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# Determining soil nitrogen content in working forests

Trees need nitrogen to grow. If soil nitrogen levels are low, then growth is limited. The ability to accurately monitor the amount of soil nitrogen in a working forest is helpful for predicting future growth and for knowing when to take corrective action (fertilizer, altered management practices) when soil nitrogen levels decline.

Efforts to monitor soil nitrogen levels have traditionally focus on a soil depth within one meter. For instance, the USDA Forest Inventory and Analysis Program monitors soils to a depth of 0.2 meters. Studies, however, show that a substantial amount (7% to 35%) of soil nitrogen exists in all soil types below one-meter depth. In addition, conifers in temperate forests can extend their roots well below one meter (old growth Douglas-fir stands can extend roots ten meters below ground) and can therefore affect nitrogen cycling at lower depths. The nitrogen present at levels below one meter is often not accounted for in ecosystem assessments, and the lack of accounting may affect the accuracy of nitrogen pool and cycling measurements.

In order to quantify the amount of deep-soil nitrogen located in Pacific Northwest working forests, researchers led by Rob Harrison at the University of Washington surveyed 22 intensively managed Douglas-fir sites in Oregon and Washington. Trees at each site were at similar age and located in a region bounded by the Pacific Ocean and the Cascade mountains. The nitrogen level was recorded at varying soil depths (maximum depth at 2.5 meters) and total nitrogen content in the soil was compared to total nitrogen estimates based on shallow sampling. Their research was partially funded by the USDA-NIFA through NARA and recently published in the Forest Ecology and Management journal.

> Read Deep soil: Quantification, modeling, and significance of subsurface nitrogen here.

## Total nitrogen distribution

The amount of total soil nitrogen varied extensively between sites. The site with the most soil nitrogen contained ten times more total nitrogen than the lowest rated site. The sites represented a wide range of soil types. On average, the greatest concentration of soil nitrogen occurred between 0.1 and 0.5 meters; however, 31% of the total available nitrogen was present at a depth below one meter.

Based on the total nitrogen amounts determined from the 2.5 meter sampling, the authors note that shallow soil sampling (less than 1.0 m depth) would have underestimated soil nitrogen stocks, which could bias both the magnitude and direction of nitrogen movement.

## Equations to account for deep soil nitrogen

Determining the total nitrogen content from soil samples to a depth of 2.5 meters is often not practical due to time, budget, safety and logistical limitations. The authors therefore, tested various equations to project total nitrogen content based on nitrogen amounts from samples taken at a maximum depth of 1 meter and 1.5 meters. They then compared the projected results with total nitrogen based on samples collected up to 2.5 meters by applying the logarithmic function, Langmuir equation, log-log function and exponential function to extrapolate total

nitrogen content based on sample data. Models using the data from 1 meter sampling had a mean error across all 22 sites that ranged from -10.9% to -27.7% with the logarithmic function providing the closest estimation to the total nitrogen content established with the 2.5 meter sampling. Models using the data from 1.5 meter sampling reduced the mean error to -7.6% using the Langmuir equation.

