TECHNICAL NOTE

Artificial regeneration of hardwoods

Plantation planning and site preparation

Institut de resecherche sur les feuillus nordiques
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INTRODUCTION

Unlike softwoods, hardwoods have specific growth requirements, making site suitability a critical factor. Key site conditions include soil depth, texture, structure, acidity, slope, and drainage, along with climatic factors like precipitation, temperature, and wind (Gauthier et al., 2014). Other considerations include topography, accessibility, and the presence of wildlife such as deer and moose (Agence forestière de la Montérégie, 2007a). Establishing hardwood plantations is highly demanding, as most species require deep, fertile, moist, and well-drained soils (Von Althen, 1972).

Hardwoods will not produce high-quality timber on dry, exposed slopes, shallow topsoil, or compacted clay subsoils (Von Althen, 1964). Proper silviculture practices are crucial, particularly for species like sugar maple, where plantation establishment and survivability are challenging. While previously hardwood-covered sites are ideal for plantations, replicating high-quality stands on types such as old fields, or clearcuts with extreme bouts of raspberry or cherry regeneration pose significant challenges regardless of what was on the site in the past. This suggests there is no ideal condition where planting would replace sustainable hardwood management.

Current research is exploring high-quality hardwood potential across the province, identifying areas where soil and climatic conditions could support future hardwood growth. This work is essential for plantation planning, underplanting, and climate adaptation strategies, particularly as softwood habitats become less suitable under changing environmental conditions.

HIGHLIGHTS

SITE ASSESSMENT

Select sandy loams or loams for optimal water retention. Refer to soil maps, surveys, and consult a soil specialist or agronomist for site-specific guidance. Ensure sufficient soil depth to reduce drought risk. Avoid poorly drained areas and sites with excess water.

SOIL PREPARATION

Adjust soil nutrients on a small scale with fertilizers and lime as needed; but fertilization isn't recommended during the first growing season unless soil tests show nutrient deficiencies. Sugar maple growth may not always respond to fertilization, and liming at an industrial scale is complicated and costly.

SITE PREPARATION

Plowing and discing are the best method for comprehensive site preparation. Destroys weeds, loosens soil, stimulates microbial activity, and improves soil aeration, providing optimal conditions for seedling establishment. High initial costs are offset by long-term benefits, including improved seedling growth. Although, this should be combined with other methods.

SPRING PLANTING

Sugar maple struggles with root establishment due to early leaf emergence and limited root growth. Sugar maple roots begin growing as early as mid-February, but limited root growth can affect the establishment of foliage. Use of growth inhibitors like abscisic acid can help delay shoot emergence and allow root establishment. Early spring planting is recommended in preparation for optimal root development.

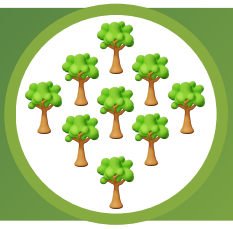
HIGHLIGHTS

FALL PLANTING

Challenges of fall planting include low physiological potential for root regeneration, frost heaving, and heavy browsing. Higher risk of seedling mortality compared to spring planting.

OPTIMAL PLANTING DENSITY

A planting density of over 1600 trees/ha is ideal for hardwoods to minimize large branch growth, with a minimum of 1200 trees/ha to ensure optimal straight-bole development.



THINNING STRATEGY

Aim to cultivate a moderate number of high-quality sawlog/veneer trees per hectare. Use a structured thinning approach to remove undesirable trees and retain the best-forming crop trees for long-term growth.

PLANTATION SPACING & STOCKING

Proper spacing promotes growth and timber quality. Sugar maples are sensitive to competition, requiring careful spacing to avoid stagnation. Wider spacing improves diameter growth but can lead to poor form, while narrower spacing is better for high-quality timber. We recommend following the 4ft by 4ft spacing of traditional maple sugary plantations for sugar maple, as it has been proven to work.

FACTORS INFLUENCING SITE SUITABILITY

Sugar maple will frequently serve as an example throughout this technical note and other hardwood artificial regeneration materials. Its prominence stems from its economic and social significance, making its sustained health a critical concern in both managed and unmanaged forests. Additionally, sugar maple is particularly challenging to cultivate artificially, which drives a strong demand for research in this area.

A natural, mature sugar maple stand has a dense canopy high above the seedlings, letting in very little light, most of which is diffuse. It's important to keep in mind the typical adaptability traits seen in sugar maple may only appear under this layered canopy, rather than in younger, plantation-style stands (Paquette et al., 2007).

Sugar maple naturally grows along creeks and streams, on lower slopes and depressions, abandoned orchards and gardens, and on agricultural fields where A & B soil horizons are at least 45 cm deep. For optimum growth, a minimum depth to water table of 3.5 feet has been recommended, with a pH range of 5.7 – 7.3 (von Althen, 1964).

