NUTRIENT BUDGET FOR TREE SEEDLINGS

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Abstract

The goal of nursery management is the production of high quality planting stock that has an excellent chance of establishment and survival on widely diverse planting sites. This goal can be reached only by properly managing the nursery's most permanent and defining quality - the SOIL. Plant tissue analyses show concentrations of nutrients in the plant parts which not only reflect nutritional status but also amounts of nutrients removed by the seedlings over a period of two to three years before they are lifted for outplanting. By estimating the removal of nutrients by seedlings and losses from various soil processer (OUTPUT) and subtracting this value from estimates of nutrients added via fertilizers, microbial decomposition of organic matter and atmospheric sources (INPUT), it is possible to calculate a nutrient budget. Excess inputs over outputs indicate a buildup in the soil, whereas excess outputs over inputs result in nutrient depletion. The goal of a soil fertility program is to maintain nutrient levels that will optimally suit the needs of the seedlings thereby producing nutritionally balanced stock and at the same time economizing on fertilizer use. To maintain these optimum levels the plant nutrient budget must be balanced, that is, inputs must equal outputs.

Introduction

The forest nursery is the place where the life of trees begins, and where the trees remain during their early development. The characteristics which a tree acquires during this stage will affect the future of the planted stands.

Among the problems of forestry, few are as difficult as the maintenance of fertility and the control of parasites in nursery soils. In order to succeed in growing seedlings year after year on the same area, nursery managers are forced to apply commercial fertilizers, fungicides, herbicides and insecticides. All of these chemicals enter into numerous reactions with the soil constituents and cause partial or complete destruction not only of the parasitic, but also the useful mircoorganisms. Producing quality nursery stock is more complicated than producing quality consumable plants. Nursery stock is not evaluated by appearance, volume, or weight of the crop, but by its vigor and ability to withstand adverse climatic and biotic factors when outplanted on cutover lands. The size of planting stock is seldom correlated with its potential performance. More significant criteria are provided by the ratios of the heights of trees to their stem diameters and of tops to roots or the surface area for root absorption. Of no lesser importance for the resistance of planting stock against adverse climatic influences and fungal diseases are its concealed attributes, including an adequate and well balanced supply of major as well as trace nutrient elements.

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Regardless of the original state of soil fertility selected as a tree nursery site, the content of organic matter and nutrients will be depleted in the course of time by cultivation, leaching by rain and irrigation water, microbial activity and nutrient uptake by seedlings. These losses must be balanced by periodic additions of both organic matter and nutrients. Because our present knowledge of the annual losses is not very precise, soils from nurseries should be analyzed annually and a fertility maintenance program followed that is based on a diagrammatic record of fertility factors (Wojahn and Iyer, 1974), Fig. 1. Fertility factors are determined by following standard procedures outlined in Soil and Plant Analysis for Tree Culture by Wilde et al (1979) 5th Rev. Ed.

Assessment of fertilizer needs requires application of chemical analytical methods to soil samples and sampling of soils in nurseries plays a significant part. Soil sampling methods are described in the publication entitled "Sampling Soils in Forest Nurseries, Seed Orchards, Plantations and Natural Stands for Testing." (Bockheim et al, 1986).

Nutrient Budget Study

To study the nutrient budget, information was needed as to the amount of nutrients taken up by the seedling in relation to the amount of nutrients added to the soil via fertilizers and organic matter. Red pine being a commercially important species in Wisconsin was selected for analyses of nutrient content in the roots, stems and needles. The distribution of these within the plant parts were also documented. Yield data was obtained to calculate the amount of nutrients taken up by seedlings and the amount of nutrients in lbs/A removed based on a density of one million seedlings per acre.

