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Influence of seasonal planting date on field performance of six temperate deciduous forest tree species

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Abstract

Most afforestation hardwood plantations in the Central Hardwood Forest Region, USA, are established with bareroot seedlings planted in late winter or early spring. This brief planting season is preferred for several logistical and physiological reasons, yet interest in fall planting has increased as a means to extend the planting season. We evaluated effects of a wide range of planting dates on 2-year survival and growth for six different temperate deciduous forest tree species grown as 1 + 0 bareroot stock at a southern Indiana, USA, nursery and outplanted onto an afforestation site in southeastern Indiana. In 2001–2002 and again in 2002–2003, seedlings were planted on 10 and 9 different planting dates, respectively, between November and July. Planting date only affected survival of *Prunus serotina* Ehrh. and *Juglans nigra* L. in 2001–2002, and *Liriodendron tulipifera* L. in 2002–2003. Planting date did not consistently affect seedling growth of any species; however, low precipitation in summer of 2002 apparently limited growth of late season plantings. These results suggest that the planting season could effectively be extended given adequate soil moisture.

Keywords: Afforestation; Fall planting; Hardwood seedlings; Plantation establishment; Planting date

1. Introduction

In the Central Hardwood Forest Region (CHFR), USA, most hardwood plantations are established with bareroot seedlings planted in late winter or early spring (Hannah and Turner, 1981; Wray, 1998; Pijut, 2004). This brief planting season (approximately 1 March–15 May) is preferred for several logistical and physiological reasons. During this time period, climatic patterns of the region provide cool air and thawed, moist soil that create ideal planting conditions (Purdue University, 1992). Because water stress is recognized as a primary cause of transplant stress (Rietveld, 1989; Burdett, 1990; Margolis and Brand, 1990; Jacobs et al., 2004a), having adequate soil moisture at planting is crucial to seedling establishment. By early spring, nurseries have also had adequate time to lift, grade, package, and store their annual stock. Regional nurseries do not typically lift bareroot seedlings before the onset of seedling dormancy in late fall (Jacobs, 2003). Dormancy prior to lifting is essential for maintaining seedling vigor, as the relationship between physiological seasonal changes (i.e., onset of dormancy) is an important determinant of seedling stress resistance during lifting, storage, and planting operations (Ritchie et al., 1985; McKay, 1997; Jacobs, 2003). Finally, as opposed to late spring or summer planting, spring planting before budbreak provides seedlings with the advantage of a full growing season.

In lieu of the aforementioned benefits, interest in an extended planting season has increased based upon several potential advantages. Fall planting may allow for increased root growth prior to shoot growth as a result of root elongation during fall and spring, promoting greater root system proliferation during the first growing season (Taylor and Dumbroff, 1975; Good and Corell, 1982). Larger root systems may in turn lead to increased exploitation of soil for water and nutrients (Carlson, 1986; Struve, 1990; McMillin and Wagner, 1995) and improved plantation establishment success (Rose et al., 1997; Jacobs et al., 2005b). Fall planting also eliminates the need for prolonged cold storage of seedlings, which could

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reduce the risk of physiological damage from desiccation, disease incidence, or depletion of storage reserves. Sites that remain wet throughout spring (i.e., bottomlands) may be more effectively planted during the fall when conditions are drier (Wray, 1998). Finally, with an extended annual time frame for planting, a greater quantity of seedlings may be planted in a given year.

Fall planting has been investigated with conifers in the southern and western USA (Barber, 1989; Dierauf, 1989; Adams et al., 1991), but effects of annual time of planting have not been adequately evaluated for temperate deciduous forest tree species in the CHFR. While studies evaluating fall planting have often reported successes, results are highly variable, with documented levels of improved, neutral, or negative results dependent on interactive effects of site characteristics, climatic conditions, species, and cultural practices. Consequentially, many forest managers are reluctant to integrate fall planting into operation due to concerns over factors such as increased stress from early lifting or the potential for frost heaving after outplanting. Thus, our objective in this experiment was to examine the response of forest tree seedlings to annual variation in time of planting by testing the effects of a wide range of planting dates on the establishment success of six temperate deciduous species. To help account for annual variation in climatic conditions, the experiment was repeated over two consecutive yearly periods.

