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Growth and Nutrient Status of Black Spruce Seedlings As Affected by Water Table Depth

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Abstract

A greenhouse experiment was conducted to study the effects of soil water level on growth, biomass accretion, and inorganic element uptake by black spruce. One-year-old containerized seedlings were grown for 3 years at three water table depths. All trees survived for the duration of the study confirming that black spruce has a certain degree of survival tolerance to high water tables. However, tree height, diameter growth, and biomass production significantly increased as the depth to water table increased.

The foliar levels of N, P, K, Mg, Fe, Zn, and B increased and those of Cu and Mn decreased with the increasing depth to the water table. For ash and Ca, differences were significant but did not follow a consistent trend. In shoots, the level of N, Ca, and Mg increased and those of ash, K, Fe, Cu, B, Al, and Mn decreased with the increasing depth to the water table. The level of P was not affected by the water table. In roots, the level of N and Ca increased and the level of ash, Mn, Fe, Al, and Cu decreased with increasing depth to the water table. The level of P, Mg, and Zn was significantly different but did not follow any trend.

Foliar concentration of ash, Ca, Na, Mn, Fe, Zn, Cu, Al, and B increased and concentration of N, P, K, and Mg decreased with the increasing foliage age. In shoots, ash, Ca, Al, Fe, and Zn increased and N, P, K, Mg, and B decreased with the increasing tree and shoot age. In roots, Fe, Mn, Na, and Al increased and N, P, and Cu decreased with the increasing tree age.

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Introduction

Black spruce (*Picea mariana* (Mill) B.S.P.) is an important component of the spruce-fir forest of northern Maine. It occupies about 6 to 7 percent of spruce-fir forest area. The species occurs naturally on a variety of soil and site conditions, but most frequently it is associated with swamps, extensive flatlands, and fringes of lakes where seomewhat poorly drained to very poorly drained soils occur. Many sites are occasionally flooded for prolonged periods, but the species seems to be morphologically adapted to survive periodic inundation.

Since black spruce is the least susceptible of all spruces to spruce budworm (*Choristoneura fumiferana* Clem.) infestations, it has become a favored species for reforestation programs. Extensive plantations are being established on sites that vary in soil drainage conditions, and containerized seedlings are most commonly used as planting stock. Since soil drainage is of utmost importance to forest growth, the establishment of physiologically healthy plantations on poorly drained soil may be a problem. The soil conditions and the stresses likely to affect plant growth from excessive soil moisture have been well discussed in many publications. They were reviewed by Cannell and Jackson (1981).

Examples of adverse effects on height and diameter growth of southern pine seedlings resulting from high water tables were presented by Burton (1971), McKee and Shoulders (1974), McKee and others (1984), and Mueller-Dombois (1964). Little has been written concerning the effects of excessive moisture or of soil drainage on black spruce. Czapowskyj (1982) reported that mechanical drainage of very poorly drained soils in northern Maine resulted in a positive response by young natural black spruce. Thus, there is a need to evaluate the influence of the soil water table level on black spruce growth and nutrient uptake during initial stages of plantation establishment given the growing interest in artificial regeneration using this species.

The objective of this study was to determine the effect of different soil water table levels on growth, biomass production, and nutrient accumulation in black spruce seedlings growing under greenhouse conditions over three growing seasons after transplanting.

Study

Black spruce seedlings were planted in plastic pots in the spring of 1981 and were grown in the greenhouse with three water table regimens for three growing seasons.

Seedlings

One-year-old container grown seedlings were obtained in May 1981 from the Great Northern Paper Company overwintering beds in Millinocket, Maine. The seedlings were raised from seeds obtained from J. D. Irving, Ltd., Juniper, New Brunswick—Lot No. SB 58 Restigouche Region—and were grown in a peat moss-vermiculite mix in Japanese paper pots (FH-408) starting in May 1980 for 12 weeks in a greenhouse. During this period, the seedlings were fertilized 6 times at 6- to 10-day intervals using commercial fertilizer formulations, 4 times with 20-20-20 followed by two applications of 9-45-15, at a rate of about 12 grams per 1,000 seedlings plus one application of micronutrients (0.5 gm/ 1,000 seedlings). In August 1980, the seedlings were transferred from the greenhouse and placed in outside beds to harden off and overwinter. During April and May of 1981, the seedlings received additional fertilizer treatments; five applications of 9-45-15 plus five applications of micronutrients at the same rates as the previous year. Mensurational data and nutrient concentrations of the seedlings at the beginning of this study are given in Table 1.

