Soil–Site Relations for Trembling Aspen in Northwest Ontario

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ABSTRACT. *Past harvesting in Northwest Ontario has produced increased regeneration and increased forest areas supporting trembling aspen stands, resulting in greatly increased utilization of aspen. Thus there is a critical need to accurately estimate site quality and growth and yield for trembling aspen and for identifying productive sites where more intensive aspen forest management can be practiced.*

Soil-site relations were studied using 95 plots located in mature, fully stocked, evenaged, undisturbed trembling aspen stands. On each plot site index (SI_{BH50}) estimation was based on stem analysis of three to five dominant and codominant trees. Each plot also had soil profile descriptions and soil analyses for four major soil horizons (A, B, BC, C). Plots were located on morainal soils, glaciofluvial soils, and lacustrine soils. Multiple regression analyses showed: (a) for morainal soils site index was correlated (adj $R^2 = 0.63$) to depth to a root restricting layer, silt plus clay content of the A horizon, and coarse fragment content of the C horizon; (b) for glaciofluvial soils site index was correlated (adj $R^2 = 0.64$) to depth to a root restricting layer and to drainage class: and (c) for lacustrine soils site index was correlated (adj $R^2 = 0.65$) to depth to mottles and to clay content of the C horizon.

Results are applicable only to medium and good sites where mature, fully stocked, merchantable trembling aspen stands commonly occur. North. J. Appl. For. 15(3):146–153.

Trembling aspen (*Populus tremuloides* Michx.) is among the most widespread and economically important forest trees in North America (Perala 1990). For Northwest Ontario[1] the volume of aspen on production forestlands is only exceeded by volumes for jack pine and for black and white spruce (Ontario Ministry of Natural Resources 1993). The large volume and area of trembling aspen is related to wildfire and past harvesting that has produced extensive even-aged stands mostly regenerated from root suckers. Recent surveys have shown that areas of aspen are increasing in Ontario due to harvesting practices that frequently convert conifer stands to aspen or to mixedwood stands (Hearnden et al. 1992). This increasing area and volume for aspen has resulted in greatly increased aspen utilization for a wide variety of forest products. Several symposia and literature reviews emphasize needs for better utilization and management of an increasingly valuable aspen forest resource that until recently was viewed as a forest weed (Davidson et al. 1988, Adams 1990, Navratil and Chapman 1991, Peterson and Peterson 1992, Navratil et al. 1994).

Intensive forest management for trembling aspen requires the ability to estimate site quality and the growth and yield produced from lands having different levels of site quality. This knowledge of site quality and yield is particularly important since on good sites aspen regenerates well, grows rapidly, produces large yields, and maintains good growth for at least 70 or 80 yr. In contrast, aspen growth is slow on poor sites, yields are small, defects and disease are common, and "stand breakup" occurs at relatively young ages (Fralish 1972, Shields and Bockheim 1981, Carmean 1985, 1996b)

Several direct and indirect methods have been developed for estimating forest site quality (Carmean 1975, Carmean 1996b). These methods usually are based on tree height growth, and these methods have long been widely used for estimating site quality in North America (Spurr and Barnes 1980, Pritchett and Fisher 1987), and in Europe (Hagglund

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[1] The former North Central and Northwestern Administrative Regions of the Ontario Ministry of Natural Resources were combined into a single Northwest Region in June 1993.

1981) The relationship between tree height and age provides a good estimate of site quality in fully stocked, even-aged stands because: (1) height and age are easily measured; (2) height growth of dominant and codominant trees is closely related to volume growth; and (3) for most species height growth is not greatly influenced by stand density (Carmean 1975, Hutsch et al. 1982, Lanner 1985). Estimating site index from forest trees using site-index curves is the most commonly used method for directly estimating site quality (Carmean et al. 1989). Polymorphic site-index curves have recently been developed for trembling aspen in Northwest Ontario (Carmean et al. 1996). These curves based on stem-analysis data from 188 aspen plots define site index as total height at a breast-height age of 50 yr (SI_{BH50}).

