.6	Mg	11	9.09	S	11	9.09

[1] The factor may be used to determine the actual weight of a nutrient in a fertilizer. For example, to supply 50 kg of N as ammonium sulfate (21-0-0), multiply 50 by the N factor: 50 x 4.76 = 238 kg ammonium sulfate.

Table 9. Nutrient elements applied during one crop rotation for 19 nurseries In the Northwest (data from OSU Nursery Survey).

	N	P	K	Lime	Mg	S
Presowing treatment						
Nurseries applying nutrient, %	21	84	58	37	16	53
Application rates, kg/ha[1]						
Average	42	46	73	1,500	38	61
Range	22-56	5-87	18-148	750-2,240	22-50	14-185
Median	45	45	55	1,000	40	55
Year 1 top dressing						
Nurseries applying nutrient, %	84	68	37	0	0	42
Application rates, kg/ha						
Average	103	69	43	…..	…..	79
Range	36-152	10-139	23-62	…..	…..	9-130
Median	110	75	45	…..	…..	85
Year 2 top dressing						
Nurseries applying nutrient, %	84	68	42	0	11	53
Application rates, kg/ha						
Average	152	78	107	…..	30	134
Range	53-306	20-140	23-208	…..	28-33	33-248
Median	160	75	110	…..	30	150

[1] To convert to lb/acre, multiply by 0.89.

into the soil before bed formation (Table 10). Where seed is drill sown, P fertilizer can be banded into the soil 3 to 5 cm below the drill. Banding ammonium phosphate fertilizer (e.g., 11-55-0) below drill-sown white spruce and Engelmann spruce [*Picea engelmannii* Parry ex Engelm,] substantially improves growth and is standard practice in many nurseries.

Top dressings of P fertilizers are relatively ineffective except on very sandy soils. Only relatively soluble P fertilizers such as ammonium phosphate (11-55-0 or 21-55-0) should be used for top dressings if they are to be applied at all, and this should be done early in the year, for example, March or April of the second year for 2+0 seedlings.

Calcium superphosphate (0-20-0) is a good P fertilizer for acid, sandy soils because it supplies Ca and S as well as P (Table 8) and tends to reduce soil acidity. Triple superphosphate (0-45-0) can be used if soil pH is too high or if soil Ca level is already high. Ammonium phosphate (11-55-0) should be used if the superphosphates do not provide adequate P nutrition.

In agricultural practice, heavy applications of P fertilizer have sometimes caused micronutrient deficiencies [50]. Zn and Cu are the elements most frequently affected by high P levels, and calcium superphosphate can accentuate Cu deficiency in conifers [13].

Potassium.—Positive growth responses of conifer seedlings to K fertilizers are seldom detected in Northwest nurseries, probably because maintenance dressings of K fertilizer prevent decline in soil K levels. However, a small increase in Douglas-fir root dry weight due to K fertilization was detected in a sandy loam nursery soil containing 0.25 meq K/ 100 g [71]. Both quantity and frequency of application seemed to affect growth. Evidence of K deficiency (yellowing and necrosis of apical needles and 0.3% foliar K) also has been noted in white spruce 2+0 seedlings and transplants from this nursery. More frequent top dressing of K fertilizer throughout the second growing season seems to have remedied the problem. There also is evidence that excessive K fertilization can result in undesirably high soil K levels, which reduce seedling growth [67]. Douglas-fir crops growing on soils containing more than 0.45 meq K/100 g should not be fertilized with K.

Table 10. Recommended yearly total applications of N, P, and K and typical fertilizer schedules for three crop age classes.