Growth Medium

The seedlings were planted in soil collected from the spodic horizon from the Telos soil series (coarse-loamy, mixed, frigid, Aquic Haplorthods). This soil is somewhat poorly drained and occurs in extensive, contiguous blocks in the spruce-fir region of northern Maine. It is associated with the moderately well drained Chesuncook and the poorly drained Monarda soils. The Telos soil occurs in gently sloping areas and has slow or very slow permeability in the substratum because of its dense, low-porosity nature. The upper soil layers above the dense basal till are moderately permeable and of lower density. The soils are extremely to very strongly acid (pH 4.2 to 5.0). The combination of little relief and slow permeability result in a high water table in the spring and fall and in periods of high rainfall during the growing season. Soil was transported to the greenhouse, air dried, and sieved through a sieve with 1.3-cm openings.

Study Layout

Sixty plastic pots, 30 cm in height with a surface area of 6.5 dm^2, were filled with approximately 20 kg of soil. Each pot was planted with three seedlings, for a total of 180 seedlings. A 3-cm layer of peat moss was placed on the soil surface in each pot to simulate the organic layer usually found on forest sites. The pots were then placed in a 1.25-m × 2.50-m water tank with a fixed overflow elevation to simulate three water table levels. The polyethylene-lined plywood tank was constructed in such a way that each water table regime contained 20 pots. The water table levels were 4, 10, and 20 cm below the mineral soil surface—WT 4, WT 10, and WT 20, respectively.

Water was automatically pumped from an overflow reservoir into the tank at timed intervals in order to replace losses due to evaporation. At the initiation of the study, the pH of the

Table 1.—Physical characteristics and concentration of nutrient elements in 1-year-old containerized seedlings prior to planting[1]

Seedling characteristic and nutrient element	Foliage	Shoot	Root	Total seedling
Height, cm	—	13.4	—	—
RCD,[2] mm	—	2.0	—	—
Oven-dry weight, g	0.29	.11	0.19	0.59
Nitrogen, percent	1.43	.85	.54	1.04
Phosphorus, percent	.27	.12	.29	.25
Potassium, percent	1.08	.86	.74	.78
Calcium, percent	.87	.35	.79	.76
Magnesium, percent	.13	.12	.39	.22
Manganese, mg/kg	200	100	100	183
Iron, mg/kg	181	174	2056	745
Zinc, mg/kg	124	125	366	205
Copper, mg/kg	16	60	42	32
Boron, mg/kg	31	20	76	44
Aluminum, mg/kg	100	100	200	133
Ash, percent	4.44	2.76	7.60	5.21

[1]Based on a sample of 25 seedlings.
[2]Root collar diameter.

water in the tank was adjusted to match the typical pH of forest soil solution.

At the end of October in each growing season, the pots were drained and placed in an outside unheated trailer for overwintering. At mid-April of the second and third growing seasons they were transferred to the greenhouse and arranged in the same order and placed under the same water table regime as they were during the first growing season.

Growth Analyses

Survival counts, height, and diameter (at ground line) were measured at 2-week intervals from the beginning of May to mid-October during each growing season. Each year at the end of October one seedling was harvested from each pot for growth and biomass measurements as well as to determine nutrient concentrations of foliage, shoots, and roots. Roots were separated and washed in distilled water, foliage was separated from the shoots, and the components were dried at 65°C to constant weight. Because the trees were small, three composite samples were prepared from 20 trees in each treatment. Samples were ground to pass a 20-mesh screen and stored for chemical analyses.

Chemical Analyses

The samples were dry-ashed at 480°C, and ash content was determined gravimetrically. The ash was taken up in dilute HCL, and phosphorus (P), calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), manganese (Mn), zinc (Zn), iron (Fe), aluminum (Al), and boron (B) were determined by inductively coupled plasma emission spectroscopy (ICP) at the Universeity of Maine. Nitrogen (N) was determined from Kjeldahl digestions by an autoanalyzer. All analyses were performed in duplicate on the oven-dry (65°C) samples.