Site index cannot be directly estimated where stands are very young, uneven in age, poorly stocked, or where clearcutting or partial cutting has removed dominant and codominant trees. Such areas lack suitable stands and trees for directly estimating site index. However, site index can be indirectly estimated using soil–site methods based on studies where site index has been directly measured on site plots representing the full range of site quality, soil, and topography of a particular area or region. Site index directly measured on these plots is then correlated with associated soil and topographic features measured on the plots. The resulting multiple regression equations expressing relations between site index and specific closely correlated soil, topographic, and climatic features can be used for developing site-index prediction tables for use in areas where stands and trees are not suitable for directly estimating site index (Carmean 1975, 1996b).

Soil–site studies have been published for many North American (Coile 1952, Carmean 1975, 1996b, Spurr and Barnes 1980, Pritchett and Fisher 1987), and European (Hagglund 1981) forest species. Soil–site studies for trembling aspen have been published for Minnesota and Wisconsin (Kittredge 1938, Stoeckeler 1948, 1960, Meyer 1956, Voigt et al. 1957, Strothmann 1960, Fralish and Loucks 1975). These earlier studies consistently show that trembling aspen site index is closely related to A horizon depth, soil texture, coarse fragment content, and depth to water table. More recent studies show that site index for trembling aspen is not closely related to soil mapping units in northern Minnesota (Esu and Grigal 1979), or to soil types used for forest ecosystem classification in northwestern Ontario (Carmean 1996a). Unfortunately, no recent soil–site studies for aspen have been published even though trembling aspen has a very wide range and has greatly increased commercial value in North America.

Soil-site studies for trembling aspen have not been made in Ontario. However, in view of the increasing forest area and utilization of aspen, there is need for means to more precisely estimate site quality for trembling aspen and thus provide for more precise estimates of aspen growth and yield. More precise site-quality evaluation tools will provide for identifying the most productive soils for intensive aspen forest management, as well as for identifying poor ("off site") soils for aspen where less intensive management and forest species other than aspen should be favored. Accordingly, the objective of this aspen soil–site study is to quantitatively identify the specific soil and topographic features closely correlated with aspen site index. This research thus will provide quantitative tools for constructing site-index prediction tables for forestlands of Northwest Ontario that lack aspen stands and trees suitable for directly estimating trembling aspen site index using site-index curves.

Methods

Stem-analysis and soils data were collected from 95 0.08 ha plots (Table 1) located in relatively pure, well-stocked, mature, even-aged stands in Northwest Ontario (Figure 1). The study included 56 plots used for developing trembling aspen site-index curves (Deschamps 1991), and 39 additional plots established by Li (1991) for better representation of trembling aspen on soils having poorer site quality.

Plots were located on three major mineral soil groups (Table 1), having the following general soil and site-quality conditions:

1. *Deep morainal soils.* These soils vary greatly in depth to bedrock; rooting depth is restricted by bedrock, basal till, gley, or mottles. Soil texture and content of coarse fragments also vary greatly for different soil horizons. Jack pine (*Pinus banksiana* Lamb.) soil–site relations have been intensively studied in North Central Ontario (Schmidt and Carmean 1988), and in Northeastern Ontario (LeBlanc 1994). Soil-site relations for jack pine differ somewhat from those for aspen, but for morainal soils best sites for both species are usually soils that are deep to a root restricting layer, and that have few coarse fragments.
2. *Glaciofluvial soils.* These are outwashed or deltaic sands and silts that have few or no coarse fragments. Stratified sand or silt bands often occur in subsoils (B and C horizons) resulting from the sorting action of glacial meltwater. Rooting depth may be restricted by very coarse sandy subsoils or by mottling where soils are imperfectly drained. Good site indices for jack pine in North Central Ontario were found on level areas having glaciofluvial soils that were deep to root-restricting layers (Schmidt and Carmean 1988).
3. *Lacustrine soils.* These are clayey and silty soils deposited in lakes formed by glacial meltwater. Topography usually is flat or undulating, but steeper slopes occur in uplifted (isostatic rebound) areas or areas incised by streams. Subsoils have high bulk

Table 1. Trembling aspen soil–site studies in Northwest Ontario were based on 95 plots on 3 mineral soil groups.