It is important to understand the factors contributing to sugar maple growth and health. Soil moisture deficiency or excess, nutrient deficiencies of magnesium, calcium, and potassium, highway de-icing salts, and extreme weather events including late spring frosts, midwinter thaw-freeze cycles, glaze damage, and atmospheric deposition are some of the abiotic agents. For more in-depth information, refer to Soil Factors that Influence High Quality Sugar Maple Potential.

Sugar maple has different energy allocation strategies than other hardwood species (especially different from softwoods) and it has consistently shown slower root growth, poorer root establishment, and higher mortality rates in plantations (von Althen and Webb, 1978, Webb, 1977).

Some of this is explained in our ARM guidebook volume 1: Seed collection and nursery practices, and more will be discussed in the planting section below.

Table 1 - A list of commonly planted species in order of typical climate range from cold-adapted to warm-adapted.

Species	Soil drainage class	Soil type	Depth required	Growth	Typical climate range
White Birch	Good to moderate	Sandy to loamy	30 cm	Fast	Cool to temperate
Sugar Maple	Good to moderate	Sandy to loamy	40 cm	Slow	Cool to temperate
Black Ash	Moderate to poor	Loamy to clayey	30 cm	Medium	Cool to temperate
Northern Red Oak	Fast to moderate	Sandy to loamy	30 cm	Moderately fast (avoid calcareous soils)	Temperate
Swamp White Oak	Moderate to poor	Loamy to clayey	50 cm	Moderately fast	Temperate
Silver Maple	Moderate to poor	Loamy to clayey	30 cm	Fast	Temperate
Shagbark Hickory	Good to moderate	Loamy	50 cm	Slow	Temperate
Black Cherry	Good to moderate	Sandy to loamy	30 cm	Fast	Temperate to warm temperate
Bur Oak	Good to imperfect	Loamy	50 cm	Moderately fast in early stages	Temperate to warm temperate
White Oak	Good to moderate	Loamy	50 cm	Slow	Temperate to warm temperate
Bitternut Hickory	Good to imperfect	Loamy to clayey	50 cm	Moderately slow	Temperate to warm temperate
Black Walnut	Good to moderate	Loamy	80 cm	Fast	Temperate to warm temperate

SITE ASSESSMENT AND SOIL PREPARATION

PLANTING ASSESSMENT	FACTOR	INSTRUCTIONS
	Soil Texture and Structure	Select sandy loams or loams for optimal water retention. Sandy or gravel soils increase drought risk, while clay-heavy soils may compact, impeding drainage and seedling establishment. Refer to soil maps, surveys, and consult a soil specialist or agronomist for site-specific guidance.
	Site Moisture	Ensure sufficient soil depth to reduce drought risk, especially for young seedlings with shallow roots. Avoid poorly drained areas and sites with excess water, which can restrict oxygen flow, hinder nutrient uptake, and increase disease risk.
	Slope	Avoid steep slopes, which lead to soil erosion and can deplete the fertile soil needed for hardwood growth. South- and west-facing slopes: less favorable for species adapted to shade and moisture East- and north-facing slopes: favor more shade-tolerant and moisture-demanding species (Barkley, 2007).
	Vegetation Survey	Conduct a vegetation survey before planting. Some species, like goldenrod and aster, interfere allelopathically with sugar maple, reducing dry weight, altering nutrient contents, and decreasing nitrogen and phosphorus availability (Von Althen, 1972).
	Soil Chemistry	Adjust soil nutrients on a small scale with fertilizers and lime as needed. Fertilization isn't recommended during the first growing season unless soil tests show nutrient deficiencies. Sugar maple growth may not always respond to fertilization (Von Althen, 1972).

SITE CONDITIONS FOR SUGAR MAPLE

Table 2 -Optimal Site Conditions for Establishing a Sugar Maple Plantation (adapted from Gautier et al. 2014)

Texture Category	Soil Textures	Excessive Drainage (0)	Rapid Drainage (1)	Good Drainage (2)	Moderate Drainage (3)	Imperfect Drainage (4)	Poor Drainage (5)
Fine Textures	Sandy clay	n.d.	Poor	Moderate	Poor	Poor	Poor
Medium Textures	Silty clay loam	Poor	Moderate	Moderate	Moderate	Moderate	Poor
	Clay loam	Poor	Moderate	Good	Moderate	Moderate	Poor
	Sandy clay loam	Poor	Moderate	Good	Moderate	Moderate	Poor
	Silt	Poor	Moderate	Excellent	Good	Moderate	Poor
	Silty loam	Poor	Moderate	Excellent	Good	Moderate	Poor
	Loam	Poor	Moderate	Excellent	Good	Moderate	Poor
Coarse Textures	Sandy loam	Poor	Moderate	Excellent	Good	Moderate	Poor
	Silty sand	Poor	Moderate	Good	Moderate	Poor	Poor
	Sand	Poor	Poor	Poor	Poor	Poor	Poor

