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Impacts of forest-based bioenergy feedstock production on soil nitrogen cycling

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ABSTRACT

We investigated impacts of simultaneous production of biomass for biofuel and quality timber on soil nitrogen (N) cycling in a poorly drained forest soil of eastern North Carolina, U.S.A. Treatments included traditional loblolly pine (PINE) and pine-switchgrass intercropping (PSWITCH). Treatments were replicated three times on 0.8 ha plots drained by parallel open ditches which were 1.2 m deep and spaced 100 m apart. Net N mineralization (N_m) and nitrification (N_n) rates were measured in the field using sequential *in-situ* technique over two years with multiple measurements in each year and laboratory by incubating soil samples for one-, two-, eight-, and thirteen weeks. Soil incubation *in-situ* or sample collection for laboratory incubation was conducted at nine sampling points within a 30 × 40 m subplot at each plot center and 20 cm from the soil surface. Soil samples were composited by location including near tree (NT), between two trees on the same bed (BT), and in the middle of four trees on two adjacent beds (M4T). Composite samples from NT and BT were categorized as tree-bed (BED), while those from M4T were grouped as interbed (INT). Field results showed that total soil N availability and its temporal variations over two years were not significantly affected by PSWITCH. However, it significantly reduced N_n rates, particularly in the INT. The plot-level mean N_m rates in PINE were 0.21 and 0.26 mg N·kg soil^{-1} d^{-1}, while in PSWITCH they were 0.10 and 0.21 mg N kg soil^{-1} d^{-1} in 2011 and 2012, respectively. The plot-level mean N_n rates in PINE were 0.09 and 0.10 mg N kg soil^{-1} d^{-1} in 2011 and 2012, respectively, while in PSWITCH they remained at 0.03 mg N kg soil^{-1} d^{-1} across these two years. At the INT, mean N_n rates in PINE were 0.11 and 0.12 mg N kg soil^{-1} d^{-1} in 2011 and 2012, respectively, while in PSWITCH, N_n rate remained at 0.02 mg N kg soil^{-1} d^{-1} over two years. Laboratory results indicated that change in litter quality inputs (changing from mixed species to switchgrass) in the INT did not significantly affect N_m rates. Results of this study contributed to a better understanding of the changes in soil N cycling due to loblolly pine-switchgrass interactions, which is important in sustainable nutrient management of this new land use. Further, the results suggested that growing switchgrass as intercrop to managed loblolly pine has positive water quality implication since ammonium N is less mobile in soil than nitrate N.

1. Introduction

Managed forest lands offer one of the best alternatives as a source of biomass for bioenergy since the need to increase food and fiber production for the rapidly growing human population is already putting pressure on current agricultural lands. Forest lands of the southeastern United States have a potential to be utilized for bioenergy feedstock production. For instance, simultaneous production of biomass for biofuel and quality timber is currently being explored by intercropping switchgrass with managed loblolly pine. However, compared to traditional loblolly pine plantation, pine-switchgrass intercropping requires a more intensive set of management practices. Highly intensive site preparation, herbicide application, fertilization and annual harvesting operations in addition to differences in litter quantity and quality between switchgrass and loblolly pine can alter soil nitrogen availability and dynamics.

