Fall Planting in Northern Forests as a Reforestation Option: Rewards, Risks, and Biological Considerations

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Abstract

This paper examines the option for fall planting in northern forests to help foresters make informed silvicultural decisions regarding plant date. A literature review determined that 75 percent of fall-planting trials conducted in northern forests had field survival and/or growth that was comparable with, or higher than, spring- or summer-planted seedlings. Nonetheless, 25 percent of trials did not show fall planting to be effective, thus illustrating risks associated with this planting option. Reasons for an unsuccessful fall-planting program were related to nursery hardening practices and planting into stressful environmental conditions. The annual phenological cycle must be considered for developing hardened seedlings suitable for fall planting. This information allows foresters and nursery managers to determine when and where fall planting is a viable option for northern reforestation programs.

Introduction

Silviculturists have long considered fall planting as an option for reforestation programs (Toumey 1916). Currently, its use in reforestation programs is dictated by regional climatic conditions. In regions where late spring and summer are hot and/or dry, fall planting is a standard operational practice. For example, 60 percent of all containerized seedlings are planted from October through December in the southeastern United States, with the remainder planted during winter (Starkey et al. 2015). Fall planting of oak (*Quercus*) species in Mediterranean ecosystems is also a recommended practice (Sánchez-González et al. 2016). Furthermore, in southern Europe, approximately 66 percent of seedlings are planted during October and November (Ivetić 2021), with a multiple site survey showing comparable survival between fall- and spring-planting programs (Ivetić 2015). With increasing latitude, however, the use of fall planting decreases. In central Europe, fall planting occurs, but it is not a primary reforestation practice (Repáč et al. 2017). In the Pacific Northwest, 10 to 20 percent of seedlings are fall planted in Oregon and Washington (Swain 2021) and in British Columbia (Anonymous 2020). In Finland, 10 to 20 percent of seedlings are fall planted before onset of colder fall conditions (Riikonen 2021). Recent surveys in Nordic countries reported fall planting into October as viable for Norway spruce (*Picea abies* [L.] H. Karst.), but not Scots pine (*Pinus sylvestris* L.) (Luoranen et al. 2018, Pikkarainen et al. 2020). Overall, these observations indicate that fall planting at northern latitudes is an option, though regional climate and species performance determines whether it can be successfully used in reforestation programs.

When deciding whether to fall plant, each reforestation manager needs to clearly understand why they want a fall-planting program. The most common operational reasons for considering fall planting in a northern reforestation program are limited access to sites during the preferred spring-planting window and too many seedlings for the available workforce to properly plant during the spring- and summer-planting windows (Farquharson 2020). The reforestation site environmental conditions that lead silviculturists to consider fall planting are the exposure of spring-plant seedlings to frost or drought, or summer-plant seedlings to drought (Grossnickle 2000). Furthermore, fall planting provides an environmental window that gives seedlings an opportunity to grow roots and become established before onset of winter (Krumlik 1984, Mitchell et al. 1990, Rose 1992, Toumey 1916).

Silvicultural decisions are based on a risk/reward decision process. Foresters need to understand the risks and rewards of fall planting so they can make effective management decisions when deciding whether to incorporate this practice into their reforestation program. This article presents an introduction to the physiological capability of fall-planted seedlings and their response to field site climatic conditions. This information will help foresters to make sound, biologically based decisions on whether to implement this planting practice into northern reforestation programs.

Literature Review

We reviewed articles covering fall planting for multiple species and field conditions at northern forest sites (tables 1 and 2). When examined as a whole, 75 percent of trials found fall-planted seedlings had field survival and/or growth that was comparable with, or higher than, spring- or summer-planted seedlings. In northern latitude forests (table 1), montane forests (table 2), and coastal forests (table 2), 81, 60, and 83 percent, respectively, of trials found fall-planting field performance to be comparable with, or better than, spring, or summer planting. This finding shows that, depending on local environmental conditions and program objectives, fall planting can be considered as an option for northern reforestation programs.

Rewards Related to Fall Planting

One benefit of fall planting at northern reforestation sites is that seedlings are planted in the window between hot, dry summer and cold, late-fall environmental conditions. During this period, milder edaphic conditions typically prevail at the planting site and are conducive to root growth and thus seedling establishment. Root growth reaches its maximum at soil temperatures between 10 and 20 °C, decreases at temperatures below 10 °C, and stops at temperatures below 5 °C (Grossnickle 2000). Soil water near field capacity is optimal for root growth (Grossnickle 2000), but soil water less than 35 percent field capacity decreases root growth (Spittlehouse and Stathers 1990). White spruce (*Picea glauca* [Moench] Voss) seedlings fall planted into soils near field capacity, initiated root growth within 10 days after outplanting and continued growing during a 40-day trial (Day and MacGillivary 1975). Other studies have also shown mild edaphic conditions during late summer and early fall are favorable for root growth of recently planted seedlings before onset of colder edaphic conditions (Folk et al. 1994, Folk et al. 1996, Luoranen et al. 2006, Luoranen 2018). Just after spring snowmelt, soil temperatures in the rooting zone can quickly rise above 5 °C (Spittlehouse and Stathers 1990) allowing root growth to resume.