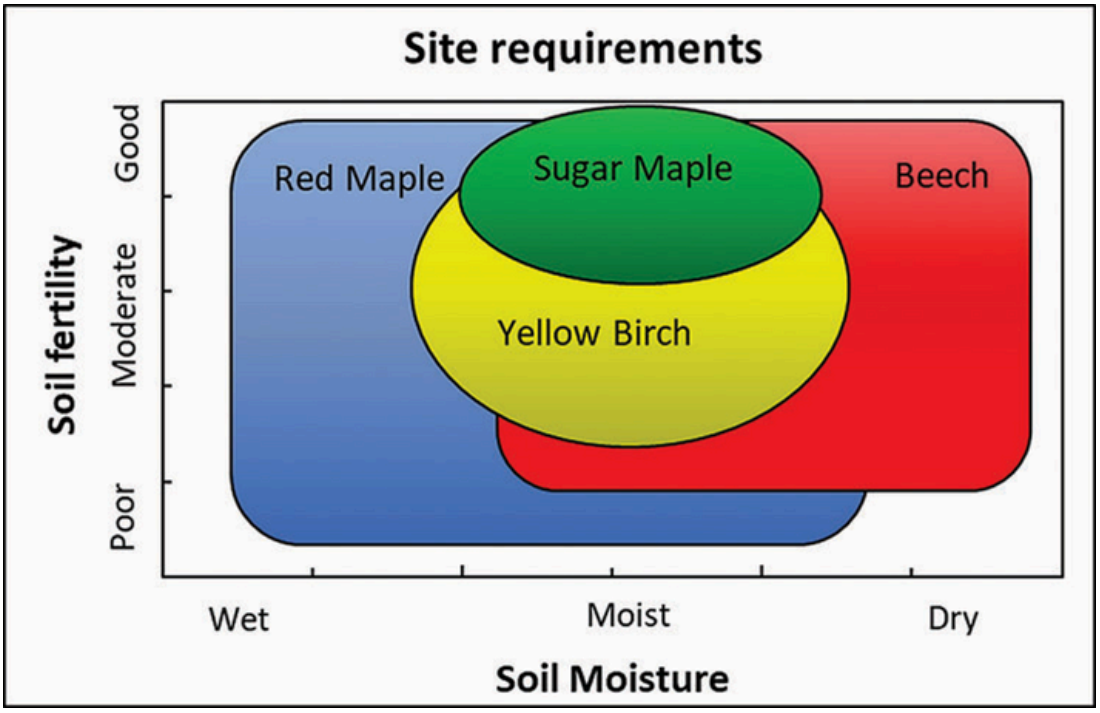


Figure 1 - A graphical representation of site requirements of other commercial hardwoods.

SITE PREPARATION

The second most important factor in plantation establishment next to site selection is site preparation. This is the creation of favourable growing conditions for tree seedlings.

- Proper site preparation enhances seedling survival and growth by improving soil conditions and minimizing competition.
- Benefits include increased nutrient availability, better aeration, and improved water infiltration, among others.
- Risks of improper preparation: soil erosion, water quality degradation, and negative impacts on biodiversity and wildlife (Edge, 2004; von Althen, 1981).

Figure 2 - Pin cherry and raspberry competition already present at planting site will make it extremely challenging to establish a hardwood plantation, regardless of extreme measures.

Herbaceous plants negatively affect hardwood seedlings by:

- Competing for light, moisture, and nutrients.
- Smothering seedlings with accumulated dead plant material.
- Providing habitat for pests like rodents and rabbits.
- Some weeds having toxic or allelopathic effects (von Althen, 1964).

Figure 3 – An oak seedling surrounded by grass and herbaceous competition in an open field setting, with maintenance very high and survivability extremely low.

FACTORS INFLUENCING SITE PREPARATION CHOICE

The choice of site preparation method depends on:

- Soil type and texture.
- Topography and vegetation density.
- Accessibility and operational capacity.
- Cost considerations.
- Direct seeding versus planting seedlings (direct seeding methods will be presented in another technical note).

Although some methods have high upfront costs, their long-term benefits in seedling establishment and growth may outweigh these initial expenses.