Soil group	No. of plots	Range of site index (m) (SI_{BH50})	Mean site index (m) (SI_{BH50})
Morainal	35	13.7–23.6	18.8
Glaciofluvial	40	15.5–25.1	20.0
Lacustrine	20	17.0–25.1	20.6
Totals	95	13.7–25.1	

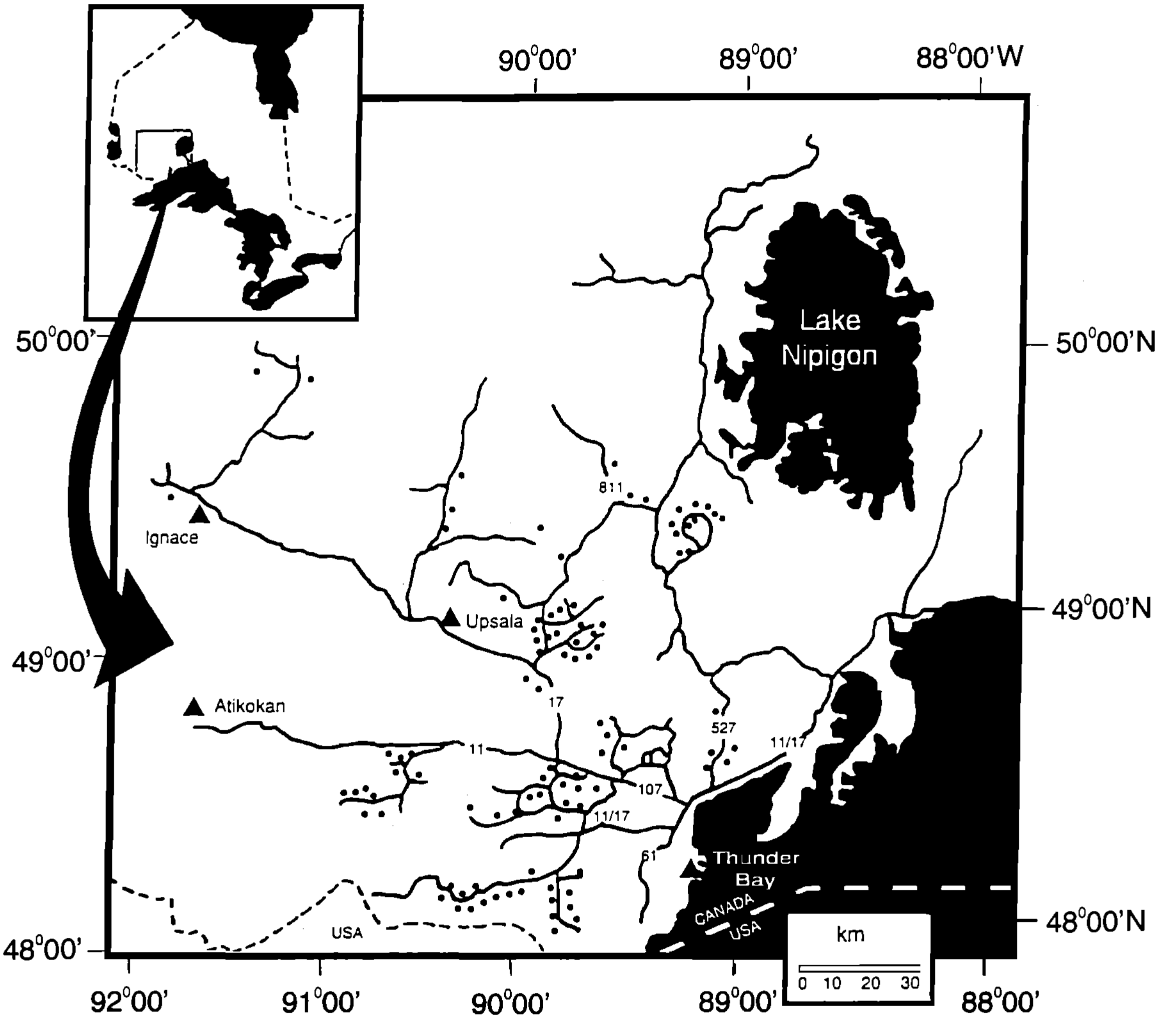

Figure 1. Soil–site studies for trembling aspen were based on 95 plots (solid dots) located in Northwest Ontario.

densities, low macropore space, few roots, and usually are mottled or gleyed in poor and imperfectly drained areas. Good site indices for jack pine in North Central Ontario were found for well-drained lacustrine soils having deep surface soil layers (Ah, Ae horizons), and where acid subsoils characterize red lacustrine clays (Schmidt and Carmean 1988).

Stem-analysis data were taken from three to five well-formed dominant and codominant trembling aspen trees on each plot (Deschamps 1991, Li 1991, Carmean et al. 1996b). Paired height and age values from each tree were used to construct individual tree height-growth curves. On each plot most of these individual tree curves had similar shapes, and tree height at index age also was similar. A few trees were discarded when obvious abnormal height-growth patterns were observed that probably were due to top breakage or dieback. Obtaining suitable site trees was particularly difficult for poorer sites due to heart rot or top dieback, and a few poorer site plots were represented by only a single usable tree. The individual tree curves on each plot were corrected for a bias (Carmean 1972, Dyer and Bailey 1987) that occurs when height at a sectioning point underestimates the actual tree height attained for that particular year. These corrected individual tree curves then were combined into an average height-growth curve for each plot. Site index (SI_{BH50}) on each plot was directly observed from the average plot curve and was defined as the average total height of the dominant and codominant trees 50 yr after they reached breast height (1.3 m). Data from the average curve for each plot also were used for developing site-index curves and site-index prediction equations for trembling aspen (Carmean 1996b, Carmean et al. 1996).