The combination of fall root growth and subsequent early spring root growth can result in well-established seedlings on the reforestation site (figures 1 and 2). Sufficient root growth is critical for newly planted seedlings to avoid planting stress by coupling them into the site hydrologic cycle (Grossnickle 2005). Due to greater root development, fall-planted seedlings can have lower levels of daytime water stress compared with spring-planted seedlings (figure 3), thus improving their transition into the establishment phase during their first full growing season after outplanting (Grossnickle 2000).

Unlike root growth, subsequent shoot growth has no consistent trend for better performance of spring- or fall-planted seedlings. Many studies show improved shoot growth in spring-planted seedlings (e.g., Miller 1981 a,b; Luoranen and Rikala 2013; Narimatsu et al. 2016), other studies show greater shoot growth in fall-planted seedlings (e.g., Ellington 1984; Barber 1989, 1995; Luoranen 2018), and some studies show equal shoot growth in both spring- and fall-planted seedlings (e.g., Folk et al. 1994, Folk et al. 1996, Luoranen and Rikala 2015, Suwa et al. 2016). Shoot growth of fall-planted seedlings is determined by seedling quality at planting in response to field site conditions (Grossnickle and MacDonald 2018).

Risks Related to Fall Planting

Our literature review found 25 percent of fall-planting trials were not successful in northern forest reforestation programs (tables 1 and 2). By understanding reasons for unsuccessful fall planting, foresters can better manage risks.

In early trials, insufficiently hardened fall-planted seedlings had reduced ability to tolerate stressful field site environmental conditions resulting in lower survival compared with spring-planted seedlings (Cram and Thompson 1981, Miller 1982, Sinclair and Boyd 1973). At that time, nursery cultural practices were not refined enough to adequately harden seedlings for fall planting. In recent decades, improved cultural practices have been developed to properly harden

Table 1. Field performance of seedlings in fall-planting reforestation programs in northern latitude forests globally. Performance was defined by comparing first-year survival (and growth if presented) of fall-planted (FA) seedlings with spring- (SP) or summer- (SU) planted seedlings in the same trial. Where only fall-planted seedlings were identified in the trial, first-year survival greater than 75 percent was classified as good field performance. Stocktypes are defined when both bareroot (BR) and container-grown (CON) were planted in the trial.

Species	Fall program		Comment	Reference
	Good	Poor		
			Northern latitude forests	
Pinus banksiana Lamb.	√		SP and FA survival equal with SU lower survival	Bunting and Mullin 1967
Picea glauca (Moench) Voss & *Picea mariana* (Mill.) B.S.P.	√		SP and FA survival equal	Mullin 1968
Pinus resinosa Sol. ex Aiton & *Pinus strobus* L.		√	SP survival higher than FA due to lack of hardening	
Picea glauca (Moench) Voss		√	SP survival higher than FA due to lack of hardening	Cram and Thompson 1981
Picea pungens Engelm.	√		SP and FA survival equal	
Pinus sylvestris L.	√		SP and FA survival equal	
Picea mariana (Mill.) B.S.P.	√		FA survival equal to, or better than, SP	Alm 1983
Picea glauca (Moench) Voss	√			
Pinus sylvestris L.	√		SP, SU, and FA survival equal	Valtenan et al. 1986
Larix sibirica Ledeb.	√			
Pinus strobus L.	√		SP and FA survival equal	Dierauf 1989
Pinus sylvestris L.	√		SP and FA survival equal	Kinnunen 1989
Picea abies L. Karst.	√			
Picea abies L. Karst.	√		SP and FA had comparable survival; SU had lower survival due to nonhardened seedling frost damage; SU and FA had greater height growth than SP	Luoranen et al. 2006
Picea abies L. Karst.	√		SP, SU, and FA survival equal; multiple trials found >70% survival	Luoranen et al. 2011
Picea abies L. Karst.	√	√	SP and FA survival equal for BR; SP survival higher than FA for CON	Repác et al. 2011
Fagus sylvatica L.	√	√		
Pinus sylvestris L.	√		SP and FA survival comparable for both BR and CON	
Larix decidua Mill.	√			
Acer pseudoplatanus L.	√			
Pinus sylvestris L.	√		SP, SU, and FA survival equal; shorter FA height resulted in shorter seedlings at year 5	Luoranen and Rikala 2013
Pinus sylvestris L.	√		SP, SU, and FA survival equal; SP and FA had shorter seedlings at year 3	Luoranen and Rikala 2015
Larix kaempferi (Lamb.) Carr.	√		FA survival higher than SU due to greater drought tolerance and summer drought	Harayama et al. 2016
Larix kaempferi (Lamb.) Carr.	√		SP, SU, and FA survival equal; FA lower root growth due to low soil temperature	Narimatsu et al. 2016
Chamaecyparis obtusa (Siebold & Zucc.) Endl.	√		SP, SU, and FA survival equal; comparable height growth for SP and FA	Suwa et al. 2016
Picea abies L. Karst.	√	√	Early FA (September) comparable to SU (August), but late FA (November) lower due to cold temperatures	Wallertz et al. 2016
Pinus sylvestris L.	√		SP, SU, and FA survival equal; FA lower initial root growth, but better shoot growth at year 2	Luoranen 2018
Picea abies L. Karst.	√			
Pinus sylvestris L.		√	FA seedlings sensitive to harsh winter conditions	Luoranen et al. 2018
Picea abies L. Karst.	√		FA planted in October when suitable sites are selected	
Pinus sylvestris L.		√	FA had lower survival than SP and SU, though all planting dates had low survival (40-55%)	Pikkarainen et al. 2020
Picea abies L. Karst.	√		SP and FA had equal survival and were greater than SU	
Pinus sylvestris L.	√		SP and FA had equal survival for both BR and CON	Repác et al. 2021
Picea abies L. Karst.	√		SP and FA had equal for BR, whereas SP CON had higher survival	