2. Materials and methods

2.1. Study area and climatic conditions

The study site was located at the Southeast Purdue Agricultural Center in Indiana, USA (39°01′N, 85°35′W). The soil at the study site is classified as a Muscatatuck series (fine-silty, mixed, active, mesic, Fragic Hapludalf) (USDA NRCS Pedon I.D. S021IN-079-001), formed in forest vegetation with a visible plow layer from intermittent cultivation (Soil Survey Staff, 2004). The soil has a bulk density of 1.31 g cm^{-3} with 2.5–2.9% organic matter and 5.9 pH (von Kiparski, 2004). This study was established over two extended planting seasons: fall 2001 through spring 2002 (PS01) and fall 2002 through summer 2003 (PS02). Methods employed were similar for each planting season with discrepancies noted below. The site was previously in row crop production and disked prior to the first planting.

Weather data was collected from the NOAA monitoring station North Vernon 2 NE, Jennings County, IN (39°02′N, 85°36′W), approximately 8.5 km west of the study site (NOAA, 2005). Seasonal variation in precipitation and temperature was evident (Figs. 1 and 2). Total annual (November–October) precipitation (1527.8 mm and 1232.4 mm) and mean annual temperature (13.8 °C and 11.8 °C) were greater for 2001–2002 than 2002–2003, respectively. Seasonal temperature trends were similar for both planting seasons; however, precipitation patterns varied.

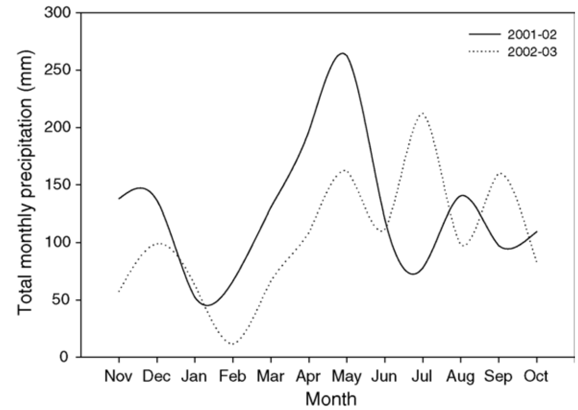

Fig. 1. Total monthly precipitation for 2001–2002 and 2002–2003 planting season as reported by NOAA weather station North Vernon 2 NE.

PS01 maintained a wetter spring, yet drier summer and early fall (Fig. 1).

2.2. Plant material and experimental design

Seedlings of six species (*Fraxinus americana* L., *Juglans nigra* L., *Liriodendron tulipifera* L., *Prunus serotina* Ehrh., *Quercus alba* L., and *Quercus rubra* L.) commonly planted in the CHFR (Jacobs et al., 2004b) were planted on 10 separate dates for PS01 and 9 dates throughout PS02 (Table 1). Seedlings (1 + 0 bareroot) were grown under standard nursery cultural practices at the Indiana Department of Natural Resources Vallonia State Tree Nursery in southwestern Indiana (38°48′N, 86°06′W). Jacobs (2003) presents a comprehensive overview of nursery production of hardwood seedlings in this region. Seedlings for the first four planting dates were lifted from nursery beds the day prior to planting. All seedlings for subsequent dates were lifted and packaged the day prior to the fourth planting date (17 December for PS01 and 29 December for PS02), and then cold stored (0.5–1.7 °C) at the nursery until the day prior to planting. Early planting dates (November–December) required lifting before complete leaf abscission for all species except *J. nigra*. For stock lifted for November

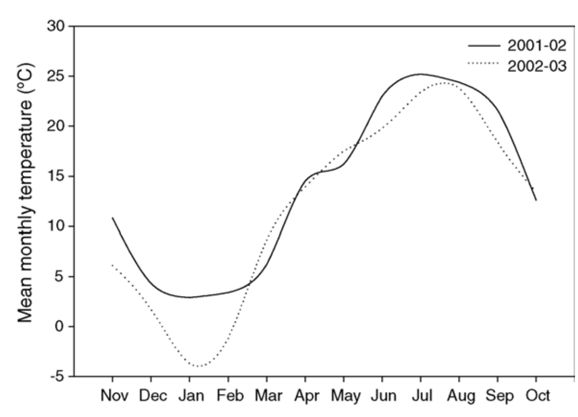

Fig. 2. Mean monthly temperature for the 2001–2002 and 2002–2003 planting season as reported by NOAA weather station North Vernon 2 NE.