Seedling Analyses

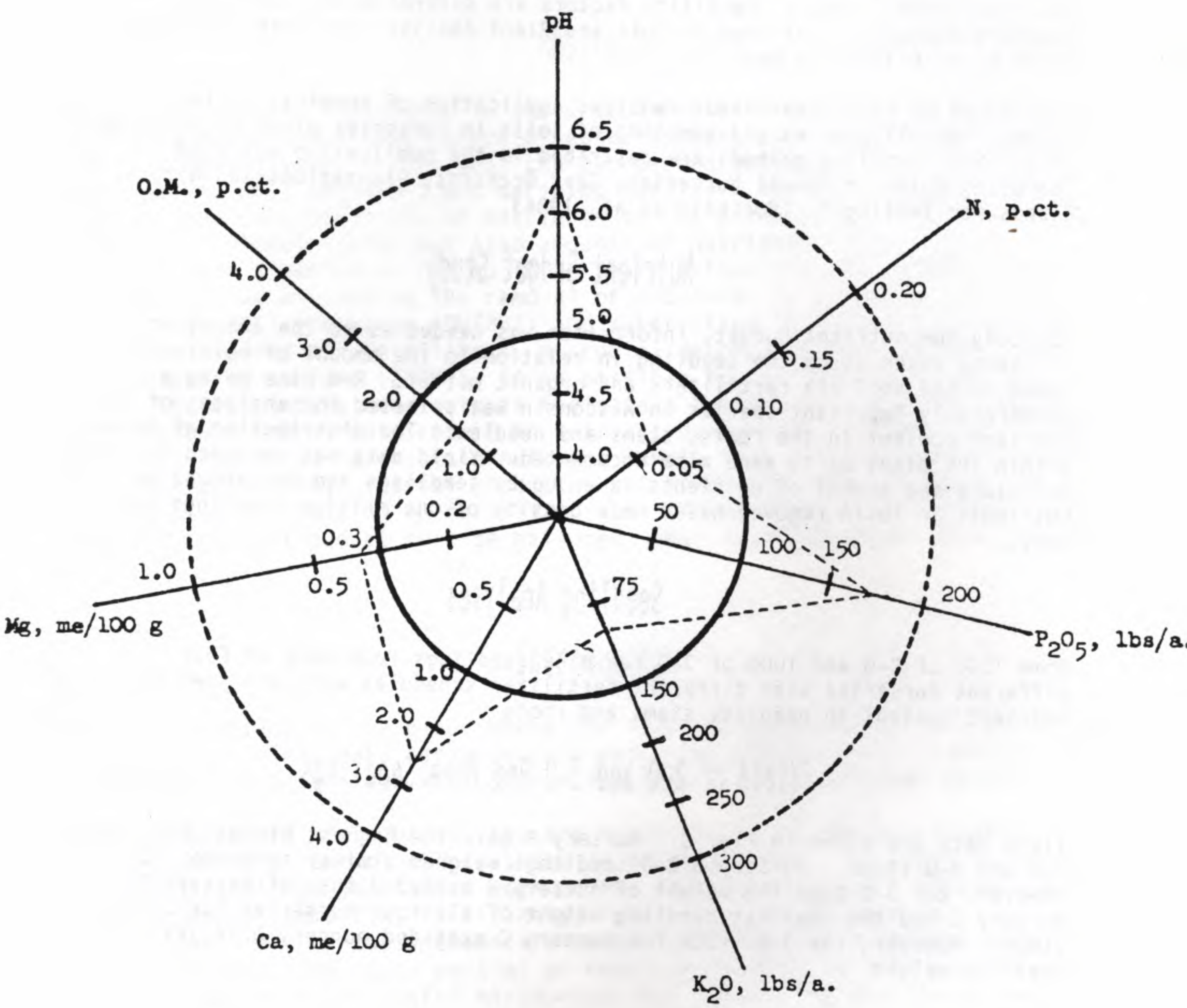
Some 1000 of 2-0 and 1000 of 3-0 red pine seedlings from each of four different nurseries with different fertilizer schedules were analyzed for nutrient content in needles, stems and roots.

Yield of 2-0 and 3-0 Red Pine Seedlings

Yield data are shown in Fig. 2. Nursery A gave the highest biomass for both 2-0 and 3-0 stock. Nursery B 2-0 seedlings weighed similar to nursery D. However, the 3-0 seedling weight of nursery B exceeded that of nursery D. Nursery C had the smallest seedling weight of all four nurseries for 2-0 stock. However, the 3-0 stock for nursery C exceeded nursery D in its seedling weight.

Figure 1

MAGIC CIRCLES
of Wisconsin **Forest Nursery Soils**



Legend: The values along the inner circle delineate the minimum level of a productive nursery soil for raising Wisconsin native conifers; the values of the outer circle mark the maximum ecologically or economically acceptable levels of fertility factors. The polygon indicates *an* unbalanced state of soil fertility in a nursery block: deficiency of nitrogen and potassium, excess of phosphorus, and unbalanced Ca/Mg ratio.