Table 2. Field performance of seedlings planted in fall-planting reforestation programs in western North American montane and coastal forests. Performance was defined by comparing first-year survival (and growth if presented) of fall-planted (FA) seedlings with spring- (SP) or summer- (SU) planted seedlings in the same trial. Where only fall planted-seedlings were identified in the trial, first-year survival greater than 75 percent was classified as good field performance.

Species	Fall program		Comment	Reference
	Good	Poor		
Montane forests				
Abies grandis (Dougl.) Lindl.		√	SP survival higher than FA due to lack of hardening	Sinclair and Boyd 1973
Larix occidentalis Nutt.		√		
Picea engelmannii Parry		√		
Abies grandis (Dougl.) Lindl.		√		
Pseudotsuga menziesii var. *glauca* (Beissn.) Franco		√	SP survival higher than FA due to lack of hardening	
Pinus monticola Dougl.	√		SP and FA survival equal; FA had lower height growth	Miller 1981a
Pseudotsuga menziesii var. *glauca* (Beissn.) Franco	√		SP and FA survival equal; FA had lower height growth	Miller 1981b
Thuja plicata Donn		√	FA poor survival due to poor hardening	Miller 1982
Picea engelmannii Parry	√		SP and FA survival and growth equal	
Abies magnifica A. Murray	√		FA survival and growth higher than SP	Ellington 1985
Larix occidentalis Nutt.	√		FA survival and growth higher than SP	Barber 1989
Pseudotsuga menziesii var. *glauca* (Beissn.) Franco	√		Early FA had high survival and good growth	Adams et al. 1991
Pinus monticola Dougl.	√			
Pinus ponderosa Laws.	√			
Larix occidentalis Nutt.	√		FA survival and growth higher than SP	Barber 1995
Pseudotsuga menziesii var. *glauca* (Beissn.) Franco	√	√	Later FA survival was high due to drought avoidance	Taylor et al. 2009
Larix occidentalis Nutt.	√	√		
Populus tremuloides Michx.	√		SP, SU, and FA survival equal; hardening reducing shoot dieback due to frost	Landhäusser et al. 2012
Coastal forests				
Pseudotsuga menziesii (Mirb.) Franco	√		SP and FA survival equal	Winjum 1963
Abies procera Rehd.	√			
Pseudotsuga menziesii (Mirb.) Franco	√		5-year SP and FA survival was comparable; *T. heterophylla* survival was lower due to drought	Arnott 1975
Tsuga heterophylla (Raf.) Sarg.	√			
Thuja plicata Donn	√		SP and FA had comparable survival; FA had greater initial root growth and end of season diameter growth; SP had greater height	Folk et al. 1994
Chamaecyparis nootkatensis (D. Don) Spach		√	SP higher survival than FA due to fall drought; FA greater initial root growth; SP and FA equal shoot growth	Folk et al. 1996

seedlings for fall-planting programs (see Nursery Cultural Practices section).

