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Using Stable Isotopes to Trace Nitrogen Fertilizers in Forest Plantations

Aerial fertilization of loblolly pine plantation in the southern United States. CAFS researchers have demonstrated that use of enhanced efficiency nitrogen fertilizers can reduce volatilization losses by 15% which could save forest industry at least $15 million annually. Photo courtesy of CAFS member Thrash Aviation.

The growth of many forest plantations is limited by the amount of nitrogen available in forest soils. Researchers at the CAFS have demonstrated that forest productivity can be substantially enhanced by fertilization with enhanced efficiency nitrogen fertilizers. These enhanced efficiency fertilizers reduce losses due to nitrogen volatilization and can thus improve the crop tree uptake efficiency. This breakthrough provides foresters a new tool that can be used to improve growth and sustainability of forest plantations.

This research has increased understandings of the fate of applied nitrogen and the fundamental processes controlling nitrogen transformations in forest ecosystems. Researchers have finally determined how much of the fertilizer nitrogen was taken up by the trees and the understory vegetation, as well as how much was retained in the forest floor and the soil at each site.

Fertilization with nitrogen can be used to increase the growth and productivity of forest ecosystems that commonly grow on relatively infertile soils. Urea is the most frequently used nitrogen fertilizer. However, recent advances in fertilizer technology have produced enhanced efficiency nitrogen fertilizers that may be more effective and have less environmental impacts than urea. In this research, CAFS scientists compared three different types of enhanced efficiency fertilizers with urea to determine how effective they are when used in forestry. They studied three of the major types of forests in the United States: loblolly pine in the South, Douglas fir in the Pacific Northwest, and walnut in the Midwest.

Results demonstrate that enhanced efficiency fertilizers can be used to reduce volatilization losses following nitrogen fertilization in forest ecosystems and that the majority of the nitrogen added to the ecosystem in the fertilizer remains. This nitrogen may be available to be taken up by the trees through time and may lead to continued growth increases.

These findings will enable foresters and land managers to more efficiently apply nitrogen fertilizers in forests. This will decrease the amount of fertilizer needed to achieve a given level of growth, which will increase financial returns and help increase the competiveness of the US forest industry. It will also reduce negative environmental impacts of forest fertilization because the precise amount of fertilizer needed can be applied to forests.

Economic Impact: This breakthrough will lead to improved forest productivity and more efficient use of high cost nitrogen fertilizer. It will enable forest managers to optimize growth and minimize potential environmental impacts from excessive fertilizer use. Society will benefit from increased productivity of plantation forests (more wood from less land) with less environmental impacts. Over the last 10 years, forest industry in the southern United States has fertilized between 800,000 and 1,500,000 acres of pine plantations annually to ameliorate nutrient deficiencies and increase forest productivity and growth. Based on 2013 fertilizer prices, forest fertilization in the South currently costs around $125/acre. This translates into annual investment by forest industry of between $100 to $187.5 million. This work by CAFS scientists has shown that losses from nitrogen volatilization can be reduced by around 15%. This is allowing forest managers to apply 15% less fertilizer and still obtain the same growth response following fertilization. If enhanced efficiency fertilizers were used on all acres fertilized in the South, this could save the equivalent of $15 to $28 million in fertilizer nitrogen lost through volatilization annually.

