Current trends in management practices for European larch in North America[1]

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European larch (*Larix decidua* Miller) was introduced to North America in the mid-19th century. Its rapid growth led to its use as a reforestation species in northeastern North America during the early part of the 20th century. Proper site selection and vegetation management are crucial to the successful establishment and productivity of this species. On comparable sites, yields of European larch commonly exceed those of native species. Management practices and applied research for this species in North America include the refinement of 1) site selection criteria, 2) growth and yield tables, and 3) optimal density management and stocking levels, 4) product utilization and marketing, and 5) the advancement of tree improvement programs.

Key words: growth and yield, productivity, silviculture, tree improvement

Le mélèze européen (*Larix decidua* Miller) a été introduit en Amérique du Nord au milieu du XIXe siècle. Sa croissance rapide l'a amené à être utiliser comme espèce pour le reboisement dans le nord-est de l'Amérique du Nord au début du XXe siècle. La sélection adéquate de la station et le contrôle de la végétation sont essentiels pour une croissance réussie et la productivité de cette espèce. Sur des stations comparables, les rendements du mélèze européen excèdent habituellement ceux des espèces indigènes. Les pratiques d'aménagement et la recherche appliquée pour cette espèce en Amérique du Nord touchent le raffinement 1) des critères de sélection des stations, 2) des tables de croissance et de rendement, 3) de l'aménagement selon une densité optimale et les niveaux de densité relative des tiges, 4) l'utilisation et la mise en marché des produits, et 5) la poursuite des programmes d'amélioration génétique.

Mots-clés : croissance et rendement, productivité, sylviculture, amélioration génétique

Introduction

European larch [*Larix decidua* (Miller) also *Larix europaea* (De Candolle)] plantations have been established throughout Europe (McComb 1955, Genys 1960), Great Britain (Michie 1885, Dallimore *et al.* 1967) and northeastern North America (Cook 1939, Aird and Stone 1955, Nyland 1965, Carter and Selin 1987). Within its natural range, European larch is a species component in two mixed forest types of the European Alps: 1) the spruce-fir-larch-beech type (*Picea excelsa* Link., *Abies pectinata* D.C., *L. decidua*, *Fagus sylvatica* L., with or without, *Pinus sylvestris* L.) and 2) the spruce-larch type. Early planting failures in Europe and North America resulted from plantations being established on unsuitable sites (Michie 1885, McComb 1955, Genys 1960).

European larch was introduced to Great Britain in 1629 (Michie 1885, Genys 1960, Mitchell 1963) and introduced to North America in the mid-19th century (Cook 1939, Genys 1960, Nyland 1965). The availability of planting stock from Europe at a time when native nursery stock was lacking was the principal reason for the establishment of European larch, Scots pine, and Norway spruce plantations in the United States during the post-Civil War time period (Baldwin 1953). The impressive height and volume growth of European larch led to extensive plantation establishment for timber production in Great Britain (Michie 1885) and the northeastern United States (Cook 1939, Nyland 1965).

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Geographic Races

The natural range of European larch is non-contiguous and is represented by four geographically isolated races: the Sudeten, Polen, Alpen, and Tatra races (McComb 1955, Genys 1960, Boyle *et al.* 1989). The greater frost resistance of European larch relative to Japanese larch (*Larix leptolepis* Sieb. and Zucc.) makes this species of upland larch desirable for high-yield plantation programs in the Lake States and northeastern North America (Carter *et al.* 1981, Lee and Schabel 1989). The rapid early height growth and resistance to larch canker (McComb 1955, Genys 1960, Giertych 1979) of the Sudeten race makes it an attractive candidate for planting programs in this region (Robbins 1985). Genys (1960) reported the Polen race to be similar to the Sudeten race in all characteristics with the exception of its greater resistance to the woolly larch aphid (*Adelges laricis* Vallot.)