KEEP YOUR SOIL WITHIN THE MAGIC CIRCLES;
DO NOT LET SOIL FACTORS FLY OFF ON A TANGENT

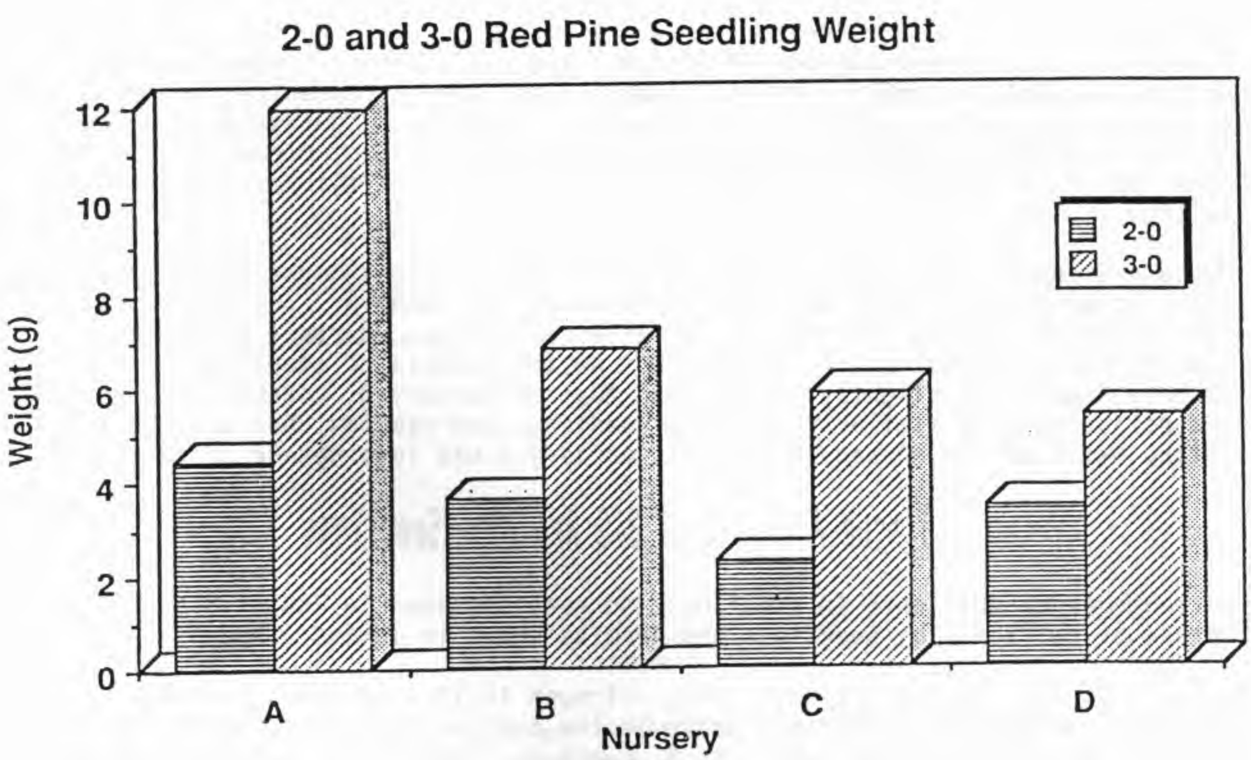

2-0 and 3-0 Red Pine Seedling Weight
Weight (g)
0
2
4
6
8
10
12
2-0
3-0
A
B
C
D
Nursery

FIGURE 2

Tissue Analyses of 2-0 Red Pine Seedlings

Percentages of nutrients in seedlings and needles given in Table 1 and 2. Uptake of nutrients by seedlings and needles given in Table 3 and 4.

Nursery A. Concentration of nitrogen in the entire seedlings was the smallest compared to nurseries B, C and D whereas, nitrogen concentration of needles was similar to B and D. Potassium and magnesium concentrations in seedlings were close to nursery B and in needles the concentration of potassium and magnesium were close to nurseries C, B, and D, respectively. Phosphorus concentration in seedling and needles were similar to nursery D and the calcium concentration was close to nursery B. However, due to the large biomass of seedlings in this nursery, the uptake of nutrients in mg/seedling were highest.

Nursery C. The concentrations of nitrogen and calcium were highest in the entire seedlings as well as needles, but had the lowest concentration for phosphorus in entire seedlings and in needles compared to nurseries A, B and D. This nursery produced the smallest biomass weight for 2-0 compared to the other nurseries and the lowest uptake in mg/seedling for all nutrients except calcium.

Nursery B and D. The concentrations of nitrogen and phosphorus were higher and calcium concentration was lowest in nursery D. However, the concentration of nitrogen in needles of both nurseries were similar. Nursery D had the lowest needle concentration of calcium. As the biomass of seedlings in nursery B was only slightly higher than that of nursery D, uptakes of nitrogen and potassium were similar for entire seedlings and needles, but phosphorus uptake was lower in nursery B, whereas nursery D had less uptake of calcium.

Tissue Analysis of 3-0 Red Pine Seedlings

Percentages of nutrients in seedlings and needles shown in Tables 5 and 6. Uptake of nutrients by seedlings and needles shown in Tables 7 and 8.

Nursery A. The concentration of only nitrogen in the seedlings was the smallest, whereas all other nutrients in the entire seedlings and needles were similar to or higher than nurseries B, C and D. The uptake of all nutrients were the highest due to the extremely large biomass.

Nursery C. The 3-0 seedlings followed the same trend as its 2-0 with concentration of nitrogen being highest and phosphorus lowest in seedlings and needles. The uptake in mg/seedling for nitrogen was higher in nursery C than in nursery D. However, the uptake of phosphorus was still higher in nursery D.

Nursery B. Though the biomass of seedlings produced in this nursery was higher than nursery C and D, the concentrations of all nutrients except phosphorus were closer to nursery C. The phosphorus concentration was higher in nursery B. Due to the higher biomass nursery B had a higher uptake of all nutrients except calcium compared to nurseries C and D. The calcium content was similar to nursery C.

TABLE 1

Concentration of major and secondary nutrients in entire seedlings of 2-0 red pine.