Soil profile descriptions were taken from a single soil pit located in a representative part of each plot where microtopography and soil conditions were unbroken by depressions, windfalls, or living trees. Soil profile descriptions followed standard Canadian methods (Day 1983, Sims et al. 1989). Four major soil horizons (A, B, BC, C) were sampled for laboratory determination of percentages of sand, silt, and clay, coarse fragment content, soil pH, and percent organic matter (McKeague 1978). Forest soil types (S-types) on each plot were identified using the FEC (Forest Ecosystem Classification) system for Northwestern Ontario (Sims et al. 1989). Topographic features (aspect, slope position, slope steepness, and slope shape) were described for each plot.

Analysis

Site-index (SI_{BH50}) values and associated soil and topographic data for each plot were used for computing a multiple regression for the entire 95 plot data set. This analysis showed relatively poor precision (adjusted $R^2 = 0.48$; $SEE = 1.71$ m) when data for all 95 plots were combined for a single regression analysis. Accordingly, further analysis was restricted to developing separate multiple regression equations for each of the three mineral soil groups.

A total of 59 soil and topographic values were considered as possible independent variables, thus preliminary screening was done to eliminate variables that had little or no relation to site index. The procedure followed methods used by Schmidt and Carmean (1988) for a jack pine soil–site study in North Central Ontario; details are given by Li (1991). Briefly, Pearson product-moment correlation coefficients (r) were computed where site index (SI_{BH50}) was correlated with each of the 59 possible soil and topographic variables. Principal component analysis (Chatfield and Collins 1980) also was used as a means for identifying independent variables that were closely correlated with site index and with each other.