A survey of over 100 fall-planted sites in Finland reported approximately 10 percent of poor seedling performance was due to drought and/or frost (Pikkarainen et al. 2020). Stressful environmental conditions (i.e., unfavorable soil moisture and soil temperature conditions, plus frosts) after outplanting are factors that can affect field performance of fall-planted seedlings (Grossnickle 2000, Margolis and Brand 1990).

Fall-planting programs can fail even when hardened seedlings are planted into droughty soils (Folk et al. 1996, Taylor et al. 2009), resulting in water stress and potential mortality, especially if new root growth is inadequate (Grossnickle 2005). Recent fall-plant-

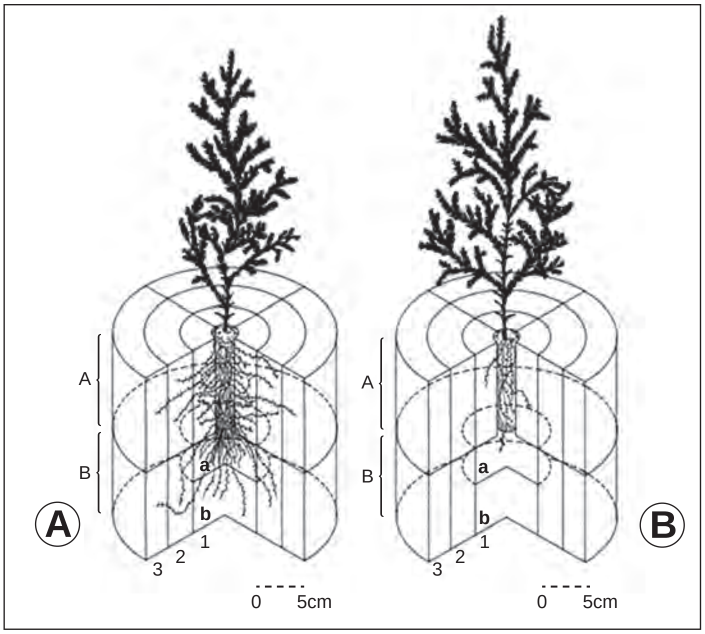


Figure 1. Diagrammatic representation (n= 20) of morphological development in western redcedar (*Thuja plicata* Donn ex D. Don) seedlings that were (a) fall planted (mid-September) or (b) spring planted (mid-April) on an afforestation site. Seedlings from both planting dates were assessed in mid-May. New root growth out of the container plug into the surrounding soil was significantly greater (t-test,α = 0.05) in fall-planted seedlings (400 mg +/- 25) than spring planted seedlings (70 +/- 12 mg). (Adapted from Folk et al. 1994 and Grossnickle unpublished data)

Figure 2. Root development of a western redcedar (*Thuja plicata* Donn ex D. Don) seedling that was fall planted (mid-September) and excavated in early May. (Photo by Dennis Farquharson 2020)

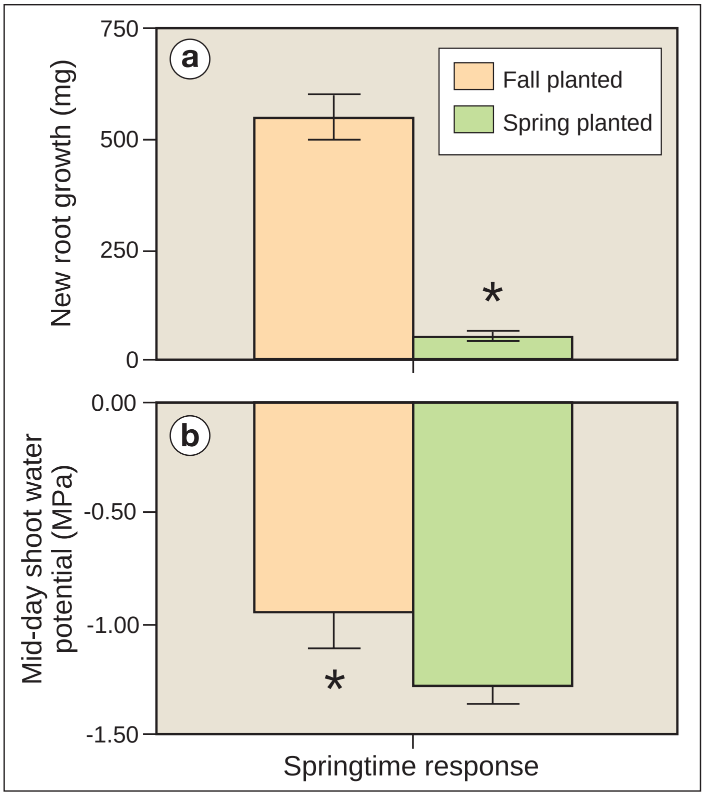


Figure 3. Fall-planted and spring-planted yellow cypress (*Cupressus nootkatensis* D. Don) seedlings differed significantly (t-test, α = 0.05) for (a) end of spring new root dry weight (mean +/- standard error) and (b) mid-day shoot water potential (mean and standard error). Shoot water potential means are based on 6 measurement dates from mid April (just after spring planting) through June. (Adapted from Folk et al. 1996)