TYPES OF SITE PREPARATION METHODS

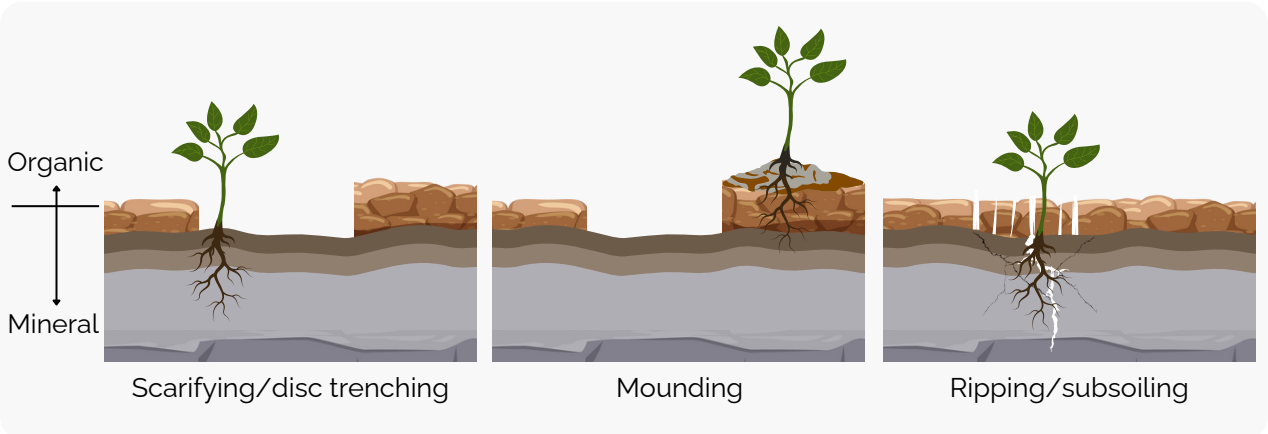


Figure 4 – Schematic description of three types of mechanical site preparation and their main effect on soil structure (modified from Lof et al 2012)

Our partners at AV Group, planting maple on License 1 site almost two years after mechanical scarification.

Some of this is explained in our ARM guidebook volume 1: Seed collection and nursery practices, and more will be discussed in the planting section below.

COMMON SITE PREPARATION PRACTICES WITH USAGES AND EXAMPLES

PLOWING AND DISCING

Considered the best method for comprehensive site preparation. Destroys weeds, loosens soil, stimulates microbial activity, and improves soil aeration. Enhances nutrient cycling and provides optimal conditions for seedling establishment. High initial costs are offset by long-term benefits, including improved seedling growth (Van Althen, 1972).

Figure 5, top left - AV Group site scarification.

Figure 6, bottom left - Image of a disc trenchers https://www.brackeforest.com/products/disc-trenchers

MOWING OR CLIPPING

Commonly used for removing vegetation around hardwoods but less effective over time, as mown plants regrow quickly. Useful for gaining initial access and providing short-term weed control.

Figure 7, right- UNB graduate student James Broom tending a hardwood plantation at Kingsclear provincial nursery by clipping

SUBSOILING OR RIPPING

Loosens dense subsoils to improve root penetration and reduce compaction. Exposes less mineral soil compared to other methods, which helps avoid establishment of unwanted pioneer species. Trenches may take a full growing season to close, which can expose seedling roots and reduce survival if not properly closed (Raper, 2005).

Figure 8 - Subsoiling (ripping) operation (continuous MSP) on a former agricultural field in the Lower Mississippi Alluvial Valley, southern USA. The rig is spraying a band of herbicide over the ripped row. (Ray Soute, retrieved from Löf et al 2012).

BEDDING (MOUNDING)

Used for poorly drained or clay-rich soils by raising the root zone above the water table and poor soil conditions. Enhances seedling survival in wet areas.

Figure 9 - Mounding on a wet clay soil in eastern USA (Justin Schmal, retrieved from Löf et al 2012).

CHEMICAL WEED CONTROL

Herbicides offer a more economical control, but many hardwood species are highly susceptible to damage by the dosages necessary for effective control. The chemical weed control information in this guide is only meant to be informative. No specific brands or doses of herbicide are specifically condoned by NHRI or our collaborators. All chemical weed control must follow provincial and local legislation. We have included some guidance for New Brunswickers in this guide for your information, but official legislation and guidelines for inside and outside New Brunswick should be consulted before applying any herbicide. Each province has their own jurisdiction when it comes to the application of herbicides, and we use New Brunswick as an example. The Department of Environment and Local Government (DELG) enforces several pesticide regulations in New Brunswick, which includes glyphosate herbicides. These measures add increased safety for human health, the environment, and wildlife living near any provincial treatment sites. Refer to Appendix, Table A2 Case Study: A New Brunswick Example of Herbicide Regulations as of 2023.

PLANTATION ESTABLISHMENT

Options for establishing a plantation: starting your own nursery, purchasing seedlings, purchasing seeds, or contracting nurseries (Landis, 1995). If you opt to collect your own seeds and grow maple, please see Artificial Regeneration of Maple volume 1 from our resource toolbox. Please contact us for information on growing other species.