Table 1
P-value results from analysis of covariance for testing the effect of planting date on first-year and total survival and growth attributes for six temperate deciduous forest tree species in southeastern Indiana, USA

Species	Planting year	Survival		Diameter growth		Height growth	
		First-year	Total	First-year	Total	First-year	Total
F. americana	2001–2002	0.5135	0.3506	0.0001*	0.0001*	0.0007*	0.0003*
	2002–2003	–	–	0.0227*	0.9213	0.0044*	0.2142
J. nigra	2001–2002	0.1145	0.0287*	0.0121*	0.0511	0.0001*	0.1694
	2002–2003	0.0966	0.2313	0.0020*	0.6359	0.1126	0.4868
L. tulipifera	2001–2002	0.9995	0.9987	0.0001*	0.0026*	0.0005*	0.0197*
	2002–2003	0.0001*	0.0001*	0.0003*	0.0384*	0.0004*	0.1743
P. serotina	2001–2002	0.0156*	0.0159*	0.0039*	0.0083*	0.0159*	0.0133*
	2002–2003	0.1210	0.2092	0.0017*	0.2020	0.0014*	0.1297
Q. alba	2001–2002	0.2324	0.1830	0.1038	0.4429	0.2653	0.8179
	2002–2003	0.5152	0.2698	0.0012*	0.0444*	0.0509	0.3106
Q. rubra	2001–2002	0.0366*	0.2344	0.3173	0.7153	0.1021	0.6587
	2002–2003	0.2835	0.2112	0.0084*	0.0158*	0.1696	0.5050

The experiment was conducted in both 2001–2002 and 2002–2003; results were analyzed separately for each planting year. *Note*: survival for *F. americana* was 100% for 2002–2003.

* Denotes significant response at $P \leq 0.05$.

planting dates, we visually observed that *L. tulipifera* was still nearly 100% green, *F. americana* and *P. serotina* were approximately 90% green, and *Q. alba* and *Q. rubra* showed fall colors on approximately 50% of foliage. It was not until the initial lifting in December that there was a noticeable change in leaf color from the first November lifting.

The study was designed as a completely randomized design with four replications. At each planting date, 25 seedlings per species were outplanted into treatment plots using a tractor-hauled coulter with trencher and packing wheels. A fence to exclude deer from the experimental area was maintained throughout the study. All plantings were treated with 0.7342 kg ha^{-1} (active ingredient) of simazine prior to budbreak. Immediately prior to planting, shoot height and root-collar diameter were measured on each seedling. Following each growing season, survival, height, and ground-line diameter of seedlings were quantified.

2.3. Statistical analysis

Data analysis was accomplished using JMP IN® Statistical Discovery Software (SAS Institute, Cary, NC, USA). Due to differences in climatic conditions and planting dates, data from PS01 and PS02 were analyzed independently. Analysis of covariance (ANCOVA) was used to test the effect of species and planting date on growth and survival attributes because the strong influence of initial shoot height and ground-line diameter on seedling growth necessitated their use as covariates in the respective analyses. ANCOVA treatment effects for survival and growth data were considered statistically significant at $P \leq 0.05$. Due to the significance of species × planting date interactions (PS01, $P = 0.0437$ and PS02, $P < 0.0001$), species were separated for analysis of the effect of planting date on growth and survival.

3. Results

3.1. Survival as affected by planting date

Planting date significantly affected total survival of *P. serotina* and *J. nigra* ($P = 0.0159$ and $P = 0.0287$, respectively) for PS01. Seedlings of *P. serotina* planted on 20 November exhibited the lowest survival (45%), while seedlings planted on 19 June exhibited the highest (94%). Late fall and early winter plantings also yielded the poorest survival for *J. nigra* seedlings for PS01, with 85% survival in 4 December plantings compared to a high of 99% in 24 April plantings. First-year survival of *Q. rubra* was also significantly ($P = 0.0366$) affected by planting date for PS01, but additional mortality prior to the end of the second growing season negated this effect (Fig. 3). The only species with survival significantly affected by planting date for PS02 was *L. tulipifera* (Table 1). Highest survival (99%) was observed in 10 April plantings, while lowest (77%) was noted for late fall and early winter plantings (Fig. 3).