ing recommendations suggest planting into loamy soil rather than sandy soil, when there is sufficient soil water for root growth (Luoranen et al. 2018). Sub-optimal soil temperatures (below 10°C) can be a late growing-season stress in cool, temperate conifer forests (Niinemets 2010) because they limit root growth and water uptake (Grossnickle 2000, Luoranen 2018, Wallertz et al. 2016).

Fall-planting programs can fail when seedlings are planted into frosty sites (Landhäusser et al. 2012, Luoranean et al. 2006, Pikkarainen et al. 2020). Properly hardened seedlings can handle minor, but not severe, frost events (Bigras 1996, Sakai and Larcher 1987). After fall-planted seedlings are exposed to cold temperatures at the planting site, they develop freezing tolerance at a sufficient level to handle freezing temperatures of mid- to late fall and winter (Bigras 1996, Grossnickle 2000, Sakai and Larcher 1987).

Frost heaving is a concern after fall planting when the planting date does not allow for adequate root development before winter (Krumlik 1984). Frost heaving occurs on planting sites with fine-textured soils, high soil water content, and no snow cover (Grossnickle 2000). When air temperatures are just below freezing, temperatures in the upper soil layer fluctuate around 0 °C, resulting in ice-lens formation. These ice lenses cause seedlings to frost heave if there is inadequate root growth to anchor seedlings into the surrounding soil (Goulet 1995, Örlander et al. 1990). In a recent survey of 93 fall-planted sites in Finland, however, frost heaving accounted for only 1 percent of reported losses (Luoranen et al. 2018), indicating it was only a minor concern. Frost heaving can be minimized by mulching exposed mineral soil, creating microsites that have an overlying organic layer (Grossnickle 2000, Luoranen et al. 2018), and planting seedlings deeply, if appropriate for the species (Luoranen 2018).

Winter desiccation is a common phenomenon in conifer trees (Sakai and Larcher 1987) and occurs under conditions of frozen, snow-covered soils, bright sun, and dry air. On northern reforestation sites, winter desiccation can occur where snow does not consistently cover recently planted seedlings (Krasowski et al. 1993). Winter desiccation depends on the depth to which the soil is frozen, the amount of shoot system exposed to atmospheric conditions (i.e., freezing air temperature, low humidity, and wind) (Grossnickle 2000), and the extent of new root growth. Fall-planted Scots pine seedlings can be at risk of winter desiccation because they are typically planted in coarse-textured soils resulting in poorly rooted seedlings (Luoranen et al. 2018). In contrast, seedlings planted in fine-textured soils with readily available soil water had minimal winter desiccation (Luoranen and Rikala 2013; Luoranen 2018). Field site conditions that cause winter desiccation damage in fall-planted seedlings can also occur for spring- and summer-planted seedlings (Grossnickle 2000, Krasowski et al. 1993).

Nursery Cultural Practices to Support A Successful Fall-Planting Program

In nature, northern tree species undergo an annual cycle of morphological and physiological changes that have