Nursery	N	P	K	Ca	Mg	Total Weight
	%					- g -
A	2.64	0.51	1.68	0.68	0.38	4.48
B	2.83	0.43	1.69	0.64	0.39	3.64
C	3.81	0.36	1.72	0.91	0.43	2.28
D	3.29	0.55	1.61	0.37	0.41	3.43

TABLE 2

Concentration of major and secondary nutrients in needles of average 2-0 red pine seedlings.

Nursery	N	P	K	Ca	Mg	Weight of needles
	%					-- g --
A	1.35	0.19	0.68	0.28	0.12	2.61
B	1.37	0.15	0.64	0.27	0.13	2.25
C	1.74	0.13	0.67	0.38	0.15	1.52
D	1.37	0.19	0.65	0.18	0.13	2.24

TABLE 3

Content of major and secondary nutrients in entire seedlings of average 2-0 red pine seedlings.

Nursery	N	P	K	Ca	Mg	Total Weight
	---------- mg/seedling ----------					- g -
A	49	7.9	27	11.2	5.9	4.48
B	41	5.4	22	7.8	4.7	3.64
C	34	2.9	14	7.8	3.3	2.28
D	41	6.3	20	5.8	4.6	3.43

TABLE 4

Content of major and secondary nutrients in needles of average 2-0 red pine seedlings.

Nursery	N	P	K	Ca	Mg	Weight of Needles
	---------- mg/seedling ----------					-- g --
A	35	4.8	18	7.3	3.5	2.61
B	31	3.4	14	6.1	2.8	2.25
C	26	2.0	10	5.8	2.2	1.52
D	30	4.2	14	4.0	3.0	2.24

TABLE 5

Concentration of major and secondary nutrients in entire seedlings of 3-0 red pine.

Nursery	N	P	K	Ca	Mg	Total Weight
	%					- g -
A	2.35	0.38	1.15	0.68	0.37	11.94
B	2.78	0.34	1.51	0.68	0.37	6.85
C	3.00	0.27	1.31	0.72	0.31	5.84
D	2.42	0.42	1.05	0.59	0.33	5.35

TABLE 6

Concentration of major and secondary nutrients in needles of average 3-0 red pine seedlings.

Nursery	N	P	K	Ca	Mg	Weight of needles
	%					-- g --
A	1.20	0.14	0.46	0.31	0.13	5.93
B	1.31	0.13	0.55	0.27	0.12	4.16
C	1.38	0.11	0.54	0.30	0.10	3.48
D	1.16	0.15	0.37	0.24	0.11	3.43

TABLE 7

Content of major and secondary nutrients in entire seedlings of 3-0 red pine.

Nursery	N	P	K	Ca	Mg	Total Weight
	---------- mg/seedling ----------					- g -
A	106	16.0	49	30	15	11.94
B	74	8.2	36	15	7.6	6.85
C	66	5.7	28	15	6.0	5.84
D	52	7.8	20	12	6.0	5.35

TABLE 8

Content of major and secondary nutrients in needles of average 3-0 red pine seedlings.

Nursery	N	P	K	Ca	Mg	Weight of Needles
	---------- mg/seedling ----------					-- g --
A	71	8.6	27	18	7.6	5.93
B	55	5.4	23	11	5.2	4.16
C	48	3.9	19	11	3.7	3.48
D	40	5.2	13	8.2	4.0	3.43

Nursery D. This nursery had the least biomass of all the nurseries. The 3-0 stock had N concentration in seedlings and needles somewhat similar to nursery A. However, the concentrations of potassium and calcium were lowest and phosphorus was highest in the seedlings as well as the needles compared to the seedlings from nurseries A, B and C. The uptake of nitrogen, potassium and calcium were lowest and the uptake of phosphorus was comparable to nursery B in spite of the difference in biomass between the two nurseries.

The major portion of the nutrients were taken up by the needles in all four nurseries (Table 9). The 3-0 stock in nursery A had a larger proportion of its nutrients in the stems compared to nurseries B, C, and D (Table 10).

Nutrient Removal

Nutrients in lbs/A removed by 2-0 and 3-0 seedlings are shown in Tables 11 and 12. Looking at nutrient removal based on a million seedlings/A (all nurseries do not have the same density but the actual values were not available), nursery A 2-0 and 3-0 stock took up the largest amounts of all nutrients which can be attributed to the large biomass produced in nursery A. Nursery B and D having about the same biomass for 2-0 stock removed about the same amounts of all nutrients except calcium which was higher in nursery B. However, the 3-0 stock of nursery B removed 40 lbs N, 36 lbs K, 11 lbs Ca and 5 lbs Mg more than nursery D except for phosphorus which was about the same. The increase in the amounts of nutrients removed by nursery B is due to the increase in biomass of 1.5g/seedling over stock of nursery D. Nursery C with the smallest biomass of 2-0 stock removed the lowest amounts of nutrients except for Ca compared to nurseries A, B and D. The 3-0 stock from nursery C removed more N, K and Ca and less P and Mg compared to the 3-0 stock of nursery D. The biomass in this nursery of 3-0 stock also exceeded that of nursery D. This increase in biomass in the 3rd year can be attributed to the high N concentration in the 2-0 stock as a result of N uptake during the second growing season in nursery C.

