Afforestation in the Central Hardwood Forest Region of the USA

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Introduction

The Central Hardwood Forest Region (CHFR) of the USA is dominated by fine hardwood species such as black cherry (*Prunus serotina* Ehrh.), black walnut *(Juglans nigra* L.), and northern red oak *(Quercus rubra* L.*)*. Tree species in this region are highly valued for veneer and lumber and as sources of wildlife food and habitat. Despite the important economic and ecological contributions of forests to the region, there has historically been a strong focus on agricultural production which has resulted in an overall loss of forest cover. Recently, however, increasing numbers of private landowners are choosing to afforest marginal agricultural land throughout much of the Central Hardwood Forest Region (CHFR) of the USA. In seven Midwestern states there was a total increase in forestland of 5 million ha between 1980 and 2000 (Potts et al. 2004); however, despite this increase, many states are well below historical forest cover levels. Indiana, for example, was approximately 85% forested 200 years ago, but only about 8% at the beginning of the 20th century and is now approximately 21% (Tormoehlen et al. 2000).

Despite recent efforts to increase forest cover, the success of plantation establishment on private lands is variable and can be improved. In Indiana, approximately 65% of seedlings planted on non-industrial private forest (NIPF) lands survive at the end of five growing seasons (Jacobs et al. 2004). It would appear that most mortality occurs in the first growing season as there was little change in survival following the first year. Correspondingly, about 22% of seedlings had three or more leaders one and five years following outplanting, while over 32% of seedlings had 3 or more leaders three years after outplanting.

In the same study, the percentage of seedlings that were free-to-grow ranged from less than 3% in year one to almost 50% in year five. Further examination of the 6 most commonly-planted species at year 5 revealed that approximately 80% of black cherry, 70% of white ash (*Fraxinus americana* L.), 65% of yellow poplar (*Liriodendron tulipifera* L.), 50% of white oak (*Quercus alba* L.), 40% of black walnut, and 30% of northern red oak seedlings were free-to-grow. The relatively low percentage of black walnut seedlings that were free-to-grow at year 5 was attributed to a number of evident species-by-site mismatches.

Mortality and poor form of planted seedlings are often attributed to competing vegetation and damage due to animal browse. While specific silvicultural practices are able to mitigate these pressures, there has been little synthesis of the effects of silvicultural practices on plantation establishment success in this region. The plantation establishment figures presented by Jacobs et al. (2004) identify that the pressures placed within the first three years following outplanting are critical to avoid as a means of improving plantation establishment success.

The objective of this paper is to present a review of current, relevant research relating to hardwood seedling quality issues, some potential benefits associated with use of alternative seedling production methods, and the effects of various forms of early stand silviculture used in afforestation in the CHFR. Collation of this information should aid nursery managers and foresters in assuring the availability of high quality hardwood seedlings to enhance outplanting success.

Mitigating Outplanting Stresses Through Improved Seedling Quality

While hardwood seedling production in the USA is not well tracked, hardwood species represent only a fraction of the more than 1.6 billion seedlings produced annually in the USA (Moulton and Hernandez 1999, Jacobs and Davis 2005). Given the importance of successful plantation establishment, the seedlings used must be of high quality. However, the question of what constitutes a quality seedling is difficult to answer. Quality may be defined as “superiority in kind” (Merriam-Webster 2004), and therefore one may say that a quality seedling is one which meets its desired level of performance upon outplanting (Duryea 1985; Mattsson 1996). However, seedling quality must be defined within a myriad of parameters. These include the cost of the seedling, planting operation, and subsequent tending, the actual cost of establishment (i.e. at maturity, how much did it cost to plant that tree), site conditions, seedling availability, and growth rate to name

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but a few. As well, seedling quality is directly influenced by the genetic composition, size, vigor, environmental conditions, handling, planting, and storage practices.

Seed zones

Well-documented genotype × environment interactions in forest tree species illustrate the importance of tracking seed source. Use of seed geographically adapted to a specific region can increase resistance to pest and pathogen damage (Macdonald 1986) and yield higher seedling survival and better performance (Williams et al. 1974; Bresnan et al. 1994). As mentioned earlier, extensive guidelines for transfer of conifer seed and seedlings exist in the USA. The development of seed transfer zones for southern pine species [i.e., loblolly (*Pinus taeda* L.), slash, (*P. elliottii* Engelm.), longleaf (*P. palustris* Mill.), virginia (*P. virginiana* Mill.), shortleaf (*P. echinata* Mill.), and sand (*P. clausa* (Chapm. ex Engelm))] was based on yearly average minimum temperatures (Schmidtling 2001). In Washington, USA seed zones have been developed based on genetic information in addition to climatic, vegetative, and topographic data (Randall and Berrang 2002).

The importance of provenance tracking extends to hardwood species as well. In British Columbia, transfer of red alder (*Alnus rubra* Bong.) beyond 100 km towards or from the coast led to a decrease in survival and height growth (Hamann et al. 2000). In the case of fine hardwoods, provenance testing resulted in the recommendation that black walnut may be moved northward as much as 322 km without risk of cold damage (Bey 1980; Bresnan et al. 1994). The findings of Bey (1980) were extrapolated by Deneke et al. (1980) to develop "Preliminary seed collection zones for black walnut." The recommendations yielded 22 seed collection and planting zones; however, these recommendations are not enforced and generally not followed.