Data Analysis

The data were tabulated by seedling age, component age, and by the depth to water level. Tree growth attributes (height, diameter, and oven-dry weight), percentage of ash, and nutrient concentrations were analyzed statistically by analysis of variance. Duncan's new multiple range test was used for mean separations.

Results and Discussions

Survival

Seedling survival was not affected by the depth to the water table. All trees remained alive for the duration of the study, indicating the ability of black spruce to survive under high water table levels.

Buds started to break 1 week after the pots were returned from the overwintering environment to the greenhouse. Buds broke first on trees with treatment WT-20. The WT-4 and

WT-10 treatments had bud break delayed for 6 to 8 days. Delayed bud break on trees subjected to waterlogging is a common phenomenon that has been observed in the past (Coutts 1981). In addition, the foliage of trees with WT-4 and WT-10 regimens was consistently chlorotic, as is typical of saturated soil conditions.

Height and Diameter Growth

Biweekly measurements taken during the growing season revealed that shoots grew for about 8 weeks regardless of the water table regime. However, the diameter growth of seedlings in the WT-4 regime ceased after 12 weeks, but continued in the WT-10 and WT-20 regimes for a total of 20 weeks.

Average annual height and diameter growth (Table 2) show tree response to differences in water table levels. These responses were significant ($p = 0.05$) and both the mean height and mean diameter were ordered as follows: WT-4 $\bar{x}$ < WT-10 $\bar{x}$ < WT-20 $\bar{x}$. This pattern held for the entire study period.

Table 2.—Mean height and diameter at root collar of black spruce as affected by depth to water table and growing season

Tree characteristic	WT-4	WT-10	WT-20
Tree Age, 1 + 1—60 trees sampled			
Height, cm	18.2b[2]	19.9a	20.2a
RCD,[1] mm	2.9c	3.2b	3.5a
Tree age, 1 + 2—40 trees sampled			
Height, cm	26.4c	30.2b	35.7a
RCD, mm	4.0c	5.0b	6.2a
Tree age, 1 + 3—20 trees sampled			
Height, cm	29.6c	34.0b	41.9a
RCD, mm	5.1c	6.5b	8.5a

[1]Root collar diameter.
[2]Lower case letters designate differences between water table levels of the same year at the 0.05 level, using Duncan's New Multiple Range Test.

Biomass Allocation

Data presented in Table 3 show the means and differences in biomass allocation by tree component for the three water table regimens. For each of the 3 years, biomass responded to water table regimes similarly to tree height and diameter. The differences were significant for all years and the means were ordered as follows: WT-4 < WT-10 < WT-20. By expressing the data in Table 3 in relative terms (percent), the experiment wise (years x water level) allocation of extra biomass attributable to better drainage was ordered as follows: foliage > shoots > roots. The differences in root:shoot ratios were negligible: 37;38;41 percent for WT-4, WT-10, and WT-20, respectively, at the conclusion of the study.

All three growth measurements (height, diameter, and biomass) provide additional evidence that the high water table had a negative effect on the performance of black spruce. Trees that were grown under the high water tables (WT-4 and WT-10) showed signs of stress from poor aeration resulting in reduced oxygen diffusion. The stress symptoms—reduced growth, chlorosis, abscission of the foliage, and deformation of root systems—were consistent with those reported by Norby and Kozlowski (1983) for other species.

Further examination of the data given in Table 2 and 3 and Figure 1 shows that lowering the water level by 6 cm (from 4 to 10 cm) resulted in height increases of 15 percent, diameter increases of 27 percent, and total biomass increases of 68 percent. Height increased by 42 percent, diameter increased by 67 percent, and biomass nearly doubled when the water table was lowered to 20 cm.

Concentrations and Distribution of Ash and Mineral Elements

The effects of both water level and seedling age on concentrations of ash, and selected elements in the foliage, shoots, and roots are readily apparent in Table 4. Because of a lack of trends and the small magnitudes in differences, the values for ash and Al concentrations were presented as averages of all three water table levels (Table 4). A summary of analysis of variance showing significant differences is presented in Table 5. Changes in nutrient composition varied considerably among individual components, water table levels, and component age classes.

