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Effects of forest-based bioenergy feedstock production on shallow groundwater quality of a drained forest soil

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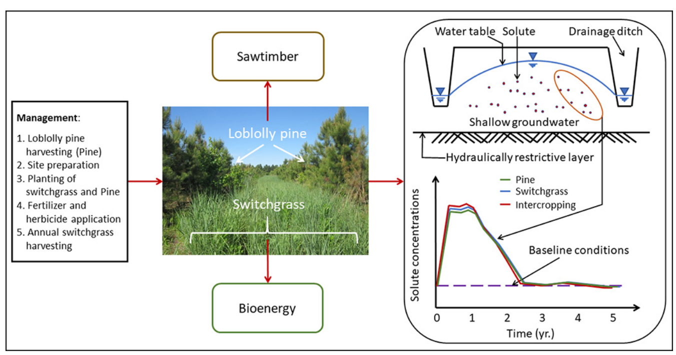
HIGHLIGHTS

- We assessed impacts of switchgrass-loblolly pine intercropping for bioenergy.
- Overall, intercropping did not significantly impact shallow groundwater quality.
- The system's response to site management was comparable to loblolly pine production.
- Temporal dynamics of nutrient concentrations was similar to managed loblolly pine.

GRAPHICAL ABSTRACT



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ABSTRACT

Managed forests in southern U.S. are a potential source of lignocellulosic biomass for biofuel production. Changes in management practices to optimize biomass production may impact the quality of waters draining to nutrient-sensitive waters in coastal plain regions. We investigated shallow groundwater quality effects of intercropping switchgrass (*Panicum virgatum* L.) with managed loblolly pine (*Pinus taeda* L.) to produce bioenergy feedstock and quality sawtimber in a poorly drained soil of eastern North Carolina, U.S.A. Treatments included PINE (traditional pine production), PSWITCH (pine-switchgrass intercropped), SWITCH (switchgrass monoculture) and REF (mature loblolly pine stand). Each treatment was replicated three times on 0.8 ha plots drained by parallel-open ditches, 1.0–1.2 m deep and 100 m apart. Water samples were collected monthly or more frequently after fertilizer application. Water samples were analyzed for organic nitrogen (ON), ammonium N (NH_4^+- N), and nitrite +nitrate N (NO_3^- + NO_2^-- N), orthophosphate phosphorus (OP), and total organic carbon (TOC).
Overall, PSWITCH did not significantly affect shallow groundwater quality relative to PINE and SWITCH. ON, NO_3^- + NO_2^-- N, and TOC concentrations in PSWITCH, PINE and SWITCH were substantially elevated during the two years after tree harvest and site establishment. The elevated nutrient concentrations at the beginning of the study were likely caused by a combination of rapid organic matter decomposition of the abundant supply of post-harvest residues, warming of exposed soil surfaces and reduction of plant nutrient uptake that can occur after harvesting, and pre-plant fertilization. Nutrient concentrations returned to background levels observed in REF during the third year after harvest.

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1. Introduction

Managed loblolly pine (*Pinus taeda* L.) plantations cover approximately 20% (13.7 million ha in 2014) of the southeastern U.S. forest land base (Huggett et al., 2013) and are highly productive (Prestemon and Abt, 2002). Growing switchgrass (*Panicum virgatum* L.) as an intercrop on these forests has emerged as a potential source of bioenergy feedstock (Susaeta et al., 2012; Blazier et al., 2012) and has been implemented on an operational scale by Catchlight Energy, LLC, a Chevron|Weyerhaeuser joint venture (Nettles et al., 2015). Utilizing land resources between pine trees to produce an energy crop can potentially reduce the demand for land resources used to produce food; however, converting conventionally managed forest land to this new intercropping system constitutes changes in land use and associated management practices, which may affect the environmental sustainability of the land.

Conventional forest management currently involves intensive silvicultural management practices (ISMPs) including site preparation, bedding, fertilization, thinning, and harvesting. In coastal plain regions, improved drainage in the form of open ditches is required for some of these forest lands to enhance trafficability and provide optimum soil water conditions for tree growth. While ISMPs are largely responsible for the increased forest productivity in southern United States over the past three decades (Fox et al., 2007b), specific management operations involved in ISMPs can impact the quality of water draining from managed forests (Shepard, 1994; Amatya et al., 2006; Grace et al., 2006; Beltran et al., 2010). Studies in eastern North Carolina reported increases in N and P concentrations and exports after fertilization of managed pine plantations (Shepard, 1994; Beltran et al., 2010). Several studies in the same region on artificially drained forest lands showed that increased N losses can occur as a result of harvesting (e.g. Ensign and Mallin, 2001; Lebo and Herrmann, 1998; Fisher, 1981), harvesting and regeneration combined (Shepard, 1994; Amatya et al., 2006), and thinning (Grace et al., 2006). While management operations can increase nutrient exports, these exports return to background levels within two to three years of the operation (Shepard, 1994; Beltran et al., 2010). Despite short-term increases in nutrient and sediment exports in response to management operations, the cumulative impact of conventionally manged forests is small when compared to other land uses such as agriculture (Fiqueprona et al., 2013; Shelby et al., 2005).

