

USER'S GUIDE

Controls Regulating Biological Nitrogen Fixation in Longleaf Pine
Ecosystems: the role of Fire and Stand Development

SERDP Project RC-2328

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Fire is critical for maintaining the structure and diversity of longleaf pine ecosystems, but it also removes a substantial amount of nitrogen, which is essential for plant growth. If longleaf pine depends on frequent fire, how is nitrogen replaced? The answer lies in the soil, where a select group of organisms carries out biological nitrogen fixation, the process where atmospheric nitrogen gas is converted to a usable form. Longleaf pine ecosystems hold a diverse group of these "nitrogen-fixers" including bacteria in leaf litter, biological soils crusts and herbaceous legumes that form a symbiotic relationship with soil bacteria.

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Forest Manager's Guide to Nitrogen Fixation in Longleaf Pine Ecosystems

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Fire is critical for maintaining the structure and diversity of longleaf pine ecosystems¹⁻³, but it also removes a substantial amount of nitrogen⁴, which is essential for plant growth. If longleaf pine depends on frequent fire, how is nitrogen replaced? The answer lies in the soil, where a select group of organisms carries out *biological nitrogen fixation*, the process where atmospheric nitrogen gas is converted to a usable form⁵.

Longleaf pine ecosystems hold a diverse group of these “nitrogen-fixers” including bacteria in leaf litter, biological soils crusts and herbaceous legumes that form a symbiotic relationship with soil bacteria (Figure 1). These nitrogen-fixers play an important role because they have the unique ability replace the nitrogen lost from fire and other disturbances.



Figure 1 Nitrogen-fixers in longleaf pine ecosystems include bacteria in leaf litter, soil crusts and herbaceous legumes. Photos: Nina Wurzburger and Shialoh Wilson.

How do nitrogen-fixers differ in their contribution to nitrogen fixation? In total, nitrogen fixation introduces 0.1-1 kilogram of nitrogen per hectare per year⁶. Legumes make the greatest contribution to this amount, followed by bacteria in leaf litter and soil crusts⁶. Leaf litter and soil crusts are most important in younger stands (< 20 years old) of longleaf and decline in their importance over stand age. In contrast, legumes are relatively consistent in their contribution to fixation over stand age.

What controls fixation by legumes? Legumes do not consistently fix nitrogen over time; they can turn the bacterial symbiosis on or off depending on their need for nitrogen^{7,8}. Because of this, the presence of a legume does not always equate to nitrogen fixation. Rather, the presence of root nodules – the structures that house nitrogen-fixing bacteria – is a diagnostic tool for determining if a plant is fixing nitrogen. At Fort Benning, 50% of legume individuals have nodules in sandhill sites, but at Eglin Air Force Base only 3% have nodules. Three factors help predict whether a legume is producing nodules and fixing nitrogen. First is species identity. Under controlled conditions, *Tephrosia virginiana*, *Mimosa quadrivalvis* and *Centrosema virginiana* tend to fix more nitrogen than other species, such as *Chamaecrista fasciculata*, *Desmodium floridanum* and *Lespedeza spp*⁷. Second is soil phosphorus. Legumes fix more nitrogen in

soils that have higher soil phosphorus availability. For example, the difference in legume nitrogen fixation between Fort Benning and Eglin Air Force Base sandhill sites is due to differences in soil

phosphorus⁶. Third is fire. Legumes fix more nitrogen when they experienced a fire within the last year⁶. All three of these factors affect the growth of legumes and their nitrogen demand, and therefore determines how much nitrogen it needs to fix.

Does nitrogen fixation balance losses of nitrogen from fire? Fire removes a substantial amount of nitrogen from the ecosystem (Figure 2), mostly from the combustion of organic matter on the



Figure 2 Longleaf pine stands following prescribed fire. Mature stands at Fort Benning (left) and Eglin Air Force Base (right). Photos: Nina Wurzbarger and Shialoh Wilson.

forest floor, but also from the combustion of understory vegetation. We estimate that an average of 33 and 17 kilograms of nitrogen per hectare per year are lost due to fire in sandhill longleaf stands at Fort Benning and Eglin Air Force Base, respectively⁶. The difference between sites is due to a higher fire frequency at Benning. In a stable ecosystem, we expect that nitrogen inputs from fixation are enough to balance the losses from fire⁹. Surprisingly, nitrogen fixation is much lower than what is necessary to balance fire nitrogen losses⁶. Even after accounting for nitrogen inputs from atmospheric deposition, there is still more nitrogen leaving the ecosystem than is coming in.

Is the nitrogen imbalance a cause for concern? While the nitrogen budget is imbalanced, only 0.1% of total ecosystem nitrogen is lost on an annual basis. In addition, the supply of available nitrogen (nitrogen mineralization) is very high, especially in young stands⁶ when compared to other temperate forest ecosystems¹⁰. This suggests that land-use history (e.g. agriculture, grazing or lack of prescribed fire) and mechanized site preparation (e.g., drum chopping) combined with chronic nitrogen deposition have led to an excess of nitrogen in longleaf pine ecosystems. In support of this idea, nitrogen fertilization did not stimulate longleaf pine growth at Benning or Eglin across stands that ranged from 5 to 227 years old. Longleaf pine are adapted to the nitrogen-poor conditions caused by frequent fire and sandy soils. Rather than fire causing concern for removing too much nitrogen, it seems more likely that fire is serving as a “relief valve” to remove the excess nitrogen that has accumulated in the ecosystem. If situations arise that lead to nitrogen limitation, such as severe fire or physical disturbances due to military training, nitrogen-fixers, and especially legumes, have a large potential to replenish this lost nitrogen.

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