Age class	Application method	kg/ha[1]	Fertilizer	kg fertilizer/ha
		Nitrogen		
		0 to 120 kg/ha		
1 + 0	Band at sowing	30	11-55-0	280
	Top dress as at least 4 separate doses	22	21-0-0 or 33-0-0	106 (x4) 67 (x4)
		112 to 165 kg/ha		
2 +0	Top dress in early March	30	11-55-0	280
	Top dress as at least 6 separate doses	22	21-0-0 or 33-0-0	106 (x6) 67 (x6)
		90 to 180 kg/ha		
Transplants	Top dress as at least 4 separate doses	45	21-0-0 or 33-0-0	210 (x4) 134 (x4)
		Phosphorus		
		67 to 134 kg/ha		
1 + 0	Work in before sowing	67	0-20-0 or 0-45-0	770 340
	Band at sowing	67	11-55-0	280
		0 to 67 kg/ha		
2 +0	Top dress in early March	67	1 I-55-0	280
		67 to 134 kg/ha		
Transplants	Work in before planting	67	0-20-0 or 0-45-0	770 340
		Potassium		
		50 to 75 kg/ha		
1 + 0	Work in before sowing	50	0-0-53	112
	Top dress in July	25	0-0-53	56
		25 to 75 kg/ha		
2 + 0	Top dress in April	25	0-0-53	56
	Top dress in June	25	0-0-53	56
	Top dress in August	25	0-0-53	56
		50 to 100 kg/ha		
Transplants	Work in before planting	50	0-0-53	112
	Top dress in June	25	0-0-53	56
	Top dress in August	25	0-0-53	56

[1] To convert to lb/acre, multiply by 0.89.

Potassium fertilizers can be worked into the soil before sowing, but some top dressings are strongly advised from July onwards during the first growing season and throughout the second (Table 10).

Calcium.—A high level of Ca is undesirable in conifer nurseries because it raises soil pH and tends to promote growth of pathogenic fungi. Adding ground limestone may be justified if soil pH is much below 5: the quantity required can be determined from Table 7. Low soil Ca level (less than 3.0 meq Ca/ 100 g soil) or low seedling Ca content (less than 0.1 % Ca in 1+0 shoots) also may necessitate addition of ground limestone. A single dressing of not more than 2,240 kg/ha (2,000 lb/acre) should be applied and well worked into the soil. Dolomitic limestone is commonly preferred in forest nurseries because it provides Mg as well as Ca. Because excessive liming can impair the nursery's ability to produce good-quality stock, considerable caution and expert advice are recommended.

Magnesium.—Nursery conifer crops seldom seem to require Mg fertilizers: nevertheless, Mg is applied in dolomitic limestone and occasionally in other fertilizers. Magnesium sulfate is a common fertilizer which occurs in two forms. One (Epsom salts) is very hydrated, requiring 10 kg (22 lb) of salt to provide 1 kg (2.2 lb) Mg: the other, a less hydrated form (Kieserite), requires 5 kg (11 lb) of salt to obtain 1 kg Mg. At least one manufactured fertilizer (Sul-Po-Mag®) containing K, Mg, and S also is available (Table 8).

Sulfur and micronutrients.—Because many fertilizers contain S (Table 8), nurseries are unlikely to show S deficiencies. Should the fertilizer schedule contain inadequate S, the simplest remedy is to switch to fertilizers containing S, such as calcium superphosphate, potassium sulfate, and ammonium sulfate. Flowers of sulfur and calcium sulfate (gypsum) can be used when only S is required. S should be applied at about 30 to 60 kg/ha (26 to 52 lb/acre).

So far as is known, no micronutrient deficiencies have been detected in bareroot nurseries of the Northwest. Iron chlorosis is apparently fairly common in conifer nurseries where soil pH is high and Ca is abundant [9], but it can be corrected by spraying with ferrous sulfate [36]. Should micronutrients be found deficient, various soluble fertilizers supplying the nutrients are available. Chelated micronutrients, although more expensive, may be more effective in correcting deficiencies.

7.6.3.2 Application methods

Fertilizers can be applied to conifer nurseries in several ways, depending on time of treatment during the rotation and nutrient being applied. For example, N is usually required in greater quantities during the second year of a 2-year rotation and so must be top dressed: but P must be placed as close to the roots as possible and so is mainly incorporated into the soil before sowing.