Option	Benefits	Drawbacks
Purchasing Seedlings	Saves time and money; avoids nursery management responsibilities	Limited control over thegrowing process
	Reduces risks and hassles of growing seedlings	Seedlings may not be fully adapted to the planting environment
Purchasing Seeds	Cost-effective and allows for greater control over genetic selection	Requires additional time, expertise, and resources to grow seedlings
	Easier to store and transport	Higher risk of germination failure or poor seedling development
Contracting Nurseries	Ensures professional expertise and high-quality seedlings	Can be more expensive than managing your own nursery
	Offers flexibility and reduces the need for in-house nursery management	Limited control over the growing process and timing

Spring planting: the reality is that conditions needed for operations delay spring planting and miss the optimal root establishment window for sugar maple.

PLANTING

Planting timing varies by species and season, with no universal solution. For spring-planted sugar maple seedlings, success depends on allowing enough time for root establishment before the rapid growth phase. Sugar maple has relatively slow root development compared to other species (Kramer and Kozlowski, 1960). This is due to its longer chilling requirements and lower root regeneration capacity (Webb, 1977). Sugar maple's roots need time to develop, but the species often flushes quickly after a few warm days in April or May. Root growth can restart as early as mid-February or March, depending on temperature and light. However, the reality is that operations delay spring planting until roads are clear, and snow has melted, leading to late spring planting that misses the optimal root establishment window. This delay affects foliage development, as new growth relies on stored carbohydrates, which may already be depleted by late planting (Dumbroff and Webb, 1978).

Poor root growth in sugar maple is also linked to the "check" condition—growth stagnation—frequently observed when seedlings face significant herbaceous competition (Webb, 1976). To optimize spring planting, consider applying growth inhibitors like abscisic acid to delay bud emergence, allowing roots more time to establish. Alternatively, invest in tools and preparation for early spring planting to take advantage of thawed soils.

Fall planting presents its own challenges for all hardwood species, including low root regeneration potential at that time of year (Larson, 1970), as well as increased risks of frost heaving and heavy browsing. Both factors make fall planting less favorable for sugar maple, and other hardwoods.

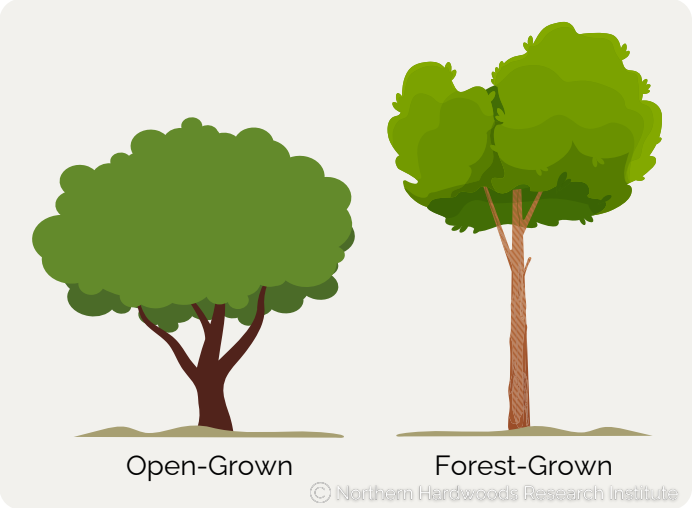
Key points to remember during planting:

- Bare-root seedlings should be planted so that all roots are buried, well-spread, and not coiled.
- Bare-root seedlings should be buried up to the root collar.
- For container-grown seedlings, the root system should be level with the soil.
- Seedlings must be planted as vertically as possible.
- The soil should be compact enough so that the seedling does not move when pulled.
- Ideally holes are filled with silicone and packed with extra soil to provide moisture retention and prevent frost pockets

Figure 10 – A planted Bur oak seedling that has been browsed and is now frost-covered.

PLANTATION SPACING AND STOCKING CONSIDERATIONS

Proper spacing in hardwood plantations is critical for promoting growth and ensuring high-quality timber production. But spacing can be achieved one of two ways: Initial spacing or proper thinning schedules. Both overly dense or too sparse planting can negatively impact height growth, with sugar maple being particularly sensitive to competition, leading to growth stagnation or "check." The optimal spacing depends on the desired end product, thinning frequency, and expected seedling survival.



Wider spacing encourages faster diameter growth but may result in undesirable tree forms, such as excessive taper or knotty wood. While wider spacing may suit pulpwood production, narrower spacing is preferred for high-quality timber.

The tradeoff of a larger diameter and crown versus increased branching, and its relationship with sawlog yield is now well-known (Prediction Tool for Product Basket by Using Tree Form and Risks - Northern Hardwoods Research Institute, Stand Competition-Tree Characteristics & Wood Quality-SM - Northern Hardwoods Research Institute).