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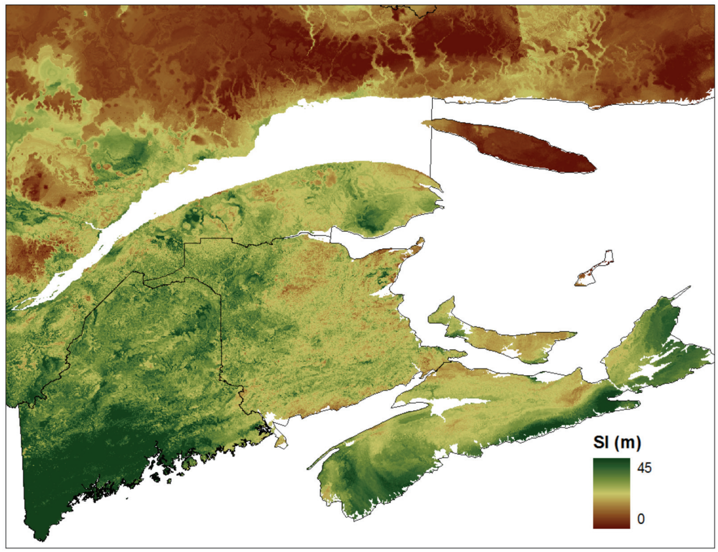
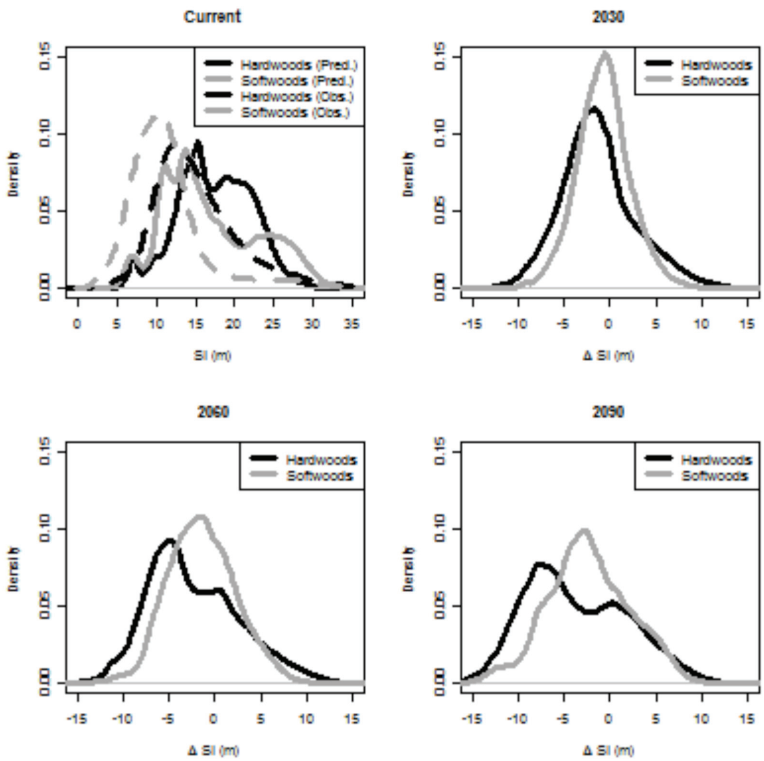
Refinement of Growth and Yield Models for Naturally-Regenerated, Mixed-Species Stands

Forest growth models are widely used by forest managers and researchers to forecast future growth, update forest inventory information, and assess alternative forest management strategies. Growth models are also used to test hypotheses about future tree growth and mortality patterns. Currently used computer simulation models across the Northeastern United States typically show significant biases. Because of these biases, improved growth and yield tools have recently become a top research priority by Maine's industrial forest landowners. This CAFS project has developed a computer simulation tool that better reflects present-day forest conditions and can more accurately represent alternative forest management regimes across the Northeast.



Map of current climate-derived "value of site" index (SI). Higher site indices are generally associated with higher forest productivity. The SI is a driving factor in several forest growth models like the one described here. SI is also used to stratify forestland ownership, develop forest inventory programs, and evaluate forestland values, all of which influence forest management decisions.

Compared to plantations, growth and yield models for naturally regenerated, mixed-species stands have received relatively little attention. This project also provides a tool that can be used by forest managers in a variety of settings. First, this model uses data generated from diverse sets of stand conditions and forest management regimes (>3 million observations are typical). Second, it is specific enough to predict individual tree growth in the complex mixed-species stands that comprise much of the Northeast. As a result, outputs are flexible enough to account for varying forest types and stand histories. Third, this project uses model-fitting techniques that are capable of flexibly accounting for dynamic growth patterns. At the same time, alternative measures of site productivity are being tested to find out which measures best correlate to and model forest growth. Finally, similar models are being developed to accurately represent common forest management practices such as thinning, an attribute that existing models lack.



Current observed and predicted, as well as projected future change, in climate site indices (SI; m) for both hardwood and softwood species based on several downscaled global circulation models (GCM). On average, softwood species will limit change in the site index, while hardwood species are projected to decrease over the coming decades.