These results indicate the differences in fertilizing practices between nurseries which includes sources, amounts, timing and climatic influences. All four nurseries have produced seedlings of high nutrient content and biomass ranging from 2.5 tons/A to 5 tons/A for 2-0 stock and from 5.8 tons/A to 13 tons/A for 3-0 stock based on 1,000,000 seedlings per acre. Densities can vary in nurseries anywhere from 23 to 35 per square foot (1,000,000 to 1,525,000 per acre).

Nutrient Input and Output Balances for N, P, and K

Figure 3 illustrates the sources of input and output (losses) that can occur in soil.

Nitrogen

Nitrogen is an essential constituent of proteins which lie at the core of all life processes. In farm practice, nitrogen is often called "the balance wheel of plant nutrition." Nitrogen is one element which is in need of calibration

Table 9

Distribution of Nutrients in Seedlings

	2 - 0 Red Pine		
	Needles	Stems	Roots
Nitrogen	74% to 77%	12% to 19%	7% to 11%
Phosphorus	62% to 68%	16% to 27%	11% to 13%
Potassium	64% to 72%	13% to 26%	9% to 15%
Calcium	65% to 74%	13% to 25%	9% to 13%
Magnesium	60% to 68%	16% to 28%	11% to 16%

	3 - 0 Red Pine		
	Needles	Stems	Roots
Nitrogen	68% to 76%	16% to 25%	7% to 10%
Phosphorus	55% to 68%	20% to 35%	10% to 12%
Potassium	56% to 68%	21% to 36%	8% to 12%
Calcium	60% to 69%	20% to 33%	7% to 10%
Magnesium	50% to 64%	25% to 41%	9% to 14%

TABLE 10

Distribution of major and secondary nutrients in 2-0 red pine seedlings in individual nurseries.

Nutrient	A N*	A S	A R	B N	B S	B R	C N	C S	C R	D N	D S	D R
	%											
Nitrogen	74	19	7.3	75	16	8.6	77	12	11	74	15	11
Phosphorus	62	27	11.0	63	25	12.0	68	16	15	67	20	13
Potassium	64	26	9.5	66	23	12.0	72	13	15	72	17	11
Calcium	65	25	9.4	70	22	8.7	74	13	13	70	20	10
Magnesium	67	22	11.0	60	28	12.0	68	16	16	65	23	12

*N = needles
S = stems
R = roots

Distribution of major and secondary nutrients in 3-0 red pine seedlings in individual nurseries

Nutrient	A N*	A S	A R	B N	B S	B R	C N	C S	C R	D N	D S	D R
	%											
Nitrogen	68	25	7.1	74	16	9.9	73	17	11	76	16	7.8
Phosphorus	55	35	9.7	66	23	11.0	68	20	12	67	22	11.0
Potassium	56	36	7.8	64	25	12.0	68	21	11	65	24	10.0
Calcium	60	33	7.1	67	23	10.0	69	20	11	69	22	8.2
Magnesium	50	41	9.1	61	27	12.0	61	25	14	64	25	10.0

*N = needles
S = stems
R = roots

TABLE 11

Total amount of major and secondary nutrients removed by 2-0 red pine seedings in individual nurseries.

Nursery	N	P	K	Ca	Mg
	lbs/a				
A	104	17.0	60	25	13.0
B	90	12.0	48	19	10.5
C	75	6.3	31	17	7.3
D	90	14.0	44	13	10.0

TABLE 12

Total amount of major and secondary nutrients removed by 3-0 red pine seedlings in individual nurseries.

Nursery	N	P	K	Ca	Mg
	lbs/a				
A	232	34	108	66	34
B	161	18	79	37	19
C	146	13	61	34	13
D	115	17	43	26	14

