

Advances in Fertilization for Forest Regeneration

Douglass F Jacobs

Douglass F Jacobs is the Fred M. van Eck Professor of Forest Biology with the Hardwood Tree Improvement and Regeneration Center, Department of Forestry and Natural Resources, Purdue University, West Lafayette, IN 47907; E-mail: djacobs@purdue.edu

Jacobs, DF. 2014. Advances in Fertilization for Forest Regeneration. In: Wilkinson KM, Haase DL, Pinto JR, technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—2013. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-72. 3-5. Available at: http://www.fs.fed.us/rm/pubs/rmrs_p072.html

Abstract: Advancements in fertilizer products and application methods have led to improvements in reforestation and restoration productivity. Supplemental nutrition through fertilization is necessary to produce high quality nursery seedlings and is important to help overcome nutrient deficiencies on some field sites. Nursery nutrient loading is a relatively new technique that may be used to maximize seedling nutrient content; these nutrients may then be re-translocated (mobilized from old to new tissues [Salifu and others 2008, 2009a]) to support new growth following field planting. While effects on plant cold hardiness are a potential risk when applying high fertilization rates in fall, most studies have shown a positive relationship between nitrogen fertilization and frost resistance. Field fertilization using controlled-release fertilizer has also recently emerged as an effective means of stimulating early growth of planted trees. Increased browse susceptibility of field-fertilized trees is a valid concern, but responses are species-specific and past research has mainly focused on broadcast applications of immediately available fertilizer. Future research examining targeted root zone application of controlled-release fertilizer across more silvicultural systems may continue to provide important new insight into the relationship.

Key Words: controlled-release fertilizer, nitrogen, nutrient loading, nursery propagation, seedling quality

Introduction

This paper presents an overview of recent research by the Hardwood Tree Improvement and Regeneration Center (HTIRC) at Purdue University and elsewhere to examine new techniques in fertilization for reforestation and restoration. Much of the HTIRC's work has focused on hardwood species, although some projects have examined responses of conifers. Many of the discoveries and advances in regeneration technologies made over the last several decades with conifers have since been tested for a diverse group of temperate deciduous species in eastern North America including oaks, walnuts, chestnut and cherry (Jacobs 2011). This paper covers a brief overview of why and when to fertilize, the concept of nursery nutrient loading and its application to hardwoods, the influence of nutrient loading on seedling cold hardening, recent advances in fertilization at field planting, and the influence of fertilization on browse susceptibility.

Why and When to Fertilize?

Following germination, most forest trees quickly deplete nutrients stored in seeds and must rely upon nutrient taken up from the soil. Many basic plant physiological processes depend upon adequate plant nutrient levels, and nutrient-deprived seedlings generally have reduced photosynthesis, grow poorly, and are more susceptible to stresses. Thus, quality of seedlings grown in nurseries depends strongly on provision of supplemental nutrition. Large, nutrient rich seedlings usually establish better in the field, especially under harsh site conditions characteristic of many forest restoration projects (Villar-Salvador and others 2012). As expectations for reforestation productivity continue to rise, fertilization at or soon after planting is also increasingly used to overcome site limitations especially when the goal is to maximize fiber production (Fox

2000). For these reasons, fertilization has long been a part of nursery propagation and silvicultural management in the field; technological advances over the last several decades have made fertilization programs more commonplace and efficient (Jacobs and Timmer 2005; Haase and Jacobs 2013).

Nutrient Loading of Nursery Stock

Introduced in the late-1990s, nursery nutrient loading has been studied extensively with boreal conifers and relies upon the premise that fertilization inputs should be matched to plant demand by exponentially increasing supply over the course of the growing period (Timmer 1997). As detailed in Salifu and Jacobs (2006), the goal of nutrient loading is to maximize plant nutrient (i.e., nitrogen) content by fertilizing at a level that promotes luxury nutrient uptake without causing toxicity. This is done most effectively through exponential increases of fertilizer supply, which helps to improve fertilizer use efficiency and decrease nutrient leaching (Dumroese and others 2005).

