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Competition for ^{15}N labeled nitrogen in a loblolly pine–cotton alley cropping system in the southeastern United States

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ABSTRACT

The ecological sustainability of agroforestry systems is dependent on minimizing competitive interactions between system components. However, our understanding of resource competition and resource use efficiency in agroforestry systems such as alley cropping is limited. The objective of this study was to quantify the extent of competition for nitrogen (N) between loblolly pine (*Pinus taeda* L.) and cotton (*Gossypium hirsutum* K. Koch.) and its effect on fertilizer-use efficiency and N movement, and the role of trees in capturing the N that is leached below the root zone of cotton. Two pine–cotton alley cropping systems, established in 1999, with narrow (8 m alley width) and wide (16 m width), were studied. Belowground competition between pines and cotton was eliminated through the installation of a belowground polyethylene root barrier in half the number of plots to provide two treatments – barrier and non-barrier. Percentage of N derived from fertilizer (%NDF) and fertilizer-use efficiency (UFN) were determined using ^{15}N-enriched ammonium sulfate (5% atom enrichment) applied at 89.6 kg N ha^{-1}. The barrier treatment in both the narrow and wide alley resulted in higher total cotton biomass (36% and 14%, respectively) compared to the non-barrier treatment. Mean %NDF of cotton was significantly lower in barrier treatment in both systems, representing 14% and 55%, respectively, for the narrow and wide alleys, compared to the non-barrier treatment. For %UFN, this trend was reversed, with plants in barrier treatment having a higher %UFN. Root trenching did not affect loblolly pine foliar N concentration, NDF and UFN, but it affected total leaf N content. In soil, N recovery at 90–120 cm depth was lower in non-barrier treatment, indicating tree root uptake of fertilizer N. It is likely that tree roots were able to capture N in non-barrier treatment, resulting in lower rates of leaching below the root zone. The alley cropping systems in this study demonstrates potential for efficient N cycling, given the apparent ability of loblolly pine to intercept and uptake fertilizer from deeper soil layers and return to surface soil via litterfall.

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1. Introduction

Minimizing resource competition between trees and crops, while maximizing the use of available resources, is central to improving yield and overall productivity in alley cropping and similar agroforestry systems. Alley cropping, an agroforestry practice, involves the planting of row crops or pasture in alleys formed by single or multiple rows of trees or shrubs (Garrett and Buck, 1997; Gillespie et al., 2000). In the southern United States, cotton (*Gossypium* spp.), peanut (*Arachis hypogaea* L.), maize (*Zea mays* L.), soybean (*Glycine max* L. (merr)), wheat (*Tricum* spp.) and oats (*Avena* spp.) are important crops for alley cropping that are normally combined with trees such as pines (*Pinus* spp.), and pecan (*Carya illinoensis* K. Koch) (Allen et al., 2004a,b; Wanvestraut et al., 2004; Zamora et al., 2006, 2007).

Alley cropping is getting recognition in the southern United States because of its environmental and economic benefits. The effects of trees in alley cropping systems is of interest environmentally, in part, because trees are capable of capturing and recycling fertilizer nutrients from deeper soil horizons, and thus may help in improving nutrient use efficiency and in mitigating groundwater contamination (Rowe et al., 1999; Allen et al., 2004b). Ground water contamination through nitrogen (N) leaching has been a long-term environmental problem because of the practice of intensive agricultural production (Bonilla et al., 1999; Ng et al., 2000). Over application of N increases the production cost of farmers by millions of dollars each year (Marshall and Bennett, 1998). Further, the negative effects of nitrate leaching on rivers, lakes and rural residential wells are of increasing public and scientific concern (Marshall and Bennett, 1998; Bonilla et al., 1999;

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Ng et al., 2000). Agroforestry, alley cropping in particular, has been identified as a land use practice with potential for alleviating some of these problems (Rowe et al., 1999; Jose et al., 2000a, 2004; Allen et al., 2004a,b).

Trees and crops in alley cropping systems possess a high potential for interspecific competition for nitrate in the top soil, depending on factors such as rooting depth, water availability and tree species phenology (Jose et al., 2000a, 2004). Plant components in alley cropping systems can compete heavily for N when zones of depletion in the soil overlap with neighboring plants (Allen et al., 2004a). Competitive forces in alley cropping systems can be even more intense, as most tree species have the bulk of their fine, feeder roots in the top 30 cm soil layer, placing them in a zone of competition with crops species for water and nutrients (Rao et al., 1993; Lehmann et al., 1998; Wanvestraut et al., 2004; Zamora et al., 2007). Generally, tree roots can exploit subsoil N and other nutrients (Williams et al., 1997). In some cases, intercropped trees can receive benefits when fertilizer is applied to nearby crops, as some of the nutrients will be intercepted and taken up by tree roots.