Growing switchgrass between loblolly pine trees on drained lands requires more intensive site preparation and management operations than needed for normal timber production. Switchgrass requires a well-prepared seedbed to ensure maximum seedling emergence (Parrish and Fike, 2005); therefore, substantial removal of woody debris between rows of pine trees (interbeds) is required to expose soil for switchgrass planting. This increases the amount of soil disturbance and exposure over that which occurs in conventional forestry practices. Since nitrogen fertilization increases switchgrass yield (e.g., Lemus et al., 2008) optimum production of intercropped switchgrass requires annual fertilization, which increases the frequency of fertilizer applications over the typical two or three applications made over the entire 25- to 30-year rotation in traditional loblolly pine plantation (Fox et al., 2007b). This herbicide application is also necessary to initiate vigorous switchgrass establishment, one of the pre-requisites for long-term productivity (Parrish and Fike, 2005).

Movement and transformations of nitrogen (N), phosphorus (P) and carbon (C) in the new intercropping system will likely be different than in conventional forest management, simply due to the increased site and soil disturbance and increased N and P fertilization required to introduce a switchgrass crop between the trees. The change in vegetation between tree rows from normal understory (mixture of native woody trees and shrubs, vines, forbs, and grasses) to switchgrass will also affect nutrient movement and transformations. The timing and intensity of nutrient demands of switchgrass is different than of pine trees or most native vegetation. A planted and cultivated switchgrass crop will have more immediate nutrient demands than the demands of widely spaced pines or volunteer vegetation naturally regenerating on disturbed lands. Minick et al. (2014) observed that inorganic N (NO_3^--N and NH_4^+- N) was significantly reduced in the top 10 cm of soil under interplanted switchgrass compared to soil under normal understory for pine. Since the reductions were observed during the active switchgrass growing season, they postulated that switchgrass was utilizing the excess N when N supply was greater than potential uptake by pine trees. Additionally, they observed that soil mineral N content was higher under pine trees in the intercropped systems than under trees in the conventional system.

Nutrient movement and transformations will be different in soil under a pine-switchgrass intercropping system than under conventional forest management which will result in different amounts and forms of nutrients in the root zone. In high water table soils, these nutrients can leach to the shallow groundwater, the quality of which reflects the cumulative impact of nutrient transport and transformations occurring in the soil above. This study addresses the question of how changes in soil nutrient dynamics due to this land use change affect the nutrient concentrations of shallow groundwater in high water table soils. Specifically, we test the hypotheses that concentrations of NO_3^-- N, NH_4^+- N, OP and DOC in shallow groundwater are different under pine-switchgrass intercropping compared to conventional loblolly pine management. The hypotheses are tested using samples collected from groundwater wells at different depths and at different times over a three-year period from one year after site preparation until the end of the fourth switchgrass cropping year.

2. Materials and methods

2.1. Research site description and experimental treatments

Our research site was managed by Catchlight Energy, LLC, a Chevron/Weyerhaeuser Joint Venture, on lands owned by Weyerhaeuser Company in eastern (Lenoir County) North Carolina, U.S.A. (35° 15′ N and 77° 27′ W). Soils on the site were classified as Pantego (fine, loamy, siliceous, semiactive, thermic Umbric Paleaquults) or Rains (fine, loamy, siliceous, semiactive, thermic Typic Paleaquults), both of which are poorly drained under natural conditions (USDA Soil Survey, 2013). Experimental treatments on 0.8 ha replicated plots were conventional pine production (PINE), pine intercropped with switchgrass (PSWITCH), switchgrass only (SWITCH), and a 38-yr. loblolly pine stand as a reference stand (REF) (Fig. 1). Site preparation and management practices differed between treatments (Table 1). REF, which was planted in 1975, had a narrower bed spacing of approximately 2.65 m compared to the bed spacing (6.0 m) of PINE and PSWITCH (Cacho et al., 2015). It underwent commercial thinning operations in December 1980 and December 1991, leaving 210 crop trees per hectare during the time of this study (Cacho et al., 2015), but did not experience any silvicultural operation since then. Each treatment was replicated three times and drained by ditches 1.00–1.20 m deep and spaced at 100 m. Due to the design of the randomized plot study, the nutrient concentrations of drainage water in the ditches represented multiple treatments and could not be sampled in a way that would isolate the treatments. A more detailed description of the experimental treatments and study