

**EFFECTS OF BIOCHAR ON YIELD AND NITROGEN NUTRITION OF
WARM-SEASON BIOMASS GRASSES**

A Thesis

presented to

the Faculty of the Graduate School
at the University of Missouri-Columbia

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

CHATHURI SUGANDHIKA WEERASEKARA

Dr. Shibu Jose, Thesis Supervisor

DECEMBER 2015

© Copyright by Chathuri Sugandhika Weerasekara 2015

All Rights Reserved

The undersigned, appointed by Dean of the Graduate School, have examined the thesis entitled

**EFFECTS OF BIOCHAR ON YIELD AND NITROGEN NUTRITION OF
WARM-SEASON BIOMASS GRASSES**

presented by Chathuri Sugandhika Weerasekara,
a candidate for the degree of Master of Science,
and here certify that, in their opinion, it is worth of acceptance.

Dr. Shibu Jose (Chair)

Dr. Ranjith P. Udawatta

Dr. Newell R. Kitchen

*Affectionately Dedicated to My
Loving Parents and Teachers*

ACKNOWLEDGEMENTS

First and foremost, I dedicate my sincere gratitude to my advisor Dr. Shibu Jose, Director, The Center for Agroforestry, University of Missouri, Columbia for awarding me the assistantship for my research and providing me an opportunity to study in the field of agroforestry. I am grateful for his precious advice, guidance and commitments in making this research a success.

I am very much grateful to my committee members Dr. Ranjith P. Udawatta, The Center for Agroforestry and Dr. Newell R. Kitchen, USDA – ARS for their constant encouragement and all the support in my research work. I also would like to express my sincere thanks to Dr. Sougata Bardhan, The Center for Agroforestry, for his invaluable help in various ways throughout the study.

Mr. Phil Blom, “Terra Char” distributor, Columbia, Missouri, provided the biochar for carrying out my experiments and his help is greatly appreciated. Dr. Stephen H. Anderson and Mr. Samuel Haruna (PhD candidate), Department of Soil, Environmental and Atmospheric Sciences, University of Missouri, provided valuable support in conducting the water holding capacity measurements. Dr. Manjula Nathan, Division of Plant Sciences, Soil Testing and Plant Diagnostic Service Laboratory, University of Missouri, helped analyze my potting media and biochar samples. I take this opportunity to express my sincere and heartfelt gratitude to all of them.

I offer great recognition to my loving husband, Chamara Weerasekara, for being with me all the time and his continuous encouragement and support given during this

period. Moreover, I would like to express my gratitude to my friend Badger Johnson (MS candidate), The Center for Agroforestry, for his help during the research.

I extend my special thanks to Barry Eschenbrenner, Kenny Bader, and Nancy Bishop, Horticulture and Agroforestry Research Center (HARC), New Franklin, Missouri for their valuable support given during my research at HARC.

Finally I convey my heartfelt gratitude to my parents, relatives and all my friends for their never ending support and for being there for me as my strength and inspiration to reach my goals and achieve success.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS	ii
LIST OF TABLES	vi
LIST OF FIGURES	vii
ABSTRACT	viii
CHAPTER 1	1
INTRODUCTION	1
References	4
CHAPTER 2	7
LITERATURE REVIEW	7
Global Energy Supply	7
Renewable energy.....	8
Bioenergy.....	9
Switchgrass (<i>Panicum virgatum</i> L.), Big bluestem (<i>Andropogon gerardii</i> Vitman), and Indian grass (<i>Sorghastrum nutans</i> (L.) Nash) as Biomass Feedstock	10
Switchgrass as a bioenergy crop.....	12
Nitrogen management in switchgrass as a biomass energy crop.....	14
Biochar	16
Impacts of biochar on soil quality and plant growth	18
Effects of biochar on nitrogen	21
References	22

CHAPTER 3	28
EFFECTS OF BIOCHAR ON YIELD AND NITROGEN NUTRITION OF WARM- SEASON BIOMASS GRASSES.....	28
Abstract	28
Introduction	29
Materials and Methods	33
<i>Location</i>	33
<i>Planting Materials</i>	33
<i>Experimental Design and Measurements</i>	34
<i>Statistical analysis</i>	37
Results and Discussion.....	37
<i>Aboveground biomass yield</i>	37
<i>Belowground biomass yield</i>	39
<i>Root:shoot ratio</i>	40
<i>Net photosynthetic rate of switchgrass</i>	41
<i>Plant available water content of potting media</i>	42
Conclusions	43
Acknowledgements	44
References	44
CHAPTER 4	61
CONCLUSIONS.....	61

LIST OF TABLES

Table No.		Page
Table 3.1	Elemental analysis of SEA-90®	51
Table 3.2	Chemical and physical properties of biochar	52
Table 3.3	Chemical and physical properties of potting media with 25% sand and different rates of biochar.....	52
Table 3.4	Chemical and physical properties of potting media with 90% sand and different rates of biochar.....	53
Table 3.5	Treatment combinations applied in the experiment.....	53
Table 3.6	Analytical methods for biochar and potting media mixtures.....	54
Table 3.7	Volumetric water content of potting media at field capacity and permeant wilting point.....	55

LIST OF FIGURES

Figure No.		Page
Figure 2.1	World energy consumption by fuel.....	8
Figure 2.2	U.S. energy consumption by energy source in 2012.....	9
Figure 3.1	Mean above ground biomass of switchgrass, big bluestem, and Indian grass with different rates of N (A) and biochar (B) in 2014. Bars with different letters denote significant differences among treatments at $\alpha \leq 0.05$	56
Figure 3.2	Mean above ground biomass of switchgrass and Indian grass with different rates of N (A) and biochar (B) in 2015. Bars with different letters denote significant differences among treatments at $\alpha \leq 0.05$	57
Figure 3.3	Mean below ground biomass of switchgrass with different N and biochar rates in 2014. Error bars denote significant differences among treatments at $p \leq 0.05$	58
Figure 3.4	Mean belowground biomass of switchgrass with different N rates in 2015. Bars with different letters denote significant differences among treatments at $\alpha \leq 0.05$	58
Figure 3.5	Root:shoot ratio of switchgrass and Indian grass with different rates of N in 2015. Bars with different letters denote significant differences among treatments at $\alpha \leq 0.05$	59
Figure 3.6	Net photosynthetic rate of switchgrass with different N rates in 2015. Bars with different letters denote significant differences among treatments at $\alpha \leq 0.05$.	59
Figure 3.7	Plant available water content of potting media with 25% and 90% sand with different biochar rates.	60