3.2. Growth as affected by planting date

First-year and total ground-line diameter growth of *L. tulipifera*, *F. americana*, and *P. serotina* were significantly affected by planting date for PS01 (Table 1). These species exhibited reduced diameter growth in late season plantings (Fig. 4). First-year diameter growth of *J. nigra* was significantly affected by planting date (Table 1), but by the end of the second growing season, differences were no longer statistically significant.

First-year and total ground-line diameter growth of *L. tulipifera*, *Q. alba*, and *Q. rubra* were significantly affected by planting date for PS02 (Table 1). Diameter growth trends varied by species, except for a nearly species-wide decrease in the 17

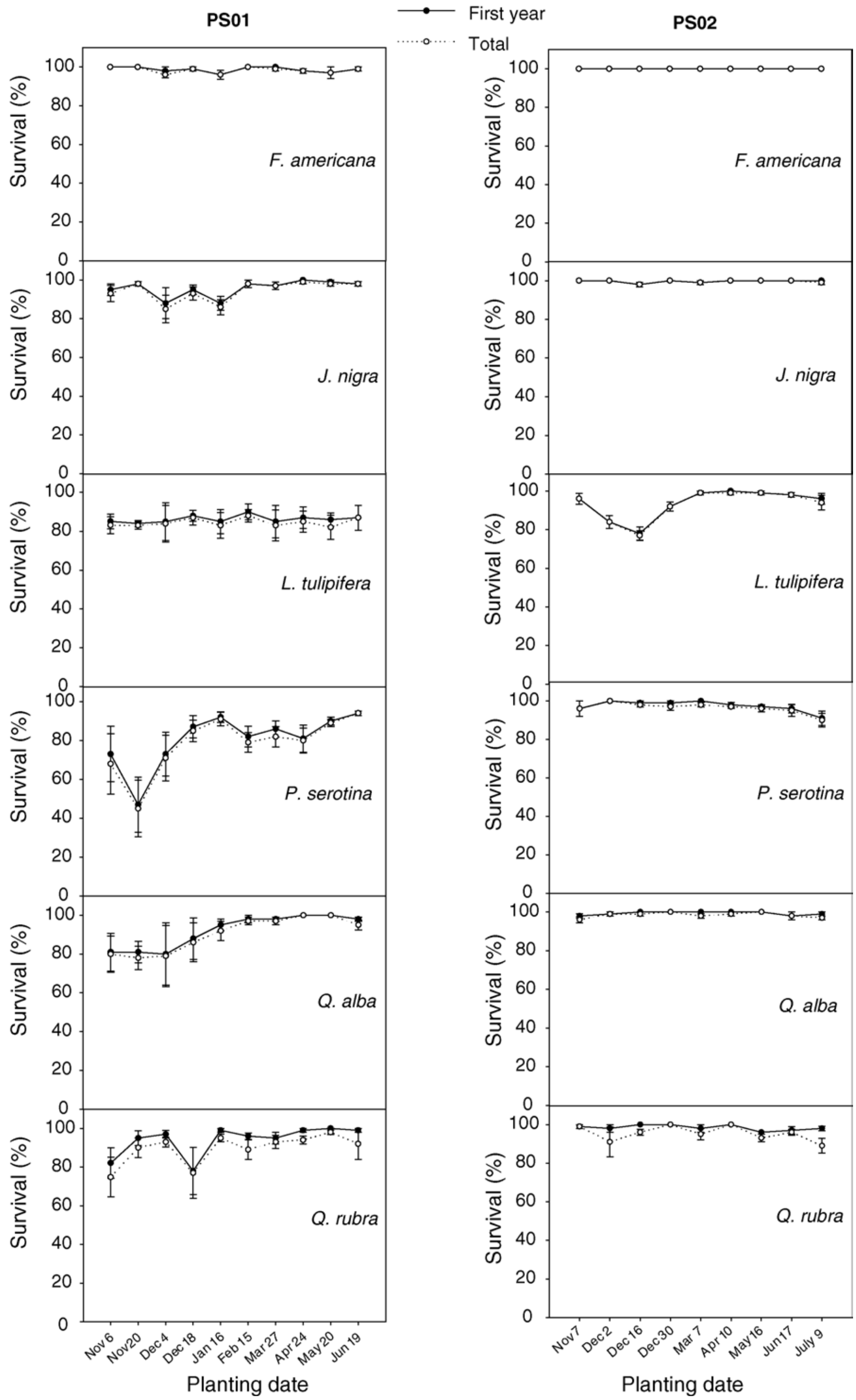

Fig. 3. Total and first-year seedling survival as affected by plating date for the six species studied. Data are shown separately for the 2001–2002 (PS01) and 2002–2003 (PS02) seasons. Error bars represent the standard error of the mean.

June planting, followed by increased growth for the 9 July planting (Fig. 4). The effect of planting date on diameter growth of *F. americana*, *J. nigra*, and *P. serotina* was only detected for the first growing season.

Height growth for PS01 closely followed the species and seasonal trends observed for diameter growth. First-year and total height growth of *L. tulipifera*, *F. americana*, and *P. serotina* were significantly affected by planting date (Table 1). These species exhibited lowest first-year and total height growth in May and June plantings with only slight differences between earlier planting dates (Fig. 5). First-year height growth of these same species (*L. tulipifera*, *F. americana*, and *P. serotina*) was also affected by planting date for PS02. However, all differences observed in PS02 plantings were negated after two growing seasons and planting date did not affect total height growth of any species.