Needles. Mean concentrations of N, P, K, Mg, Fe, B, and Zn increased and those of Mn and Cu decreased with increasing depth to water table. For ash and Ca, the differences in concentration were significant but did not follow a consistent trend. Concentrations of Al did not differ between water levels.

Concentrations of ash and all mineral elements varied greatly with foliage age. The overall mean concentrations of ash, Ca, Na, Al, Zn, Fe, Cu, and B increased and those of N, P, K, and Mg decreased with an increasing foliage age from current-year to 2- and 3-year-old needles. Inconsistencies were observed in Mg concentrations, but the differences were small (Table 4).

Shoots. Mean concentrations of N, Ca, and Mg increased and those of ash, K, Fe, Cu, B, Mn, and Al decreased along the gradient of increasing depth to water table level. No

Table 3.—Mean component weight of black spruce seedlings raised under three depths of water table for a period of 3 years (average of 20 trees sampled)

Biomass	WT-4		WT-10		WT-20	
	g	*percent*	*g*	*percent*	*g*	*percent*
			Tree Age, 1 + 1			
Foliage	0.8c[1]	42	1.1b	44	1.4a	45
Shoots	.6c	32	.8b	32	1.0a	32
Roots	.5b	26	.6b	24	.7a	23
Total	1.9c	100	2.5b	100	3.1a	100
Root: Shoot Ratio	.29		.32		.38	
m1000[2]	.68		.80		.78	
			Tree Age, 1 + 2			
Foliage	2.8c	43	3.8b	43	6.9a	40
Shoots	2.0b	30	2.6b	29	5.7a	32
Roots	1.8b	27	2.5b	28	4.8a	28
Total	6.6c	100	8.9b	100	17.4a	100
Root: Shoot Ratio	.38		.39		.37	
m1000	.69		.65		.74	
			Tree Age, 1 + 3			
Foliage	4.8c	41	8.2b	42	13.1a	38
Shoots	3.5c	30	6.0b	31	11.8a	35
Roots	3.4c	29	5.4b	27	9.2a	27
Total	11.7c	100	19.6b	100	34.1a	100
Root: Shoot Ratio	.37		.38		.41	
m1000	.69		.74		.69	

[1]Lower case letters designate differences between water table levels of the same year at the 0.05 level, using Duncan's New Multiple Range Test.

[2]1,000 needles weight.

Table 4.—Mean concentrations of ash and nutrient elements in black spruce as related to water table level and seedling age

Tree component	Tree age	Component age class	WT-4 + 10 + 20 (average)	WT-4	WT-10	WT-20	WT-4	WT-10	WT-20
	Year	*Year*	Ash, *percent*		N, *percent*			P, *percent*	
Needles	1−1	0+1	5.77 (.67)[1]	1.37c[2]	1.62b	1.97a	.14a	.14a	.17a
	1−2	0	3.92 (.70)	.62b	.67b	1.12a	.08a	.08a	.10a
		1+2	5.49 (.76)	.64b	.73b	1.00a	.07b	.06b	.08a
	1−3	0	4.32 (.22)	.76b	.65b	1.07a	.09a	.09a	.11a
		1	5.35 (.26)	.74b	.68b	1.05a	.07a	.08a	.08a
		2+3	6.49 (.42)	.68b	.65b	.98a	.07a	.07a	.07a
Shoots	1−1	0+1	1.68 (.25)	.80b	.86b	1.00a	.11a	.09a	.10a
	1−2	0	1.44 (.17)	.35b	.38b	.53a	.05b	.05b	.06a
		1+2	1.54 (.16)	.27b	.27b	.33a	.03a	.03a	.04a
	1−3	0	1.65 (.08)	.33a	.38a	.46a	.07a	.07a	.08a
		1	1.63 (.10)	.28a	.31a	.38a	.05a	.04a	.04a
		2+3	1.74 (.11)	.26a	.22a	.34a	.03a	.03a	.03a
Roots	1−1	—	3.85 (.59)	.66a	.68a	.85a	.10a	.08a	.09a
	1−2	—	3.63 (.52)	.50a	.45a	.52a	.05a	.05a	.05a
	1−3	—	4.11 (1.29)	.57a	.39b	.48ab	.06a	.05ab	.05a