These preliminary analyses indicated that each of the three soil groups had about ten variables that were closely related to site index and were promising variables for multiple regression analysis. Backward stepwise multiple regression was used for developing preliminary multiple regression equations. These computations were made using SAS version 6.04 statistical software (Nie 1983). The residuals (actual site index versus predicted site index) for the three preliminary soil group equations were examined for possible outliers using Bonferroni's t-test ($P < 0.05$) (Weisberg 1980). Scatter plots of residuals for each equation also were examined for heteroscedasticity (Chatterjee and Price 1977); a standard error of estimate (SEE), R^2 value, and R^2 value adjusted for sample size (adj. R^2) was calculated for each equation.

Final analyses for each of the three soil groups involved testing curvilinear expressions of significant variables to determine if these transformations improved precision of estimate. Also all possible two-way interactions between significant independent variables were considered as a possible means for improving the precision for each of the soil group equations.

Results and Discussion

A wide range of site index (SI_{BH50}) was observed for trembling aspen growing on each of the three mineral soil groups with 13.7 m being the lowest observed site index (Table 1). Site index for jack pine and black spruce (*Picea mariana* [Mill.] B.S.P.) in Northwest Ontario also varied widely on these three mineral soil groups, but these species consistently had much lower site indices than observed for trembling aspen. Poorest observed site indices for jack pine and black spruce on mineral soils were 8.6 m and 4.8 m, respectively (Carmean 1996b).

Individual features significantly correlated with these wide ranges in site index are shown by Pearson product-moment correlation coefficients (r) for each of the three soil groups (Table 2). The final multiple regression equations for the three soil groups are given in Table 3. These equations were used for constructing trend graphs illustrating relations between trembling aspen site index and each of the significant features listed in the regression equations (Figure 2). These equations also were used for constructing site-index prediction tables (Table 4) for use in estimating site index for trembling aspen on lands where aspen stands and trees are absent or are not suitable for directly estimating site index using trembling aspen site-index curves (Carmean et al. 1996).

Morainal Soils

The soil features most closely correlated (adj. $R^2 = 0.63$) to site index are depth to a root restricting layer, coarse fragment content of the C horizon, and silt plus clay content

Table 2. Pearson product-moment correlation coefficients (r) between site index (SI_{BH50}) and individual independent variables.

Variable	Morainal soils	Glaciofluvial soils	Lacustrine soils
Depth (cm) to root restricting layer (DRL)	0.45*	0.68*	
Thickness (cm) of BC horizon (ThBC)	0.42†		
Depth (cm) to mottles (DM)	0.45†		0.65*
Coarse fragments (%) in B horizon (CoFragB)	–0.39†		
Coarse fragments (%) in C horizon (CoFragC)	–0.70*		
Sand in A horizon (%) (SaA)	–0.35†		
Silt in A horizon (%) (SiA)	0.40†		
Clay in BC horizon (%) (ClBC)			0.48†
Clay in C horizon (%) (ClC)		0.50*	0.77*
Site + clay in A horizon (%) (SiClA)	0.65*		
Drainage class†† (DC)		0.51*	

* = significant (< 0.01 P)
† = significant (<0.05 P)
†† = drainage class (1 = very rapid, 2 = rapid, 3 = well, 4 = mod. well), after Sims et al. (1989).