Economic Impact: Forest growth models allow landowners to forecast future wood supply and evaluate management alternative. As a result of this research, there has been substantial external financial and database support from CAFS member organizations for developing and testing of this new model. The reason for this strong support from the forest industry is that prediction bias for net stand basal area growth with the current Forest Vegetation Simulator Northeast Variant (FVS-NE) model is 10.7% per year of projection. Assuming a conservative board foot volume to basal area ratio of 50, this represents nearly 84 bdft/ac/yr of bias. If we multiply that across the 8.3 million acres represented by our CAFS members and using an average stumpage value ($120/Mbdft) for spruce-fir sawlogs, this represents a $83.6 million prediction error that must be born annually by the Maine forest industry alone. The CAFS modeling efforts have reduced this bias by over 75%. In addition, a useful forest science spin-off in the development of Acadian Variant of FVS was the production of a high-resolution map of current and future potential forest site productivity for the Acadian region (images above). Such maps have a number of ecological and management applications. They are currently being used for forest sampling stratification and forest management planning by several CAFS members.

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Predicting the Quality Value of Fast Grown Wood

A managed planation forest.

CAFS researchers at the University of Georgia have been dissecting trees and analyzing the wood grown throughout the South under the range of forest management intensities and have put their findings into prediction models that can predict wood density, stiffness, and strength. Most importantly, they have integrated these wood quality predictions into the growth and yield models foresters use for evaluating volume gains from advanced genotypes and intensive silvicultural treatments such as weed control, thinning, and fertilization. This allows wood growers, for the first time, to incorporate the quality of wood in their planning along with the quantity of wood. Results are helping sponsors to better understand wood quality impact on forest product mix. Large timberland owner such as Plum Creek need to understand value of wood that is grown as it relates to their customers' needs. This work is a breakthrough because it enables direct predictions of value along with volume, linking the tree grower with the wood buyer and the lumber manufacturer.

Over the last two decades foresters have dramatically increased growth rates and yields of the South's forests through intensive plantation management (advanced forestry systems). What is the quality of this fast grown wood compared to historic wood products? Until now that question has either been avoided or addressed with very limited data and a good bit of speculation. Forest landowners rely on long term forecasting models of forest growth and yield as they plan these intensive management regimes. Traditional forecasting models predict the timber volumes but do not take into account important qualities of the wood produced, such as lumber stiffness and strength. Wood growers currently do not have good understandings of the quality of the wood they are growing. There has been no region-wide consensus among wood growers on how to manage for wood quality, nor is there a broad understanding among wood products manufacturers about the value of trees grown in different ways.

Economic Impact: This outcome of this project will improve how timber is grown and marketed, because it will allow wood quality and value to be factored into the long term forest management decisions. This in turn will help manufacturers better market their products to end-users. It will result in more competitive pricing for timber based on wood quality. It should also dispel myths about plantation grown wood that have negative market impacts and could improve sales of the products. By factoring wood quality into silvicultural decisions, growers may increase the proportion of high quality sawtimber by 25% or more. This could mean gains in value at harvest of $1000 or more per acre; that could easily reach $1 billion in new value annually across the South.

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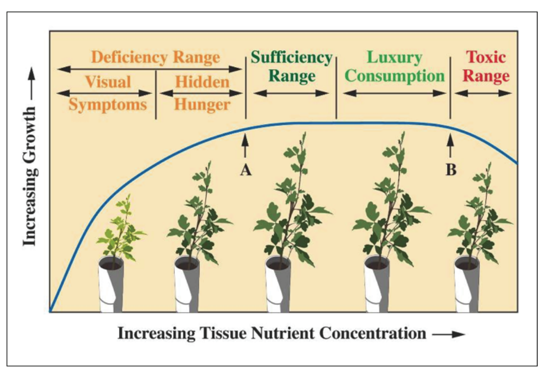
Exponential Nutrient Loading

A new approach referred to as "exponential nutrient loading" has been developed by researchers at CAFS to pre-condition black walnut grafts in the greenhouse for field planting. The technique increases the morphological and nutritional quality of grafted plants, as well as stores nutrients in roots for later utilization to benefit early plantation establishment success. This protocol, allows for a higher growth rate of the grafts in their first year after planting in the field. Black walnut grafts that have been grown exponentially will be used in intensively cultivated plantings. In intensive cultivation, this is important because the response to fertigation and weed control is higher and rotation age will be decreased, which brings substantial financial benefits. In extensive cultivation, the rapid growth and competitiveness exhibited by exponentially nutrient loaded grafts will accelerate plantation growth to reach free-to-grow status sooner, which increases the chances of crops escaping damage from animal browsing and weed competition. Intensively cultivated clonal black walnut plantings are currently being offered as a financial opportunity for long-term investors.