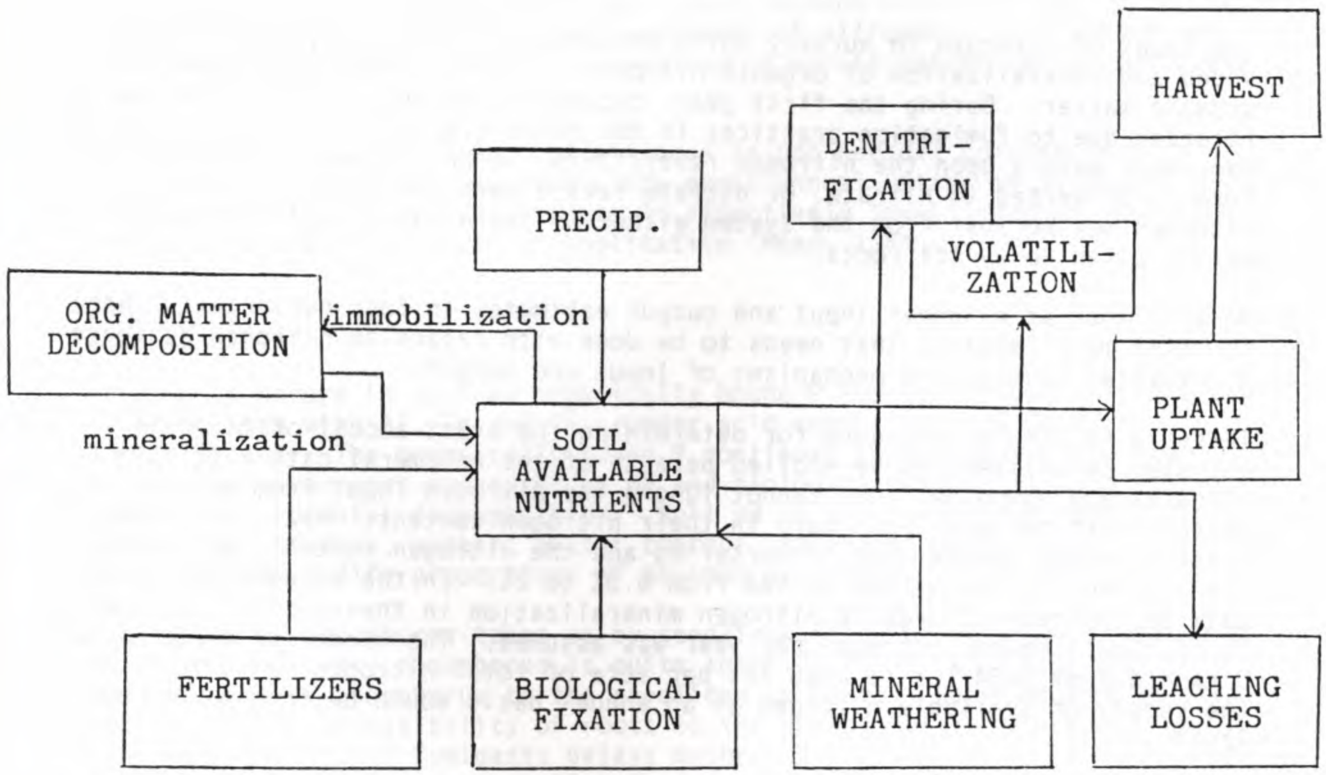


Fig. 3. Sources of nitrogen, phosphorus and potassium (N,P,K) input and output (losses) that can occur in soil.

and interpretation to maintain nutrient balance as this is one fertilizer that all nurserymen add without hesitation to obtain luscious green foliage color which may not necessarily be to the benefit of the outplanted seedlings.

The addition of nitrogen fertilizer almost immediately intensifies the green hue of the foliage and this effect is followed by accelerated rate of growth. Excess nitrogen produces abnormally large, succulent crowns and stems of plants. The resulting decrease in thickness of the cell walls and the reduction in the amount of sclerenchymatous tissues decreases the resistance of plants to drought, frost, snow press and parasites.

The input of nitrogen in nursery soils depends upon the nitrogen fertilizer added and mineralization of organic nitrogen i.e. from native and added organic matter. During the first year, decomposition of organic matter may be retarded due to fumigation practices in the nurseries, so the seedlings are dependent mainly upon the nitrogen fertilizers. When nitrogen in the ammonium form is converted to nitrate, or nitrate fertilizers are added, nitrate nitrogen may be lost from the system either by leaching, or denitrification unless taken up by the roots.

We will look at nitrogen input and output estimates in four nurseries. There is still more research that needs to be done with regard to nitrogen as there are several sources and mechanisms of input and output.

There is no simple procedure for determining the exact amount of mineral nitrogen fertilizers to be applied because of the ephemeral nature of both nitrates and ammonium. One cannot ignore the nitrogen input from organic matter additions which can vary in their nitrogen content. Peat is the major organic matter source used in nurseries and the nitrogen contents of peats used in the four nurseries varied from 0.5% to 2%. In the absence of research data on the rate of organic nitrogen mineralization in these soils, a value of 2% of total organic nitrogen per year was assumed. The nurseries A, B, C, and D ranged from 2064 lbs to 2688 lbs per acre of total nitrogen in soil, thus the supply of available nitrogen on an annual basis would be from 41 lbs to 54 lbs/A.

In many instances, the nitrogen released by soil microorganisms is not sufficient because of the low supply of organic matter, crowded seedbeds, presence of raw organic material of a high C/N ratio, intensive leaching by rains and irrigation or suppressed microbiological activity. The latter condition may be expected in nursery soils treated with potent eradicants. I all such cases the content of available nitrogen must be augmented by application of ammonium or nitrate fertilizers, added either prior to seeding the nursery crop, or as a solution or top dressing on the growing stock. However, one must refrain from overfertilizing with nitrogen as a surplus of this nutrient can have adverse effects in three ways:

1. Produce succulent overgrown stock vulnerable to frost, drought and disease.

2. Contribute to acidifying the soil if added as ammonium N or urea.

3. Pollute the groundwater with the leached nitrates.

A good rule to follow in nitrogen fertilization is to apply too little rather than too much. A deficiency can be corrected by a second application, an excess produces planting stock lacking vigor.