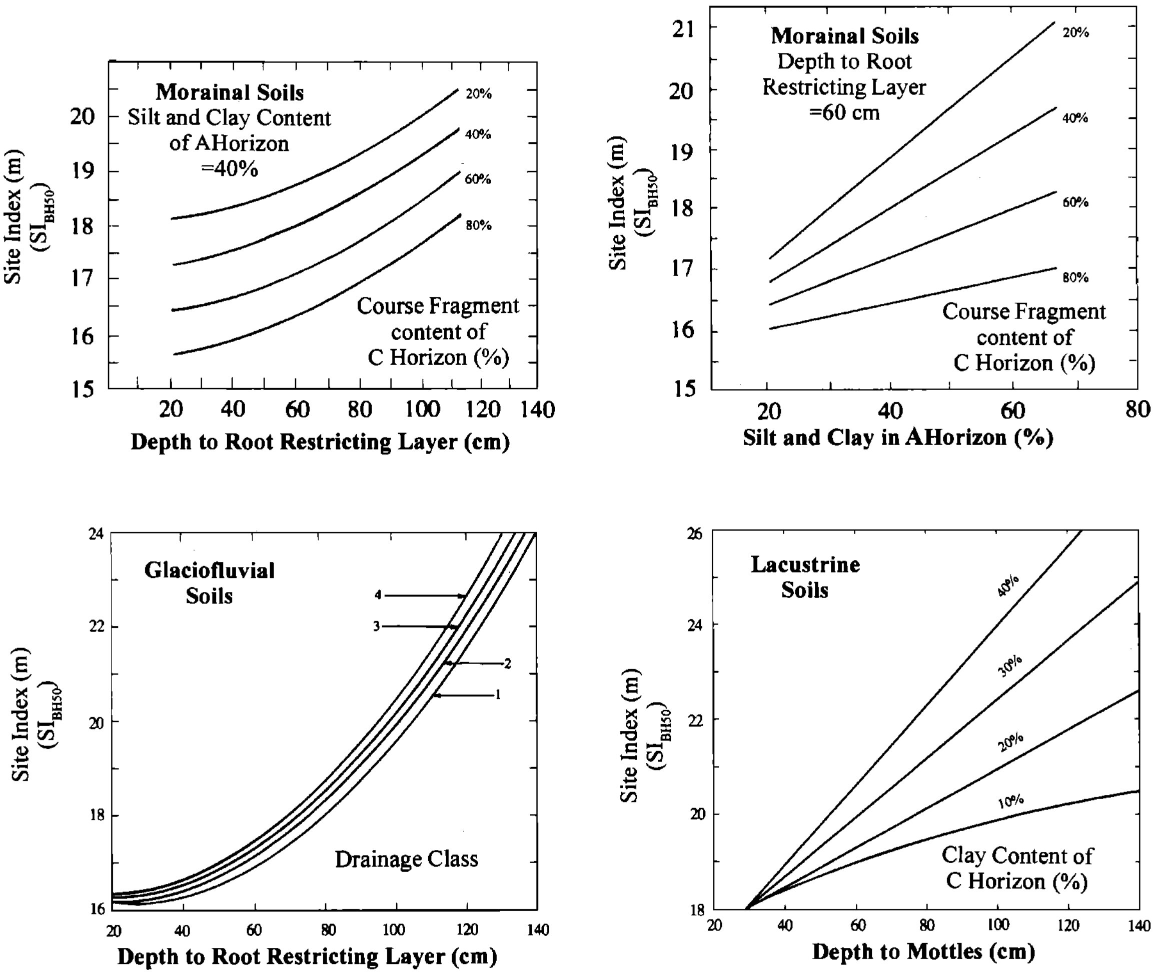

Figure 2. Soil-site relations for trembling aspen on morainal, glaciofluvial, and lacustrine soils in Northwest Ontario. On morainal soils (upper left and upper right) site index (SI) is significantly related to depth to a root restricting layer, coarse fragment content of the C horizon, and silt plus clay content of the A horizon. On glaciofluvial soils (lower left) site index is significantly related to depth to a root restricting layer and to drainage class. On lacustrine soils (lower right) site index is significantly related to depth to mottles and to clay content of the C horizon.

of the A horizon (Table 3). These relationships are illustrated in Figure 2 (upper left and upper right), and Table 4 includes a site-index prediction table for trembling aspen on morainal soils. Great increases in site index associated with increased depth to a root restricting layer and decreased coarse fragment content also has been found in North Central Ontario for jack pine (Schmidt and Carmean 1988), and for white spruce (*Picea glauca* [Moench] voss) plantations on morainal soils (Carmean and LaValley 1996).

Glaciofluvial Soils

The soil features most closely correlated (adj. $R^2 = 0.64$) to site index are depth to root restricting layer and drainage class (Table 3). Figure 2 (lower left) illustrates these relationships and shows that increased depth to a root restricting layer is associated with very large increases in site index while, in contrast, drainage class has a relatively minor role. Table 4 includes a site-index prediction table for trembling aspen on glaciofluvial soils. Depth to a root restricting layer also was

Table 3. Multiple regression equations expressing relations between trembling aspen site index and features of soil and topography for three mineral soil groups in Northwest Ontario.