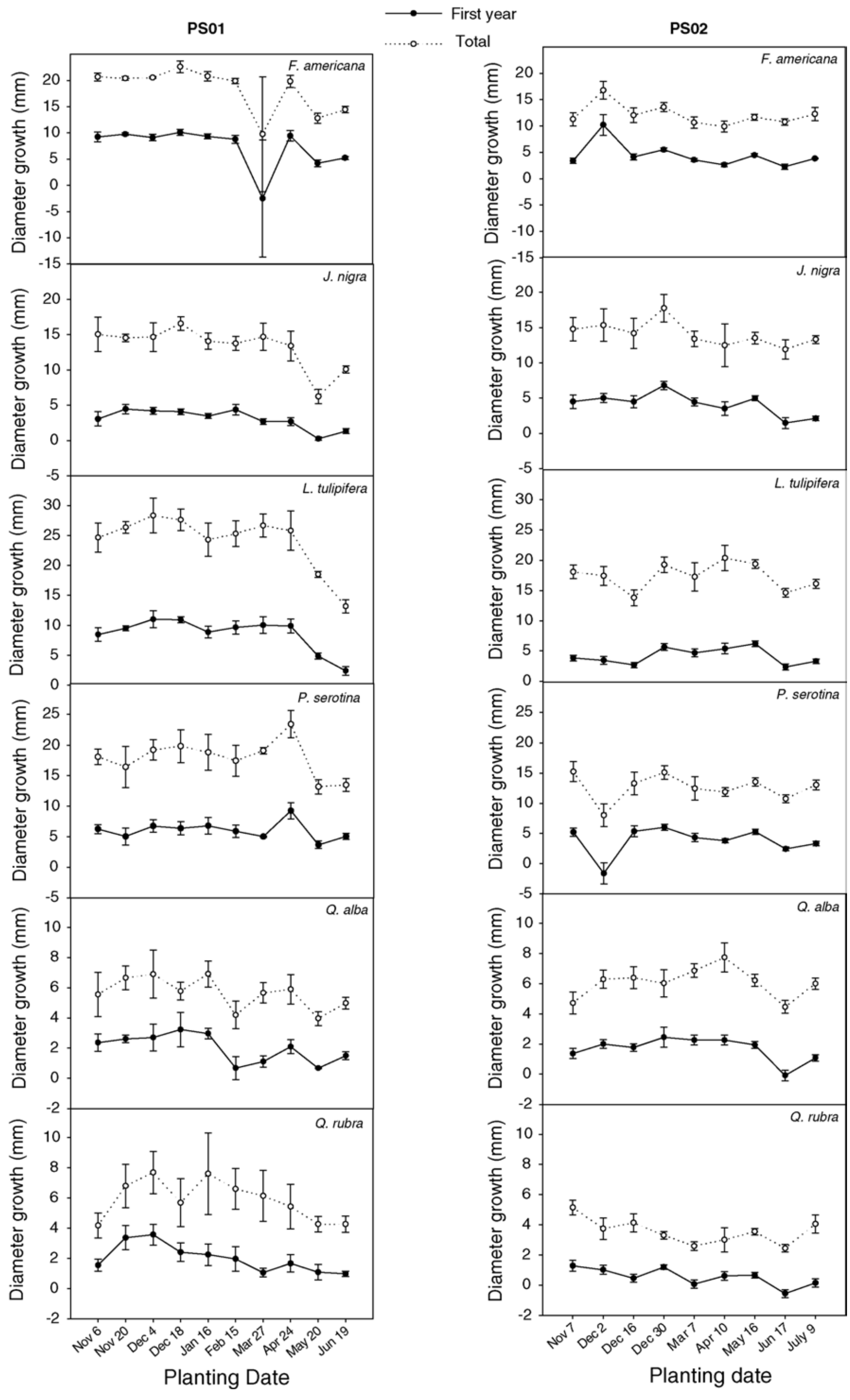

Fig. 4. Total and first-year seedling diameter growth as affected by plating date for the six species studied. Data are shown separately for the 2001–2002 (PS01) and 2002–2003 (PS02) seasons. Error bars represent the standard error of the mean.

4. Discussion

4.1. Survival as affected by planting date

Significant differences in survival between planting dates were only observed for *P. serotina* and *J. nigra* in PS01, and for *L. tulipifera* in PS02 (Fig. 3). These species each had lowest survival in late November and early December plantings. Overall seedling survival in this study was high compared to operational plantations in the CHFR. For instance, Jacobs et al. (2004b) surveyed 87 operational hardwood plantations in Indiana 1–5 years after planting, noting a mean survival rate of 66% across all years. The high survival rates in this study may be attributed to the exceptional care taken in establishing these plantings (i.e., handling of stock, planting quality, weed control, deer fencing), as has been reported in similar experimental