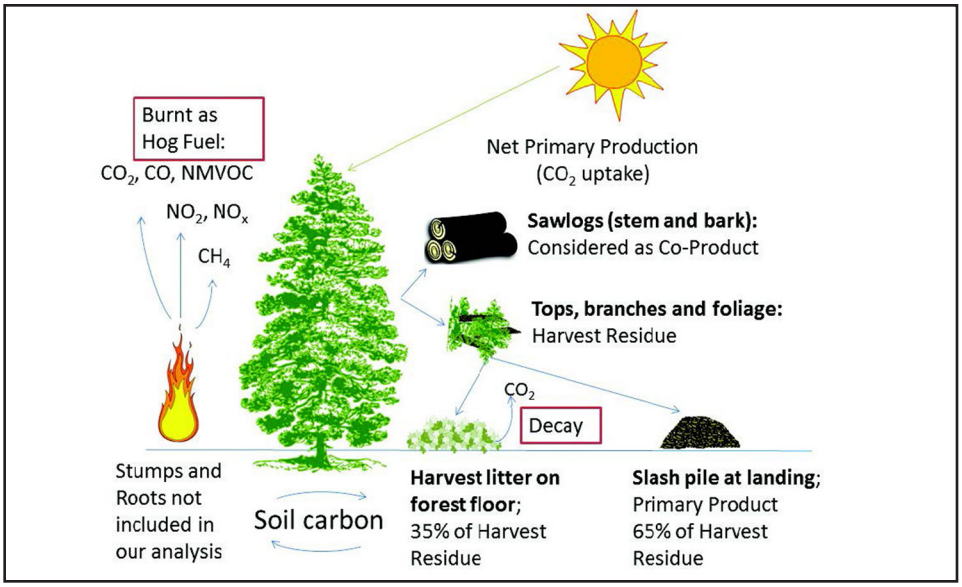
## Conclusion

This paper does four things: 1) quantifies the amount and relative distribution of nitrogen in the soil, 2) determines the effect of sampling depth on soil nitrogen estimates, 3) evaluates the ability for mathematical models to accurately predict total nitrogen at 2.5 meters based on shallower sampling to 1 and 1.5 meters, 4) assesses which soils are most important to sample deeply for nitrogen.

The results from this paper suggest that measuring total nitrogen based on surface soil samples can bias estimates. Measures used to determine total soil nitrogen should incorporate sampling to at least 1-1.5 meters in depth or as deep as possible. A statistically significant difference in total nitrogen was recorded all the way down to 2 meters; however, modeling total nitrogen with samples taken within 1-1.5 meters can produce reasonably accurate results.

If researchers desire a greater number of samples in space, then designing a limited subset of deep soil samples at each site/stand could maximize their capability to model deep soil nitrogen from their more shallow samples.

This research contributes well to NARA's efforts. Establishing accurate methods to monitor nitrogen levels in working forests is a critical step in evaluating the environmental sustainability of using forest residuals to produce biojet fuel and other co-products.




Representation of carbon balance in the working forest

# Determining $CO_2$ emissions over time

The USDA-NIFA, through NARA, funds research to determine the environmental impact from a wood-based biofuel and chemical industry. To gauge how this industry would affect greenhouse gas (GHG) levels, a life cycle assessment (LCA) is being developed. In this case, the net amount of air emissions generated from harvesting forest residuals through to product development, a span often referred to as "cradle to grave", will be determined. The results are used to compare the global warming impacts of one conversion process to another. For instance, NARA will compare the amount of greenhouse gas (GHG) emissions produced during the jet fuel production process from using forest residuals relative to petroleum. These comparisons weigh heavily in global strategies to reduce the level of GHG emitted into the atmosphere.

Calculating the net emission from an industrial process using woody biomass is complicated since $CO_2$ is being sequestered and released in the forest over a long time period. To address the temporal flow of $CO_2$ in a working forest, NARA researchers at the University of Washington and the University of Padua in Italy recently published an analysis that incorporates the temporal aspects of carbon sequestration within the LCA framework.

View Evaluation of environmental impacts of harvest residue-based bioenergy using radiative forcing analysis

## Study parameters

The composition of working forests and how they are managed vary, so the authors based their initial evaluation on a typical Pacific Northwest harvesting operation in Grays Harbor County, WA using a rotation age of 45 years. A whole tree harvesting method was employed where the felled tree is hauled to a landing before the limbs and tops are removed. The study assumes that 61% of the above ground biomass harvested is used for timber products (logs) and 39% is residual biomass (primarily, tops and branches). Further, the study bases its calculations on the assumption that one bone-dried metric ton (BDmT) of residual biomass at the landing site is derived from 1.7 BDmT of total residual biomass harvested. It was assumed that 0.7 (35%) of the 1.7 BDmT harvested tree remains on the forest floor or at the landing due to limbs breakage during harvest and hauling.

## Calculating net global warming

To maintain the focus on biomass-based bioenergy, all the carbon balance calculations in the study are based on the

residual biomass, and the carbon credits or debits associated with timber products (e.g., lumber) are excluded using mass allocations principles. The authors calculated the GHG outputs generated from the harvesting, processing and transporting of the forest residuals to a bioenergy refinery. They also calculated the rate of decay of the residuals left on the forest floor. It was assumed that over time 90% of the residuals decomposed and generated carbon emissions into the atmosphere while 10% decays into the soil. In addition, the emissions generated from burning the residuals to produce energy were determined.