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Provenance tests at the Petawawa Research Forest in Ontario indicated that the fastest growing Tatra provenances are less productive then the Sudeten and Polen races (Boyle *et al.* 1989). Evidence from provenance tests in Europe suggests a lack of genetic uniformity within the Alpen race (McComb 1955). This coupled with its relatively slow growth rate and its high susceptibility to larch canker (*Lachnellula willkomii* (Hartig) Dennis) (Genys 1960, Boyle *et al.* 1989) that is present in the Northeast (Ostaff 1987, Boyle *et al.* 1989) makes the Alpen race unattractive for planting programs. Long-term research in North America indicates that the Sudeten race of European larch is the most favourable for plantation programs focusing on fibre production followed by the Polen and Tatra races with the Alpen race having the greatest variability in stem form and greatest disease susceptibility.

Protection from Insect, Diseases, Birds, and Mammals

One of the primary concerns associated with the incorporation of European larch into large-scale planting programs in North America is the susceptibility to native and exotic pests and the acquired preference for exotic larch foliage, buds, twigs and bark by several native warm-blooded animals.

The larch sawfly (*Pristiphora erichsonii* (Hartig)) is a defoliator native to Europe that is capable of causing substantial mortality during severe outbreaks. Between 1880 and to 1890, a larch sawfly outbreak in Maine killed considerable volumes of upland tamarack (*Larix laricina* (Du Roi) K. Koch) in the Northeast (Coolidge 1963). Another defoliator, the larch casebearer (*Coleophora laricella* (Hübner)) was also introduced from Europe but appears to have reached an equilibrium point with its host and predators and parasites in the Northeast (Pendrel 1987). The eastern larch beetle (*Dendroctonus simplex* LeConte), a bark beetle, is native to the North American continent and is reported by Pendrel (1987) as being the greatest killer of Maritime larch in recent history. This is unusual in that prior to this time tree mortality was not associated with the eastern larch beetle in that it did not attack healthy trees. Similar uncharacteristic behaviour of this insect attacking healthy trees was reported in the Adirondack Mountains of New York and the Green Mountains of Vermont where thousands of healthy tamarack were killed during the 1970s.

European larch has a greater susceptibility to the larch canker than Japanese larch but both species have greater susceptibility on poorly drained sites (Michie 1885, Dallimore *et al.* 1967, Robbins 1985). Artificial inoculations of European larch with Scleroderris canker (*Gremmeniella abietina*) showed that Japanese larch had greater resistance to canker infection than European larch or native tamarack (Skilling 1981, Skilling and Riemenschneider 1984). Two needle cast diseases are known to infect European larch in North America (Robbins 1985). The Sudeten and Polen races of European larch, Japanese larch, and European and Japanese larch hybrids appear to have greater resistance to the needle cast fungus *Mycosphaerella laricina* than Alpen sources of European larch (Robbins 1982). *Meria laricis* is a needle cast disease more common in western North America for which Japanese larch was found to have greater resistance than European larch (Phillips 1963). Annosus (*Heterobasidion annosum*) and Armillaria (*Armillaria mellea*) root rots are native to North America and known to infect larch and may be a future problem (Robbins 1985).

The red squirrel (*Tamiasciurus hudsonicus*) causes slight damage to individual trees by feeding on the small twigs of larch and larch seed, as does the winter feeding of the pine grosbeak (*Pinicola enucleator leucora* (Müller)) (Hunt 1932, Cook 1969). The porcupine (*Erethizon dorsatum* Linnaeus) feeds on both the foliage and inner bark of all larches but appears to have a preference for Japanese larch. This mammal has caused severe girdling damage to young larch trees throughout the Northeast (Hunt 1932, Cook 1969, Holst 1974, Robbins 1985).

Uses of Larch

Larch lumber was used to a great extent for centuries. Indeed, much of the city of Venice is supported by ancient larch pilings (Botkin 1990). Items constructed from larch lumber included ploughs, harrows, carts, wheelbarrows, rakes, ladders, tables, chairs, household furniture, fencing, posts, gates, and bridges (Michie 1885). Other products derived from larch included tannin, turpentine and charcoal. During the latter half of the 19th century and early 20th century, tamarack harvested in Maine was used for railroad ties, ship timbers and telegraph poles (Coolidge 1963, Judd 1989). Currently in the United States exotic larches are utilized primarily for pulp, with secondary uses as decorative panelling, moulding, landscape timbers, fence posts and fuel wood. A strong potential exists for the use of exotic larches as cabin logs. Whether hand-scribed or in prefabricated kit form where logs are shaped to a uniform diameter, the rapid growth, straight form and natural decay resistance makes *Larix* species ideal for building construction where solid logs are required.

