Agriculture, Ecosystems and Environment 248 (2017) 20–28

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Converting bahiagrass pasture land to elephantgrass bioenergy production enhances biomass yield and water quality

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ARTICLE INFO

Keywords:
Bioenergy crops
Evapotranspiration
Water use efficiency
Water quality
Ecosystem services

ABSTRACT

Changing pasture land to the production of bioenergy crops will affect regional water dynamics. Returning by-products of industrial conversion of bioenergy crops like fermentation residual or biochar back to the field could be used to improve sustainable nutrient management, but could also impact water quantity and quality in ways that are poorly understood. The objective of this study was to assess the effects of land-use conversion from low-input bahiagrass (*Paspalum notatum* Flüggé) pastures to elephantgrass [*Pennisetum purpureum* (L.) Schum.] for bioenergy production under different nutrient management practices on biomass yield, crop water dynamics and nitrate-nitrogen (NO_3-N) leaching during growing and dormant seasons. Treatments evaluated were 1) bahiagrass + 50 kg N ha^{-1}; 2) elephantgrass + 50 kg N ha^{-1}; 3) elephantgrass + 50 kg N ha^{-1} + fermentation residual; 4) elephantgrass + 50 kg N ha^{-1} + biochar; and 5) elephantgrass + 250 kg N ha^{-1}. Data were collected on crop evapotranspiration (ET), water use efficiency, drainage, NO_3-N leaching, and aboveground dry matter accumulation. Dry matter yield of elephantgrass was 4- to 7-fold greater than bahiagrass after the first growing season, but was similar among elephantgrass treatments. Elephantgrass produced with no residual amendments reduced drainage (approx. 43% across all growing seasons) compared to bahiagrass, and this reduction was exacerbated in the residual treatments. Reduced drainage was associated with increased ET. Elephantgrass, regardless of treatment, reduced the amount of NO_3-N lost through drainage compared to bahiagrass. Therefore, replacing bahiagrass with elephantgrass will increase cropping system water use and diminish the rate of groundwater replenishment during the growing season, which could have detrimental effects for other ecosystem processes that rely on this water resource. However, elephantgrass increased the efficiency with which water was used to produce biomass and reduced NO_3-N leaching to groundwater.

1. Introduction

The increasing demand for renewable fuels and chemicals from agricultural crops and residues will likely result in more land planted with non-food bioenergy crops (Perlack et al., 2005). Elephantgrass or Napiergrass is a perennial C4 tall grass adapted to sub-tropical conditions that has been identified as a potential bioenergy crop for the southeastern United States based on high biomass production (Woodard and Prine, 1993). Elephantgrass dry biomass yields surpassing 30 Mg ha^{-1} are commonly reported in the southeastern U.S. region depending on management practices (Knoll et al., 2012; Fedenko et al., 2013; Na et al., 2015). Bioenergy crops like elephantgrass are likely to be grown on large areas, but not where food crops are already grown (Perlack et al., 2005). Bahiagrass perennial grasslands used for animal feed are a major land use in the southeastern U.S. with over 2 million hectares in the state of Florida alone (Newman et al., 2014). Bahiagrass pastures grown on marginal lands represent a likely candidate cropping system to be converted to elephantgrass for bioenergy. Although elephantgrass has demonstrated relatively high yield potential on similar marginal lands, the impacts on ecosystem services, such as water quantity and quality, of converting low input bahiagrass grassland to elephantgrass bioenergy cropping systems are not well understood.

