Can Enhanced Efficiency Fertilizers Affect the Fate of Nitrogen in Loblolly Pine Plantations?

By Jay Raymond, Thomas Fox and Brian Strahm

Field experiments with isotopically labeled fertilizer N in managed loblolly pine (*Pinus taeda* L.) forests across the southern U.S. showed total soil and tree system N recovery ranged from 58 to 100% the first year after fertilization. The forest floor still contained 40 to 80% of the applied N at the end of the first year. Volatilization losses were less with enhanced efficiency N fertilizers compared to urea.

Forests in the United States provide a multitude of functions and services for society including clean water and air, wood and food products, wildlife habitat, and a variety of recreational opportunities. Forests are also providing an increasing supply of the raw materials needed to meet the demands of the emerging bioenergy industry. How forests are managed to meet these competing demands and interests is a fundamental question facing society in the 21st century (Sedjo, 1997).

Most forests in the U.S. are extensively managed with minimal silvicultural inputs. In these systems productivity is relatively low, with growth rates averaging around 2 to 3 m^3/ha/yr for southern pine—a rate insufficient to sustainably produce the raw materials required to support the competing interests of the existing forest products, the expanding bioenergy industries, and additional societal values. More intensively managed forest plantation systems, producing up to 10 to 12 m^3/ha/yr, will be required to sustainably supply the increasing demand for raw materials (Fox et al., 2007a). Theoretical models, empirical field trials, and operational experience indicate that growth rates in loblolly pine plantations exceeding 20 m^3/ha/yr with stand rotations of less than 15 years are biologically possible, financially attractive, and environmentally sustainable in the southern U.S. (Fox et al., 2007b)

Dramatic gains in growth can be obtained when intensively managed forest plantations are treated as agro-ecosystems, and site-specific silviculture prescriptions that ameliorate growth-limiting factors are implemented. Most forest plantations in the southern U.S. are established on relatively infertile soils with chronically low levels of available soil nutrients such as N and P that limit growth. Low nutrient availability restricts leaf area production, the main factor driving photosynthetic capacity and growth. Results from fertilization trials in loblolly pine stands indicate that most nutrient limitations can be easily and cost effectively ameliorated with fertilization. The growth response to a combination of 224 kg N/ha plus 60 kg P_2O_5/ha averages 3 m^3/ha/yr for an 8-year period (Albaugh et al., 1998). Fertilization is a common silvicultural treatment used to increase tree growth on over 400,000 ha of loblolly pine plantations annually.

The precise fate of applied fertilizer N incorporated into crop trees, and within the general forest system, is not well understood. Only a small proportion (10 to 25%) of fertilizer N applied to forest plantations is taken up by the tree crop. The remainder of the fertilizer N is either "tied up" in other ecosystem components (soils, competing vegetation, litter, etc.) or lost (gaseous losses, leaching). The low rate of N uptake by the crop trees decreases the returns from investments. A better understanding of the fate of applied N fertilizer in plantation forests is needed to improve economic returns from investment in fertilization and to reduce negative environmental impacts.

Abbreviations and Notes: N = nitrogen; P = phosphorus; NH_3 = ammonia; NBPT = N-(n-butyl) thiophosphoric triamide, MAP = monoammonium phosphate, PCU = polymer coated urea.

Loblolly pine plantation that is extensively managed (top) compared to a plantation that is intensively managed (bottom).

Comparison of Urea and Enhanced Efficiency N Fertilizers

Enhanced efficiency N fertilizers (EENFs) are often used in agronomy to increase fertilizer N uptake, but urea is almost exclusively used as the N source in forest fertilization. This research was initiated to compare the uptake efficiency and environmental fate of N from urea and EENFs applied to loblolly pine plantations in the southern U.S. Urea was compared with three different EENFs: NBPT (urease inhibitor) treated urea (NBPT); MAP-coated urea treated with NBPT (CUF), and polymer-coated urea (PCU).