ABSTRACT

Majority of the global energy supply depends on fossil fuel sources such as coal, petroleum, and natural gas. Energy production by these sources has significant environmental impacts such as air and water pollution, global warming, and environmental degradation. These issues have become the driving forces of searching for cleaner burning fuels. Bioenergy is a form of renewable energy, produced from plant and animal based materials which are called biomass feedstocks. Switchgrass (*Panicum virgatum* L.), Big bluestem (*Andropogon gerardii* Vitman), and Indian grass (*Sorghastrum nutans* (L.) Nash) are perennial (C₄) warm-season grasses native to North America with great potential as energy crops. They are highly adapted to growing under diverse growing conditions with low inputs, particularly on marginal lands. Improving water holding capacity and soil fertility of marginal lands could potentially increase biomass yield of energy crops on marginal lands. Biochar is a carbon-rich solid material produced by thermal decomposition of biomass under limited supply of oxygen (O₂), and at relatively low temperatures (<700 °C) that can be applied as an organic soil amendment, for improving water and nutrient retention in marginal sandy soils. The hypothesis tested was N fertilization with biochar application to low fertile soils would increase biomass production for switchgrass, big bluestem, and Indian grass. I conducted two greenhouse experiments one in 2014 and one in 2015, to evaluate the effects of biochar amendments with different N rates on growth and biomass production of warm-season grasses and water holding capacity of the potting media. The experimental design was a randomized complete block design (RCBD) with four blocks. In the first study, potting media was prepared by homogenously mixing Promix[®] starter mix and sand at

the volume ratio of 3:1, and 0, 5, 20, 35 Mg ha⁻¹ rates of biochar. In the second study, the potting mix and sand (1:9 by volume) were mixed to create sandy marginal soils found along floodplains of major rivers. Four nitrogen (NH₄NO₃ fertilizer) application rates (0, 60, 120, 180 kg N ha⁻¹) were used in both experiments. Above and belowground biomass yield, net photosynthetic rate, and water holding capacity of the potting media were measured in both years. Biochar and nitrogen interactions were not significant with relative to aboveground biomass and photosynthetic rate for any species in both years. However, interaction effect was significant for belowground biomass of switchgrass in 2014 where 20 Mg ha⁻¹ biochar and 60 kg N ha⁻¹ resulted the highest belowground biomass. Root:shoot ratio of both switchgrass and Indian grass declined significantly with increasing N rates in 2015. Water holding capacity of the potting media did not increase with increasing rates of biochar in both media, however there was a positive trend observed in the medium with 90% sand for volumetric water content at field capacity with increasing biochar rates. Further studies should include long-term experimentation in marginal sandy soils to explore the benefits of using biochar for herbaceous biomass crop production at field and regional scale.

Key words: Big bluestem, biomass energy, Indian grass, marginal sandy soils, switchgrass

CHAPTER 1

INTRODUCTION

Energy derived from renewable resources such as solar, wind, rain, tidal waves, biomass, and geothermal are naturally replenished and considered sustainable. Bioenergy is a form of renewable energy in which biomass feedstocks are used to produce electricity, liquid transportation fuels, or chemicals (Bracmort, 2013). Furthermore, biomass energy is resulted by burning or transformation of the harvested solar energy into liquid or gaseous forms (Parrish and Fike, 2005). Hence, bioenergy is observed to be a viable alternative energy source which is capable of offering solutions for increasing prices of fossil fuels and climate change caused by accumulation of greenhouse gases in the atmosphere (Pedroso et al., 2013). U.S. Department of Energy (2006) has identified cellulosic feedstocks as a principal raw material in the bioenergy production. Perennial grasses, trees, and some annual crops can be grown to yield uniform and quality feedstocks in large quantities for the production of biofuel and bio-power (U.S. Department of Energy, 2011).

According to U.S. Department of Energy, switchgrass (*Panicum virgatum* L.) has been identified as a model herbaceous biomass feedstock for bioenergy production (Grabowski et al., 2004; McLaughlin and Kszos, 2005). Big bluestem (*Andropogon gerardii* Vitman), and Indian grass (*Sorghastrum nutans* (L.) Nash) are also desirable as biomass energy crops, particularly on marginal lands (U.S. Department of Energy, 2011). Many other native warm-season grasses have also been identified as having potential for biomass production in the United States (Grabowski et al., 2004).

Switchgrass, big bluestem, and Indian grass are perennial warm-season grasses (C₄) that are native to North America (U.S. Department of Energy, 2011). They have several characteristics that are desirable as biomass energy crops. Each species is highly adaptive to diverse growing conditions such as marginal lands with shallow top soil and low soil fertility (U.S. Department of Energy, 2011). Furthermore, switchgrass has high biomass potential, high nitrogen (N) use efficiency (Kering et al., 2012), and is considered desirable in relation to the energy produced, moisture and ash contents which are primary components of the biomass combustion (Sadeghpour et al., 2014).

Although switchgrass tolerates low-fertility soils, N fertilizer is required for optimizing the yield (U.S. Department of Energy, 2011). The optimum N rate varies for switchgrass managed for biomass (Mitchell et al., 2008); however, yield will decline if inadequate N is applied, and proper N application will result in the sustainable biomass yield (U.S. Department of Energy, 2011).