This practice has recently been studied for hardwoods in the Central Region of the U.S., which are usually produced in bareroot nurseries and characterized by survival rates around 65% (Jacobs and others 2004). Many hardwood seedlings are also planted onto relatively harsh sites, such as those being reclaimed after mining operations. We have shown that exponential fertilization can be successfully applied to nursery propagation of container (Salifu and Jacobs 2006) and bareroot (Birge and others 2006) seedlings. These stored nutrients may then be re-translocated to support new growth following field planting (Salifu and others 2008; 2009a), which may enhance field performance (Salifu and others 2009b). Increased nutrient storage in nutrient loaded trees along with demonstrated improvements in fertilizer use efficiency through exponential fertilization have prompted some operational nurseries to begin using this fertilization technique.

Nutrient Loading and Cold Hardening

One potential concern of nutrient loading via high rates of fertilizer application late in the growing season is that seedlings may not adequately harden prior to exposure to fall frost. Research results concerning effects of fertilization on frost hardiness of forest trees vary widely, but a recent review of about 50 papers published since 1990 examining responses of plants (i.e., mainly forest trees) reported that the positive effects of nitrogen for plant frost hardiness exceeded the negative effects (Taulavuori and others 2014). Responses varied largely on nutrient supply, nitrogen source, and tissue nitrogen concentrations. We examined red pine (*Pinus resinosa*) cold hardiness in response to fall fertilization with a wide range of ammonium nitrate rates (Islam and others 2009). In support of the aforementioned trend, seedlings fertilized at the highest rate (89 kg N ha^{-1} [79 lb N ac^{-1}]) had greater cold tolerance than those fertilized at 0 or 11 kg N ha^{-1} (9.8 lb N ac^{-1}). Thus, while knowledge of late-season fertilization is still incomplete, nutrient loading is unlikely to negatively effect cold tolerance if done with informed caution.

Fertilization at Planting

Field fertilization provides another means of alleviating nutrient deficiencies in forest trees during the plantation establishment phase. Improvements in controlled-release fertilization technology allow for targeted application of fertilizer to seedling root systems (figure 1) and gradual fertilizer release for up to 2 years with a single application

(Jacobs and Timmer 2005; Jacobs and others 2005). This has been shown to improve early plantation growth in a variety of silvicultural systems. For example, fertilization with 60 g (about 2 oz) per seedling of a 15N-9P-10K (plus other macros and minors) 16-18 month release rate controlled release fertilizer increased first-year height and root-collar diameter growth by 52 and 33%, respectively, for three hardwood species on an afforestation site in Indiana (Jacobs and others 2005). Similarly, Sloan and Jacobs (2013) reported that 15N-9P-10K controlled-release fertilizer improved growth of white spruce (*Picea glauca*) and aspen (*Populus tremuloides*) compared to unfertilized controls on a mine reclamation site in northern Alberta. In this study, controlled-release fertilization produced equal or better responses to fertilization with a 20N-20P-20K immediately available fertilizer, but at 90-95% lower nitrogen application rates.

Fertilization and Browse Damage

Regardless of whether nutrient loading or field fertilization is used to enhance seedling tissue nutrient levels in forest regeneration programs, another potential concern is the possibility for increased susceptibility of fertilized trees to browsing. Burney and Jacobs (2013) recently reviewed the literature on this topic and concluded that while a generally higher likelihood of browsing occurs for fertilized trees, species-specific exceptions to this trend exist. For example, western red-cedar (*Thuja plicata*) preferentially allocates nutrient resources toward plant chemical defenses (e.g., terpenoids), which may actually



Figure 1. Targeted application of controlled-release fertilizer to the root zone of white spruce (*Picea glauca*) on a field planting site.

decrease likelihood of browsing for fertilized trees (Burney and Jacobs 2011; Burney and others 2012). Additionally, most past studies on this theme have used broadcast application of immediately available fertilizer, thereby increasing nutritional value not only for trees, but for all vegetation on the site (Burney and Jacobs 2013). Thus, future research with controlled-release fertilizer across more combinations of species and silvicultural systems may find that growth benefits could generally outweigh the negative impacts of browse.