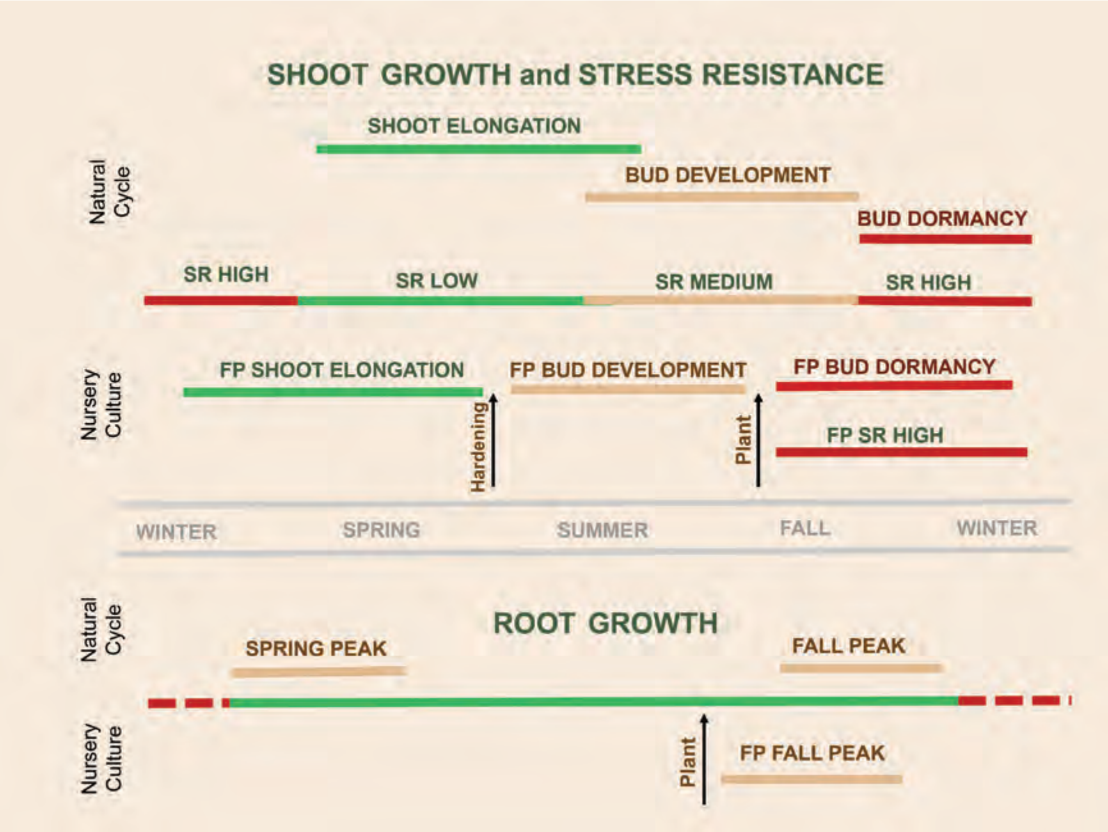


Figure 4. This chart illustrates the phenology of growth (roots and shoots), dormancy (shoots), and stress resistance (SR) of northern conifers in response to their natural cycle compared with nursery cultural practices to produce containerized fall-planted seedlings (FP). Green lines represent periods of growth and low stress resistance, tan lines represent periods of bud development and increasing stress resistance, and red lines represent periods of inactivity and high stress resistance.

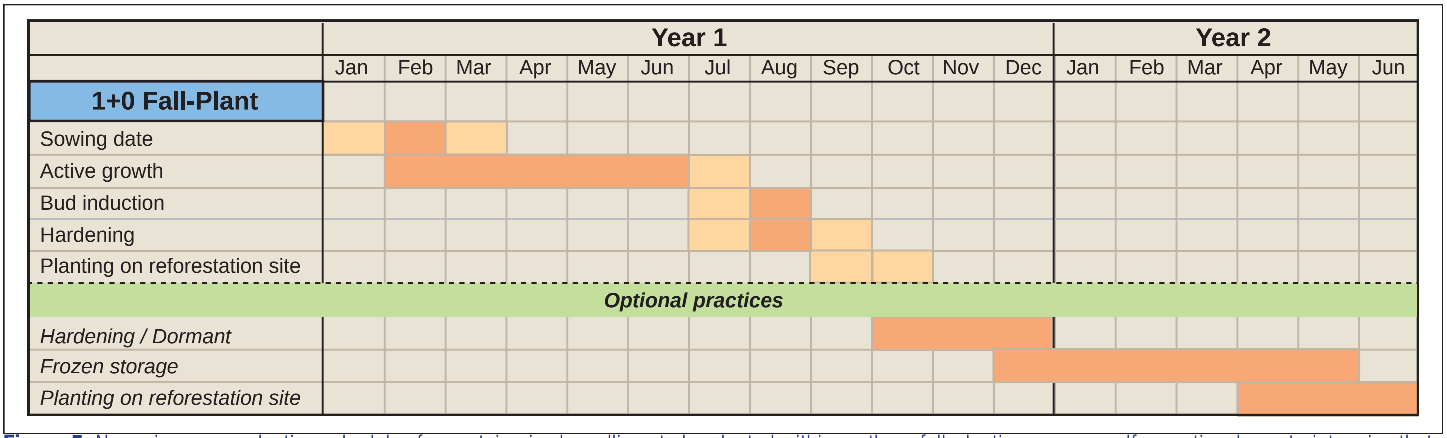
evolved in response to seasonal environmental conditions to ensure species survival (Fuchigami et al. 1982, Lavender 1985). Thus, northern conifers at different latitudes and elevations have distinctive seasonal phenologies (figure 4). These seasonal shoot (Fuchigami et al. 1982) and root (Ritchie and Dunlap 1980) growth cycles overlap with seasonal cycles of stress resistance (i.e., freezing [Fuchigami et al. 1982, Sakai and Larcher 1987] and drought [Teskey et al. 1984]). Nursery cultural practices have been designed to account for these phenological cycles (Burr 1990, Ritchie and Tanaka 1990). Nursery hardening practices cue the start of multiple morphological and physiological processes. Thus, nursery practices can be used to shift the phenological cycle to earlier in the year, resulting in properly hardened seedlings for a fall-planting program (figure 4).