One way to enhance soil water and nutrient retention ability is the addition of organic matter or carbon rich materials in soils with low-fertility to enhance water holding capacity and cation exchange capacity of the soil. Biochar is a carbon-rich solid material produced by thermal decomposition of biomass under limited supply of oxygen (O₂), and at relatively low temperatures (<700 °C). Biochar differs from charcoal since it is produced to be applied as a material for improving soil productivity, enhancing soil water storage, or carbon (C) storage (Lehmann and Joseph, 2009). Several studies on biochar effects on crops have been carried out for species such as wheat (*Triticum aestivum* L.) (Tammeorg et al., 2014), oat (*Avena sativa* L.) (Schulz and Glaser, 2012), sunflower (*Helianthus annuus* L.) (Albuquerque et al., 2014), common beans (*Phaseolus*

vulgaris L.) (Rondon et al., 2007), radish (*Raphanus sativus* var. Long Scarlet) (Chan et al., 2007, 2008), maize (*Zea mays* L.) (Major et al., 2010), and sorghum (*Sorghum bicolor* L.) (Steiner et al., 2008). However, few reports are available on major biomass species such as switchgrass.

Chan et al. (2007, 2008) reported positive interactions when N fertilizer and biochar were applied together. According to Steiner et al. (2008), more N fertilizer remained in the biochar amended soil than soils without amendments. Furthermore, the ability of biochar to retain and prevent leaching of N can increase N fertilizer use efficiency, thereby maintain crop yield under smaller N inputs (Chan et al., 2007).

The overall goal of this project was to enhance soil water and nutrient availability on marginal land so that biomass yield could be increased. The hypothesis tested was biochar application with N fertilizers in the soil would enhance both water and N retention. Few studies have been conducted to evaluate the effects of biochar amendments on plant productivity, particularly in switchgrass (Krapfl et al., 2014; Allaire et al., 2015). To the author's knowledge, no studies have been conducted to study the impact of biochar on biomass productivity of big bluestem and Indian grass. Therefore, the specific objectives were:

1. Evaluate the interactive effects of biochar and N on above and belowground biomass production of switchgrass, big bluestem, and Indian grass under greenhouse conditions, and

2. Determine the impact of biochar addition on the water holding capacity of potting medium mixed with high and low levels of sand

The remaining chapters will provide a review of the current state-of- knowledge and experimental details of greenhouse trials undertaken as part of this project.

References

- Alburquerque, J.A., J.M. Calero, V. Barrón, J. Torrent, M.C. del Campillo, A. Gallardo, and R. Villar. 2014. Effects of biochars produced from different feedstocks on soil properties and sunflower growth. *Journal of Plant Nutrition and Soil Science* 177: 16–25. DOI: 10.1002/jpln.201200652.
- Allaire, S.E., F.S. Lange, L. Smith, and others. 2015. Carbon dynamics in a biochar-amended loamy soil under switchgrass. *Canadian Journal of Soil Science* Available at <http://pubs.aic.ca/doi/10.4141/cjss-2014-042> (verified 14 October 2015).
- Bracmort, A. 2013. Biochar: Examination of an emerging concept to sequester carbon. p. 79-104. *In*. W.A. Green and L.G. Wayman (eds.), *Carbon Considerations: Biochar, Biomass, Biopower, and Sequestration*. Nova Science Publishers, Inc. New York, USA.
- Chan, K.Y., L. Van Zwieten, I. Meszaros, A. Downie, and S. Joseph. 2008. Using poultry litter biochars as soil amendments. *Australian Journal of Soil Research* 46(5):437-444.
- Chan, K.Y., L. Van Zwieten, I. Meszaros, A. Downie, and S. Joseph. 2007. Agronomic values of green waste biochar as a soil amendment. *Australian Journal of Soil Research* 45(8):629-634.
- Grabowski, J.M., S.D. Edwards, and J.L. Douglas. 2004. Evaluation of warm-season grass species and management practices to improve biomass production potential in the Mid-South. USDA, Natural Resources Conservation Service, Jamie L. Whitten Plant Materials Center Coffeerville, Mississippi. pp 1-3.
- Kering, M.K., T.J. Butler, J.T. Biermacher, and J.A. Guretzky. 2012. Biomass yield and nutrient removal rates of perennial grasses under nitrogen fertilization. *Bioenergy Research* 5:61–70. DOI 10.1007/s12155-011-9167-x
- Krapfl, K.J., J.A. Hatten, S.D. Roberts, B.S. Baldwin, R.J. Rousseau, and M.W. Shankle. 2014. Soil Properties, Nitrogen Status, and Switchgrass Productivity in a Biochar-Amended Silty Clay Loam. *Soil Science Society of America Journal* 78(S1): S136–S145.
- Lehmann, J. and S. Joseph (eds.). 2009. Stability of biochar in the soil. *In* *Biochar for Environmental Management - Science and Technology*. London, Earthscan. pp 1-2.