Despite research identifying the importance of seed origin to hardwood seedling performance (Williams et al. 1974; Rink 1984; Rink and Van Sambeek 1985; Williams et al. 1985), there are few examples of seed source regulation with regards to hardwood species in the eastern USA beyond the aforementioned recommendations for black walnut. While many factors (e.g., animal browse, competing vegetation, and weather) determine the success of plantations, it is possible that the use of seed of unknown origin accounts for some of this mortality. Failed efforts to establish plantations of hardwood seedlings in Tennessee, USA have been partially attributed to a lack of seed zones, prompting the development of seed zones based on ecoregions, elevation, and weather data (Post et al. 2003). Combining spatially explicit seed transfer zones with provenance testing could help to improve plantation establishment success.

In a survey of hardwood nurseries in the eastern USA (A.S. Davis, unpublished data), approximately 71% of respondents stated that they identify seed zones for hardwood seedling production. However, those zones range quite liberally in definition, some being as vague as 'within a couple of states' to others which are as clearly defined as a specific county. Of those nurseries that identify seed zones, 30% do not attempt to ensure that the zone of seed collection corresponds to the intended outplanting zone. Approximately 75% of nurseries that responded stated that they thought seed zones were beneficial to forestry in their region, indicating that perhaps greater development of and adherence to seed zones will occur in the future.

Genetic improvement

In the eastern USA, approximately 6.8% of hardwood seedlings produced are of genetically superior origin, compared to 36% of conifers produced in the same region (Jacobs and Davis 2005). According to that same survey, most respondents (64%) indicated that they intend to increase their use of genetically improved material in the next 10 years. With improved micro-propagation techniques developing for many hardwood species (Navarette et al. 1989), one would expect to see an increase in improved material in the future.

Seedling quality

Recent investigation of the relative contribution of above and below-ground morphological parameters to prediction of outplanting success will enable nursery managers to better quantify hardwood seedling quality. Jacobs et al. (in press a) found that for predicting first-year height and diameter growth of three hardwood species, initial root-collar diameter, height, and root volume were the most important morphological characteristics. Further identification of how seedling morphological and physiological characteristics can be applied to predict field performance is necessary to improve seedling quality.

Similarly, research examining the relationship between seedling size and drought stress will enable foresters to target for stock with a greater likelihood to thrive under specific environmental conditions. For example, a greenhouse experiment conducted to investigate the recovery of bareroot northern red oak seedling after simulated drought stress found that seedlings with larger root volumes were less able to mitigate drought stress than those with smaller root volumes (Jacobs et al. in press b).

Alternatives to Bareroot Seedlings

The majority of seedlings planted in the CHFR are bareroot nursery stock. Given limited plantation establishment success using bareroot seedlings, other stocktypes, such as container seedlings, may be more effective at establishing forest cover on harsher sites characteristic of the region (e.g., former surface coal mines or floodplains). Reclamation of surface coal mines can demand large portions of nursery stock (approximately 20% of seedlings grown at Indiana Department of Natural Resources Division of Forestry nurseries are purchased for mine reclamation).

Container-grown seedlings

Presently, containers used for operational hardwood seedling production in the CHFR are large (> 4 L) and costly. However, use of this stock has been shown to help promote free-to-grow status at time of outplanting (Jacobs et al. in press), an important consideration in the effort to mitigate heavy animal browse pressures on seedling growth and survival.

Loss of roots during lifting is a major cause of transplant shock (Struve and Joly 1992). Given that containerized seedlings maintain their entire root system when transplanted, transplant shock can be considerably reduced through use of containerized seedlings (Miller 1999; BCMOF 2001). Container seedlings also maintain higher water potential during the first year following out-planting compared to bareroot seedlings (Dixon et al. 1983; Crunkilton et al. 1992; Davis 2003), which can further reduce shock to the seedling caused by site acclimatization. Reduction of transplant shock can lead to increased survival and growth rate, as Vyse (1981) estimated that transplant shock could equate to the loss of 1 or 2 years of growth. Container seedlings often yield more uniform growth than do bareroot seedlings upon out-planting (van Eerden 1999; Wilson and Vitols 1999), along with a more fibrous root system (WRP 1993). Given the multitude of container shapes and sizes available, it is possible to produce a specific size and shape of seedling roots for a specific purpose such as mined land reclamation (e.g., shallow containers for shallow soils) (Bainbridge 1994).

New methods for production of broadleaf container forest tree seedlings are in need of development, as present methods are in many cases poorly refined and unable to provide optimal growing conditions. Application of horticultural methods to forest tree seedling production will likely accelerate this process. For example, overhead irrigation, which is typically used in hardwood seedling container production, results in salt buildup on foliage and low irrigation uniformity. Irrigating from below using flood irrigation may provide a viable alternative and ameliorate this problem.

