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Research Paper

Biochar and mill ash improve yields of sugarcane on a sand soil in Florida

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A B S T R A C T

The addition of organic residues to sand soils can improve soil properties and sugarcane productivity. However, biochar use can have variable effects on crops, and few studies have evaluated the effect of mill ash applications on sand soils. This study aimed to determine the effect of mill ash, and three biochars on yields of sugarcane grown on sand soils of South Florida near the Everglades Agricultural Area (EAA). Nine treatments and a control were evaluated. Treatments consisted of mill ash (AS) and biochars produced from hardwood yard waste (HY), horse barn shavings (HM), and rice hulls (RH) incorporated at 1% and 2% (by weight) prior to the plant-cane crop of a lysimeter experiment that extended for two crop cycles. A standard practice treatment of mill ash applied at 6% was also included. Results show that mill ash applied at 6% and 2% (AS6 and AS2), and rice hulls biochar applied at 2% (RH2) produced significantly greater biomass and sucrose yields compared with the control in the plant-cane and the first-ratoon crops. Soil silicon concentrations increased with AS and RH in the plant-cane crop, which may have contributed to improved yields. Treatments AS6 and RH2 may have also increased sugarcane yields through improved soil properties. Our results show that mill ash and rice hulls biochar amendments can potentially improve sugarcane yields on sand soils near the EAA.

1. Introduction

The sugarcane (*Saccharum officinarum*) industry of south Florida is a major contributor to the economy of the state, providing more than $4.5 billion annually and approximately 47,000 jobs (Hodges et al., 2004). Approximately 78% of sugarcane is grown on organic soils that are predominantly in Palm Beach County. The remaining 22% (35, 696 ha) is cultivated on mineral or sand soils in Hendry, Glades, and Martin counties (Van Weelden et al., 2016). Greater biomass yields are obtained from organic soils than from sand soils (Rice et al., 2010). This is especially true for plant cane and first ratoon yields which have been between 17 and 31% higher yields on organic compared with sand soils (Roka et al., 2009). Since lower sugarcane yields are obtained on sand soils, greater amounts of fertilizers, and frequency of fertilizer applications are required to increase yields, which ultimately increases production costs and risk of water pollution (Gilbert et al., 2008). However, even with the extra fertilizer added, sugarcane yields are still lower on sand soils.

The two main factors that make sugarcane growth more challenging in sand soils are their low water holding capacity and low nutrient retention mainly due to low organic matter content. However, sugarcane cultivation on sand soils is increasing as sugarcane grown in organic soils (Histosols) faces more restrictive environmental management and higher land costs, and areas under citrus cultivation in sandy soils is decreasing due to citrus greening disease (Roka et al., 2009; Florida Agricultural Statistics Service, 2009). Thus, sugarcane cultivation is expected to expand into less productive sand soils northwest of the Everglades Agricultural Area (EAA). With this challenge in mind, sustainable agricultural management practices are being developed and evaluated to improve sugarcane production in sand soils. The use of agricultural organic residues as soil amendments is a practice with the potential to enhance sand soil properties and sugarcane production, while reducing waste.

The addition of organic matter through organic residue application can improve water holding capacity, cation exchange capacity (CEC), nutrient cycling, and soil structure, all of which can enhance plant nutrient supply and storage (Bot and Benites, 2005). Thus, using organic amendments to build soil organic matter can be beneficial not only for soil properties, but also for sugarcane production and long-term management costs (Todd et al., 2014; Gilbert et al., 2008).

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In South Florida, the sugarcane industry produces several organic by-products during the process of sugar extraction in the mills. Mill mud and mill ash are two of the most common sugarcane mill by-products. Mill ash is the residue cleaned off the sugar mill boilers after the bagasse fueling process, while mill mud is the solid material left after filtering the cane juice. Mill ash applied at 50 Mg ha^{-1} improved plant height, number of tillers, and biomass yield of wheat (*Triticum aestivum*) (Khan, 2011). An average increase of 69% in sugarcane biomass and sucrose yields was also observed with the application of mill ash compared with a control with fertilizer only in a sand soil (Gomez, 2013).

The use of organic residues to produce biochar to be used as soil amendments has also gained substantial attention in the last couple of decades (Lehmann and Joseph, 2009). Biochar is a by-product that is rich in carbon and is obtained through the process of pyrolysis, which is the thermal decomposition of organic material under low oxygen conditions (Lehmann and Joseph, 2009). However, biochars differ widely based on the nutrient composition of the original feedstock and pyrolysis conditions, which can result in variable plant yield (Chan and Xu, 2009). In addition, diverse effects can result from the application of biochar to different soil types, and different crop yields can be obtained depending on plant species and their nutrient demands (Chan and Xu, 2009; Liu et al., 2013; Van Zwieten et al., 2010; Rajkovich et al., 2012).

Feedstock nutrient composition is a strong determinant of the nutrients that could be available in biochar form. Biochars made from high nutrient feedstocks such as animal manures or herbaceous plants generally improved corn (*Zea mays*) growth, while food waste biochar resulted in reduced corn yield (Rajkovich et al., 2012). Positive effects on sunflower (*Helianthus annus*) plant dry biomass have also been shown with the use of wheat straw and olive tree (*Olea europaea*) pruning biochar; however, negative or no effects were observed with wood-based biochars (Alburquerque et al., 2014). An experiment conducted with sugarcane showed that bagasse biochar increased sugar yield by 78%, and biochar from biosolids increased biomass yield by 20% (Chen et al., 2011).

Although environmental conditions and diverse chemical composition of organic amendments can result in variable agricultural productivity, mill ash and biochar applications in soils with low pH, sand texture, and low organic matter have generally resulted in improved yields. We hypothesized that higher rates of amendment incorporation would increase biomass and sucrose yields of sugarcane because organic matter additions can improve soil physiochemical properties, which can ultimately enhance plant nutrient availability and increase crop productivity. The objective of this lysimeter study using a sand soil was to evaluate the effects on sugarcane yields and leaf nutrients of various application rates of mill ash and three biochars, produced from residues of three locally available materials over two years of growing season.

2. Materials and methods

2.1. Materials

Biochars were produced from three local residue feedstocks in south Florida. Hardwood yard waste (HY) from the Solid Waste Authority of Palm Beach County, barn shavings with horse manure (HM) from the Palm Beach Polo Equestrian Club; and rice (*Oryza sativa*) hulls (RH) from a rice mill in the EAA. The feedstocks were dried at 65 °C for two weeks to ensure approximate 20–30% moisture content. The dried feedstocks were sent to North Carolina State University where pyrolysis machinery was used to produce the biochar at temperatures ranging between 350 and 400 °C. This collaboration was accomplished with the help of AgriTech Producers. Mill ash (AS) was also used as a soil amendment and it was obtained from the sugarcane mill of the Sugar Cane Growers Cooperative located in Belle Glade, Florida.

Elemental compositions of biochars and mill ash were analyzed at the UF/IFAS Soil Testing Laboratory in Gainesville, Florida. Repeated additions of nitric acid and hydrogen peroxide (EPA, 1996, Method 3050b) were used to digest biochar and mill ash samples, which were then analyzed using an inductively coupled plasma optical emission spectrometry (ICP-OES) (Spectro Arcos, Kleve, Germany) to determine their concentrations of P, K, Ca, Mg, Zn, Cu, and Fe. Silicon (Si) content of the amendments was determined by an autoclave-induced digestion with hydrogen peroxide and sodium hydroxide (Elliott and Snyder, 1991).

The pH of the amendments was determined using a 1:1 water to amendment (v/v) mixture and bulk density was calculated by dividing the mass of the amendment by a fixed volume (Thomas, 1996). Water holding capacity (WHC) was determined by the saturation procedure (Peron et al., 2007). Water was slowly added to each amendment, while stirring with a glass rod until excess water was observed, and the samples were then drained by gravity for 24 h. The water held by the amendments was calculated as the difference between the wet mass and dry mass of the sample (Peron et al., 2007). Organic matter was calculated through loss on ignition (LOI) (Mylavarapu et al., 2002). The amendments were ashed for approximately 16 h in the muffle furnace (500 °C) and the difference between dry and ashed soil was used to estimate the OM content.

Total phosphorus (TP) was analyzed by digesting the ashed samples. Total P was measured on an Alpkem Auto Analyzer (O.I Analytical, Glattburgg, Zurich) using EPA Method 365.4 (EPA, 1983). Cation exchange capacity (CEC) was estimated using the ammonium acetate (pH 7) method (Sumner and Miller, 1996). Ammonium was analyzed by flow injection analysis on a Lachat analyzer (Hach Company, Loveland, CO; Lachat Instruments, 2008). A Costech ECS 4010 elemental analyzer was used to determine total carbon (TC) and total nitrogen (TN) contents of the amendments and calculate their carbon to nitrogen (C:N) ratios.

An Immokalee sand (Sand, siliceous, hyperthermic Arenic Alaquods) was used for this experiment. The soil was collected from a sugarcane field near Whiddens corner, Hendry County, Florida (Table 1).

Nutrient properties of the sand soil were determined using Mehlich-3 extraction, and soil Si was determined with a 0.5 N acetic acid extraction (Mehlich, 1984; Korndorfer et al., 2001). Soil pH was determined with a 1:2 soil-to-water ratio, and organic matter was determined by LOI (Mylavarapu et al., 2002). The original sand soil used in this experiment had low organic matter content (0.8–1%) and a pH of 5.9, which are representative characteristics of sand soils used to grow sugarcane in this region (McCray et al., 2015).

2.2. Experimental design

This study used sugarcane plants of cultivar CP 00-1446 (Comstock et al., 2009). Two sugarcane plants were transplanted to each 265 L-lysimeter containing Immokalee sand soil only (Control) or

Table 1
Physiochemical properties of the sand soil used in this experiment.

Property	Unit	Amount
pH		5.9
Organic matter	%	0.8
Total phosphorus	%	0.01
Total Kjehdahl nitrogen	%	0.07
Mehlich 3 phosphorus	mg kg^{-1}	81
Ammonium	mg kg^{-1}	3.4
Nitrate	mg kg^{-1}	59
Potassium	mg kg^{-1}	8.0
Calcium	mg kg^{-1}	381
Magnesium	mg kg^{-1}	30
Silicon	mg kg^{-1}	5.5
Cation exchange capacity	cmolc kg^{-1}	0.83