*Northern red oak (*Quercus rubra*) seedlings that were subjected to a fertilizer dose response trial to maximize nitrogen (N) storage for use in subsequent field planting. While sufficiency was detected at 25 mg N per plant, luxury consumption occurred thereafter and so optimum N uptake occurred at 100 mg N per plant. This trial demonstrated how exponential nutrient loading, which has been previously studied for conifers, can also be applied to hardwood regeneration systems.*

Exponential nursery nutrient loading of forest trees utilizes the concept of luxury consumption whereby with increasing nitrogen (N) fertilization, tissue nutrient concentration increases in a linear manner. However, plant growth (or biomass) increases to Point A (sufficiency), beyond which luxury nutrient consumption occurs and plants continue to accumulate N reserves until Point B (optimum), beyond which toxicity occurs. The optimum fertilization rate allows for maximum storage of N to be used in subsequent field planting. Illustration credit: Thomas D. Landis



Economic Impact: In the past 10 years, forest cover has increased by 300,000 acres. Many of these acres are populated with trees produced with this new technology. This method makes possible a two-year reduction in the long-term production cycle or a 6% increase in return on investment. Based on today's prices for black walnut timber, this new method of tree production is increasing the profitability of one CAFS corporate partner by an estimated $8 million over the expected production rotation period. This corporate partner employs over 50 staff annually. The increased profitability allows the company to maintain its current level of employment. This technology has been adopted by a number of large public nurseries. It is increasing their competitiveness by allowing them to sell higher quality products and thus stay more competitive in the current recessionary market. Consumers who buy these products from public nurseries experience increased success in plantation establishment and increased return on their investment.

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Precocious Flowering in Populus

Trees have not been domesticated to the same extent as agronomic row-crops because of their extended juvenile periods. Moreover, significant amounts of sugars fixed as a result of photosynthesis are diverted away from vegetative growth (e.g., stems, branches, roots, and leaves) to form reproductive structures (e.g., cones, flowers, seeds, etc.) after trees have undergone the transition to maturity.

CAFS scientists now have a variety of effective model systems for testing flower-control constructs, without having to conduct lengthy, expensive field trials.

Federal regulators have made it clear that a transgene confinement system is likely to be needed before genetically engineered trees can be deployed commercially. CAFS researchers are attempting to genetically engineer flowering control as a way to satisfy this requirement.

In order to test the efficacy of the genetic constructs inserted in the poplar genome for their ability to affect floral development, researchers must wait for plants to acquire the competence to produce flowers. The long delay before the onset of flowering in poplars (they have a juvenile period of five to seven years) and their resistance to various conventional flower-induction treatments have been serious impediments to engineering sterility. CAFS researchers obtained a genotype of *Populus alba* from the University of Tuscia (Viterbo, Italy) that flowered nine months from when the seed was sown. Vegetative propagules from this line remained true to type (i.e., they flowered in nine months). However, this genotype had to be regenerated in vitro and grown under aseptic conditions before it could be imported into the United States. The regeneration process caused this genotype to lose its ability to flower early. CAFS researchers experimented with a variety of inductive treatments and discovered one that restored the early-flowering phenotype. Center researchers have also obtained a genotype of *Juglans regia* that is capable of producing flowerings on nine-month-old plantlets and have identified conditions required to induce flower formation on *Prunus serotina* grown in vitro.

Economic Impact: It is estimated that annual value of the United States poplar industry is about $300 million. Poplars are grown for fiber to manufacture paper, window and door casings, moldings, pallets, core stock for plywood, and, increasingly, as a feedstock for biofuel production. Through better understandings of the process by which trees control the onset of flowering, it may be possible switch flowering on or off at will, through genetic engineering. This will shorten breeding cycles. This will allow for more rapid selection of trees that produce more biomass and are resistant to various biotic and abiotic stresses, thus minimizing economic losses and increasing profits. Preventing flowering allows for more photosynthate to be used for vegetative growth. Because there are so many tree species grown for a diverse range of products, it is difficult to quantify the benefits associated with this technological advance.

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