Table 4.—Continued

Tree component	Tree age	Component age class	WT-4	WT-10	WT-20	WT-4	WT-10	WT-20	WT-4	WT-10	WT-20
	Year	*Year*	Ca, percent			*K, percent*			*Mg, percent*		
Needles	1−1	0+1	1.24a	.93b	1.02b	.75b	.83ab	.91a	.15ab	.14b	.16a
	1−2	0	.71b	.70b	.88a	.60ab	.53b	.69a	.12b	.12b	.15a
		1+2	1.29a	1.18a	1.24a	.36b	.37b	.61a	.10b	.10b	.13a
	1−3	0	.71a	.67a	.79a	.65a	.72a	.70a	.16ab	.14b	.19a
		1	1.15a	1.05a	1.30a	.33b	.54a	.55a	.15a	.14a	.15a
		2+3	1.54a	1.28a	1.48a	.40a	.35a	.50a	.14a	.12a	.17a
Shoots	1−1	0+1	.37a	.30b	.32ab	.26a	.21ab	.17b	.08a	.06a	.07a
	1−2	0	.27b	.29b	.34a	.14a	.14a	.16a	.05b	.05b	.07a
		1+2	.38a	.36a	.36a	.12a	.13a	.13a	.05a	.04a	.05a
	1−3	0	.27b	.30ab	.37a	.18a	.17a	.15a	.06a	.06a	.07a
		1	.31a	.34a	.37a	.23a	.19a	.19a	.05ab	.04b	.06a
		2+3	.37a	.37a	.38a	.12a	.10a	.12a	.05a	.04a	.05a
Roots	1−1	—	.25a	.25a	.27a	.38a	.36ab	.28b	.14a	.11b	.12ab
	1−2	—	.28c	.31b	.34a	.29a	.31a	.27a	.12a	.12a	.13a
	1−3	—	.26b	.29ab	.33a	.31a	.29a	.34a	.15a	.11a	.14a

Table 4.—Continued

Tree component	Tree age	Component age class	WT-4	WT-10	WT-20	WT-4	WT-10	WT-20	WT-4	WT-10	WT-20
	Year	*Year*	Mn, *percent*			*Zn, mg/kg*			*Cu, mg/kg*		
Needles	1−1	0+1	.21a	.15b	.11b	222a	272a	244a	16a	12b	11b
	1−2	0	.27a	.18b	.12c	116b	163a	189a	3a	2a	3a
		1+2	.30a	.18b	.12c	229b	312a	297a	4ab	3b	5a
	1−3	0	.41a	.25b	.12c	128a	125a	141a	10a	9a	8a
		1	.54a	.30b	.15c	205a	217a	238a	10a	9a	8a
		2+3	.48a	.28b	.13c	269a	282a	292a	10a	8b	8b
Shoots	1−1	0+1	.07a	.05b	.03c	120a	139a	127a	17a	15b	12c
	1−2	0	.10a	.07b	.03c	72b	101a	105a	8a	8a	7a
		1+2	.09a	.06b	.03c	93b	118a	95b	8a	8a	6b
	1−3	0	.14a	.10b	.04c	99a	95a	92a	10a	7b	6b
		1	.14a	.08b	.03c	99a	107a	94a	7a	5a	7a
		2+3	.12a	.07b	.03c	101a	101a	90a	7a	7a	10a
Roots	1−1	—	.06a	.04b	.03c	114b	155a	118b	19a	18ab	16b
	1−2	—	.08a	.05b	.02c	116a	145a	134a	17a	14b	9c
	1−3	—	.11a	.08b	.03c	126a	130a	125a	17a	13b	13b