Fertilizers can be broadcast with many types of agricultural spreaders. When P or Ca fertilizers are applied before bed shaping, broadcast spreaders with rotary flingers, which cover an 8- to 10-m swath, can conveniently be used; these presowing fertilizers are normally disked into the soil. These same spreaders can be used to broadcast top dressings of N, K, or other fertilizers, treating four or five 1.2-m-wide beds in a single swath: but they also apply fertilizer to the path, where it is largely wasted. Broadcast spreaders that use a worm-gear-driven bar to meter the fertilizer, which then falls by gravity, can apply fertilizer to individual beds with little waste. Thorough watering is essential after top dressing to wash fertilizer off the crop to prevent fertilizer burn.

In some nurseries, P fertilizers are banded below the drill at a depth of about 3 cm immediately before sowing with a modified wheat drill. The relative insolubility and immobility of P make banding a very efficient method of applying this fertilizer.

Fertilizer can be applied to foliage through overhead irrigation systems towards the end of an irrigation period, but distribution may be uneven. Pesticide spray equipment of the high-pressure, low-volume type is more satisfactory for foliar feeding [23]. Pressure and correct nozzle selection are important because droplet size can affect crop response.

7.6.4. Foliar feeding

Many types of crops such as vegetables and fruit trees are treated with foliar nutrient sprays [80]. Nutrients are also applied to conifer seedlings in container nurseries through overhead sprays. But as far as is known, foliar nutrients are not applied in bareroot nurseries in the Northwest.

Nitrogen, in the form of urea, is the most common foliar applied nutrient, although all macronutrients and micronutrients apparently have been used on various crops. Foliar applications tend to give rapid responses, and deficiencies of immobile elements, such as Ca, can often be more easily

Table 11. Fertilizer solutions used as foliar sprays on Monterey pine seedlings in New Zealand nurseries (adapted from [35]).

Element	Chemical source	Formula	Percentage of Element	Percentage of Sulfur	Solution,[1] % wt./vol. (compound)	Nutrient applied,[2] kg/ha (element)
N	Urea[3]	NH_2CONH_2	46	0	5	11.5
Mg	Epsom salts[4]	$MgSO_4 7H_2O$	10	13	5	2.5
Fe	Ferrous (iron) sulfate[4]	$FeSO_4 7H_2O$	20	11.5	5	5.0
B	Borax	$Na_2B_4O_7 10H_2O$	11.3	…..	0.2-0.5	0.11-0.28
	Solubor	$Na_2B_8O_{13} 4H_2O$	20.5	…..	0.2-0.5	0.20-0.51
Cu	Copper sulfate[4,5]	$CuSO_4 7H_2O$	25	12	0.5	0.62
Mn	Manganous sulfate[4]	$MnSO_4 4H_2O$	24	14	1	2.4
Zn	Zinc sulfate[4]	$ZnSO_4 7H_2O$	23	11	1	2.3

[1] Safe concentration (% wt./vol.) of single-salt solution. Where two or more compounds are combined in the same spray solution, concentration of each should be substantially reduced; e.g., to supply N, Mg, and Fe together, compound concentrations of 2% wt./vol. each would be more appropriate.

[2] Rate as kg/ha for element concerned when solution applied at standard rate of 500 liters/ha.

[3] Solution strength that can be safely tolerated depends on stage of growth and climate. If frosts are likely, concentration should not normally exceed 2 % wt./vol. (equivalent to 1.15 kg/ha N), even for frost-free conditions.

[4] Mg, Fe, Cu, Mn, and Zn can alternatively be supplied in chelated form. Generally, a concentration of 0.05% wt./vol. (compound) applied in 500 liters will be suitable. EDTA chelates contain 9.8% Cu, 9.8% Mn. 6% Mg, 14% Zn, and 14% Fe (element) while EDDHAFe supplies 6% Fe.