Containerized cultural practices that improve seedling quality have been developed over the past 40 years (Tinus 1974). Growing containerized seedlings allows one to dramatically shift the nursery cultural schedule to accommodate the timely completion of the crop cycle (figure 5), which is why the containerized stocktype is preferred for fall-planting programs in northern forests. Nursery production schedules must allow seedlings to complete morphological and physiological development before lifting. This development is critical because higher quality seedlings have increased survival (Grossnickle 2012) and growth (Grossnickle and MacDonald 2018) just after outplanting. The forester and nursery manager need to develop a partnership marked by excellent communication so that seedlings for fall planting are grown with sufficient time to develop seedling quality attributes that are matched to the outplanting site (Dumroese et al. 2016).

Containerized seedlings for fall planting are sown from early January through early April (figure 5), with timing dependent on species and stocktype size. The active growth phase for shoot elongation is maintained through spring into early or mid- summer to ensure seedlings achieve the desired target height before budset (Landis et al 1989, 1992; Tinus and McDonald 1979). For fall-planting stock, the active growth phase is adjusted to end in July when hardening begins (figure 5).

Hardening involves manipulating morphological and physiological processes within seedlings that, when completed, prepare seedlings for winter stresses. Seedling stress resistance is the ability to withstand stresses associated with the reforestation process, ranging from lifting through storage to planting (Duryea 1985, Ritchie 1984), and is closely correlated with bud dormancy (Lavender 1985). Frost hardiness (Colombo et al. 1989) and drought tolerance (Grossnickle 1989) have been related to completion of bud development in northern conifers, with greater freezing- and drought-stress resistance being cued by cold temperature events (Bigras 1996, Grossnickle 2000).

Hardening begins with a dormancy-induction treatment that stops seedling height growth and starts terminal bud development (Dormling et al. 1968, Lavender et al. 1968) (figure 4). Stem diameter growth continues during and after budset (Grossnickle 2000). During hardening, photosynthates are reallocated towards woody and non-woody root growth and the initial stage of stress resistance is cued (Grossnickle 2000). Nursery cultural practices such as artificially shortened days,



	Year 1												Year 2					
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
1+0 Fall-Plant																		
Sowing date	🟨	🟧	🟨															
Active growth		🟧	🟧	🟧	🟧	🟧	🟨											
Bud induction							🟨	🟧										
Hardening							🟨	🟧	🟨									
Planting on reforestation site									🟨	🟨								
Optional practices																		
Hardening / Dormant										🟧	🟧	🟧						
Frozen storage												🟧	🟧	🟧	🟧	🟧	🟧	
Planting on reforestation site																🟧	🟧	🟧

Figure 5. Nurseries use production schedules for containerized seedlings to be planted within northern fall-planting programs. If operational constraints arise that preclude fall planting, the manager can shift to optional practices to hold seedlings over for a spring-planting program. Dark orange indicate the cultural practice occurs during that month. Light orange bars indicate that the start/stop date is variable within that month depending upon species, seed lot, stock type, or field planting schedule (Swain 2021).

reduced irrigation, and reduced fertilization, alone or in combination, are used for dormancy induction in conifer species (Landis et al. 1999, Landis 2013, Tinus and McDonald 1979). The timing, combination, and intensity of these practices are dictated by species, seedlot (i.e., genetic source), and stocktype (Swain 2021) (figure 5). For example, when applied to interior spruce (*Picea glauca* [Moench] Voss x *Picea engelmannii* Parry ex Engelm.) seedlings, hardening practices increased needle-primordia number within terminal buds and seedling stress resistance while only slightly decreasing root growth potential to a level that was still sufficient for seedling establishment (Grossnickle and Folk 2003).

Hardening practices must be of sufficient duration for seedlings to respond morphologically and physiologically (Kozlowski and Pallardy 2002). Forming the full complement of needle primordia within terminal buds takes many weeks after the start of a dormancy-induction treatment and must be completed before bud dormancy onset (MacDonald and Owens 2006, Owens and Molder 1973). As mentioned, bud dormancy is correlated with seedling stress resistance during the reforestation process, but root apical meristems must remain active after fall planting until temperatures become unfavorable for root growth. After seedlings have reached the desired level of seedling quality to optimize seedling survival (Grossnickle 2012) and growth (Grossnickle and MacDonald 2018) after outplanting, they are biologically ready to ship during the fall-planting window (See Planting Windows and Seedling Field Performance section).