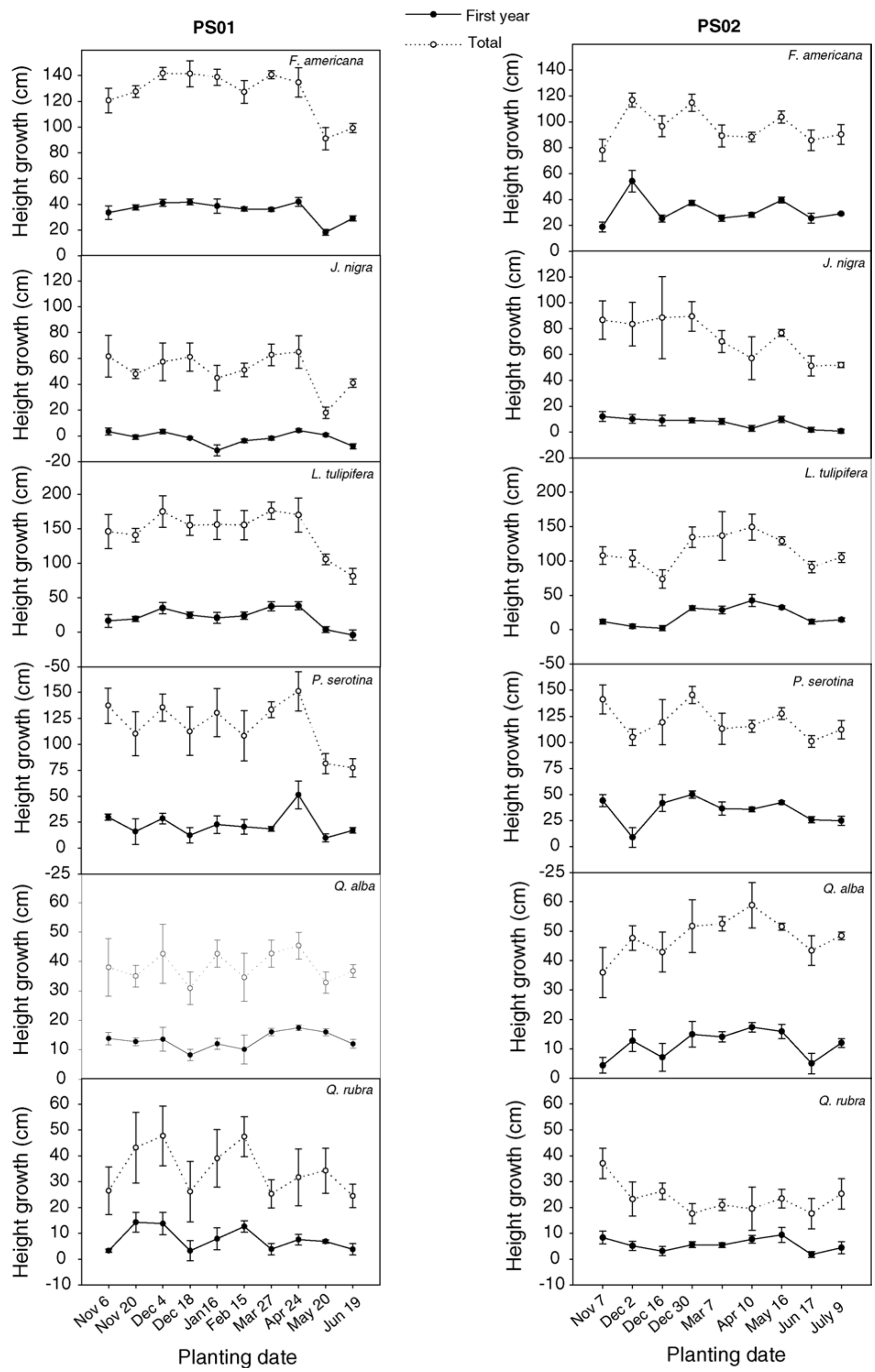

Fig. 5. Total and first-year seedling height growth as affected by plating date for the six species studied. Data are shown separately for the 2001–2002 (PS01) and 2002–2003 (PS02) seasons. Error bars represent the standard error of the mean.

plantations in this region (Jacobs et al., 2005a,b). Under the less intensive management regimes more common in operation, establishment success may have been reduced.

The nominal effects of planting date on survival of only three of the six species, along with inconsistent effects between years suggests that seedlings of these species have high tolerance for winter stresses (e.g., desiccation or frost heaving) and summer conditions (e.g., water stress) immediately following planting. This contention is supported by the low temperatures experienced in January (2.6 °C below normal) and February 2003 (2.9 °C below normal) (Fig. 2) and relatively low rainfall in June and July of 2002 (Fig. 1). Equivalent survival across planting dates is in agreement with Hannah and Turner (1981) who reported survival rates as high as 70–90% for fall planted *Betula alleghaniensis* Britt., *F. americana*, and *Acer saccharum* Marsh. in Vermont, USA. High survival of fall planted stock has also been observed with conifers in the western USA (Barber, 1989; Adams et al., 1991).

In addition to environmental factors associated with time of planting, seedlings in the various planting date treatments were simultaneously subjected to a range of lifting dates and/or storage durations. These factors have each been shown to affect seedling vigor and survival (Ritchie et al., 1985; Puttonen, 1987; Lindqvist, 2001; Cabral and O'Reilly, 2005). However, neither factor substantially affected seedling survival in this study. High survival rates of early lifted seedlings were surprising given the large proportion of green foliage observed at lifting, which suggested sustained physiological activity and relatively low stress resistance. Absence of injury expression may have been associated with the short storage duration (<24 h) and careful stock transport, handling, and planting that occurred under these controlled experimental conditions. Winter-lifted seedlings were likely dormant and better able to resist stresses associated with lifting, packing, and storage (McKay, 1997).