- Major, J., M. Rondon, D. Molina, S. J. Riha, and J. Lehmann. 2010. Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol. *Plant Soil* 333:117–128. DOI 10.1007/s11104-010-0327-0.
- McLaughlin, S.B. and L.A. Kszos. 2005. Development of switchgrass (*Panicum virgatum*) as a bioenergy feedstock in the United States. *Biomass and Bioenergy* 28:515–535.
- Mitchell, R.B., K.P. Vogel, and G. Sarath. 2008. Managing and enhancing switchgrass as a bioenergy feedstock. *Biofuels, Bioproducts & Biorefining* 2(6):530–539.
- Parrish, D.J. and J.H. Fike. 2005. The biology and agronomy of switchgrass for biofuels, critical reviews. *Plant Sciences* 24:5-6, 423-459, DOI: 10.1080/07352680500316433. <http://dx.doi.org/10.1080/07352680500316433> (accessed March 18, 2014).
- Pedroso, G.M., R.B. Hutmacher, D. Putnam, S.D. Wright, J. Six, C. Kessel, and B.A. Linquist. 2013. Yield and nitrogen management of irrigated switchgrass systems in diverse eco-regions. *Agronomy Journal* 105:311–320. doi:10.2134/agronj2012.0354.
- Rondon, M.A., J. Lehmann, J. Ramírez, and M. Hurtado. 2007. Biological nitrogen fixation by common beans (*Phaseolus vulgaris* L.) increases with bio-char additions. *Biology and Fertility of Soils* 43: 699–708. DOI 10.1007/s00374-006-0152-z.
- Sadeghpour, A., L.E. Gorlitsky, M. Hashemi, S.A. Weis, and S.J. Herbert. 2014. Response of switchgrass yield and quality to harvest season and nitrogen fertilizer. *Agronomy Journal* 106:290–296. doi:10.2134/agronj2013.0183.
- Schulz, H. and B. Glaser. 2012. Effects of biochar compared to organic and inorganic fertilizers on soil quality and plant growth in a greenhouse experiment. *Journal of Plant Nutrition and Soil Science* 175: 410–422. DOI: 10.1002/jpln.201100143.
- Steiner, C., B. Glaser, W. G. Teixeira, J. Lehmann, W.E.H. Blum, and W. Zech. 2008. Nitrogen retention and plant uptake on a highly weathered central Amazonian Ferralsol amended with compost and charcoal. *Journal of Plant Nutrition and Soil Science* 171:893–899. DOI: 10.1002/jpln.200625199.
- Tammeorg, P., A. Simojoki, P. Mäkelä, F.L. Stoddard, L. Alakukku, and J. Helenius. 2014. Short-term effects of biochar on soil properties and wheat yield formation with meat bone meal and inorganic fertilizer on a boreal loamy sand. *Agriculture, Ecosystems & Environment* 191: 108–116.
- U.S. Department of Energy. 2006. Breaking the biological barriers to cellulosic ethanol: A joint research agenda. DOE/SC-0095. US Department of Energy, Office of Science and Office of Energy Efficiency and Renewable Energy.

U.S. Department of Energy. 2011. U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry. R.D. Perlack and B.J. Stokes (Leads), ORNL/TM-2011/224. Oak Ridge National Laboratory, Oak Ridge, TN. 227p.

CHAPTER 2

LITERATURE REVIEW

Global Energy Supply

Hydrocarbons such as oil, gas, and coal are the major sources of global energy system at present which contributes approximately 80% of the total energy requirement. Energy production by these sources has significant environmental impacts, such as air and water pollution, global warming, and environmental degradation. The rest of the energy supply is derived from traditional biomass such as wood and dung (11%), nuclear (6%), and all other renewable sources (3%) (Bassam, 2010). Fossil fuels dominate the global energy supply with 388 EJ annually, with much smaller contributions from nuclear power (26 EJ) and hydropower (28 EJ), while biomass provides about 45 EJ (Bassam, 2010).

According to the International Energy Outlook 2013 (IEO 2013), the world energy consumption will grow by 56% between 2010 and 2040. Furthermore, total world energy use has been projected to be 665 billion kJ and 865 billion kJ in 2020 and 2040 respectively in comparison to 553 billion kJ in 2010 (IEO, 2013). The world's fastest-growing energy sources are renewable energy and nuclear power (Fig. 2.1), and their production is increasing 2.5% annually, while fossil fuels will contribute for almost 80% of world energy use in 2040 (IEO, 2013). At the same time, natural gas consumption, the fastest-growing fossil fuel is projected to increase by 1.7% annually (IEO, 2013). The largest share of delivered energy continues to be consumed by the industrial sector and will account for over half of global delivered energy in 2040 (IEO, 2013).

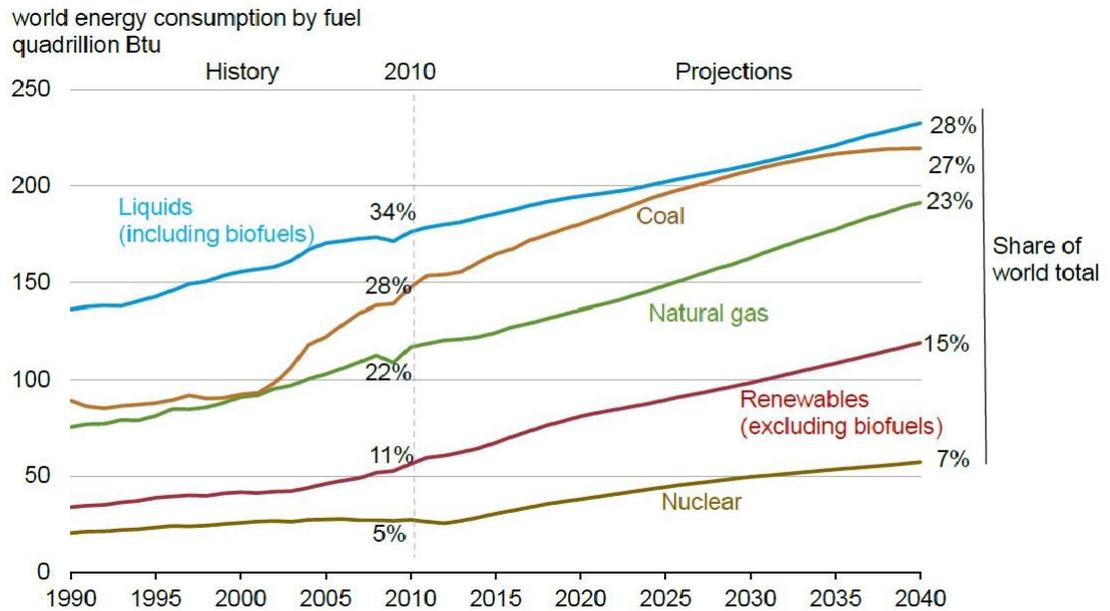


Figure 2.1. World energy consumption by fuel type

Source: EIA, International Energy Outlook 2013 (U.S. Energy Information Administration, <http://www.eia.gov/forecasts/ieo/index.cfm>)

In the United States, the search for cleaner burning fuels has drawn the attention of researchers due to several significant drivers. Those are, issues of high dependency on imported oil, the uncertainties of maintaining stable supplies of imported oil from finite resources, and the environmental costs associated with mining, processing and combusting fossil fuels (McLaughlin et al., 1999).