If there is a mid-to-late summer decision not to fall plant due to unfavorable site conditions or operational issues, then the forester needs to let the nursery manager know as soon as possible, ideally by early August (figure 4), so that a storage option can be implemented to ensure quality seedlings are available for a spring carry-over planting program (Landis et al. 2010). The nursery manager needs sufficient time to modify cultural practices to reduce the active-growth phase for roots, thereby minimizing the potential for root-bound plugs while achieving sufficient frost hardiness for frozen storage. Properly hardened seedlings can be lifted and stored with a level of high quality (Grossnickle and South 2014), and have high survival (Simpson 1990) and growth (L'Hirondelle et al. 2006) during the next growing season.

Planting Windows and Seedling Field Performance

Primary risks for spring-, summer-, or fall-planting windows are related to seedling stress resistance and environmental conditions at the reforestation site. Environmental conditions of the reforestation site in northern forests can be generalized as having some combination of the following: (1) moderate to high light intensity, (2) high soil water availability in spring and fall with potential for low soil water availability in summer and fall, (3) low to medium soil temperatures in spring and fall, (4) medium to high soil surface temperatures in summer, (5) medium vapor pressure deficits (VPD) in spring and fall and high VPD in summer, (6) incidence of spring and fall frost, (7) high wind speeds, and (8) high nutrient availability in the soil solution (Margolis and Brand 1990). These conditions broadly reflect the regional climate, but microclimatic conditions vary considerably by elevation, topography, and aspect. Site disturbance also has a direct effect upon site microclimate, thereby affecting site energy, hydrologic cycles, and nutrient cycles (Spittlehouse and Stathers 1990). In addition to potential planting site environmental conditions, timing of planting within the fall-planting window for northern forests (i.e., September through mid-October) is also dictated by forecasted weather conditions.

Seedlings can be exposed to a wide range of environmental conditions within any planting window. Ideal environmental conditions allow an optimum physiological response by seedlings, while extreme conditions can exceed their ability to withstand stresses (Grossnickle 2000). An example of the expected biological response of seedlings planted across the spring-, summer- or fall-planting windows is defined for northern spruce species based on their known ecophysiological performance capabilities relative to seasonal reforestation site climate conditions (table 3). These ecophysiological patterns, in general, fit other northern conifer species, thus providing a perspective on what to consider when choosing a planting window. Knowing the risks of fall planting, in comparison with other planting windows, allows foresters to make an informed decision on whether this window is suited to their reforestation program.

Table 3. Potential for spring-, summer- and fall-planted northern spruce (*Picea*) seedlings to be negatively affected by typical climatic environmental stresses that can occur at the reforestation site with additional details regarding stress-resistance status of fall-planted seedlings (from Grossnickle 2000).

Environmental Stress	Spring planting	Summer planting	Fall planting	Stress resistance status of fall-planted seedlings
Atmospheric				
Air temperature (frost)	High	Low	Moderate	Freezing tolerance from -10 to -15 °C
Air temperature (heat)	Low	High	Moderate	Heat tolerance to 40 °C
Vapor pressure deficit	Low	High	Moderate	Good photosynthesis and water status capability at VPD < 2 kPa
Edaphic				
Drought	Moderate	High	Moderate	Fall values at 90% of the maximum yearly level of drought tolerance for spruce species
Flooding	Moderate	Low	Low	Dormant seedlings can temporarily withstand flooded soil conditions
Low soil-root temperature	High	Low	Moderate	Root growth declines between 3 to 5 °C , but increases when > 10 °C
Soil surface temperature	Low	High	Moderate	Stem girdling occurs above 45 °C
Frost heaving	Moderate	Low	Moderate	Minimized by planting when soil temperature is > 5 °C

Recommendations

Research and operational experience from around the world have found that fall-planting programs can be successful, though challenges must be recognized and addressed for each site. The following are recommended operational steps to consider in maximizing the likelihood of a successful fall-planting program.

- Plan ahead to select sites with suitable environmental conditions and to determine appropriate species and stocktypes for each site.
- Nursery managers and foresters need to work together to plan the crop so there is sufficient time to grow seedlings to proper size and still have adequate time for the required hardening process before outplanting.
- Prepare sites in advance for fall planting, but also develop contingency plans (e.g., alternative sites, short-term storage for lifted seedlings, etc.) in case the plant date must be adjusted due to forecasted, adverse weather conditions.
- Develop a contingency plan with the nursery for overwinter storage and spring planting if stressful site conditions or other operational constraints arise and seedlings cannot be planted within the fall-planting window.

Foresters need to understand the rewards and risks for fall planting in northern forests. By considering these recommended steps, they can make informed decisions on whether to implement fall planting within their reforestation program.

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