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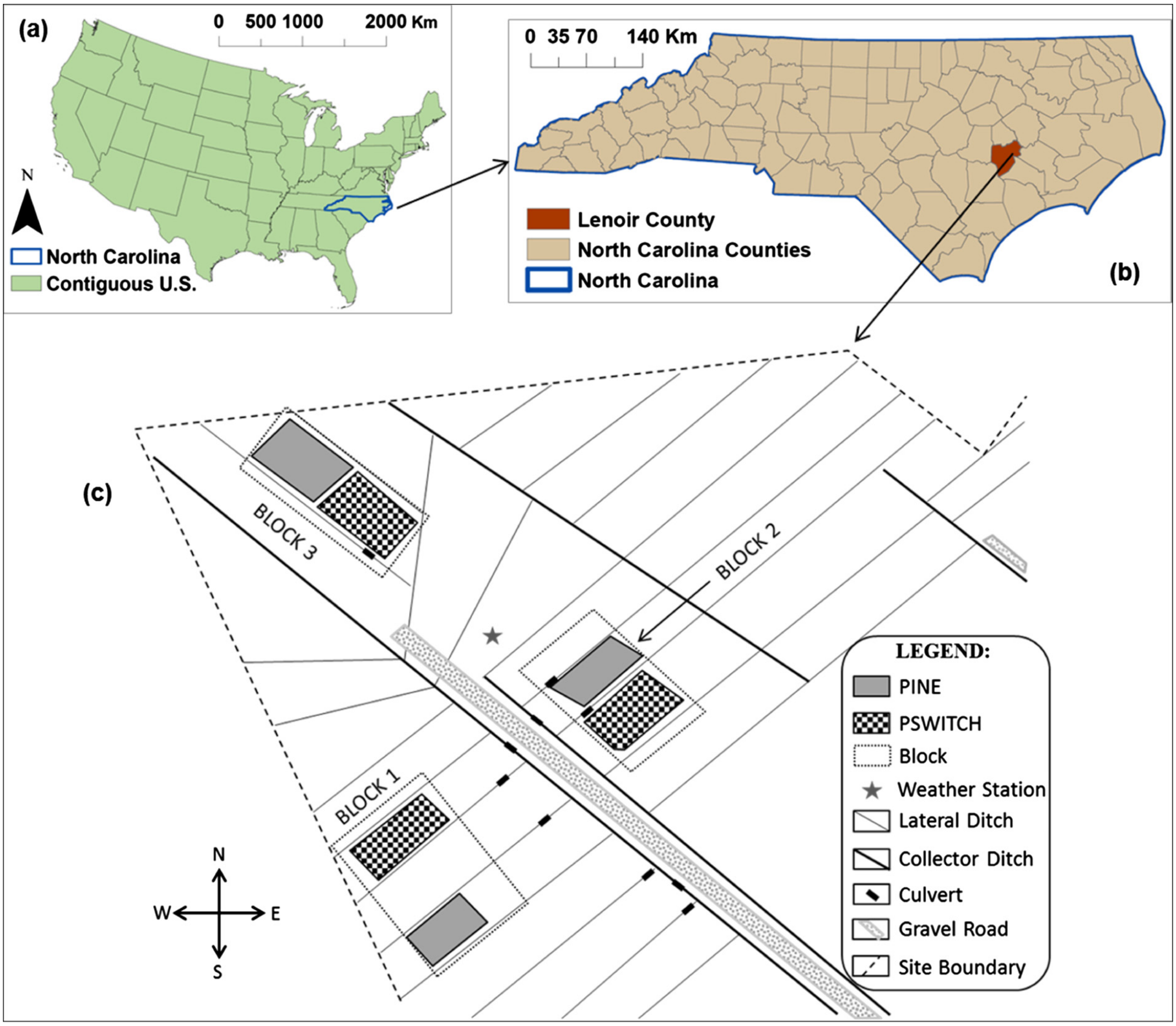

Fig. 1. The study site; (a) contiguous United States, (b) State of North Carolina, and (c) schematic of experimental treatments (not drawn to scale). . Adapted from Cacho et al. (2015)

Nitrogen (N) often limits productivity of southeastern U.S. forests (Pritchett and Smith, 1975). The primary sources of N in managed forests are nitrogen mineralization (N_m) and inorganic fertilizer application. Knowledge of N supplying capacity of the soil along with plant nutrient requirements is critical for optimum fertilizer recommendation to sustain maximum productivity and minimize offsite environmental impacts.

Management practices associated with establishment of switchgrass between rows of loblolly pine trees can have unintended effects on N transformation rates. Relatively intensive site preparation requirement and annually repeated switchgrass harvesting operations can cause soil compaction (Cacho et al., 2015) which can negatively impact soil N availability (e.g. Breland and Hansen, 1996; Rasiah and Kay, 1998; Li et al., 2003) as it reduces total porosity and thereby soil aeration. Switchgrass intercropped in loblolly pine may need more intensive herbicide application, because understory vegetation can dominate a traditional loblolly pine stand for about five years after planting (Sampson et al., 2011). Herbicides can impact non-target organisms, and at higher doses can affect N_m and nitrification (N_n) (Goodroad, 1987; El-Ghamry et al., 2000)

The change in species composition by replacing mixed understory vegetation in between rows of loblolly pine with switchgrass is another factor that could impact soil N availability. Plant species affect N dynamics due to differences in nitrogen use efficiency (NUE) and varying influence on the inputs and losses (Knops et al., 2002). Further, species differences in both litter quantity and quality can affect microbial communities in addition to species-induced changes in the soil microclimate (Paul and Clark, 1996). In terms of photosynthetic pathways, loblolly pine is classified as a C3 species, while switchgrass belongs to the C4 group of plants. Past studies on C3 and C4 grasses indicate that NUE differences between these two species generally result in higher tissue C:N ratio in C4 than in C3 grasses (Wedin and Tilman, 1990; Wilsey et al., 1997), which often correlated with the differences in the rates of decomposition of their litter and associated N_m (Wedin and Tilman, 1990; Vinton and Burke, 1997). Moreover, Wynn and Bird (2007) found in a C3/C4 mixed soil, C4 derived soil organic carbon had higher decomposition rate than its C3 counterpart. In forested sites across North America, variation in net N_m rates over a wide range of stand age classes was explained more by litter quality (lignin: N ratio) than climatic factors (Scott and Binkley, 1997).

Soil N availability and transformation rates in forested watersheds under different types of vegetation and management practices have been well examined around the world (e.g. Hart and Gunther, 1989; Vestgarden et al., 2003; Blumfield et al., 2005; Sartori et al., 2007; Ullah and Moore, 2009). In the southeastern United States, several studies have been conducted on the impacts of various management practices on soil N_m and N_n in loblolly pine plantations (Vitousek and Matson, 1985; Piatek and Allen, 1999; Li et al., 2003; Gurlevik et al.,