Renewable energy

Renewable energy is derived from natural sources that can be sustainably replaced. They come from several sources: solar energy, wind energy, biomass energy, hydroelectric power, geothermal energy, and ocean energy (Natural Resources Defense Council, 2014).

Renewable energy is important in many ways since it provides several environmental, economic, and health benefits. They improve the air quality by reducing the effects of burning of fossil fuels, since those are clean sources of energy. Renewable energy will run for future generations as they are infinite sources. Furthermore, they decrease the dependency for foreign fossil fuel, by producing renewable energy within the country and will create more employment opportunities for new income sources (Natural Resources Defense Council, 2014).

The U.S. Energy Information Administration (2014) reported that, the consumption of renewable sources in the United States was about nine quadrillion Btu or about 9% of all energy used in 2012 (Fig. 2.2). From the 9% renewable energy used, biomass contributed for 49% (Fig 2.2).

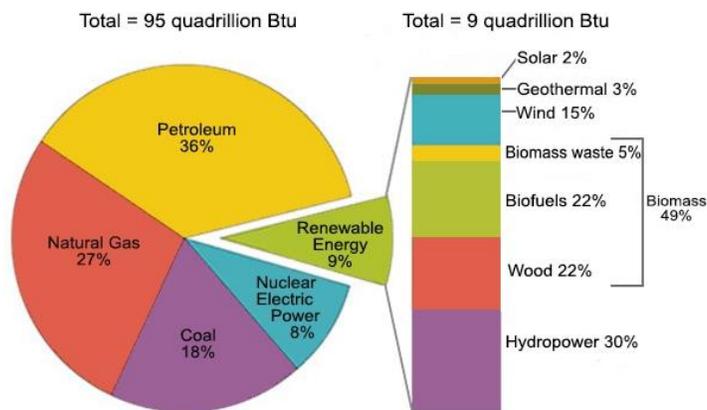


Figure 2.2. U.S. energy consumption by energy source in 2012

Source: U.S. Energy Information Administration

(http://www.eia.gov/kids/energy.cfm?page=renewable_home-basics)

Bioenergy

Bioenergy is a form of renewable energy that is produced from the plant and animal based materials which are called biomass feedstocks (Bracmort, 2013). The solar

energy is stored in the biomass, and plants capture and store the solar energy within its cells through photosynthesis (Bracmort, 2013). The stored energy in biomass is released by both biological processes such as anaerobic digestion and chemical processes such as combustion (Bracmort, 2013). Biomass can be converted to other forms of energy such as heat, bio-power, and transportation fuels.

Generation of electric power from the biomass feedstocks is called bio-power and it was about 1% of the electric generation in 2008 (Bracmort, 2013). Since biomass feedstocks can be used for continuous power production, a bio-power plant is considered a base load power source as well (Bracmort, 2013). Furthermore, biofuels such as ethanol and biodiesel can also be made from biomass feedstocks by fermentation (e.g. corn, sorghum, and barley grains) or by breaking down the cellulose in woody fibers of trees and grasses (U.S. Energy Information Administration, 2014).

Biomass feedstocks that are used for bioenergy generation can be classified into several types. Those are primary biomass feedstocks; materials harvested or collected directly where they are grown (e.g. grains, grasses), secondary biomass feedstocks; by products of the processing of primary feedstocks (e.g. corn stover), and tertiary feedstocks that includes post-consumer residues and wastes (e.g. construction and demolition wastes) (Bracmort, 2013).

Switchgrass (*Panicum virgatum* L.), Big bluestem (*Andropogon gerardii* Vitman), and Indian grass (*Sorghastrum nutans* (L.) Nash) as Biomass Feedstock

Switchgrass, big bluestem, and Indian grass are native perennial warm-season grasses with C₄ photosynthetic system, that are indigenous to most areas of North

America, except for the areas west of the Rocky Mountains and north of 55° N latitude (U.S. Department of Energy, 2011). The plants grow up to 1 to 3 m tall with most of the root mass located in the top 0.3 m of the soil profile (U.S. Department of Energy, 2011).

Switchgrass exhibits vigorous growth during late spring and early summer, while providing good pasture and high quality hay for livestock (USDA-NRCS, 2011). It is adapted to a wide range of sites including the critical areas such as sand dunes, dikes, gullies, and the grass is also suitable for low windbreak plantings in the crop fields (USDA-NRCS, 2011). Switchgrass provides excellent nesting and cover for pheasants, quail, and rabbits, and at the same time the seeds provide food for pheasants, quail, turkeys, doves, and songbirds (USDA-NRCS, 2011). Furthermore, switchgrass has the ability to produce moderate to high biomass yields on marginal lands that is resulted in using the switchgrass in several bioenergy conversion processes such as cellulosic ethanol (USDA-NRCS, 2011). There are several cultivars of switchgrass can be identified and those include Alamo, Blackwell, Bomaster, Carthage, Cave-In-Rock, Central Iowa Germplasm, Dacotah, Durham Germplasm, Forestburg, Kanlow, Nebraska 28, Pathfinder, Shawnee, Shelter, Sunburst, Summer, Grenville, Stuart, and Wabasso (USDA-NRCS, 2011).

Big bluestem is the dominant grass species in the Midwestern tall grass prairie (Wennerberg, 2006). It grows well in the moist soils, and can also be used for mine recovery and restoration areas that are drought and sandy in conditions (Wennerberg, 2006). Big bluestem can be planted to stabilize soil for erosion control and also provide aboveground protection against wind erosion (Wennerberg, 2006). Furthermore, it is grown as a pasture grass and used for hay making since it provides high quality forage for

all livestock species (Wennerberg, 2006). Moreover big bluestem provides shelter for nesting birds and insects as well (Wennerberg, 2006). The cultivars of big bluestem include Bison, Eldorado, Earl, Kaw, Niagara, and Rountree (Wennerberg, 2006).

Indian grass can be cultivated in mixtures with other native grasses and provide livestock forage on range land, pasture land, and hay land (Mike, 2011). Indian grass is used for erosion control and in restoration of native prairie areas and longleaf pine understory sites (Mike, 2011). Furthermore, its foliage is browsed by white-tailed deer and seeds are consumed by birds and small mammals (Mike, 2011). Indian grass cultivars include Holt, Llano, Lometa, Osage, Rumsey, Tomahawk, Americus, and Cheyenne (Mike, 2011).