	No. of plots	Equation	Adj. R^2	SEE (m)
Morainal	35	$SI = 14.97 + 0.00017\,(DRL)^2 + 0.00097\,[SiClA\,(100\text{–}CoFrag\ C)]$	0.63	1.32
Glaciofluvial	40	$SI = 16.43 + 0.00058\,(DRL)^2 - 0.003\,[DRL\,(10 - DC)]$	0.64	1.38
Lacustrine	20	$SI = 21.20 + 0.00210\,[(ClC)\,(DM)] - 1.508\,[\ln\,(ClC + 10)]$	0.65	1.46

SI = Site index (SI_{BH50}) is total height (m) of dominant and co-dominant trees at 50 yr breast-height age;
DRL = depth to root restricting layer (cm) [e.g., bedrock, coarse sandy subsoil (C horizon), mottles, gley, water table, carbonates or basal till];
DM = depth to mottles (cm);
SiClA = silt plus clay content of A horizon (%);
ClC = clay content of C horizon (%);
CoFrag C = coarse fragment content of C horizon (%)
DC = drainage class (1 = very rapid, 2 = rapid, 3 = well, 4 = moderately well) after Sims et al. (1989).

Table 4 Site-index (SI_{BH50}) prediction tables for trembling aspen on three mineral soil groups in Northwest Ontario Depth to root restricting layer is depth to coarse sandy subsoil (C horizon), mottles, gley, water table, or basil till. Drainage classes after Sims et al. (1989).

Morainal soils

Silt and clay content of A horizon	Coarse fragment content of C horizon (%)	Depth to root restricting layer (cm)			
		30	60	90	120
		Site index (m)			
20	1	17.0	17.5	18.3	19.3
	30	16.5	16.9	17.7	18.8
	60	15.9	16.4	17.1	18.2
40	1	18.9	19.4	20.2	21.3
	30	17.8	18.3	19.1	20.1
	60	16.8	17.1	17.9	19.0
60	1	20.9	21.3	22.1	23.2
	30	19.2	19.7	20.4	21.5
	60	17.5	17.9	18.7	19.7
80	1	22.8	23.3	24.0	25.1
	30	20.6	21.0	21.8	22.8
	60	18.2	18.7	19.5	20.5

Glaciofluvial soils

Depth to root restricting layer (cm)	Drainage class	
	Very Rapid (1)	Mod. Well (4)
	Site index (m)	
30	16.1	16.4
60	16.9	17.4
90	18.7	19.5
120	21.5	22.6

Lacustrine soils

Depth to mottles (cm)	Clay content of C horizon (%)			
	10	20	30	40
	Site index (m)			
40	18.3	18.4	18.5	19.0
60	18.9	19.2	19.8	20.6
80	19.3	20.0	21.1	22.3
100	19.7	20.8	22.3	24.0
120	20.1	21.6	23.6	25.7

a highly significant factor for jack pine (Schmidt and Carmean 1988) and drainage class also was a feature associated with site index for white spruce plantations on glaciofluvial soils in North Central Ontario (Carmean and LaValley 1996).

Lacustrine Soils

The soil features most closely correlated (adj $R^2 = 0.65$) to site index are depth to mottles and clay content of the C horizon (Table 3). Figure 2 (lower right) illustrates these relationships and shows that increased depth to mottles is associated with large increases in site index. Increased clay content of the C horizon also is associated with increased site index. Lacustrine soils having large amounts of C horizon clay have particularly large increases in site index with increased depth to mottles. Table 4 includes a site-index prediction table for trembling aspen on lacustrine soils. Thickness of the A horizon and pH of the BC horizon were features significantly related to site index for jack pine (Schmidt and Carmean 1988) on lacustrine soils. For white spruce plantations, depth to a root restricting layer, type of clay, and hue of the C horizon were significantly related to site index on lacustrine soils.