These emission values were used to calculate the accumulated abundance of GHG (as $CO_2$ equivalents) over a 100-year time frame, which is the recommended time-frame set by the Intergovernmental Panel on Climate Change (IPCC) for the assessment of the impact on climate change. Over this time period, the working forest sequesters (takes up) $CO_2$, and these values are also incorporated into the assessment. When CO2 emissions and carbon sequestration are plotted on the same graph for a 100-year time frame, a "Radiative Forcing Turning Point" is obtained at year 18. At this point, the cumulative negative radiative forcing from $CO_2$ sequestration (i.e., global cooling) offsets the cumulative positive radiative forcing from $CO_2$ emissions (i.e., global warming). In other words, the system goes from being "carbon positive" and emitting carbon into the environment to "carbon negative" and storing carbon from the atmosphere. Addressing this result, the authors state, "This study shows that carbon sequestration plays a significant role in the carbon balance and demonstrates the environmental benefits of using woody biomass-based bioenergy."

## Conclusion

International standards allow LCAs to assume carbon neutrality, for global warming indicator calculations, as the $CO_2$ generated from burning wood-based products is offset by $CO_2$ sequestration within the forest. The concept of "carbon neutrality" contributes significantly to the favorable greenhouse warming potential calculated for wood-based biofuels compared to fossil-based fuels. This study introduces a temporal component to the carbon neutrality aspect of LCA and demonstrates the significance of forest management practices on net GHG emissions.

The authors acknowledge that this study does not account for the role of below-ground biomass and natural disturbances like fire in affecting the carbon balance. In addition, this study is based on a limited geographic area and not reflective of a larger more diverse region.


Multiple commercial uses for lactic acid include food preservation, cosmetics and as a precursor for biodegradable plastics.

# Slash removal and microbial communities

The USDA-NIFA, through NARA, funds research to help expand the array of commercial products produced using post harvest forest residues. Experiments to modify the lignin-rich component of wood residuals into activated carbon, epoxies, cement additives, thermoplastics and dicarboxylic acids are underway. Extensive research has also been applied towards converting the simple sugars in wood residuals into isobutanol. Alternative conversion technologies applied to the simple sugars are being explored to produce volatile fatty acids.

Lactic acid (LA) is another product that can be generated from wood-based sugars. The global demand for LA was 800,000 tons in 2013. LA can be used as a food additive and as a feedstock molecule for solvent and biodegradable container production. NARA researcher Dr. Birgitte Ahring and her team are developing methods to generate LA from cellulosic materials like crop and forest residuals. In a recently published peer-reviewed paper funded by NARA, they evaluate a fermentation system used to generate and remove LA from corn stover material.

> Read Performance and stability of AmberliteTM IRA-67 ion exchange resin for product extraction and pH control during homolactic fermentation of corn sugars here.

## Reducing product inhibition

Organisms like bacteria and yeast that live in a closed system (like a fermentation tank) can produce molecules that, at high concentration, become toxic. The hypothesis in this study was that high concentrations of LA would reduce bacteria's ability to produce LA and that the AmberliteTM IRA-67 resin could be used to bind and remove the LA and thus

reduce the concentration in the fermentation broth. The authors confirmed that when LA concentration in the fermentation broth exceeded 20 grams per liter, the rate of LA production was reduced dramatically. This result demonstrated a classic case of "product inhibition".

To reduce product inhibition, the authors designed a fermentation system from which AmberliteTM IRA-67 resin could be inserted and removed. By periodically removing and cleaning the resin from the fermentation broth, the bound LA could be removed from the system and devoted to commercial use while product inhibition is avoided.

The authors found that the AmberliteTM IRA-67 resin bound LA quite effectively when attached in series with a bacterial fermentation system feeding on wet exploded corn stover hydrolysate. Eighty-five percent of the molecules that bound to the resin were LA, while the remaining 15% consisted of acetic acid, ethanol and other organic molecules. In addition, the resin was cleaned and reused 11 times over the experiment's duration without a loss in binding efficiency for LA. After 25 days of using this system, a LA production rate of between 10 to 13 grams per liter was maintained. Through this continuous extraction of lactic acid from the fermentation broth using the resin, the bacterial productivity was found to increase by 1.3 times when compared to a regular batch fermentation process.

Establishing low cost, highly efficient biological systems to convert wood residuals into valuable chemical products will significantly enhance the economic sustainability in using post harvest forest residuals. This paper demonstrates a potential method that could be commercially viable for LA production.

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