Table 4.—Continued

Tree component	Tree age	Component age class	WT-4	WT-10	WT-20	WT-4	WT-10	WT-20	WT-4 + WT-10 + WT-20 (average)	
	Year	*Year*	Fe, *mg/kg*			B, *mg/kg*			Al, *mg/kg*	
Needles	1−1	0+1	181ab	215a	120b	56a	61a	66a	270	(132)
	1−2	0	95b	90b	183a	54b	56b	66a	238	(117)
		1+2	270b	155b	465a	65a	69a	75a	481	(177)
	1−3	0	145a	135a	164a	67a	60a	64a	268	(41)
		1	160b	252a	222ab	76a	72a	69a	389	(59)
		2+3	415b	437a	446a	84a	74a	84a	667	(66)
Shoots	1−1	0+1	145a	92ab	55b	15a	14a	14a	108	(58)
	1−2	0	119a	48b	54b	14a	13ab	12b	96	(16)
		1+2	99a	86a	80a	12b	15a	11c	144	(21)
	1−3	0	69a	70a	77a	13a	13a	11a	116	(15)
		1	74a	81a	68a	13a	12a	10a	123	(16)
		2+3	120a	165a	86a	8a	8a	9a	204	(43)
Roots	1−1	—	1839a	1096a	1214a	24a	21ab	16b	1481	(225)
	1−2	—	4660a	1059b	1029b	32a	23b	17b	2257	(348)
	1−3	—	5967a	1387b	996b	32a	19b	16b	2916	(594)

[1]Standard deviations are in parentheses.
[2]Letters designate difference due to soil drainage conditions during the same year at the 0.05 level using Duncan's New Multiple Range Test.

Table 5.—Summary of analysis of variance showing significant effect for nutrient concentration in black spruce growing in soil with three different water table levels

Source of variation	Ash	N	P	Ca	K	Mg	Mn	Fe	Al	Zn	B	Cu	Na
	"F" values												
	NEEDLES												
Water level (W)	3*	97**	8**	15**	20**	30**	249**	5**	—	12**	3*	6*	6**
Age (A)	29**	138**	39**	80**	45**	20**	44**	22**	19**	37**	8**	62**	—
Interaction (WxA)	2*	—	—	3**	2*	—	12**	4**	3**	—	—	—	—
	SHOOTS												
Water level (W)	3*	16**	—	3*	—	12**	392**	13**	13**	9**	6**	7**	14**
Age (A)	6**	113**	62**	9**	13**	19**	36**	4**	16**	13**	14**	71**	3*
Interaction (WxA)	3**	—	—	3**	—	2*	8**	3**	2*	—	—	4**	—
	ROOTS												
Water level (W)	6*	3*	4*	21**	—	5**	196**	96**	8**	5*	32**	38**	3*
Age (A)	—	21**	54**	35**	—	—	46**	18**	55**	—	4*	41**	5*
Interaction (WxA)	—	—	—	—	—	—	14**	19**	—	—	—	5**	6**