4.2. Growth as affected by planting date

Height and diameter growth patterns followed trends similar to responses for survival, and were likely influenced by comparable factors. Planting date dictates a variety of environmental conditions (i.e., moisture availability, soil/air temperature, length of growing season) and operational practices (i.e., lifting date and storage duration) capable of affecting post-planting root and shoot growth.

Growth of *L. tulipifera*, *F. americana*, and *P. serotina* was regularly affected by planting date, and tended to be least in summer plantings (Figs. 4 and 5). This effect may largely be associated with the shortened growing season resulting from a reduction in the number of field growing days. However, this trend was not as pronounced for PS02, even with a final planting date 20 days later than in the previous year. Reduced rainfall in June and July of 2002 (Fig. 1) likely had a more pronounced influence on growth of May and June PS01 plantings than actual calendar date of planting. This contention is supported by Burdett (1990), who identified water stress as the primary contributor to planting stress. Tyree et al. (1978) also noted a rapid increase in water demand of *A. saccharum* between May and mid-June. This phenomenon may have served to exacerbate the effects of water stress in late spring planted seedlings, because root systems likely had not yet proliferated to facilitate root–soil contact.

Root system establishment of outplanted seedlings is strongly influenced by soil temperature (Larson, 1970) but may occur whenever soil is not frozen (Taylor and Dumbroff, 1975). Taylor and Dumbroff (1975) observed year-round root growth of October-planted *A. saccharum* in Ontario, Canada, except when the ground was actually frozen in December and January. Larson (1970) did not identify an optimum temperature for root growth of *Q. rubra*, but did notice severe reductions in root and shoot growth below 18 °C. Therefore, root growth from fall planted seedlings may have been slow due to cooler soil temperatures, but what limited advanced root proliferation that did occur may have helped develop root systems capable of withstanding droughty summer conditions and high water demands. Increased time for root system establishment may help to explain the greater growth observed in fall, winter, and early spring plantings.

Other studies from the western USA have reported varying results regarding the influence of soil moisture on growth performance of fall planted seedlings. Adams et al. (1991) periodically excavated seedlings of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), western white pine (*Pinus monticola* Dougl. ex D. Don), and ponderosa pine (*Pinus ponderosa* Doug. ex Laws) during the first growing season in northern Idaho and found increased dry mass of seedlings planted under conditions of adequate soil moisture in early fall compared to that of seedlings planted later in fall after soil water availability declined. Fall planted bareroot and container stock of western larch (*Larix occidentalis* Nutt.) had improved field growth versus comparable spring-planted stock in northeastern Washington, despite the observation that only one of three sites had high soil moisture at time of fall planting (Barber, 1989).

Species with growth most affected by late season planting (i.e., *L. tulipifera*, *F. americana*, and *P. serotina*) were also those that maintained active, green foliage latest into fall. Late season growth prior to lifting may have postponed dormancy and led to detrimental effects from early lifting (Ritchie et al., 1985). Lindqvist (2001) demonstrated that long-term storage of early lifted seedlings caused increased mortality and dieback in *Betula pendula* Roth. and *Quercus robur* L. Because seedlings planted on the latter planting dates were subjected to longer periods of cold storage, the effects of early lifting may have only been evident for these late season planting dates. In contrast, Webb (1976) showed that root growth potential of fall-lifted, dormant, *F. americana* increased with time of cold storage until at least May.

5. Conclusions

The general lack of differences in survival between planting dates lends support to the practice of fall and early winter planting of bareroot temperate deciduous forest tree seedlings in the CHFR. Diameter and height growth differences between planting dates were inconsistent. Growth of *L. tulipifera*, *F. americana*, and *P. serotina* appeared to be most sensitive to late season planting. Inconsistencies in general performance fail to demonstrate a pronounced negative effect of variation in annual planting date on seedling establishment success. The corresponding influence of early lifting and prolonged storage also did not appear to maintain any consistent, negative influence on seedling performance. Low precipitation during the summer of 2002 probably had a more negative influence on seedling growth than time of planting. Additional research is needed to examine effects of time of planting under a wider array of site types, nursery stock cultural and handling regimes, and plantation establishment methods. However, our study results suggest that extending the planting season from the current practice of late winter to early spring to fall through early summer, given adequate soil moisture, may be a useful tool for plantation management.

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