Direct seeding

Direct seeding is an option that, while currently not extensively practiced, has potential. Direct seeding as a means of plantation establishment could reduce stresses related to outplanting. In addition to potential benefits realized in seedling establishment, the cost of transporting seed is lower than that of seedlings (Van Sambeek 2004). Bullard et al. (1992) found that on old-field sites in the southern United States the cost of direct-seeding oak was approximately 1/3 of those of planting seedlings and that given proper stand management there would be no benefit of planting seedlings over direct seeding.

Direct-seeding operations typically involve broadcasting large volumes of seed across the area designated for reforestation (Johnson 1981, 1983). Disadvantages associated with the direct seeding of black walnut include unpredictable germination and seed predation (Van Sambeek 2004). Germination of seed prior to sowing resulted in successful plantation establishment with uniform spacing and survival rates > 90% (Jacobs and Severeid 2004). Further, Mullins et al. (1998) found no significant difference in height or diameter of bareroot, containerized or direct-seeded cherrybark oak (*Quercus falcata* Michx. var. *falcata*) seedlings five years after planting. However, not all attempts have been successful, with mixed results reported for direct-sown black walnut having somewhat poorer performance, which has been attributed to poor germination and growing conditions in the field (Robison et al. 1997).

Early Stand Silviculture

Plantation establishment

Typically, plantations in the CHFR are established late-winter through early spring (Selig et al. in review). The majority of seedlings are planted using a tractor-hauled coulter with trencher and packing wheels (Figure 1). This method is well suited to seedlings with large root systems and relatively uniform and pliable soil and site conditions. Faster planting rates, in some cases in excess of 1,000 trees per hour, have been reported for mechanical-planting (Thompson 1984; Wray 1997; Slusher 1999), compared to up to 500 trees per day for hand-planted sites (Wray 1997). Mechanical planting of this nature resulted in significantly higher survival and higher percentage of seedlings being free-to-grow than hand-planting in Indiana (Jacobs et al. 2004). This may have occurred due to less J-rooting and less exposure to drying conditions for mechanically planted seedlings.

Incorporating relatively new concepts, such as use of controlled release fertilizer at time of outplanting, into silvicultural operations may also help to improve plantation establishment success. In a study of three hardwood species, Jacobs et al. (2005) found that first-year height growth could be increased by as much as 52% with use of CRF.

Control of competing vegetation

Although commonly employed, mowing has not been identified as a substitute for subsequent chemical weed control of hardwood plantations (von Althen 1984). Herbicide application represents the most effective form of control of competing vegetation. In a study of 16 herbicide treatments on 9 commonly planted hardwood species, Seifert and Woeste (2002) found that there was a notable herbicide treatment × species interaction, but that in general herbicide application benefited seedling growth.

Figure 1. *Tractor-hauled coulter with trencher and packing wheels, also equipped for herbicide application.*

In an assessment of initial control of competing vegetation on abandoned agricultural fields in hardwood bottomlands Groninger et al. (2004) found that herbicide treatment benefited green ash (*Fraxinus pennsylvanica* Marsh.). However, soil tillage without herbicide application did not benefit seedling establishment. Correspondingly, Jacobs et al. (2004) found that herbaceous vegetation was taller and had greater percent cover when mechanical site preparation was practiced without a corresponding herbicide application. As well, Jobidon (1990) found that mechanical site preparation increased the diversity of herbaceous vegetation that subsequently re-colonized. Given the contribution of buried seed-banks to stand development, incorporation of old-field succession patterns into management planning may be beneficial (Groninger et al. 2004).

A minimum of a single application of herbicide during plantation establishment can vastly improve the likelihood of seedling survival (Baer and Groninger 2004). However, in many cases, such as for *Quercus* spp., it is important that minimum stocking levels are reached as a means of promoting seedling growth (Kruse and Groninger 2004). In some situations, this may involve allowing for volunteer tree species to contribute to stocking levels, and thus herbicide application may need to be altered accordingly.

Conclusions and Future Directions

There is a multitude of uses, in addition to timber production, for which landowners manage non-industrial private forest plantations in the Central Hardwood Forest region of the USA (Ross-Davis et al. in press). Developing quality seedlings and appropriate silvicultural treatments will help present landowners with effective management options for their land. As many plantations are established for wildlife or aesthetic purposes, it is important that foresters use all the tools available to maximize plantation establishment success and help meet landowner objectives.

Further research is needed to identify those site conditions and tending requirements that will ensure successful establishment, as well as determining the economic and ecological costs and benefits of this method for reforestation and afforestation. Tracking the long-term contribution of silvicultural treatments to plantation development will help to develop standards for future planting operations. Additionally, research into herbicides that are suitable for use with direct seeding (Willoughby et al. 2003) will lead to improved flexibility in field experimentation and ultimately in actual operational practice.

Improved seedling quality through more accurate grading standards, better understanding of the stresses associated with plantation establishment, and effective implementation of silvicultural treatments will improve plantation establishment success. Development of new technologies to produce higher quality seedlings and exploitation of genetically superior material will also benefit forestry in the region. Afforestation is an important component of forestry in the CHFR and must continue to help increase forest cover.

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