In the nitrogen balance sheet, (Table 13a and 13b) harvest losses are based on seedling analyses but values for nitrogen lost by leaching and volatilization are not available and can only be estimated by difference between inputs and harvest losses. Similarly, nitrogen inputs include actual values for fertilizer applied, but very rough estimates of nitrogen mineralized from organic matter. More research is required to obtain better values for these processes.

The low recovery by seedlings of nitrogen is not unusual considering the application rates which far exceed the gross annual uptake of nitrogen, particularly since applied nitrogen is effectively immobilized or lost from the ecosystem within a year of application (Mead, 1984).

Phosphorus

Phosphorus occurs in soil as organically bound P and as inorganic P that can be associated with Al, Fe and Ca. Under acid conditions the Ca-P is insignificant. The organically bound P continually undergoes transformations by chemical processes depending on pH and biological processes such as plant uptake and microbial decomposition. Soil pH is a major factor controlling phosphorus; however, organic matter content, amount of $CaCO_3$, and fertilization modify proportions of phosphorus forms.

The amount of phosphorus taken up by seedlings is relatively low compared to nitrogen. However, phosphorus is quite immobile in the soil and the availability of phosphorus to the seedlings is largely dependent on moisture conditions and accessibility of roots to the phosphorus in solution. In addition, the use of fumigants delays mycorrhizal colonization of 1-0 stock where the root systems are small and access to phosphorus may become limiting. Under these circumstances addition of phosphorus fertilizer at the time of seeding as well as to 1-0 stock is a necessity. Losses of phosphorus by leaching are usually insignificant.

The balance sheet (Table 14a and 14b) indicates a buildup of phosphorus over the three year period in all of the nurseries. Nursery A is close to a phosphorus balance but there appears to be a buildup of phosphorus levels in nurseries B and C over the three-year growing season. Nursery B shows a buildup of 33 lbs in the second year to 59 lbs in the third year and nursery C shows a buildup of 25 lbs in the second year to 36 lbs in the third year. Phosphorus being a relatively immobile element will tend to buildup in the soil and may eventually lead to zinc problems.

Table 13a

NITROGEN

2 - 0 Red Pine

Nursery	A	B	C	D
	----------lbs/A----------			
INPUT				
Total N in Soil - O.M.*	85	83	107	83
Fertilizer	129	225	206	137
Precip. 5 lb/yr	10	10	10	10
TOTAL INPUT	224	318	323	230
OUTPUT-				
seedling removal	-104	-90	-70	-90
Other Losses	-120	-228	-253	-140
*Total N in Soil	2136	2064	2688	2084
N release/yr.	43	41	54	42

Assumed rate of release 2% per year.

Table 13 b

NITROGEN

3 - 0 Red Pine

Nursery	A	B	C	D
	lbs/A			
INPUT				
Total N in Soil - O.M.*	128	124	161	125
Fertilizer	215	405	330	260
Precip. 5 lb/yr	15	15	15	15
TOTAL INPUT	358	544	506	400
OUTPUT				
Seedling Removal	-232	-161	-146	-115
Other Losses	-126	-383	-360	-285
*Total N in Soil	2136	2064	2688	2084
N release/yr	43	41	54	42

Assumed rate of release 2% per year.

Table 14 a

PHOSPHORUS

2 - 0 Red Pine

Nursery	A	B	C
		lbs/A	
INPUT			
Org. Phos.	8	8	11
Fertilizer	12	33	16
Precip. 2 lbs/yr	4	4	4
TOTAL INPUT	24	45	31
OUTPUT			
Seedling Removal	-17	-12	-6
Build up	+7	+33	+25

Table 14b

PHOSPHORUS

3 - 0 Red Pine

Nursery	A	B	C
		---lbs/A---	
INPUT			
Org. Phos	12	12	16
Fertilizer	20	59	27
Precip. 2 lbs/yr	6	6	6
TOTAL INPUT	38	77	49
OUTPUT			
Seedling removal	-34	-18	-13
Build up	+2	+59	+36

<u>Potassium</u>

The soluble and exchangeable forms are primarily involved in the nutrition of trees. Potassium may be lost from sandy soils by leaching or become fixed in an unavailable form in fine textured soils and require supplemental application in soluble form (Krause and Wilde, 1960). Leaching is less of a problem with potassium than with nitrogen, occurring mainly when exchangeable potassium levels are very high.

Looking at the input-output sheets (Table 15a and15b), nursery A shows a clear deficit of potassium over the three year growing season going from -33 lbs to -64 lbs/A. Nurseries B and C indicate surplus of potassium going from 41 lbs to 76 lbs/A and 133 lbs to 224 lbs/A for years 2 and 3 respectively. Excessive amounts of potassium may induce magnesium deficiency if magnesium levels are low.