Bahiagrass pastures in the region are usually managed under low fertilization and minimum irrigation. The typical fertilizer rate for low input bahiagrass ranges between 50 and 60 kg N ha^{-1} (Mylavarapu et al., 2016), but bahiagrass has been shown to have a high N uptake

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http://dx.doi.org/10.1016/j.agee.2017.07.021
Received 6 March 2017; Received in revised form 12 July 2017; Accepted 15 July 2017

capacity (Rechcigl et al., 1992), which could reduce potential NO_3-N leaching thus protecting water quality. However, bahiagrass maximum annual yield does not exceed 13 Mg ha^{-1} (Silveira et al., 2015), and thereby potential exists to produce more biomass by replacing bahiagrass with elephantgrass. Elephantgrass has high biomass productivity, which is common and desired for bioenergy cropping systems, but is also often associated with high nutrient removal and transpiration (Erickson et al., 2012; Kering et al., 2012; Singh et al., 2015). Thus, high fertility requirements and an elevated water use of bioenergy crops could reduce water quality and quantity available to recharge aquifers. For example, McIsaac et al. (2010) measured water consumptive use of bioenergy crops *Miscanthus x giganteus* and switchgrass (*Panicum virgatum* L.) compared with a conventional corn (*Zea mays* L.)-soybean (*Glycine max* L.) rotation grown in Illinois, U.S., and reported greater soil water uptake and ET for bioenergy crops, which reduced 32% of the drainage water available for natural waterways.

Additionally, dedicated bioenergy crops that produce high amounts of aboveground biomass that is completely removed from the field at harvest also tend to remove high amounts of nutrients in that biomass (Na et al., 2015; Singh et al., 2015). High biomass production of bioenergy feedstock crops, such as elephantgrass, will then require moderate to high fertilizer inputs to sustain yields over time, especially on marginal soils (Knoll et al., 2012). For instance, Woodard and Prine (1993) reported elephantgrass yield up to 47 Mg dry matter ha^{-1} in response to high fertilizer inputs (200 kg N ha^{-1}), which could encourage application of high rates of synthetic N to increase yields and profits, while also increasing the risk of NO_3-N leaching, especially in the coarse-textured soils common in the southeastern U.S. (Carlisle et al., 1988). Nutrient management practices that include internal recycling of nutrients by field application of by-products from the bioenergy processing industry could minimize reliance on external fertilizer inputs (Agyin-Birikorang et al., 2013) and potentially enhance other ecosystem services.

Biochar (thermochemical) and fermentation residual (microbial fermentation) are two common mineral-rich residuals produced from converting biomass to biofuels. Biochar is a carbon rich residual produced via pyrolysis of biomass that has been reported to affect soil nutrient and water dynamics of coarse-textured soils (Liu et al., 2013; Lehmann and Joseph, 2015). Novak et al. (2009) found a significant increase in soil moisture content of a loamy sand soil when biochar was applied. Similarly, Uzoma et al. (2011) reported that application of 20 Mg biochar ha^{-1} to a sandy soil increased water-holding capacity by 97%. Similarly, fermentation residual, also known as vinasse, produced from liquefaction plus simultaneous saccharification and co-fermentation of biomass (Gubicza et al., 2016) is a lignin- and mineral-rich residual that can also affect soil nutrient and water dynamics. Application of this fermentation residual has been known to increase the percentage of large soil aggregates improving water and nutrient holding capacity (Jiang et al., 2012). Additionally, Agyin-Birikorang et al. (2013) found that N-based application of processed bioenergy residual provided adequate amounts of P and K to support sweet sorghum (*Sorghum bicolor* L. Moench) productivity and increased sweet sorghum dry matter yield ~45% compared with inorganic fertilization.

Thus, using biochar or fermentation residual as a soil amendment will likely be a key component in converting bahiagrass pasture lands to sustainable bioenergy cropping systems that provide similar or even additional ecosystem services beyond high biomass production, such as improving groundwater quantity and quality, compared to the land use they replace (Ferchaud and Mary, 2016). However, there is currently limited information on the ecosystem services of bioenergy cropping systems in comparison to current agricultural systems. Therefore, there is a need to better understand how the conversion of current bahiagrass pasture land to an elephantgrass bioenergy cropping system will impact water quantity and quality, and how land application of bioenergy residuals might affect the provisioning of these services by the bioenergy cropping system. The objectives of the present study were to 1) evaluate the effects on the soil-water plant dynamics from converting bahiagrass pastures to an elephantgrass perennial crop for biomass production, 2) quantify NO_3-N concentration in drainage below the root zone in bahiagrass and elephantgrass treated with and without bioenergy residuals, and 3) evaluate the effects of land-application of biochar and fermentation residuals to support elephantgrass biomass production. We hypothesized that elephantgrass grown conventionally with high synthetic fertilizer inputs would negatively affect water quantity and quality draining downwards to the aquifer compared to bahiagrass, but land application of residuals to elephantgrass could reduce detrimental effects on groundwater quality from fertilizer leaching.