*Significant at 5-percent level
**Significant at 1-percent level

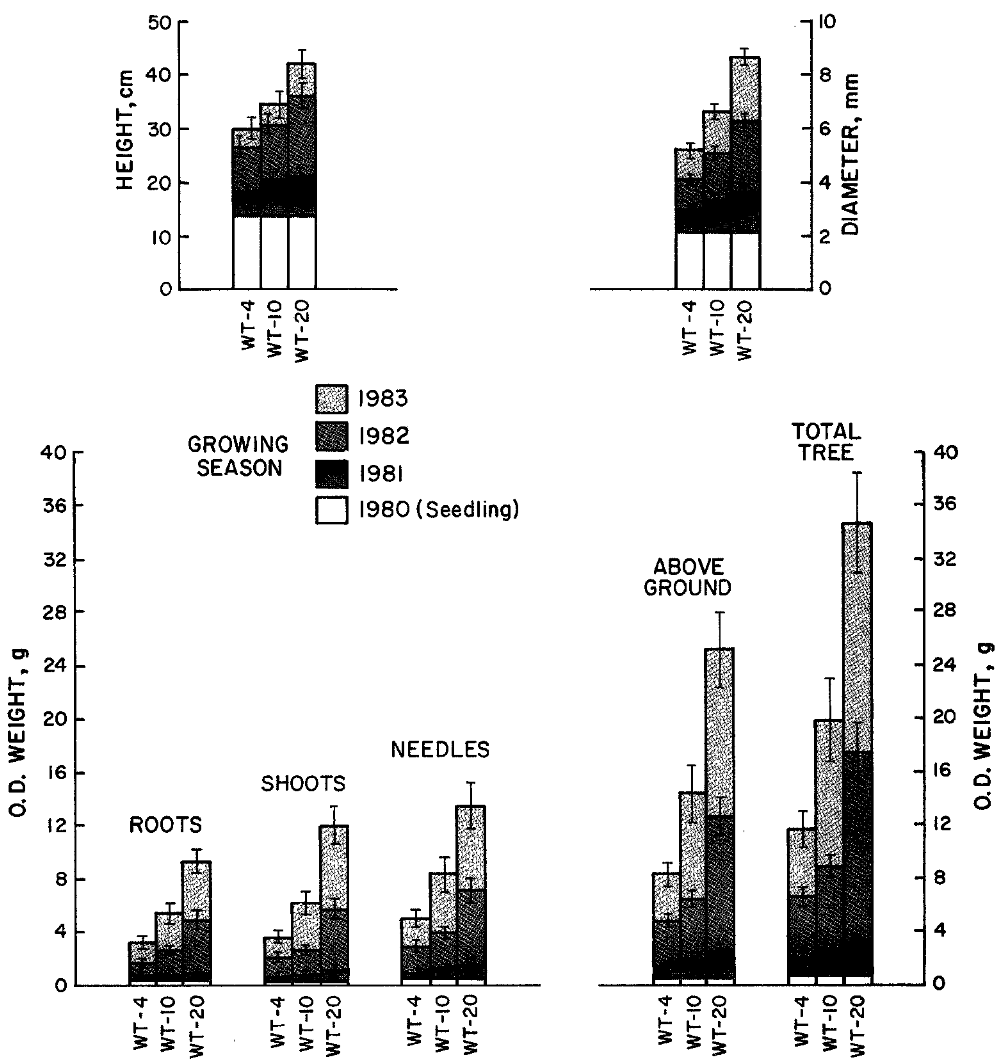

Figure 1.—Mean diameter, height, and component biomass of black spruce as related to water table level.

significant differences in concentrations of P were found due to water table level. For Zn, the differences were significant but did not follow any trend.

Concentrations of ash and all mineral elements except Fe and Cu varied with the age of seedling shoots. The overall mean concentrations of ash, Ca, Al, Fe, and Zn increased and those of N, P, K, Mg, and B decreased with increasing shoot age. The increases of Cu and Mn concentrations were somewhat inconsistent in respect to component age class. The values were also affected by wood-bark ratio, which was not quantified in this study, for respective tree ages.

Roots. Along the gradient of water table depth from 4 to 20 cm, the mean concentration of N and Ca in roots significantly increased and that of ash, Mn, B Fe, Al, and Cu significantly decreased. The values for P, Mg, and Zn were significantly different but did not follow any trend. Concentrations of K did not significantly differ between three water levels.

Mean concentration of ash, Fe, Mn, Na, and Al significantly increased and N, P, and Cu significantly decreased with increasing tree age. The overall concentrations of K, Mg, Zn, and B did not significantly differ between 1-, 2-, and 3-year-old trees.

Changes in element concentrations in trees growing under different soil water table levels were consistent with results reported in the literature. This is due to an aerobic to anaerobic gradient in soil conditions with progressively poorer soil drainage. It is not surprising that in the absence of oxygen nutrient absorption by roots in the majority of the trees is significantly curtailed, because roots grow very poorly in waterlogged soils. It appears that black spruce has some degree of tolerance to high water tables, but the mechanism is unknown to the authors.

The differences in inorganic element concentrations that occurred with plant age were consistent with the literature. Concentrations of Ca rapidly increased between current and older tree components. On the other hand, concentrations of N, P, K, and some micronutrients decreased sharply between the first and second growing seasons. This decrease was partly due to dilution by tree growth as well as due to fertilization of seedlings prior to the first growing season in the greenhouse, with nutrient reserves by the end of the first year likely being exhausted.