Pulping studies indicate that European, Japanese and hybrid larch produce kraft pulp very similar to jack pine (*Pinus banksiana* Lamb.) (Einspahr *et al.* 1983, Gagnon 1999). When processed via the mechanical pulping process there is insufficient brightness for print quality papers (Law *et al.* 1991). A comparison of fibre yields per hectare shows that the exotic larches exceed jack pine (Einspahr *et al.* 1983), red pine (*Pinus resinosa* Ait.), loblolly pine (*Pinus taeda* L.) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) (Chiang *et al.* 1988). It may be possible to include up to a 30% larch mixture in the wood supply of a pulp mill (Lawford 1987). A problem associated with the use of pulp obtained from the genus *Larix* is the amount of arabinogalactan extractives contained in the wood cells of older trees (Keith and Chauret 1988). Arabinogalactan is a water-soluble molecule typically found in the heartwood and at the heartwood/sapwood interface (Cote *et al.* 1966) of all *Larix* species. It occurs in high concentrations in the butt end logs of western larch (*Larix occidentalis* Nutt.) and the Eurasian larches *Larix gmelinii* and *Larix russica* and to a lesser degree in tamarack, European and Japanese larch. Einspahr *et al.* (1984) reported that older (50-year-plus) and slower grown larch has a high proportion of arabinogalactan. Keith & Chauret (1988), however, reported that pulp produced from short-rotation (18- to 24-year-old) plantation-grown larch had about 50 percent less extractives then the amounts reported by Einspahr *et al.* (1984). Arabinogalactan can be a detriment to the pulping process (Bobrov and Mutovina 1971, Kucherenko and Novikov 1971) and even in small amounts can prevent the setting and hardening of Portland cement (Xu 1984). Recent work, however, has shown arabinogalactan to be an economically important biomolecule. It can be used as a dietary supplement to promote beneficial gut bacteria (Robinson et. *al.* 2001), an immune system enhancer (Kim *et al.* 2002), an animal feed supplement, a skin and hair care performance additive, an extender in certain inks, and in the biomedical field as part of a process to promote non-toxic cell separation (Larex 2002).

The use of European larch as a building material in Europe has been increasing steadily over the past decade (Bonelli 2002, Reuling *et al.* 2002). Initially, there were concerns about the strength of larch lumber (Pâques 2002a) but thorough testing of the mechanical properties of larch have shown the lumber to be conducive for building construction (Reuling *et al.* 2002). A timber grade stamp has yet to be certified for larch in the United States before it can be used as a source of dimensional lumber for building construction.

Tree Improvement

There is a long history of provenance trials in the United States and Canada that have been used to demonstrate the growth potential of European and Japanese larch (Baldwin 1949, Barnes 1977, Carter *et al.* 1981, Park and Fowler 1983, Boyle *et al.* 1989, Lee and Schabel 1989, Zaczek *et al.* 1994). Generally these tests were limited to one site and some were not replicated within a site. Results from these trials often substantiated trials in Europe where the Sudeten sources tended to be faster growing (McComb 1955, Genys 1960, Giertych 1979). Alpen sources possessed variable form (McComb 1955) but eastern sources of this race appear to have superior stem form. Japanese provenances showed relatively little variation in traits relative to European provenances (Park and Fowler 1983). Selecting for frost resistance, or more importantly the timing of bud break, is important because the exotic larches are among the first conifer species to break bud in spring and often the last to terminate shoot growth in fall. Tree improvement programs can select for disease resistance but an additional trait of interest is wood relative density (Loo *et al.* 1982). In situations where hybrids were included in the provenance test, the hybrids had instances of both greater and lesser rates of growth than their parental species (Cook 1942, Patton 1944).