The safety-net hypothesis, based on the safety-net role of tree roots, assumes that trees in agroforestry systems are capable of recycling soil nutrients that leach through the crop rooting zone, thereby reducing ground water contamination and increasing nutrient use efficiency in the system (Rowe et al., 1999; Allen et al., 2004b). There is both indirect and direct evidence of the safety-net hypothesis in the literature. A study in Sweden, for example, focused on the effects of tree harvesting on natural N levels in soil (Browaldh, 1995). The study found that natural N levels increased in the vicinity of harvested sites, due to the lack of N uptake by tree roots of harvested sites. In other studies, isotopic tracers such as ^{15}N-enriched fertilizer have been used to trace movement of applied N in alley cropping systems (e.g., Rowe et al., 1999; Jose et al., 2000a; Allen et al., 2004a,b). For instance, Allen et al. (2004a,b) found that pecan tree roots played a significant role in alleviating ground water nitrate leaching through their safety-net role in a pecan-based temperate alley cropping system.

Pine-based alley cropping system is becoming popular in the southern United States. For instance, loblolly pine-based alley cropping systems offer potential for environmental and economic benefits. However, the movement of N in loblolly pine–cotton systems remains an unstudied but critical factor affecting the growth and productivity of both trees and crops in such systems. While N losses cannot be avoided completely, losses can be minimized through appropriate fertilizer and orchard management practices and by knowledge of how N moves in the soil–tree–crop systems (Herrera and Lindermann, 2001). Therefore, more information is needed of the interactive dynamics of N in tree–crop systems, in order to maximize fertilizer-use efficiency and optimize production.

This study was conducted to examine the competition for N between loblolly pine and cotton using ^{15}N-labeled ammonium sulfate fertilizer. Specific objectives of the study were: (1) determine if competition between trees and cotton can change the relative uptake of fertilizer N by cotton; (2) determine whether fertilizer-use efficiency of cotton is altered as a result of the interspecific competition; and (3) determine if loblolly pine–cotton alley cropping system can improve soil N uptake, thereby reducing NO_3–N leaching potential.

2. Materials and methods

2.1. Study area and configuration

The study was conducted at the West Florida Research and Education Center (WFREC) farm of the University of Florida, located near Jay in northwestern Florida, USA (30°47′N, 87°13′W). The climate is considered to be temperate with moderate winters and hot, humid summers. The soil is classified as Red Bay sandy loam (a fine loamy, siliceous, thermic Rhodic Paleudult according to USDA Soil Taxonomy and Acrisol according to FAO Soil Classification) with an average water table depth of 1.8 m.

A 10-ha loblolly pine alley cropping demonstration trial was established in 1999, with two different configurations: wide and narrow alleys (hereafter referred to as narrow and wide alley cropping systems). Trees in both configurations were planted in triple rows with a north-south orientation, a spacing of 1.82 m × 1.82 m and an alley width of 10 m and 18 m for the narrow and wide alley, respectively. For this study, both narrow and wide alleys were set up as separate experiments using completely randomized block design with three blocks for the narrow alley and four blocks for the wide alley system, with two plots per block. Each plot contained three rows of ten trees in each row on both sides of the narrow or wide alleys. The average tree height and diameter were 4.7 m and 13 cm, respectively. The number of crop rows established for each alley cropping system was 8 and 16 for the narrow and wide alley, respectively, with inter-row spacing of 0.91 m.

To assess tree root competition for N fertilizer, the two plots in each block were randomly assigned a barrier (trenched or sometimes referred to as barrier plants) and non-barrier (non-trenched or non-barrier plants) treatments. Barrier plots were subjected to a root pruning treatment in March 2004 in which a trenching machine was used to dig a 1.2 m deep trench along both sides of the plot at a distance of 0.91 m from the trees to separate root systems of loblolly pine and cotton. A 1.2 m trench was used since earlier studies have indicated that most tree–crop root interactions take place within this depth (Allen et al., 2004b). A double layer 0.15 mm-thick polyethylene sheeting was used to line the ditch prior to mechanical backfilling. The barrier treatment, thus, served as the tree root exclusion treatment, preventing interaction of pine tree and cotton roots, while the non-barrier plots, which did not receive this treatment, served as the tree–crop competition treatment.

2.2. Microplots and fertilizer application

Cotton (DP458B/RR) was planted in each row in late Spring (April 24, 2004), after disking of the alleys. Conventional insecticide and herbicide were applied during the growing season as recommended. In each plot, one microplot (2.50 m × 0.75 m), containing 8–10 plants, was established in the first and middle rows of cotton both in the narrow and wide alleys. The first row represents cotton growing 1.22 m away from the tree lines, while the middle row represents cotton growing in the middle of the alleys, such that row 4 for the narrow alley and row 8 for the wide alley were the sample rows. To quantify competition for belowground nutrients, ^{15}N-enriched $(NH_4)_2SO_4$ (5% atom enrichment) was uniformly hand-applied to microplots at a rate of 89.6 kg N ha^{-1} on June 2, 2004 at the same time, rate and formulation as the regular fertilizer application (Timmons and Cruse, 1990).

2.3. Sampling methods

Six cotton plants from each microplot were sampled for ^{15}N content in leaf, lint, roots, stem, and boll (seed) components. Cotton leaf sample were collected on October 22, 2004 prior to leaf senescence. The same plants were later destructively harvested at physiological maturity on November 20, 2004, and separated into stem, roots and boll (seed cotton) components. Prior to and during plant harvesting, water was supplied at the base of the plant to