Results from this soil–site study (Figure 2, Tables 3 and 4) show that very high site indices for trembling aspen occur with certain specific soil conditions. For the morainal, glaciofluvial, and lacustrine soil groups, high site indices are associated with deeper rooting as expressed by depth to a root restricting layer or depth to mottles. For morainal and glaciofluvial soils high site indices occur for soils having deep rooting depths and few coarse fragments. For well-drained lacustrine soils, high site indices have deep rooting depths and large amounts of C horizon clay.

Results of this aspen soil–site study resemble soil–site studies reported for trembling aspen in Minnesota and Wisconsin (Kittredge 1938, Stoeckeler 1948, 1960, Meyer 1956, Voigt et al 1957, Strothmann 1960, Fralish and Loucks 1975). Their results also show that site index for trembling aspen is closely related to A horizon depth, coarse fragment content, soil texture, drainage, and depth to water table. Our results show that soil–site relations for trembling aspen in Northwest Ontario are generally similar to soil–site relations for jack pine and planted white spruce in Northwest Ontario (Schmidt and Carmean 1988, Carmean and LaValley 1996). These many soil–site studies in Northwest Ontario and elsewhere confirm Coile's (1952) earlier views that soil features closely related to forest site quality are those soil properties "... which influence the quality and quantity of growing space for tree roots." These consistent correlations probably reflect causative factors important for tree growth such as soil moisture, soil nutrients, and soil aeration.

We should recognize that results of this soil–site study are only for medium and good sites where mature, fully stocked, merchantable aspen stands commonly occur. For our study we had no difficulty locating such plots. In contrast, mature aspen stands are uncommon or absent on soils having poor site indices such as very shallow to bedrock soils, coarse-textured soils, stony soils, poorly drained soils, and deep peaty soils. Aspen may regenerate on these soils but growth is slow, stem cankers soon develop, and "stand breakup" occurs at relatively young ages. Thus these "off site" aspen soils are not well represented or are absent in our studies because few mature, well-stocked, merchantable aspen stands survive on such poor sites.

Following are the FEC soil types (Sims et al. 1989) represented by plots located in this trembling aspen soil–site study:

- Soils commonly represented—deep to moderately deep, fresh to moist, well-drained, sandy to loamy soils (FEC S1, S2, S3, S5, S7, S8, SS7, SS8).
- Soils uncommonly represented—well-drained clayey soils that are unmottled or that are deep to subsoil mottles (FEC S6, S9, S10); shallow to moderately deep sandy soils (FEC SS5); organic soils with feather moss (FEC S12F).
- Soils not represented—very shallow soils (FEC SS1, SS2, SS3); very shallow boulder pavement soils (SS4); moderately deep coarse loamy soils (FEC S4, SS6); clayey or loamy soils shallow to mottles (FEC S10, SS8); peaty phase mineral soils (FEC S11, SS9); wet organic soils with sphagnum (FEC S12S).

Implications from this soil–site study are that trembling aspen should be favored for management on the medium and good site qualities observed in this study (Table 4). These are the deep to moderately deep, fresh to moist, well-drained medium and fine-textured soils where rapid and sustained height and volume growth occurs such as the FEC soils listed above where mature, merchantable aspen stands were found. In contrast, aspen should not be favored on "off site" soils having poor site indices for aspen. These are the shallow, coarse-textured, poorly drained, or peaty soils where growth is slow, defect is great, and where early stand breakup occurs such as the FEC soils listed above where mature merchantable stands were not found. Instead efforts should be made to favor conifers on such poor sites. Our observations in Northwest Ontario (Carmean 1985, 1996b) are similar to those reported for trembling aspen in northern Wisconsin showing that on poor sites, aspen growth is slow, yields are small, defects and disease are more common, and "stand breakup" occurs at relatively young ages (Fralish 1972, Shields and Bockheim 1981).

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