There are several characteristics that make these perennial warm-season grasses desirable as biomass energy crops. Once they are established, they can be harvested annually for 15-20 years before replanting, require low amount of fertilizers and nutrients, are drought tolerant, have very high yield potential with adequate water, are suitable for growing on marginal lands, provide wild life cover and erosion control, can be grown and harvested by existing farm equipment, and are planted by seeding (Bracmort, 2013).

Switchgrass as a bioenergy crop

Switchgrass was selected as the model herbaceous bioenergy crop according to the screening trials funded by U.S. Department of Energy in early 1990s. Those are explained in the reports and proceeding papers of the Oak Ridge National Laboratory's Biofuels Feedstock Development Program (Wright and Turhollow, 2010). David and

Ragauskas (2010) reported that switchgrass is a promising grass species as a biomass feedstock for bio-power and biofuel production. David and Ragauskas (2010) further mentioned switchgrass as a good candidate among other biomass species evaluated for bioenergy production through, either conversion to ethanol using the saccharification and fermentation process or for thermo-chemical conversion to pyrolysis oils. According to the energy budgets, McLaughlin et al. (1999) stated significant gains in energy return and reduction of carbon emissions are also possible with switchgrass as a biofuel. Furthermore the high cellulosic content makes switchgrass an ideal feedstock for bioenergy production which contributes to a more positive energy balance for cellulosic ethanol, by reducing the use of fossil fuels (Rinehart, 2006).

The energy values for switchgrass and other perennial warm-season grasses are between 18 – 19 MJ/kg (dry) (Bracmort, 2013). In a five year study in Nebraska Varvel et al. (2008) reported that potential ethanol yield for switchgrass was equal to or greater than the potential total ethanol yield of corn grain and harvested stover fertilized at the same optimum N rate.

Schmer et al. (2008) modeled the energy efficiency and sustainability of cellulosic ethanol from switchgrass using net energy value (NEV), net energy yield (NEY), and the petroleum energy ratio (PER). According to the results, switchgrass fields in the Midwest produced 540% more renewable energy (NEV) than non-renewable energy consumed in production over a five year period (Schmer et al., 2008). Schmer et al. (2008) also estimated the PER of 13.1, equivalent to produce 38% more ethanol per hectare than human made prairies and 191% more ethanol per hectare than low-input switchgrass in Minnesota. Furthermore, Schmer et al. (2008) reported the estimated average greenhouse

gas (GHG) emissions from cellulosic ethanol derived from switchgrass were 94% lower than the estimated GHG from gasoline which is a positive environmental impact.

Nitrogen management in switchgrass as a biomass energy crop

Nitrogen (N) is generally considered as the most limiting nutrient in switchgrass cropping systems (Lemus et al., 2008). Furthermore, N management is important for switchgrass grown for biomass feedstock as N impacts productivity, biomass yield, and contributes significantly to the cost of production (Lee et al., 2009; Anderson et al., 2013; Owens et al., 2013; Pedroso et al., 2013). In addition to that, Boyer et al. (2012) stated annual N fertilizer applications are necessary to produce higher yields that make switchgrass production for lignocellulosic biomass economically viable. However, switchgrass response to N fertilization varies with cultivar, harvest management, biomass yield, and soil and weather conditions (Lee et al., 2009; Owens et al., 2013).

Muir et al. (2001) reported maximum switchgrass biomass production was nearly 13.4 Mg ha⁻¹ yr⁻¹ on average over all sites of Stephenville and Beeville, TX in the south central USA, as response to spring application of 168 kg N ha⁻¹. A maximum yield of 22.5 Mg ha⁻¹ occurred at Stephenville with this rate of N. Greater tiller mass resulted as the plant response to increased N fertilizer while showing much smaller response of tiller density. Biomass production declined over the years in the absence of N additions.

According to Vogel et al. (2002), optimum biomass yield of Cave-in-Rock switchgrass was obtained when harvested at the maturity stages R3 to R5 (panicle fully emerged from boot to post-anthesis) and fertilized with 120 kg N ha⁻¹. With these treatments, biomass yields averaged 10.5-11.2 Mg ha⁻¹ at Mead and 11.6-12.6 Mg ha⁻¹ at

Ames in the Midwest USA. Pedroso et al. (2013) reported that significant N fertilizer input was necessary for sustaining greater switchgrass yields in intensively managed multi-harvest systems. These authors observed switchgrass yields of 9.7 and 13 Mg ha⁻¹ yr⁻¹, and N use efficiency of 30 and 44 kg biomass kg⁻¹ N applied in 2009 and 2010 respectively, with the addition of 300 kg N ha⁻¹ yr⁻¹.

Boyer et al. (2012) modeled the yield response of switchgrass to N in four landscapes in Tennessee using a linear response stochastic plateau function. For switchgrass grown on the well- to moderately-drained upland soil, the linear stochastic plateau response predicted the profit maximizing N rate as 63-82 kg N ha⁻¹. The profit maximizing N rate was 61-69 kg N ha⁻¹ for switchgrass grown on the moderately to well-drained flood plain soil. Furthermore, on the moderate to somewhat poorly-drained eroded sloping upland soil, the profit maximizing N rate was 97-109 kg N ha⁻¹, while for poorly-drained flood plain soil the profit maximizing N rate was 153-165 kg N ha⁻¹.

Mulkey et al. (2006) reported total biomass yield increased when N was applied up to 56 kg ha⁻¹, with no benefit with N application levels above 56 kg ha⁻¹ on switchgrass dominated Conservation Reserve Program (CRP) lands in South Dakota, USA. Moreover, optimizing N application level is the major concern with switchgrass management systems as a bioenergy crop, since excessive application of N fertilizers may cause adverse environmental and economic effects such as accelerated N₂O gas emission, NO₃⁻-N leaching, and an increase in production costs (Owens et al., 2013).

