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# Pine straw raking and fertilizer source impacts on nitrogen mineralization in a loblolly pine plantation

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ABSTRACT

Pine straw production can supplement traditional revenues generated by loblolly pine plantation management. However, there is concern that excessive straw removal may adversely affect nitrogen availability and thus straw and fiber productivity in these stands. This study evaluated the long-term effects of straw raking combined with or without supplemental applications of either commercial inorganic fertilizer or poultry litter on soil N and C dynamics in a loblolly pine plantation in north central Louisiana. *In situ* mineralization and nitrification were measured monthly in response to: (1) no raking or fertilizer, (2) annual straw raking for seven years, (3) annual straw raking for seven years with inorganic fertilizer application for five years, and (4) annual straw raking for seven years with annual poultry litter application for five years. Annual straw raking did not substantially alter the N and C pools observed in this study. Annual applications of inorganic fertilizer did not lead to an accumulation of N in the uppermost 15 cm of mineral soil. Annual applications of poultry litter in conjunction with straw raking increased total C, total N, and exchangeable N (particularly as $NO_3$–N), N mineralization, and nitrification in soil. Due to the greater propensity of poultry litter to increase $NO_3$–N in soil relative to inorganic fertilizer, applying poultry litter at the frequency, rate, and/or target N rate used for inorganic fertilizer may have led to application of N in excess of plantation N demand at this site.



## 1. Introduction

Pine straw, the fallen pine needles in pine plantations, is a valuable commodity in the southeastern U.S. It is used as mulch by commercial landscaping operations and represents a multimillion dollar industry (Wolfe et al., 2005; Minogue et al., 2007). Pine straw is mechanically harvested annually or periodically from the soil surface in southern pine plantations. Removals can occur throughout the life of the stand until tree harvest at 35–45 years (Duryea and Edwards, 2003).

Morris et al. (1992) reported that pine straw N inputs in loblolly pine plantations growing on fertile sites can be as much as 36 kg N $ha^{-1}$ $yr^{-1}$. Other annual inputs of N to forests such as precipitation (6.0 kg $ha^{-1}$) and biological N fixation (0.3–7.0 kg $ha^{-1}$) reported for southern pine forests by Jorgensen and Wells (1986), Boring et al. (1991), Hendricks and Boring (1999) are generally much less than that associated with needle senescence In undisturbed loblolly pine plantations, organic N accumulation in forest floors have been found to reach nearly 363 Mg $ha^{-1}$ (Jorgensen and Wells, 1986). The nutrient content in pine needles is substantial, and repetitive harvesting of pine straw removes significant amounts of organic N and other nutrients from the soil (Lopez-Zamora et al., 2001). Organic N in pine needles and woody debris that is removed or redistributed prior to raking is an important input to forest soils. Morris et al. (1992) calculated that pine straw raked annually in a slash pine plantation beginning at 10 years of age would remove 252 kg N $ha^{-1}$ over a 12-year period and exceed the N removal attributed to tree harvesting. Replenishment of this lost N would be unlikely because annual inputs from precipitation and $N_2$ fixation are relatively small compared to N inputs from the forest floor (Jorgensen and Wells, 1986). Excessive annual removals of pine straw and woody debris from plantations without nutrient amendment have the potential to decrease the amounts of N in these stands and soils.

Not only is the organic matter derived from pine needles an important source of organic N within the soil, it provides C that serves as the source of energy for soil microbes that mineralize N (Sanchez et al., 2006). Organic matter also in part determines soil water availability and temperature, which also moderates N mineralization (Attiwill and Adams, 1993). Since C and N present

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in soil organic matter are important variables that drive N mineralization within soil ecosystems (Holub et al., 2005), alteration of C and N levels or C:N ratios could also alter N mineralization (Tan et al., 2005; Sanchez et al., 2006).

Nitrogen mineralization ($N_{min}$) is a key component of the N cycle in forests and largely determines the availability of N for plant uptake and thus forest productivity (Attiwill and Adams, 1993). Intensive forest management practices that disturb soil ecosystems can impact the nutrient cycling within these stands (Vitousek and Melillo, 1979; Swank and Waide, 1980). Excessive removal of organic matter from pine straw raking or timber harvest has the potential to decrease C sources needed as energy for microbial activity (Blazier et al., 2008), and thus reduce $N_{min}$ and available N. For example, removal of the forest floor during a timber harvest in a ponderosa pine (*Pinus ponderosa* Douglas ex C. Lawson) plantation resulted in lowered potential net N mineralization up to eight years following stand re-establishment (Gomez et al., 2002). It would seem logical that decreased $N_{min}$ due to organic matter removals associated with straw raking could result in less available N similar to reductions in available soil N pools observed with increasing timber harvest frequency or intensity in loblolly pine stands (Vitousek and Matson, 1985a,b).

The annual growth requirement of N for a mature loblolly pine stand has been calculated to be 69 kg/ha, of which 40% of this N is obtained from the mineralization of N from litter (Switzer and Nelson, 1972). The availability of N generally limits pine growth in the southern U.S. (Allen, 1987). Thus pine straw litter removal and the associated reductions in available N could ultimately reduce tree growth. McLeod et al. (1979) determined that a one-time removal of pine straw from a longleaf pine plantation significantly reduced total litterfall for three consecutive years, intensified the significance of the soil in supplying nutrients, and reduced tree growth for one to two years. Repeated raking over time may exacerbate N deficiencies unless organic matter and nutrients are replenished through management (Lopez-Zamora et al., 2001).