It is often difficult to precisely determine the amount of N taken up from fertilizer in forests because a large proportion of the N in the tree is obtained from the native soil N pool. To accurately quantify the amount of N in the crop trees derived from the applied fertilizer N, fertilizer enriched with stable isotopes of N (^{15}N) can be utilized. This technique enables researchers to separate the N derived from soil from that obtained from the fertilizer. Stable isotopes have been used in agriculture and forestry research for several decades, but are usually confined to laboratory or smaller scale experiments due to the significant cost of producing ^{15}N labeled fertilizers. This study employed ^{15}N enriched fertilizers applied to large field plots in loblolly pine plantations to determine N losses through volatilization and N uptake in the trees. The four different ^{15}N enriched fertilizer N sources: (Urea, NBPT Treated Urea, MAP Coated Urea + NBPT; and Polymer Coated Urea) were applied at a rate of 224 kg N/ha to 100 m^2 circular plots mid rotation (approximately 10 to 12 years old) in loblolly pine plantations at 18 sites in the southern U.S. Six sites were installed in 2011 and 12 sites were installed in 2012. At the sites installed in 2011, the fertilizers were applied to separate plots at two different times (late winter and summer). In 2012, the fertilizers were applied during the late winter only. To better understand N losses through volatilization, a microcosm experiment was established adjacent to the plots installed during 2011, which eliminated root uptake so that gaseous N losses could be determined based on ^{15}N recovery in the microcosm through time. To assess fertilizer ^{15}N uptake by the crop trees during the growing season, foliage was collected every six weeks at the 2011 sites, and during the middle of the growing season for the 2012 sites. At the end of the first growing season after fertilization, a biomass harvest was conducted at all sites to determine the amount of applied ^{15}N present in the ecosystem using a mass balance calculation approach. The major components (crop tree, litter, understory and overstory competition, forest floor, mineral soil, etc.) at each site were collected and returned to the laboratory to determine N content (%) and ^{15}N (‰) for each sample using an IsoPrime 100 EA-Isotope Ratio Mass Spectrometer (IRMS). The ^{15}N that could not be accounted for in the mass balance for each plot was assumed to be lost from the system through NH_3 volatilization, leaching from the soil profile, or some other form of loss.

Preliminary Results

The preliminary results from one of the studies located at the Appomattox-Buckingham State Forest in the Piedmont of central Virginia are summarized. Recovery of applied ^{15}N from the microcosm experiment was used to determine NH_3 volatilization and N leaching from the soil profile. Greater ^{15}N recovery rates were observed from all EENFs compared to urea after both late winter and summer fertilizer applications (**Figure 1**). The ^{15}N recovery rates for the late winter fertilization ranged from 93 to 100% after Day 1 for the EENFs compared to 80% for Urea. After 15 days, the recovery rates for the EENFs ranged from 75 to 90% whereas urea was 73%. After 30 days, the recovery rates for EENFs ranged from 64 to 77%, whereas urea was 59%. The ^{15}N recovery rates for the summer fertilization were slightly lower for Day 1 compared to late winter fertilization. The recovery rates for EENFs ranged from 85 to 94% after Day 1 whereas urea was 76%. After 15 days, the recovery for EENFs was 88 to 89% compared to urea, which was 60%. On Day 30, the EENFs recovery ranged from 70 to 88% and urea was 45%. These initial results indicate less N is being lost through NH_3 volatilization from EENFs when compared to urea, after both later winter and summer fertilization.

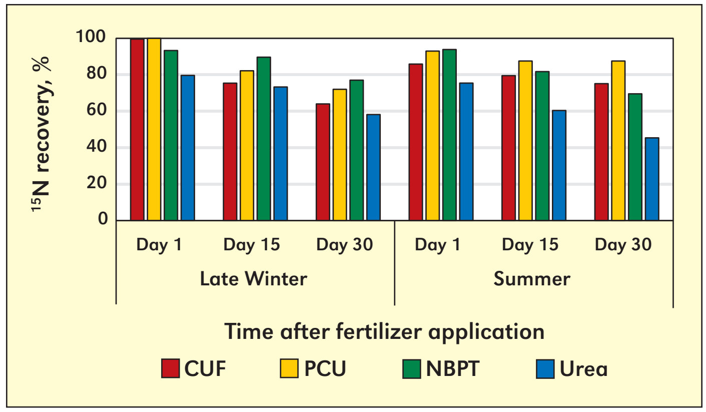


Figure 1. The percentage of ^{15}N enriched fertilizer recovered after 1, 15, and 30 days at a site in the Piedmont of central Virginia.