Biochar

Biochar is defined as a solid material that is obtained from the thermochemical conversion of biomass under limited oxygen supply and at relatively low temperatures (<700 °C) (Lehmann and Joseph, 2009; Laufer and Tomlinson, 2013). It can be used alone or as a component of a blended product, with a wide range of applications (Laufer and Tomlinson, 2013). Amazonian Dark Earths which locally known as Terra Preta de Indio (anthropogenic soils) has been identified as a result of soil management practice carried out by ancient Amer-Indian populations and the scientific research of those soils has been produced significant basic information on the functioning of soils and the effects of biochar (Lehmann and Joseph, 2009). Glaser et al. (2002) reported charcoal was reported to be responsible for high soil organic matter contents and soil fertility of Terra Preta found in central Amazonia. Furthermore, biochar can be used as an ingredient for soil improvement, improve the efficiency of resource use, reduction of environmental pollution, and greenhouse gas mitigation (Lehmann, 2007; Laufer and Tomlinson, 2013). The specific properties of biochar such as high stability against decay and superior ability to retain nutrients in comparison to other forms of soil organic matter enhance the value of this product (Lehmann, 2007).

Pyrolysis is the method that is used to produce biochar. Pyrolysis can be subdivided into slow pyrolysis and fast pyrolysis (Brown, 2009). However, the quality of the co-products resulting from pyrolysis such as bio-oil, biochar, and syngas varies according to the nature of feedstock (Laird et al., 2011). Slow pyrolysis is the heating of biomass at temperature of around 400 °C and in the absence or limited oxygen (Lehman, 2007; Laird et al., 2011). This method includes production of approximately equal

masses of syngas, bio-oil, and biochar by the decomposition of lignocellulosic biomass (Laird et al., 2011). During the fast pyrolysis method, biomass is rapidly heated to temperatures of 400-700 °C in the absence or limited oxygen (Lehman, 2007; Laird et al., 2011). Fast pyrolysis yields 60% bio-oil, 20% biochar, and 20% syngas and it is a process done in seconds (Gaskin et al., 2010). For typical inputs, the energy required to run a fast pyrolyzer is approximately 15% of the energy of its outputs. Whereas slow pyrolysis can be optimized to produce substantially more char (Gaskin et al., 2010). Furthermore, moisture content of the biomass feedstock is the critical factor for determining the energy recovery of fast pyrolysis (Laird et al., 2011). In addition to that, Laird (2008) reported biochar application to soils may build up the soil quality while leading to sustainability.

The characteristics of biochar depend on its production method and type of feedstock used. The production parameters such as temperature, rate of temperature increase, pre and post processing also affect the quality of resulting biochar including availability of nutrients to crops, physical and chemical properties of crops, and the amount of stable carbon (C) sequestered (Laufer and Tomlinson, 2013).

According to Singh et al. (2010), properties of the biochar vary depending on the feedstock and pyrolysis temperature. They produced 11 types of biochar using 5 feedstocks including [*Eucalyptus saligna* wood (at 400 °C and 550 °C both with and without steam activation); *E. saligna* leaves (at 400 °C and 550 °C with activation); paper-mill sludge (at 550 °C with activation); poultry litter and cow manure (each at 400 °C without activation and at 550 °C with activation)] using standard or modified soil chemical procedures. Biochar produced by wood had higher total C, lower ash content, lower cation exchange capacity (CEC) and exchangeable cations, and lower total N, P, K,

S, Ca, Mg, Al, Na, and Cu contents than the manure-based biochar. Above properties of leaf biochar were generally in-between. The highest total and exchangeable Ca, total Cu, and potential CEC had with paper-mill sludge biochar while having the lowest total and exchangeable K. Therefore, when applying biochar into the agricultural soils, attention should be given to the biochar properties due to its effect on soil nutrient availability (Alburquerque et al., 2014).

Impacts of biochar on soil quality and plant growth

Studies have demonstrated that biochar application can enhance several soil properties such as increase of soil pH, CEC, total C, total N, available P, water holding capacity, exchangeable cations, nutrient cycling and attracting more beneficial fungi and microbes, while decreasing available soil Al, soil strength, and soil bulk density (Yamato et al., 2006; Chan et al., 2007, 2008; Laird et al., 2010a; Major et al., 2010; Van Zwieten et al., 2010; Filiberto and Gaunt, 2013). These factors provide numerous benefits to increase biomass yield and crops yield under different conditions (Filiberto and Gaunt, 2013). Uzoma et al. (2011) have reported that biochar produced from woody feedstock enhance the soil pH, CEC, and water retention and Covell et al. (2011) have mentioned biochar from cow manure and poultry litter provide higher levels of N, P, and K.

Briggs et al. (2005) stated that biochar can retain large amounts of water due to its high porosity, and when applied to sandy soils biochar can improve the soil water holding capacity. Application of rice husk biochar at rates between 50-150 g kg⁻¹ in pot trials of lettuce (*Lactuca sativa* L.) and cabbage (*Brassica oleracea* L.) that used sandy, acidic soils in Cambodia, showed positive effects by increasing the final biomass, root biomass, plant height and number of leaves in all the cropping cycles when compared to the

control (Carter et al., 2013). Furthermore, the greatest biomass increase of lettuce (903%) and cabbage (750%) was observed in the non-fertilized soil with 50 g kg⁻¹ biochar addition (Carter et al., 2013).

Laird et al. (2010a) mentioned that application of biochar amendments have potential to improve the quality and fertility status of Midwestern agricultural soils. Moreover they have reported most of Ca, Mg, K, P, and plant micronutrients, and about half of the N and S in the biomass feedstock are partitioned into the biochar fraction, hence they can return most of the nutrients back into the soil. In addition to that, Laird et al. (2010b) stated soil biochar additions can reduce the nutrient leaching and have the capacity to absorb dissolved organic C (DOC) from the soil solution in the Midwestern agricultural soils. Hence the ability of biochar to reduce N mineralization and NO₃⁻-N leaching are important in making management options in the agriculture production (Laird et al., 2010b).