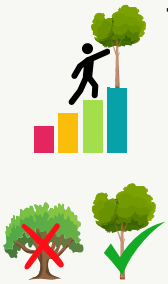
But the implementation of thinning schedules versus the negative impacts of growing maples more openly should be very well thought out. Maple syrup producers and researchers in New Brunswick have found that a wider initial spacing is a better investment. There are those who preferred an initial target spacing of 4 meters by 4 meters resulting in a stocking density of 625 stems/ha without any plans for thinning until the commercial stage.

Stocking can be calculated using the formula:

$$\text{Stocking (stems/ha)} = \left(\frac{100}{\text{Spacing between rows (m)}}\right) \text{ x } \left(\frac{100}{\text{Spacing between rows (m)}}\right)$$

DENSITY AND THINNING GUIDE

Optimal Planting Density: A high planting density (>1600 trees/ha) is recommended for hardwoods to minimize large branch growth, with an absolute minimum of 1200 trees/ha to ensure optimal straight-bole development.



Thinning Strategy:

- Start with a goal of developing a reasonable number of high-quality sawlog/veneer trees per hectare.
- Use a structured thinning approach to remove less-desirable trees and maintain the best-forming crop trees.

SPACING AND DENSITY EXAMPLES:

Table 3 - Example of a recommended spacing and thinning trial from McKenna and Farlee 2013.

		Example approximate number of trees remaining per hectare			
Example spacing (ft)	Initial number planted per ha	1st thinning (8 – 12 years)	2nd thinning (15 – 25 years)	1st harvest and thinning (35 – 45 years)	2nd harvest (50-75 years
8 x 6	2250	1240	400	148	50
10 x 6	1800	1100	400	148	50
12 x 6	1500	980	400	148	50
Percent reduction		-35	-60	-60	-30
Number of trees harvested				120- 150	75 - 100

PLANTATION LAYOUT PATTERNS

The layout of a plantation plays a significant role in its management, productivity, and aesthetic appeal. Three primary patterns are commonly used: square, row, and quincunx. Each has specific advantages and applications depending on the species being planted, the site conditions, and the intended purpose of the plantation. For aesthetic considerations, orienting rows parallel to roads can create a more natural look. Alternatively, planting a border parallel to the road while keeping the main plantation perpendicular can combine practicality and visual appeal. Windbreaks using trees with larger branches can also enhance plantation durability.

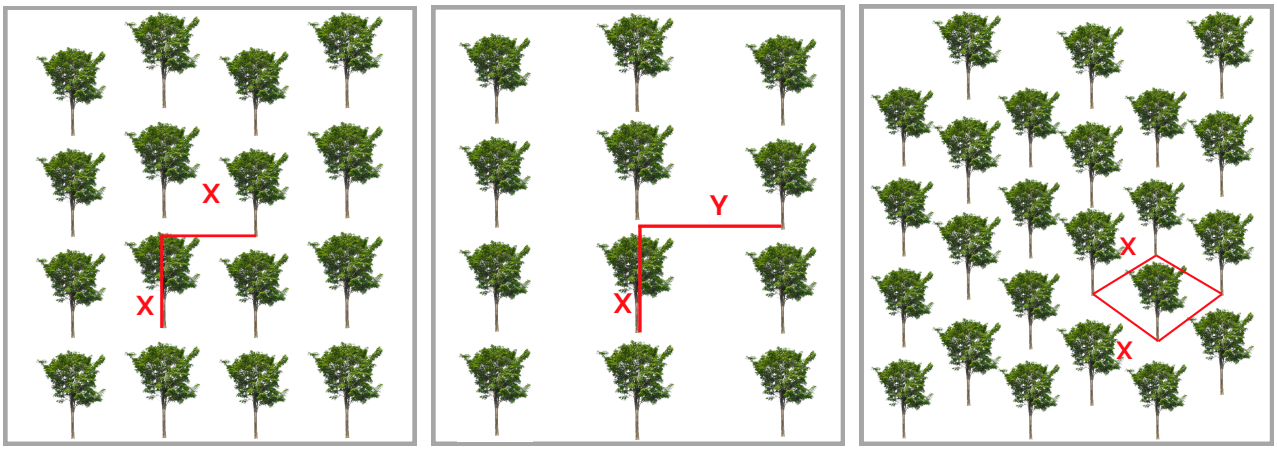
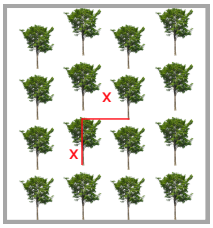
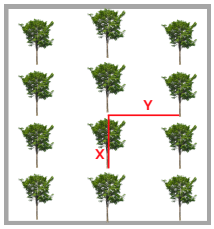
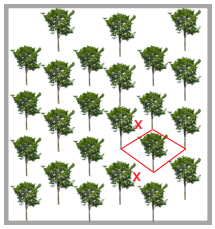
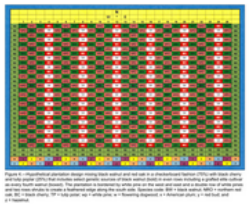
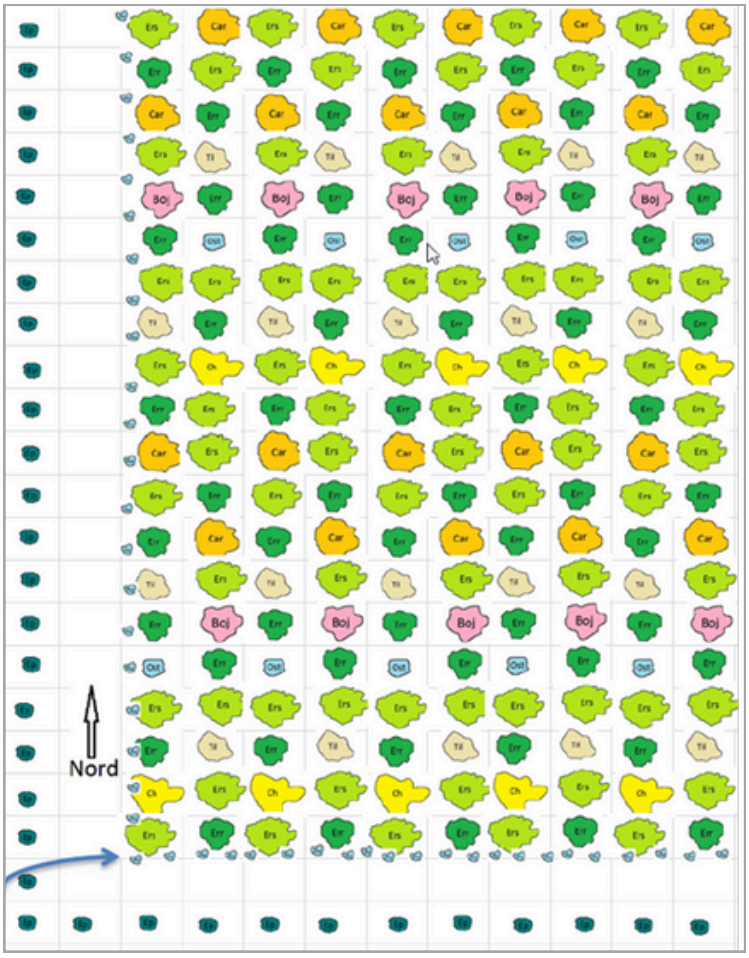