Calcium and Magnesium

Calcium and magnesium occupy more than 80% of exchange sites in soils with pH above 6.0, whereas in very acid soils aluminum may occupy a large portion of the exchange sites. A critically low content of magnesium and especially low calcium is confined to strongly acid nursery soils. In most cases the deficiencies of these elements can be safely corrected by the addition of organic material high in these nutrients, but not necessarily alkaline in reaction. In extreme cases, deficiencies of these elements must be remedied by application of dolomitic limestone (Leaf, 1957).

The amounts of calcium and magnesium removed by the seedlings are smaller than nitrogen and potassium, and more calcium than magnesium is taken up by the seedlings.

Overfertilizing with soluble fertilizers of nitrogen and potassium will lead to increased leaching of both calcium and magnesium.

Micronutrients

Concentration ranges of trace elements in 2-0 and 3-0 pine needles given in Table 16.

The micronutrient budget needs further exploration, especially for zinc, copper and boron. Though relatively small amounts of zinc, copper and boron (0.68 lbs to 1.72 lbs/A; 0.04 lbs to 0.10 lbs/A; .10 lbs to 0.2 lbs/A respectively) are removed by seedlings over a three-year period, nurseries under cultivation for a long period of time may become depleted in these elements. The advent of hydromulch and gradual elimination of galvanized screens is eliminating a major source of trace elements, especially zinc. The use of uptake model equations for trace element (Corey, 1987) may prove to be a useful tool in predicting trace element requirements of seedlings on the basis of soil tests, but a better understanding of the nutrient budgets would help determine maintenance applications.

Table 15a

POTASSIUM

2 - 0 Red Pine

Nursery	A	B	C
	lbs/A		
INPUT			
Org. K	--	--	--
Fertilizer	25	85	160
Precip. 2 lbs/yr	4	4	4
TOTAL INPUT	29	89	164
OUTPUT			
Seedling Removal	-60	-48	-31
Depletion (-) or Build up (+)	-31	+41	+133

Table 15b

POTASSIUM

3 - 0 Red Pine

Nursery	A	B	C
	lbs/A		
INPUT			
Org. K	--	--	--
Fertilizer	42	149	279
Precip. 2 lbs/yr	6	6	6
TOTAL INPUT	48	155	285
OUTPUT			
Seedling Removal	-108	-79	-61
Depletion (-) or Build up (+)	-64	+76	+224

Table 16

Concentration range of trace elements in 2-0 and 3-0 red pine needles

	2 - 0	3 - 0
Element	ppm	ppm
Zinc	42 to 76	55 to 71
Copper	3.5 to 4.0	2.8 to 3.4
Boron	8.9 to 11.0	7.8 to 8.9
Manganese	155 to 391	242 to 482

Conclusion

The results obtained in this study indicate the need for improved understanding of processes involved in balancing nutrient budgets. Annual soil analyses show the status of soil fertility factors and the nutrients needed to adjust soil fertility to economically and environmentally acceptable levels. Maintaining nutrient levels at the optimum requires that nutrient inputs and losses be balanced. Nursery trials conducted systematically starting with 1-0 through 2-0 and 3-0 stock, will be required to obtain estimates of inputs and losses that are not readily determined, i.e. mineralization rates of nitrogen and phosphorus contained in organic matter, leaching of nitrogen and potassium, denitrification of nitrate nitrogen.

Nutrients removed at lifting and nutrients added as fertilizers are readily determined. Balancing phosphorus and potassium budgets will not present as great a problem as nitrogen.

Acknowledgments

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LITERATURE CITED

Bockheim, J. G., J. G. Iyer, and E. E. Schulte. 1986. Sampling soils in forest nurseries, seed orchards, plantations and natural stands for testing. Dept. of Soil Science and Soil and Plant Analysis Lab., U.W. Extension.

Corey, R. B. 1987. Soil Test Procedures: Correlation. In Soil testing, sampling, correlation, calibration and interpretation. SSSA Special Pub. no. 21.

Krause, H. H., and S. A. Wilde, 1960. Uptake of potassium by red pine seedlings and losses through leaching from fertilizers of various solubility. Soil Sci. Soc. Am. Proc. 24:513-515.

Leaf, A. L. 1957. Diagnosis of deficiencies of available potassium, calcium and magnesium in forested soils. Ph D. Thesis. Univ. of Wisconsin, Madison, WI.

Mead, D. J. 1984. Diagnosis of nutrient deficiencies in plantations. p. 259-291. [Bowen, G. D. and E.K.S. Nambiar (ed.)] In Nutrition of plantation forests. Academic Press.

Wilde, S. A., G. K. Voigt, R. B. Corey, and J. G. Iyer. 1979. Soil and plant analysis for tree culture, Ed. 5. Oxford and IBH Publ. Co., New Delhi, Bombay and Calcutta.

Wojahn, K. E., and J. G. Iyer. 1974. Keeping a diagrammatic record of a nursery soil's fertility. Tree Planters' Notes 25:1-2.