There are two published breeding plans for larch in North America (Fowler 1986, Li and Wyckoff 1994). However, despite the long history of provenance testing in exotic larches, there has been little sustained breeding work initiated with either European or Japanese larch within the framework of a tree improvement program. As such, there has been little information on general or specific combining ability and no solid genetic evidence for the creation of seed orchards. Nonetheless, grafted seed orchards for European larch and hybrid larch exist because the exotic larches and their hybrids typically outperform native conifers (Mroz *et al.* 1988, Lee and Schabel 1989, Gower *et al.* 1991, Gerlach 2001, Gilmore 2001, Gilmore and David 2002). There is a paucity of studies on juvenile-mature correlations, the ability to predict mature phenotypes based on measurements at juvenile ages, for European larch. Such information would be valuable to larch breeders in the United States and Canada allowing them to maximize genetic gain in the shortest time frame possible. Research with European, Japanese, and hybrid provenances in Europe indicates that picking the best growing provenances in a trial can be done with reasonable accuracy during the seedling stage, but selection of the best individual trees is not efficient until at least 20 years after planting (Malinauskas and Suchockas 1998).

There is also little information about genotype and environment interactions at the level of individual families for larch in North America. Some of the best information comes from the University of Minnesota, Aspen/Larch Genetics Cooperative, which has established progeny tests of European × European larch (E × E), and European × Japanese (E × J) hybrids as well as the reciprocal hybrid cross on multiple sites. Three-year data indicates that family performance is quite variable from site to site (David and Anderson 2001). For example, an individual European larch tree, LD-1-81, used as a female in controlled pollination of E × E crosses produced families that were 94.7% of the plantation mean for E × E crosses in Newberry, Michigan but 124.7% of the plantation mean for E × E crosses in Hartland, Maine. To complicate matters, when used in hybrid crosses, LD-1-81 produced families that were 128.0 % of the plantation mean for E × J crosses in Newberry, Michigan and 107.3 % of the plantation mean for E × J crosses in Hartland, Maine. The decision to include or exclude LD-1-81 from a seed orchard would depend on which type of seed orchard (intraspecific or hybrid) is being considered and where the seed will be deployed. Results such as these underscore the necessity of progeny testing individuals on multiple sites prior to inclusion in a breeding program or a seed orchard.

Hybrids

Intraspecific and interspecific hybridization frequently occurs in the genus *Larix*. The best-known hybrid is *Larix x eurolepis* (Henry) commonly known as the Dunkeld larch. The Dunkeld larch is a hybrid of *L. decidua* and *L. leptolepis* and first occurred "naturally" at the Dunkeld estate in Perthshire, Scotland (Cook 1942, Dallimore *et al.* 1967). The Dunkeld hybrid is valued because of its rapid growth rate, which is superior to that of both parent species (Dallimore *et al.* 1967, Holst 1974, Boyle *et al.* 1989). Evidence of hybrid vigour in exotic larches has been documented (Arcade *et al.* 1996, Baltunis *et al.* 1998, Pâques 2002b) offering additional potential for increased productivity through hybrid seed orchards or selective crosses.

Concerns about interspecific hybridization and introgression with native species, particularly tamarack (*Larix laricina* (Du Roi) K. Koch), have risen in recent years. Although the possibility of cross-pollination exists, the phenology of pollen release in European and Japanese larch occurs prior to the pollen release for native tamarack. In addition, although interspecific hybrids are possible with controlled pollination techniques, seed yield from such crosses is low (Fowler *et al.* 1971). Thus, instances of unintended interspecific hybridization and subsequent survival are expected to be low. European larch, however, has successfully naturalized itself in North America (Cook 1939, Nyland 1965), as have other European tree species (Gilmore 1991), but there is no evidence to suggest that European larch is an invasive species.