Figure 11: Plantation layout: Square, Row, Quincunx (modified from Gauthier et al 2014)

Pattern	Usage and photo	Advantages
Square Pattern	Commonly used for softwoods 	Facilitates machine access for future operations
		Allows for the installation of plastic mulch
Row Planting	Suitable for most tree species 	Provides space for machinery access for maintenance (e.g., mowing, herbicide application)
		Enhances operational efficiency
Quincunx Pattern	Ideal for hardwoods 	Promotes better canopy cover
		Optimizes wood production per hectare
		Provides wind protection, particularly in exposed areas
Aesthetic Layout	Plantation borders or specific row orientation 	Rows parallel to roads enhance visual appeal
		Borders with trees producing larger branches serve as windbreaks and improve aesthetics

LAYOUT RECOMMENDATION

The layout recommendation provided by NHRI is based on a maple syrup production out of Quebec. Although maple sugaries are classified as agriculture and not forestry, there is much to be learned from plantations of sugar maple as well as other farming operations such as Christmas tree plantations.



Example 1: Quebec high diversity maple plantation
Spacing: 4m x 4m (13 ft x 13 ft)
Crown projection on the ground: 16 m² or 169 ft²
Initial planting density: 625 stems/ha
Initial planting density (maples): 406 stems/ha

The diagram shows alternating species in a systematic grid layout, optimized for biodiversity and structural goals.

LEGEND
Light Green (Ers): Sugar maple
Dark Green (Err): Red maple
Orange (Car): Hickory
Pink (Boj): Yellow birch
Teal (Ep): Alders and Spruces at the edges form a windbreak.
Blue (Ost): Ironwood
Tan (Til): Basswood

Figure 12 - David Lapointe, ingénieur forestier presentation on Maple and its Environment: What Science Teaches Us Ministère de l'Agriculture, des Pêcheries et de l'Alimentation, Quebec 2019

It is important to consider diversification of species, as suggested in the layout above. It reduces risk of pests and disease, and provides wildlife habitat in the short and long term without impacting harvest schedules. If it is true for maple syrup farms, it is true for lumber production as well.