Comparisons with Published Data

To examine the relationships among nutrients in foliage, studies by Ingestad (1967), Weetman (1968), and Adams and Allen (1985) utilized nutrient proportions, expressing all nutrient concentrations relative to N concentration which is taken to be 100 percent. Consequently, we compared our data on current year foliage with those suggested by Ingestad (1967) for optimum nutrient proportions, with the levels given by Weetman (1968) for untreated mature black spruce stands and by Swan (1969) for levels sufficient for good to very good growth of black spruce seedlings (Table 6).

Table 6.—Comparisons among current year's foliar nutrient concentrations and proportions of black spruce reported by several authors

Nutrient	Current study				Ingestad (1966, 1967) (Seedlings, optimum proportion)	Swan (1969) (seedlings, for good growth)	Weetman (1968) (mature stand untreated)
	Cont. Seedlings	WT-4	WT-10	WT-20			
N							
Percent	1.43	0.69	0.66	1.10	—	1.50-2.50	0.94
Proportion	100	100	100	100	100	100 100	100
P							
Percent	0.27	0.08	0.08	0.10	—	0.18-0.30	0.19
Proportion	19	12	12	9	8-15	12-12	20
K							
Percent	1.08	0.62	0.62	0.70	—	40-80	0.53
Proportion	76	90	94	64	50-100	27-32	56
Mg							
Percent	0.13	0.14	0.13	0.17	—	0.12-0.25	0.14
Proportion	9	20	20	15	5-10	8-10	15
Ca							
Percent	0.71	0.71	0.68	0.84	—	0.15-0.40	0.36
Proportion	50	103	103	76	5-10	10-16	38

Data in Table 6 show that the foliage of containerized seedlings prior to planting exhibited sufficient levels of N, P, and Mg for good to very good growth, and those of K and Ca are considered to be far above the optimum levels.

In planted seedlings, the relationships in the current year's foliage during the second and third growing seasons drastically changed. Concentrations of N on plots with 4 and 10 cm to the water table decreased to the levels of acute deficiency, and those with 20 cm to the water table decreased to the levels of moderate deficiency. Concentrations of P dropped to the levels of acute deficiency on all plots. Concentrations of K and Mg remained at levels sufficient for good to very good growth, and those of Ca remained at luxury consumption levels.

With decreasing N concentration, there was an increase in relative concentration of K, Mg, and Ca. Because of the decrease in absolute concentration of P, a decrease in relative levels has to be expected.

Comparisons of nutrient levels reported in this study for branches, shoots, and roots were not made because data on macro-nutrient levels in black spruce components other than the current year's foliage is nonexistent.

Furthermore, comparisons of nutrient levels reported in this study with those required for adequate or optimum growth cannot be made because information on macro-nutrient levels in black spruce components, other than the current year's foliage, is also nonexistent. Therefore, until furtner data become available it seems reasonable to accept the levels and ranges given by Young and Carpenter (1967) for branches, stems, and roots of red spruce, by McKee and others (1984) for 2-year-old loblolly pine (Pinus taeda L.) grown under flooded and drained soil conditions, and by Czapowskyj (1979) for balsam fir as affected by soil drainage. Elemental levels in the foliage, shoots, and roots reported in the current study are generally comparable, and the trends are consistent with those reported by authors referred to above for the respective tree components of other coniferous species.

Conclusions

The following conclusions can be drawn from these results:

- Containerized seedlings received adequate nourishment for good to very good growth during the initial growth period.

- Survival of black spruce seedlings was not affected by water table depths of 4, 10, and 20 cm during a period of 3 years following transplanting.

- An increase of the water table depth below the mineral soil surface significantly enhanced the growth and biomass production of the foliage, shoots, and roots.

- As the depth to the water table increased: (a) the levels of N increased and those of Na, Mn, Cu, and Al decreased in foliage, shoots, and roots; and (b) the levels of P, K, Zn, Fe, and B increased only in the foliage and Mg increased in both foliage and shoots.

- A positive response in black spruce growth would be expected if plantations were established on sites where the water table could be maintained to a depth of at least 20 cm.

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The objective of this study was to determine the effect of different soil water table levels on growth, biomass production, and nutrient accumulation in black spruce seedlings growing under greenhouse conditions over three growing seasons after transplanting.

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