[5] Burning can be avoided by adding 1.25 kg of sodium carbonate for each kilogram of copper sulfate in the spray solution.

corrected with this method. However, quantity of spray and droplet size, as well as nutrient concentration, must all be controlled to prevent foliage burn. Urea is often applied in solutions containing 400 to 800 g/100 liters (4 to 6 lb/100 gal.).

Fertilizers have been applied to foliage in New Zealand forest nurseries [35]. Stage of crop development and weather conditions have been found to affect results. Applications should not be made in cold weather. If more than one nutrient is to be applied in the same solution, the concentrations of each must be reduced so that the overall concentration of salts in solution remains about the same. Adding wetting agents to the solution may actually increase likelihood of damage by urea sprays. The 5% concentration (weight/volume, i.e., 5 kg/100 liters) recommended for Monterey pine (*Pinus radiata* D. Don) (Table 11) might be more concentrated than desirable for smaller, slower growing seedlings such as spruce.

7.7 Seedling Responses to Nutrients in the Nursery

7.7.1 Growth

Newly germinated conifer seedlings contain adequate nutrients and show little response to different levels of external nutrient supply for up to 6 weeks after germination [29]. However, nutrient uptake by a nursery crop increases continuously, if somewhat irregularly, throughout the remainder of the season [e.g., 5]. This is supported by the observation that greatest growth is achieved when frequent top dressings of soluble fertilizers are made once seedlings are past the cotyledon stage. P uptake by a 2 + 0 Douglas-fir crop may reach a maximum in September, and K may actually be lost from the soil through leaching in fall [55]. Although nutrients are required continuously throughout the season, rate of P uptake, measured as milligrams of P per gram of seedling per unit time, varies considerably in white spruce [5] and to a smaller extent in Douglas-fir [6]. In white spruce, P uptake rate is high in early summer, drops in August, and increases again in fall. By contrast, N and K uptake rates are highest at the beginning of the growing season and then decrease steadily.

Seedling growth can be reduced and sometimes modified by withholding particular nutrients. Withholding N or P tends to restrict shoot growth more than root growth [22]. This was found to be true in Monterey pine seedlings, where reducing the N supply also reduced stem diameter in relation to height and decreased the number and length of branches [79].

Because undercutting and wrenching procedures tend to remove or damage part of the root system, intensively wrenched seedlings may require additional fertilization to compensate for their reduced root systems. Additional fertilization also is sometimes necessary to offset effects of wet or cold weather when fertilizers are leached or uptake is reduced by low temperature. However, dressings of ammonium nitrate applied to 2 + 0 pine seedlings growing on wet, cool soil resulted in reduced growth and disease symptoms attributed to nitrate accumulation [38].

7.7.2 Drought stress

Under drought conditions, high N levels have generally been found detrimental to growth and survival, intermediate N levels have either been beneficial or have had no effect, and low N levels have had the least effect on tree growth [51]. High levels of N tend to promote shoot growth, and seedlings with large shoots transpire more water than those with small shoots. Even when this was taken into consideration, high N supply reduced lodgepole pine (*Pinus contorta* Doug]. ex Loud.) recovery from drought stress [28].

High levels of foliar K are associated with reduced transpiration rates in trees. In an experiment with Sitka spruce, where water-use efficiency was calculated as grams of water used per gram of new shoot dry weight, seedlings with 1.0% foliar K used 188 g water/g new shoot, whereas seedlings with 1.9% foliar K used only 156 g water/g new shoot [19]. Increased K concentration was also shown to increase drought survival of Scots pine but not Norway spruce (*Picea abies* L.) seedlings [25]. Adequate K nutrition has been shown to increase drought avoidance of young dormant Douglas-fir seedlings in frozen soil [39].

7.7.3 Cold hardiness

Nutrition can influence seasonal growth pattern, which in turn can alter seedling susceptibility to low temperature. For example, fertilization may either prolong growth in the fall or cause earlier bud flushing in spring. Heavy N fertilization is often found to delay dormancy and result in fall frost damage to nursery seedlings, but the same effect can also be achieved with heavy P fertilization [42]. The time of fertilizer application clearly influences the outcome. For example, applying N and K to nursery beds so late in the season that growth was unaffected substantially reduced frost damage to Sitka spruce and western hemlock seedlings [14].