CONCLUSION

In conclusion, successfully establishing a hardwood plantation requires careful consideration of planting density, spacing, thinning, and maintenance strategies. The planting density of over 1600 trees/ha, coupled with structured thinning, ensures healthy tree growth and high-quality timber production. Proper plantation spacing is vital for avoiding competition and ensuring good tree form, with narrower spacing favored for high-quality hardwoods, but when you consider the effort, cost, and wasted trees this method takes, many would recommend a wider spacing that follows the 4m by 4m spacing of a sugar bush plantation. The layout of the plantation should also be thoughtfully planned to enhance both productivity and aesthetics.

Until more effective direct seeding methods are developed, planting nursery-grown seedlings remains the preferred approach for better controlled establishment. While softwood planting practices have been applied to hardwoods with limited success, the right strategies, including plowing, early spring planting, and appropriate spacing, can make hardwood plantation efforts worthwhile. Further attention to maintenance practices, such as regular rototilling and protection from pests, is essential during the first few years after planting.

The next two technical notes will delve into the option of a direct seeding approach and provide in-depth guidance on tending and predation control methods to help optimize hardwood plantation success.

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APPENDIX

Table A1: Long-term plantation planning checklist

Category	Questions	Check
Initial Planning	• Have stakeholder needs been identified and prioritized?	
	• Are the plantation objectives clearly defined (e.g., climate adaptation, productivity, biodiversity)?	
	• Have site-specific factors been assessed (details in checklist below)?	
Site Assessment	• Does the site have sandy loams or loams for optimal water retention?	
	• Have soil maps, surveys, and consultations with soil specialists been reviewed?	
	• Is there sufficient soil depth to reduce drought risk?	
	• Are poorly drained areas and sites with excess water avoided?	
Soil Preparation	• Have soil nutrients been tested to determine the need for fertilizers or lime?	
	• Are nutrient adjustments planned on a small scale, avoiding fertilization during the first growing season unless more extreme methods are deemed necessary?	
	• If your soil is not idea quality, have limitations and costs of liming on an industrial scale been considered?	
Site Preparation	• Is site preparation adjusted for site conditions (ex. mounding for wet sites)?	
	• Is plowing and discing planned to destroy weeds, loosen soil, and enhance microbial activity?	
	• Are initial costs balanced against the long-term benefits of improved seedling growth?	
	• Will additional methods complement plowing and discing as needed?	
Chemical Site Preparation	• Is there a full understanding of the risks and negative impacts of herbicide use on non-target species, soil health, and ecosystems?	
	• Have alternative methods been considered, and is the chosen approach defensible based on research and site-specific conditions?	
	• Have all instructions been made clear and the legislation for the region been consulted for the region of interest?	
Spring Planting	• Is early planting planned to optimize root development before shoot emergence, especially for sugar maple?	
	• Have growth inhibitors like abscisic acid been considered to delay shoot emergence for root establishment?	

APPENDIX

Table A2: Long-term plantation planning checklist

Category	Questions	Check
Fall Planting	• Are risks of frost heaving, browsing, and low root regeneration considered in fall planting plans?	
	• Is there an alternative plan to mitigate higher seedling mortality during fall planting?	
Optimal Planting Density	• Is the tradeoff between thinning and initial spacing planned and thought out?	
	• Is a minimum density of 625 trees/ha planned?	
Plantation Spacing & Stocking	• Is spacing optimized to balance growth and timber quality?	
	• Are species sensitivity to competition and spacing needs accounted for?	
	• Is spacing calculated using the formula for stocking density (e.g., 4m x 4m = 625 stems/ha)?	
	• Will spacing and stocking influence thinning schedules and sapling selection?	
Plantation Layout Patterns	• Are layout patterns (e.g., square, row, quincunx) optimized for site conditions and plantation goals?	
	• Are aesthetics and diversification of species important?	
	• Are windbreaks included in the design using species with larger branches for durability?	
	• Have deer deterrents been considered in the layout? (ex. cedar planted around the outside as another feeding option)	
Vegetation Survey	• Has a vegetation survey been conducted to identify competing species and their growth characteristics?	
	• Are strategies in place to mitigate interference from species like goldenrod and aster?	
Monitoring and Adaptation	• Is there a monitoring system to track plantation growth and health?	
	• Are feedback mechanisms in place for iterative adjustments based on results?	

APPENDIX B: CASE STUDY: A NEW BRUNSWICK EXAMPLE OF HERBICIDE REGULATIONS AS OF 2023

Category	Roles and Responsibilities
Landowners	• Use GIS technology to minimize off-target drift. • Establish buffer zones around private land and watercourses. • Post signs detailing treatment and timelines at access points.
Provincial Government (DELG)	• Certify and train applicators; issue permits for herbicide use. • Inspect operations and enforce compliance with safety regulations.
Federal Government (PMRA)	• Review scientific research and update forestry chemical regulations and label instructions.
Crown Land Licensees (DNR)	• Submit herbicide schedules based on visual assessments or plot data for naturally regenerated cuts.
General Public Notifications	• Publish treatment notices in major New Brunswick newspapers.

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