Nutrient amendments are recommended for replenishing N, P, K, and micronutrients removed by pine straw raking in southern pine plantations (Morris et al., 1992). Fertilizers such as diammonium phosphate (DAP) and urea are commonly used for supplying N and increasing tree productivity in plantations harvested for pine straw (Ross et al., 1995). Nitrogen mineralization has also been found to increase with fertilization. Gurlevik et al. (2004) observed that $N_{min}$ increased by 19% in a 14-year-old loblolly pine plantation after fertilization and vegetation control. Three and a half years following DAP and urea application, available soil N in a 12-year-old loblolly pine plantation was significantly higher than in unfertilized stands (Hart and Binkley, 1985).

An alternative amendment used to replenish N in agricultural ecosystems is poultry litter (Tabler and Berry, 2003). Poultry litter is an important by-product of poultry production and consists of chicken or turkey manure, bedding material such as peanut hulls or wood shavings, and feed waste. Poultry litter contains macro- and micronutrients essential for plant growth (Sistani et al., 2008), with total N contents ranging from 26 to 60 g $kg^{-1}$ dry litter (Gordillo and Cabrera, 1997). Fertilization with poultry litter also adds a large amount of C to the soil which is absent in inorganic fertilizer. Poultry litter, on a dry basis, has been found to contain 29.6–41.1% organic C (DeLaune et al., 2004; Acosta-Martinez and Harmel, 2006; Brye et al., 2006; Sistani et al., 2010). The organic C is primarily derived from the bedding material included with the feces (Dick et al., 1998). The additional organic matter added to the soil may also increase $N_{min}$ by providing a substrate for the soil microbial community and improving soil moisture retention and availability. Applications of poultry litter to loblolly pine stands could potentially increase the decomposition of organic matter by increasing soil microbial biomass and activity (Blazier et al., 2008). This increased microbial activity would likely increase $N_{min}$, available N, and thus tree productivity. Friend et al. (2006) found that a single application of poultry litter (4.6 Mg/ha) to an 8-year-old loblolly pine forest increased total stem basal area by 20%. Fertilization with poultry litter has also been shown to increase pine straw productivity of southern pine plantations intensively raked for pine straw (Chastain et al., 2007).

The objectives of this study were to examine how pine straw raking and fertilizer amendments (both inorganic and poultry litter) impact $N_{min}$, N availability, and soil C dynamics. A greater knowledge on the impact of these practices will help develop ecologically sustainable management of southern pine plantations intensively managed for pine straw production.

## 2. Materials and methods

### 2.1. Study site

The study site was located in Ouachita Parish, Calhoun, Louisiana (32°30′48″N, 92°20′53″W) at the Louisiana State University Agricultural Center Calhoun Research Station. The study was established in two loblolly pine plantations located within 0.5 km of each other. The plantations were planted in the winter of 1990 at a spacing of 4.9 m × 1.8 m. Prior to tree establishment the two areas had been managed as an improved bermudagrass (*Cynodon* spp.) pasture. In 2000, the stands were thinned to 618 trees $ha^{-1}$. Pine straw raking began in fall 2000, with straw harvests occurring annually thereafter. Understory vegetation was controlled with imazapyr applied at a rate of 1.3 L active ingredient in June 2000 and glyphosate in August 2003 at a rate of 1.2 L active ingredient $ha^{-1}$. Herbicides were broadcast-applied via tractor-mounted sprayers.

The soil mapping unit at this study site is an Ora–Savannah association with 1–3% slopes. The Ora–Savannah association primarily consists of three soil series; Ora, Savannah, and Providence (Matthews et al., 1974). This association is composed of loamy soils that are nearly level to gently sloping, medium acid to very strongly acid, and low in natural fertility. These soil series are primarily classified as fine loamy, mixed, siliceous, thermic, Typic Fragiudults. The Ora–Savannah association is moderately well drained, moderately permeable, has a moderate available water capacity, and depth to the water table is about 0.3–0.9 m. The Ora–Savannah association is classified as moderately high in potential productivity and is well-suited for growing loblolly pine (Matthews et al., 1974). The climate in Ouachita Parish is mild, humid subtropical with high rainfall occurring in the winter and spring followed by dry weather in the summer and autumn. Average annual temperature is 21 °C, and average rainfall is 128 cm (Matthews et al., 1974).

### 2.2. Experimental design and treatments

Blazier et al. (2008) provided a comprehensive description of the study design and treatments in an earlier paper published from this study; key details are provided in this paper. The study design was a randomized complete block design with a one-way treatment structure and four levels of pine straw harvesting and fertilizer regime treatments. The four treatment regimes were replicated twice within a 1-ha block in each stand. Treatments were applied to 0.08-ha plots that were separated by a 3-m buffer to ensure the independence of treatments. The four treatment regimes were randomly assigned to the plots in each block. The treatment regimes were: (1) pine straw raking without fertilization (RAKE), (2) pine straw raking with application of DAP and urea as