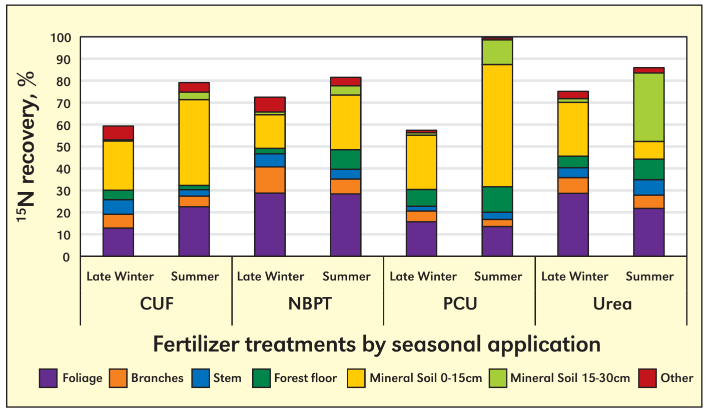
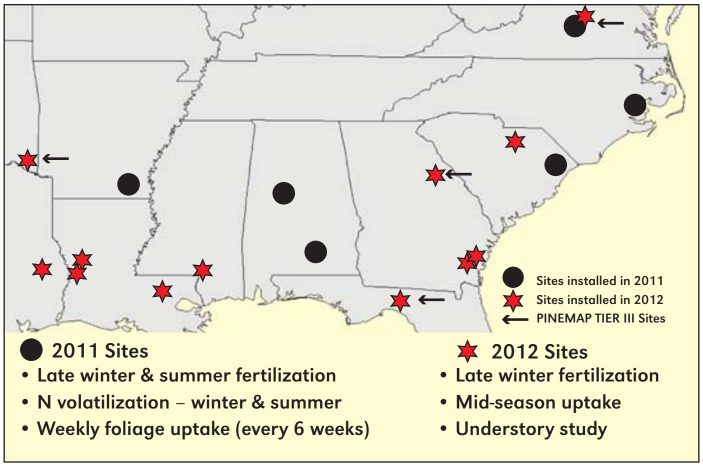


Figure 2. The percentage of ^{15}N enriched fertilizer recovered at the end of the first growing season after a spring and summer fertilization at a site in the Piedmont of central Virginia.

Total recovery following late winter fertilization ranged from 57 to 75% for all fertilizers (**Figure 2**). Summer fertilization recovery rates were slightly higher, ranging from 80 to 100%. The largest pool of ^{15}N in the loblolly pine was the foliage. Between 13 and 29% of the applied fertilizer N was in the foliage following both late winter and summer application. Total uptake in the crop trees including foliage, branches and bolewood ranged from a low of 20% in the PCU treatment after the late winter application to a high of 40% in the NBPT treatment after winter application. The majority of the ^{15}N was located in the top 15 cm of the mineral soil. The surface 15 cm of mineral soil contained between 15 and 25% of the fertilizer



Map of ^{15}N site installations.

N applied in the late winter and 8 to 55% of the fertilizer N applied in the summer. In all the treatments, between 40 and 80% of the applied fertilizer N was still in the forest floor or the mineral soil one growing season after fertilization. This residual N may continue to be available for uptake by the crop trees in subsequent years.

Summary

The preliminary results from this research indicate that volatilization losses following N fertilization were less when EENFs were applied compared to urea. Differences in ecosystem N recovery and tree uptake were more variable. Between 20 and 40% of the applied fertilizer N was taken up by the crop trees during the first growing season. Overall, the majority of the applied N remained in the forest floor and the mineral soil. Total ecosystem recovery of applied N ranged from about 58 to almost 100%, with generally greater recovery following summer N applications compared to late winter applications. BC

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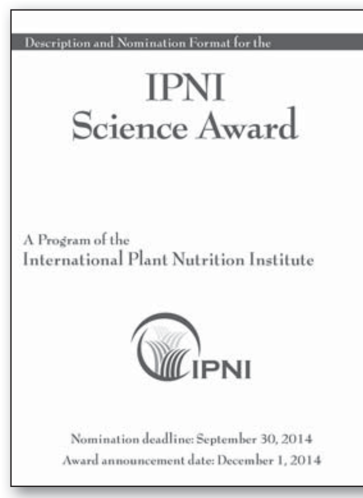
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