References

- Birge ZKD, Salifu KF, Jacobs DF. 2006. Modified exponential nitrogen loading to promote morphological quality and nutrient storage of bareroot-cultured *Quercus rubra* and *Quercus alba* seedlings. *Scandinavian Journal of Forest Research* 21:306-316.
- Burney OT, Jacobs DF. 2011. Ungulate herbivory of regenerating conifers in relation to foliar nutrition and terpenoid production. *Forest Ecology and Management* 262:1834-1845.
- Burney OT, Jacobs DF. 2013. Ungulate herbivory of forest regeneration in relation to plant mineral nutrition and secondary metabolites. *New Forests* 44:753-768.
- Burney OT, Davis AS, Jacobs DF. 2012. Phenology of foliar and volatile terpenoid production for *Thuja plicata* families under differential nutrient availability. *Environmental and Experimental Botany* 77:44-52.
- Dumroese RK, Page-Dumroese DS, Salifu KF, Jacobs DF. 2005. Exponential fertilization of *Pinus monticola* seedlings: nutrient uptake efficiency, leaching fractions, and early outplanting performance. *Canadian Journal of Forest Research* 35:2961-2967.
- Fox TR. 2000. Sustained productivity in intensively managed forest plantations. *Forest Ecology and Management* 138:187-202.
- Haase DL, Jacobs DF. 2013. Nutrient dynamics of planted forests. *New Forests* 44:629-633.
- Islam MA, Apostol KG, Jacobs DF, Dumroese RK. 2009. Fall fertilization of *Pinus resinosa* seedlings: nutrient uptake, cold hardiness, and morphological development. *Annals of Forest Science* 66:704.
- Jacobs DF. 2011. Targeting hardwoods. In Riley, L.E., Haase, D.L., and Pinto, J.R., technical coordinators. *National Proceedings: Forest and Conservation Nursery Associations-2010*. USDA Forest Service Rocky Mountain Research Station Proceedings RMRS-P-65:115-120.
- Jacobs DF, Timmer VR. 2005. Fertilizer-induced changes in rhizosphere electrical conductivity: relation to forest tree seedling root system growth and function. *New Forests* 30:147-166.
- Jacobs DF, Ross-Davis AL, Davis AS. 2004. Establishment success of conservation tree plantations in relation to silvicultural practices in Indiana, USA. *New Forests* 28: 23-36.
- Jacobs DF, Salifu KF, Seifert JR. 2005. Growth and nutritional response of hardwood seedlings to controlled-release fertilization at outplanting. *Forest Ecology and Management* 214:28-39.
- Salifu KF, Jacobs DF. 2006. Characterizing fertility targets and multi-element interactions for exponential nutrient loading of *Quercus rubra* seedlings. *Annals of Forest Science* 63:231-237.
- Salifu KF, Apostol KG, Jacobs DF, Islam MA. 2008. Growth, physiology, and nutrient retranslocation in nitrogen-15 fertilized *Quercus rubra* seedlings. *Annals of Forest Science* 65:101.
- Salifu KF, Islam MA, Jacobs DF. 2009a. Retranslocation, plant and soil recovery of nitrogen-15 applied to bareroot *Juglans nigra* seedlings. *Communications in Soil Science and Plant Analysis* 40:1408-1417.
- Salifu KF, Jacobs DF, Birge ZKD. 2009b. Nursery nitrogen loading improves field performance of bareroot oak seedlings planted on abandoned mine land. *Restoration Ecology* 17:339-349.
- Sloan JL, Jacobs DF. 2013. Fertilization at planting influences seedling growth and vegetative competition on a post-mining boreal reclamation site. *New Forests* 44:687-701.
- Taulavuori K, Taulavuori E, Sheppard LJ. 2014. Truths or myths, fact or fiction, setting the record straight concerning nitrogen effects on levels of frost hardiness. *Environmental and Experimental Botany*. <http://dx.doi.org/10.1016/j.envexpbot.2013.12.022>.
- Timmer VR. 1997. Exponential nutrient loading: a new fertilization technique to improve seedling performance on competitive sites. *New Forests* 13: 279 – 299.
- Villar Salvador P, Puértolas J, Cuesta B, Peñuelas Rubira J, Uscola, M, Heredia-Guerrero N, Rey Benayas JM. 2012. Increase in size and nitrogen concentration enhances seedling survival in Mediterranean plantations. *Insights from an ecophysiological conceptual model of plant survival*. *New Forests* 43:755–770.