Low B levels have been implicated in frost damage to tree species [21, 26], but whether this is a symptom of nutrient imbalance or due to the failure of a function performed by B alone is unknown. Internal nutrient balance may be important; Timmis [64] found that, after a hardening period, young Douglas-fir seedlings with an internal K:N ratio of about 0.6 were hardier than those with a ratio of 1.3. This result also makes it unlikely that K level alone is important in promoting cold hardiness. Other evidence now shows that high levels of K do not directly increase cold hardiness in trees [10, 25].

7.8 Nutrient Effects on Stock Performance after Outplanting

How seedling nutrient status affects performance after outplanting is not clearcut. General biological principles indicate that small chlorotic seedlings will not survive as well or grow as fast as large green seedlings after planting out [15]. In several experiments, however, the benefit of nursery fertilization to survival after planting could not be demonstrated [12, 34, 48, 63]. In an experiment with red pine and Scots pine, the 10% higher survival shown by stock fertilized in the nursery was not significant [78]. Yet nursery fertilization of jack pine (*Pinus banksiana* Lamb.), red pine, and white pine (*Pinus strobus* L.) in the Lake States gave a slight but consistent gain in field survival [58].

Fertilization generally increases seedling size, which could be advantageous on planting sites where competition with other species occurs (see chapter 24, this volume). Survival and height growth of outplanted Douglas-fir were increased by nursery fertilization, which also increased seedling size [57]. Similar results were obtained in another study with Douglas-fir [74], although competition on the planting site was minimal. This latter study suggested that an optimal foliar N concentration (close to 2%) for survival exists and that 2 +0 seedlings with needle nutrient concentrations above or below that value did not survive as well.

In maritime climates, fertilizing nursery stock in the fall after budset can increase nutrient reserves, with subsequently increased growth after planting. Two-year-old Douglas-fir seedlings were fertilized with 56 kg/ha (50 lb/acre) of N in September and outplanted the following spring [3]. Fertilized trees were still 13% taller than unfertilized trees 5 years after planting. Similar results have also been reported for Sitka spruce fertilized in the nursery after budset [15].

It seems likely that seedlings with high internal nutrient concentrations will often survive better and usually grow more than seedlings with low nutrient concentrations (see chapter 15, this volume). However, the relationship between nutrient status and performance after outplanting may be subtle, influenced by factors such as cold-storage conditions and moisture relationships at the planting site.

7.9 Conclusions

Developing and maintaining a high level of fertility in bareroot nurseries are essential for producing good-quality nursery stock. However, soil fertility is only one of a number of factors influencing stock quality: fertile nursery soil does not compensate for poor practices such as overdense sowing, unseasonal lifting, or inadequate undercutting and wrenching.

Achieving an optimal supply of nutrients to conifer seedlings growing in nursery soil over a 2-year rotation requires skill and attention to detail. Soil features such as drainage and texture, which usually vary throughout the nursery, and changes in weather must continually be taken into account. These demands undoubtedly contribute to the steady increase in popularity of container-grown seedlings, for which fertility and climate can be reasonably well controlled. Though container nurseries can provide very favorable growing conditions, they are equally less forgiving, and mistakes in technique are more disastrous than in bareroot nurseries. Yet there is little reason why the nutrition furnished to bareroot seedlings should not be comparable to that attained in container systems. Many factors contributing to nursery soil fertility can be measured and at least partly controlled, and ensuring a reasonable level of health and vigor in nursery stock should be possible by soil and seedling analysis.

Correct timing and sufficient frequency of fertilization may still be lacking in many bareroot nurseries. These points should be further investigated, as should the possible benefit of slowrelease fertilizers for maintaining a steady nutrient supply in seedbeds.

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