Steiner et al. (2007) studied the effects of charcoal addition into mineral fertilized banana (*Musa L.*) plantation and organically fertilized guarana (*Paullinia cupana* Kunth) plantation and concluded that it can increase pH, total N, available Na, Zn, Mn, Cu and soil humidity, and decrease Al availability and acidity only in the inorganic fertilized plantation. Ulyett et al. (2014) stated that biochar application into both organically and conventionally managed soils increased moisture retention and reduced soil bulk density. Major et al. (2010) studied the effect of single application of biochar on Colombian savanna Oxisol for four years (2003–2006), and found that maize yield did not significantly increase in the first year but increased by 28, 30 and 140% for 2004, 2005 and 2006 respectively at the rate of 20 Mg ha⁻¹ in comparison to the control.

Furthermore, they reported that higher crop yield and nutrient uptake was primarily due to the 77–320% increase of available Ca and Mg in soil where biochar was applied. Incorporation of 1% straw biochar increased the root penetration, root density (54%) and grain yield (22%) of spring barley (*Hordeum vulgare* cv. Anakin) that was grown on soil columns prepared with sandy sub-soils (Bruun et al., 2014).

Studies have demonstrated that biochar is important for improving the beneficial microbial populations in the soil. Because of high porous structure and large surface area of biochar it can harbor beneficial soil micro-organisms such as mycorrhizae and bacteria, and enhance the binding sites for nutrients (Atkinson et al., 2010). Therefore it would increase the bioavailability and plant uptake of key nutrients. Application of *Acacia mangium* bark charcoal amendments at the rate of 10 Mg ha⁻¹, increased the maize yield approximately 50% under fertilized condition of N:P:K (15 : 15 : 15) in an acidic, highly weathered, and infertile tropical soil in South Sumatra, Indonesia (Yamato et al., 2006). In addition to that, increase in the root amount and colonization rate of arbuscular mycorrhizal (AM) fungi was also observed in the maize fields after addition of biochar.

Solaiman et al. (2010) evaluated the effect of deep-banded oil mallee biochar (produced from the biomass remaining after oil extraction of *Eucalyptus* sp.) at different rates (0, 1.5, 3.0, and 6 Mg ha⁻¹) with two types of fertilizer (inoculated and non-inoculated) on wheat growth at a field in a low rainfall area of Western Australia. They observed that, wheat yield increased when biochar was applied with inoculated fertilizer and 30 kg ha⁻¹ non-inoculated fertilizer. Furthermore, mycorrhizal colonization in wheat roots increased significantly with biochar application with inoculated mineral fertilizer.

They hypothesized that mycorrhizal hyphae may have improved water supply to the plants which improved grain yield due to reduced drought stress. However under some conditions, there is no yield increase or even decreased yield upon biochar application (Chan et al., 2007, 2008; Gaskin et al., 2010; Tammeorg et al., 2014a, 2014b).

Effects of biochar on nitrogen

Rondon et al. (2007) evaluated the biological N₂ fixation by common beans (*Phaseolus vulgaris* L.) through biochar additions and reported that proportion of fixed N by *Rhizobium* strains increased by 72% when 90 g biochar kg⁻¹ soil was added. Bean yield was also increased by 46% with 90 g biochar kg⁻¹ soil in comparison to no biochar treatment.

Lehmann et al. (2003) mentioned that while plant uptake of P, K, Ca, Zn, and Cu was increased with higher charcoal additions, NO₃⁻-N leaching was reduced and Ca and Mg leaching was delayed by application of charcoal. Moreover, Zhao et al. (2014) reported that ability of biochar to reduce N leaching may be due to improved N adsorption and increased N immobilization and/or gaseous losses. Ulyett et al. (2014) stated biochar amendments can enhance the nitrification in conventionally managed soil with added mineral N.

Chan et al. (2007) observed a significant biochar by nitrogen fertilizer interaction with the increased yield in a pot trial of radish (*Raphanus sativus* var. Long Scarlet). A higher radish yield was resulted when biochar was applied with N fertilizers. Dry biomass yield increased 95% without biochar to 266% with 100 Mg ha⁻¹ biochar in the presence of N fertilizers. At the same time there was no significant increase in yield even

at the highest rate of biochar (100 Mg ha⁻¹) alone. In addition, Chan et al. (2008) stated non-activated poultry litter biochar produced at lower temperature (450 °C) was more effective in terms of increasing dry matter yield of radish in comparison to activated biochar produced at higher temperature (550 °C), when applied together with N fertilizer. Furthermore, according to a pot trial of wheat and radish in a yellow earth established under controlled climate conditions, Van Zwieten et al. (2010) showed that increasing biochar concentrations improved biomass production in both crop species at lower N application rates. Thus a highlight of these studies is biochar can improve N fertilizer use efficiency in plants.

References

- Alburquerque, J.A., J.M. Calero, V. Barrón, J. Torrent, M.C. del Campillo, A. Gallardo, and R. Villar. 2014. Effects of biochars produced from different feedstocks on soil properties and sunflower growth. *Journal of Plant Nutrition and Soil Science* 177:16–25. DOI: 10.1002/jpln.201200652.
- Anderson, E.K., A.S. Parrish, T.B. Voigt, V.N. Owens, C.H. Hong, and D.K. Lee. 2013. Nitrogen fertility and harvest management of switchgrass for sustainable bioenergy feedstock production in Illinois. *Industrial Crops and Products* 48:19-27.
- Atkinson, C.J., J.D. Fitzgerald, and N.A. Higgs. 2010. Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: A review. *Plant and Soil* 337:1–18. DOI 10.1007/s11104-010-0464-5
- Bassam, N.E. 2010. *Handbook of Bioenergy Crops: A Complete Reference to Species, Development and Applications*. http://books.google.com/books/about/Handbook_of_Bioenergy_Crops.html?id=zRW3_QwQhTIC (accessed March 16, 2014).
- Boyer, C.N., R.K. Roberts, J.A. Larson, B.C. English, D.D. Tyler, and V. Zhou. 2012. