Agriculture, Ecosystems and Environment 233 (2016) 415–424

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Review

# Switchgrass composition and yield response to alternative soil amendments under intensified heat and drought conditions

A.J. Ashworth[a,*], S.A. Weiss[d], P.D. Keyser[c], F.L. Allen[b], D.D. Tyler[e], A. Taylor[f], K.P. Beamer[d], C.P. West[g], D.H. Pote[a]

[a] USDA-Agricultural Research Service, Bumpers Small Farms Research Center, 6883 S. Hwy 23, Booneville, AR, 72927, USA
[b] University of Tennessee, Department of Plant Sciences, Knoxville, TN, 37996, USA
[c] University of Tennessee, Department of Forestry, Wildlife & Fisheries, University of Tennessee, Knoxville, TN, 37996, USA
[d] University of the Virgin Islands, Agronomy Department, St. Croix, 00850, USVI, USA
[e] University of Tennessee, Biosystems Engineering and Soil Science, Knoxville, TN, 37996, USA
[f] University Tennessee, Center for Renewable Carbon, Knoxville, TN, 37996, USA
[g] Texas Tech University, Department of Plant and Soil Science, Lubbock, TX, 79410, USA

ARTICLE INFO

*Article history:*
Received 3 August 2016
Accepted 30 September 2016
Available online xxx

*Keywords:*
Biochar
Legume intercropping
Alternative soil amendments
Climatic intensification
Feedstock composition
Plant adaptation

ABSTRACT

Switchgrass (*Panicum virgatum* L.) and guinea grass (*Panicum maximum* Jacq.) have been proposed as sustainable alternatives to fossil fuels in subtropical and tropical environments, respectively; although still requiring non-renewable inputs, notably, fertilizer-nitrogen (N). Furthermore, climatic intensification forecasts suggest southeastern USA may emulate more tropical or subtropical growing conditions resulting in altered N dynamics and plant physiology. Objectives were to determine: (i) effects of biochar (1 and 2 $Mg\,ha^{-1}$), two intercropped legumes [sunn hemp (*Crotalaria juncea* L.) and pigeon pea (*Cajanus cajan* L.) intercrops] versus inorganic N [67 $kg\,ha^{-1}$ and 0 $kg\,ha^{-1}$] on feedstock and soil characteristics and biomass yield; (ii) how feedstock composition is affected over three harvest dates; and, (iii) switchgrass adaptation to more extreme (tropical) growing conditions. For both species, yield and feedstock composition were influenced by harvest timing ($P < 0.05$), whereas soil amendments influenced composition to a lesser extent over the duration of this study ($P > 0.05$). In general, initial harvests had greater digestible 5- and 6-carbon sugars and N, P, and K tissue levels, whereas in subsequent harvests, higher acid- and neutral-detergent fiber levels were observed, suggesting lesser potential fermentability. Desired feedstock characteristics can therefore be manipulated by harvest timing. Yield results suggest pigeon pea and sunn hemp intercrops, and biochar (1 $Mg\,ha^{-1}$) may result in equivalent yields as N fertilizer per harvest ($P < 0.05$). However, the 2 $Mg\,ha^{-1}$ biochar rate in the tropics adversely impacted yields, perhaps due to N immobilization by biochar. Switchgrass adaptation and competitiveness was moderate (5–30% weed cover) under an intensified climate. Growth can therefore be maintained under a stochastic climate due to its $C_4$ pathway and competitive growth on marginal soils.



**Contents**



*Abbreviations:* N, nitrogen; C, carbon; P, phosphorus; K, potassium; ETREC, East Tennessee Research and Education Center; GREC, Greenville Research and Education Center; STX-AES, St. Croix Agricultural Experiment Station; MLRA, major land resource area; LRR, land resource region; CEC, cation exchange capacity; PLS, pure live seed; SH, sunn hemp; PiP, pigeon pea; NDF, neutral detergent fiber; ADF, acid detergent fiber; SGWI, switchgrass weed index.

* Corresponding author.
*E-mail address:* Amanda.Ashworth@ars.usda.gov (A.J. Ashworth).

http://dx.doi.org/10.1016/j.agee.2016.09.041
0167-8809/

## 1. Introduction

Second-generation feedstocks such as switchgrass (*Panicum virgatum* L.) have been touted as ecologically friendly alternatives to fossil fuels although they typically require inorganic nitrogen (N) for their production. At present, the upstream manufacturing of synthetic nitrogen fertilizer (i.e., Haber-Bosch) is energy-intensive, as breaking trivalent bonds of N ($N \equiv N$) requires high pressure (100–200 atm), high temperature (400–500 °C), and large amounts of fossil energy (8000 kcal $kg^{-1}$ N) for its production (USDA, 2008). As such, this carbon (C)-negative input has pricing linked to petroleum markets. Furthermore, applications of N fertilizers to cropland acidify soils and may degrade surface and ground waters (Ashworth et al., 2015b; Pimentel et al., 2008). Two alternative soil amendments that may help improve rhizosphere fertility are legume intercrops (Snapp et al., 1998) and biochar (Anex et al., 2007).

Leguminous species biologically fix $N_2$ and have been used as intercrops for centuries. Such species can be grown in tandem with food crops in lieu of synthetic N fertilizer (Peoples et al., 2009). Biological $N_2$ fixation occurs through a symbiotic relationship with soil-borne *Rhizobium*-related bacteria, which form nodules in legume roots; wherein dinitrogen ($N_2$) from the atmosphere is converted into ammonium ($NH_4^+$), a plant-assimilable form of N (Graham, 2005). Legume intercrops that supply >110 kg N $ha^{-1}$ achieve crop yields equivalent to those in conventionally fertilized grassland systems (Ashworth et al., 2015a; Tonitto et al., 2006); thereby reducing or eliminating inorganic-N requirements. Further, intercropping has proven to increase soil organic matter and N storage through enhanced additions and returns of biomass to soil (Fustec et al., 2010). However, most studies assessing intercropping impacts on productivity have been conducted in cooler, subtropical environments. Consequently, research is needed in tropical environments to assess yield impacts over a range of intensified climatic conditions.

Biochar is a C-rich by-product of thermal biomass energy extraction from organic material under low oxygen ($O_2$) and at <700 °C (Lehmann and Joseph, 2009). Applications of biochar may enhance soil quality and fertility and build soil C, thus improving the soil as a growth medium for plants (Mullen et al., 2010). For example, the absorbency of biochar may increase soil water-holding capacity and nutrient retention (Ashworth et al., 2014). Variable N concentrations have been reported in biochar (1.8–56.4 g $kg^{-1}$) and should be taken into consideration when predicting plant response. Considering, some nutrients may be rendered unavailable through adsorption and immobilization, therefore rendering them less labile for microbial transformation and plant uptake (Zheng et al., 2012). Biochar elemental composition is dependent on heating values and residence times during its formation, as well as initial elemental profile; therefore, biochars are not all equivalent (Chang and Zhihong, 2009). Furthermore, biochar is low in N relative to more stable C-bonded compounds, and therefore has a high C:N ratio (Sadaka et al., 2014) because feedstock heating causes volatilization of some nutrients, whereas others become concentrated in the remaining activated C (Ashworth et al., 2014). Additionally, biochar acts as a liming agent due to its concentrated levels of alkaline elements such as Ca and Mg. Use of biochar as a soil amendment for crop production promotes a ‘closed-loop’ system, considering this biomass by-product returns plant-available nutrients and carbon to soils.

The southeastern U.S. climate and soils are well positioned for cellulosic feedstock production that will not directly compete for arable land for food production (Jager et al., 2010). This area is characterized by its transition from humid temperate to subtropical climate, and is anticipated to be widely affected by climatic intensification and could possibly emulate more tropical climatic characteristics in the future (IPCC, 1990, 2001). Climate models predict the southeastern U.S. will continue to be affected by moderate-to-severe drought (NRC, 2010), especially during spring and summer months, the apex growing period for $C_4$ grasses. In this region, annual precipitation from 1970 to 2008 declined 7.7%, although the number of heavy downpours increased. Mean annual temperature increased 0.9 °C during this same period; and since 1901, the average number of freezing days declined from seven to four (CCSP, 2008; USGCRP, 2009). Within the next two decades, summer temperature in the southeastern U.S. is projected to continue to increase, as the number of extreme heat days is expected to increase from 90 to 150 (Rosenberg, 1993; USGCRP, 2009). Already more frequent and extreme droughts, intense rainfall events, and heat waves are impacting crop production across the region, and more data on plant response and growth under higher summer temperatures coupled with extended and intensified droughts are needed.

A data gap also exists for legume-intercropping systems for their relative yield contributions and feedstock quality impacts in perennial graminaceous feedstock systems, e.g. switchgrass and a near relative, guinea grass (*Panicum maximum* Jacq.). Guinea grass is very similar physiologically to temperate-subtropical switchgrass; however, it is adapted and naturalized to tropical environmental conditions. This tropical *Panicum* species was included in the event that switchgrass establishment failure occurred, as well as serve as a proxy for determining biomass response to alternative soil amendments in a region representative of intensified climatic. Therefore, our goal was to evaluate an ecologically sustainable, cellulosic energy-production model for reducing inorganic N requirements in a tropical environment representative of projected future climatic conditions for the southeastern U.S.