2. Materials and methods

2.1. Study site

A field experiment was conducted over three consecutive years (2013–2015) at the University of Florida Plant Science Research and Education Unit, which is located in North Central Florida, U.S.A. (29°24′N and 82°9′W). The soil was classified as Kanapaha fine sand (loamy, siliceous, semi-active hyperthermic Grossarenic Paleaquult). Physical analysis (Bouyoucos hydrometer method) of the soil found the soil to be 98.4% sand, 0.4% clay, and 1.2% silt with a bulk density of 1.61 g cm^{-3} and a pH of 6.8. Mehlich-1 chemical characteristics of the soil (0–20 cm soil depth) prior to treatment initiation were 64.7, 12.2, 20.9, and 925.2 mg kg^{-1} for P, K, Mg, and Ca, respectively. The cation exchange capacity of the soil was 7.7 $cmol_c$ kg^{-1} and the soil organic carbon was 5.67 g kg^{-1}. The climate of the area is characterized as a humid subtropical climate with average temperature of 21.3 °C and annual precipitation of 1202 mm (1981–2010; National Oceanic and Atmospheric Administration). Meteorological data during the study such as air temperature, radiation, and rainfall were retrieved from a weather station located < 1 km from the experimental site. The study site was under fallow conditions for about 6 months prior to establishment of the experiment.

2.2. Experimental design

Stem cuttings of elephantgrass breeding line 'UF-1' were obtained from a nearby nursery and sown on 11 November 2012, by placing overlapping canes in opposite orientation into furrows. Plugs of bahiagrass (cv. 'Pensacola') were planted on 18 July 2013. Plots were 90 m^2 (10 × 9 m), planted with bahiagrass or 8-rows of elephantgrass spaced 1 m. The experiment was arranged in a randomized complete block design with four replications. The treatments were: 1) bahiagrass pasture fertilized with 50 kg N ha^{-1} yr^{-1} (BHG); 2) elephantgrass fertilized with 50 kg N ha^{-1} yr^{-1} (E50); 3) elephantgrass fertilized with 50 kg N ha^{-1} yr^{-1} plus 9 Mg dry lignocellulosic fermentation residual ha^{-1} yr^{-1} (E50FR); 4) elephantgrass fertilized with 50 kg N ha^{-1} yr^{-1} plus 7 Mg dry pyrolysis biochar residual ha^{-1} yr^{-1} (E50BC); and 5) elephantgrass fertilized with 250 kg N ha^{-1} yr^{-1} (E250).

Fermentation broth was received from the University of Florida Stan Mayfield Biorefinery in Perry, Florida, following the liquefaction plus simultaneous saccharification and co-fermentation of milled sugarcane biomass (Gubicza et al., 2016), which is similar to elephantgrass biomass in terms of fiber composition (Fedenko et al., 2013) and mineral composition (Singh et al., 2015), and would be expected to produce a similar fermentation residual. The fermentation broth was air-dried to evaporate the liquid phase to produce a residual solid material that was surface applied. Both the biochar and fermentation residual were analyzed for chemical composition. Phosphorus, K, Ca, S, Mg, Mn, Zn, B, and Al were all determined in a commercial laboratory (Waters Agricultural Laboratories, Inc. Camilla, Georgia, U.S.) using inductively coupled plasma radial spectrometry following wet digestion. Total C and N were determined by combustion analysis using a Flash EA 1112 Series Elemental Analyzer (Thermo Fisher Scientific Inc., Waltham,