Growth and Yield

Site Index

The use of site index curves in conjunction with yield tables was the method of site evaluation recommended for North America by the Society of American Foresters in 1923 (Monserud 1984). Site index, determined by the height of a free-growing dominant or codominant tree at a base age, is now the most widely accepted method for estimating site quality in the United States (Carmean 1975). Two assumptions made in

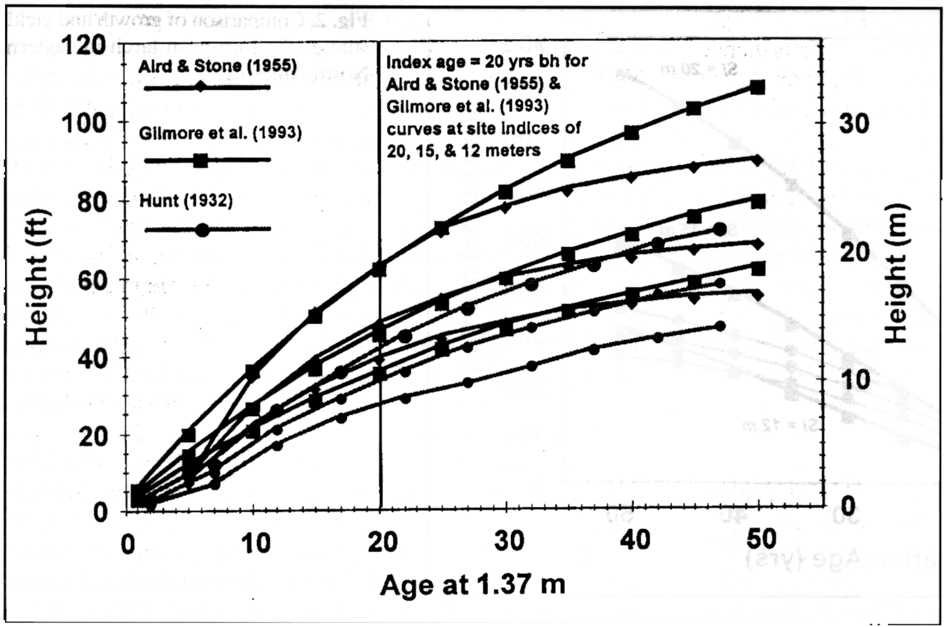

Fig. 1. Comparison of height growth patterns of European larch from separate site index studies in eastern North America.

the construction of site index curves are 1) height is an indicator of site potential and is not influenced by non-site factors such as stand density and competition control, and 2) site index is constant over time (Monserud 1984). The first assumption generally holds true although the impact of early competition control on subsequent height growth is a topic of debate (Coffman 1989). There is an accumulating body of evidence suggesting that height growth trajectories are affected by early competition control. The second assumption holds true provided there is no site degradation or site enhancement (Trettin and Jones 1989).

Intensive early competition control was not prevalent in North American forestry until the post-World War II time period. The effect of competition control on the height growth of European larch in North America can be inferred through the comparison of published height growth information. Hunt (1932) published height growth tables using data collected in 1930 from 1256 trees in 119 plots in 47 plantations located in southern New York and New England (Vermont, Connecticut, and Massachusetts). Stand ages ranged from four to 70 years. Three site classes were created (good, medium, and poor) and empirical height growth curves were developed based on average tree heights at a given age for each plot with each site class. Hunt (1932) conducted his study prior to the development of stem analysis techniques. Nonetheless, this work provides valuable information on the height growth of European larch in North America during the late 19th and early 20th century.

Aird and Stone (1955) developed site index curves using their data and that combined with others that were later formulated to an equation by Carmean *et al.* (1989) for plantations in the same region studied by Hunt (1932). Gilmore *et al.* (1993) used stem analysis on 53 trees from 17 plots in six European larch plantations in Maine to develop site index curves applicable to northern New England. All three of these studies used different approaches for analyzing their respective data. We compared height growth among studies by converting total age to breast height age (measured at 1.37 m above ground line) as suggested by Carmean *et al.* (1989) (Fig. 1).

If we assume that foresters implemented improvements in early competition control over time, then improvements in productivity as measured by height growth are suggested (Fig. 1). Alternatively, climate change may have impacted observed height growth patterns. A precise assessment of the effects of herbaceous competition on forest site potential cannot be undertaken without detailed, long-term plantation or stand records. Two long-term studies have utilized such records to assess the impact of herbaceous vegetation on forest site potential for red pine (Wilde *et al.* 1968, Coffman 1989). These studies with red pine did not account for genetic influences on site potential but this was probably unnecessary due to the genetic uniformity of this species (Rudolf 1990). A nearly three-fold increase in volume production was observed after 31 years as the result of intensive site preparation to control herbaceous competition prior to plantation establishment (Wilde *et al.* 1968). Coffman (1989) reported negative correlations between site index and the number of years required to reach breast height. In addition, Coffman (1989) presented data that showed early growth suppression (from sod competition) the first few years after planting may have reduced the rate of subsequent height growth. Increased rates of height and volume growth following release from competition are well documented (see review by Newton *et al.* 1987). The effect of early suppression, however, from either herbaceous or woody competition, on the height and volume growth of conifers after release has not been extensively studied.

Plantation Yields

In his early work, Hunt (1932) constructed a yield table for European larch using a subset of the plots in 13 of the stands used to generate his height growth curves. Again, he quantified site qualitatively (Site I, II, & III) but nonetheless we are able to compare his work with that of Gilmore and Briggs (1996) who developed yield prediction equations for European larch in Maine (Fig. 2). Interestingly, the yield table constructed by Hunt (1932) encompasses a narrow band of productivity. The yield curves generated by Gilmore and Briggs (1996) are

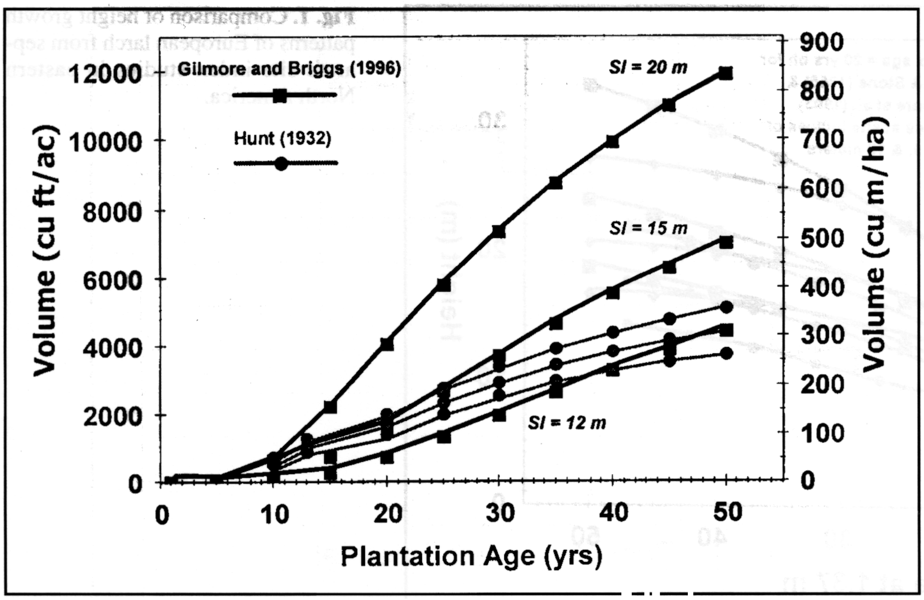

Fig. 2. Comparison of growth and yield studies for European larch in eastern North America.

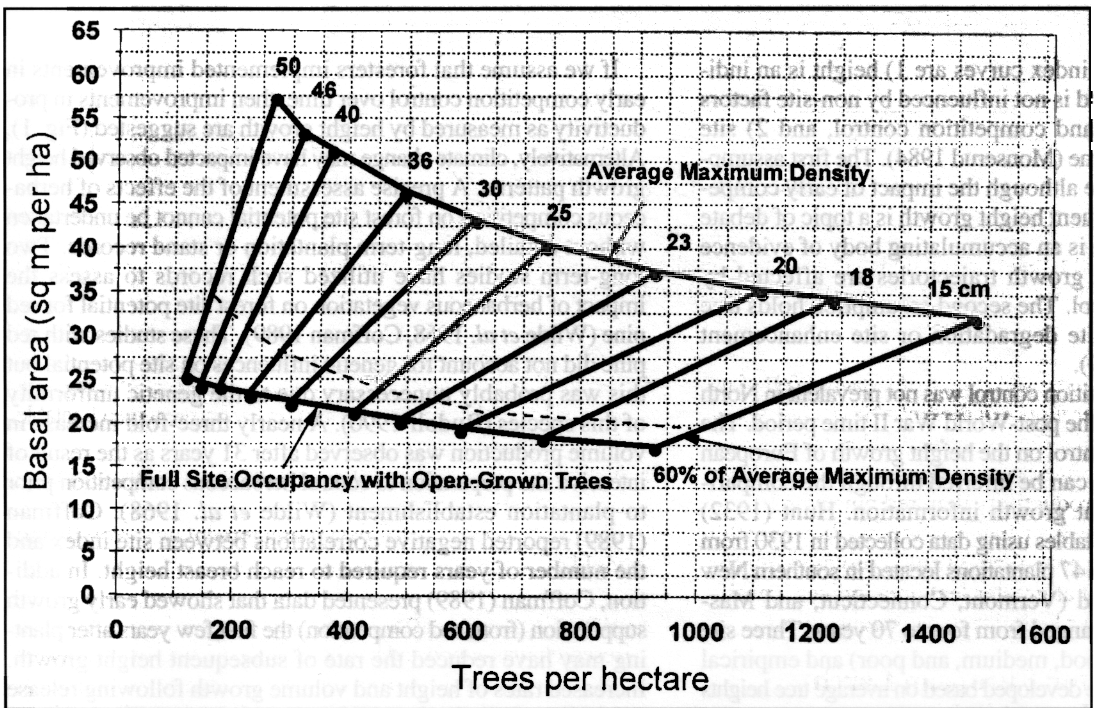

Fig. 3. Stocking chart for European larch in eastern North America. Adapted from Gilmore and Briggs (2003).

within the range of yields encountered in Maine. This suggests support for our hypothesis that early competition control enhances productivity.

Density Management

Stocking charts are based on the assumption that site quality affects the rate of growth but not the relationship between basal area and stems ha-1. Their use as a management tool is limited because they lack a temporal dimension and they cannot be readily incorporated into harvest scheduling models. Nonetheless, they provide useful guidance to foresters in determining planting densities and prescribing thinning treatments. The stocking chart developed for European larch in eastern North America (Fig. 3) supports earlier recommendations for low initial spacing densities of approximately 990 stems ha-1 (Carter and Selin 1987) in order to lower planting costs, reduce rotation lengths, and reduce thinning costs.

Soil-site Studies

There are three soil-site studies reported for European larch in North America. Aird and Stone (1955) reported a simple linear relationship between free rooting depth and site index, and soil drainage class and site index for European and Japanese larch in southern New York. Gilmore *et al.* (1994) confirmed these results with a subsequent soil-site study in Maine. They advance earlier work by developing a discriminant function to predict good and poor quality sites, based on site index, from solum thickness, percent clay content, and the amount of

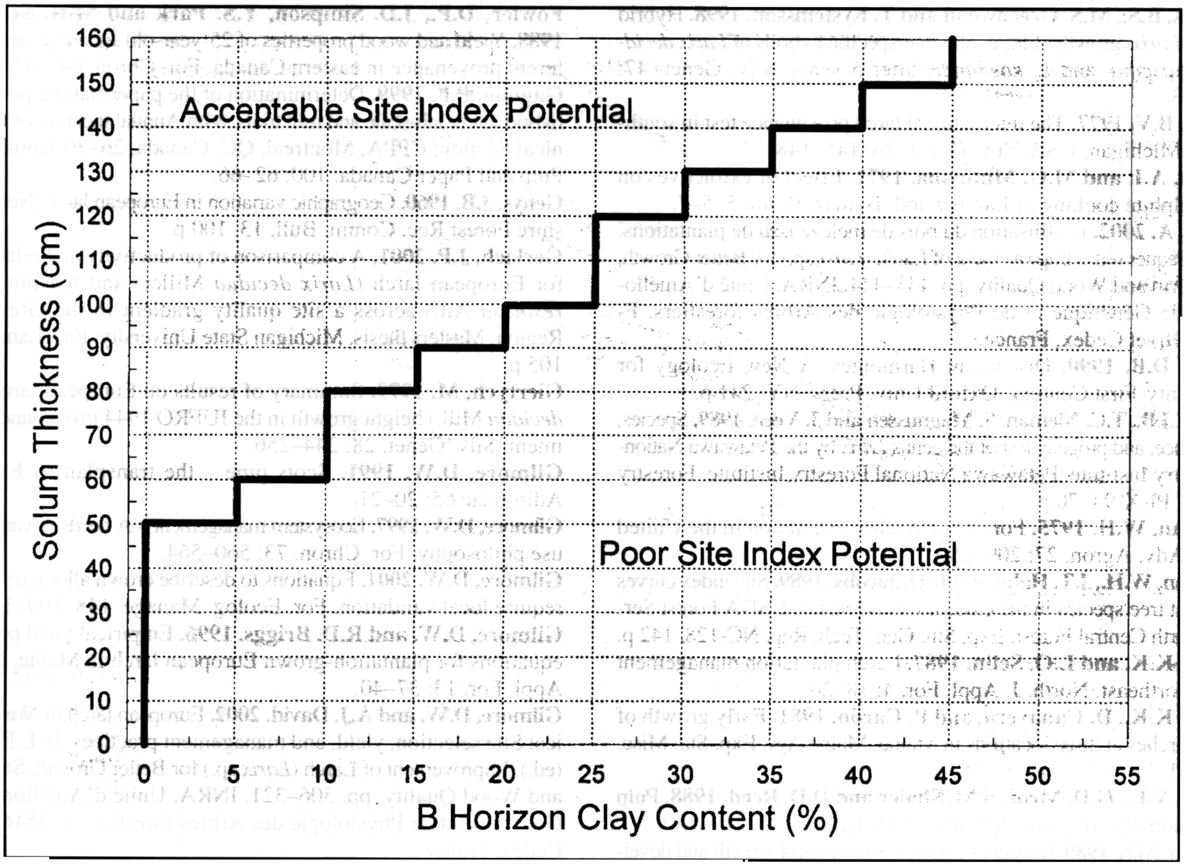

Fig. 4. Effects of solum thickness and B soil horizon clay content on the classification of site index potential for European larch with B soil horizon exchangeable K held constant at 0.09 cmol(+) kg^{-1}. Adapted from Gilmore *et al.* (1994).

exchangeable potassium in the soil (Fig. 4). Gerlach (2001) further advanced these earlier works in the Lake States in a study comparing the productivity of European larch and red pine across a site quality gradient. His major finding was that European larch plantations had greater productivity than red pine plantations given constant site conditions. More importantly, however, he found that above-ground annual net primary productivity for European larch increased at greater leaf area indices, specific leaf areas, and at greater leaf nitrogen concentrations.

Recommendations for European Larch Plantation Establishment in North America

The establishment of exotic plantations is often controversial. However, in order to balance the ecological, economic, and social demands of society (Wagner 1994, Gilmore 1997) fast-growing exotic plantation have the potential of both reducing fibre costs and the forest land base required for timber production (Seymour and Hunter 1992). Based on our experience, we suggest five general recommendations for establishing European larch plantations in North America.

1. Match the race and seed source to the planting site, paying particular attention to factors as soil drainage, climate, and potential pests. In general, Sudeten and Polen seed sources perform best in North America in terms of frost and pest resistance.
2. Control competing vegetation during plantation establishment and subsequent stand development.
3. Depending on the desired final product, wider spacings are needed for larch than for other conifers to ensure a merchantable first thinning.
4. Maintain genetic diversity by planting mixtures of different seed sources or families.
5. Monitor plantations for pest management and growth and yield.

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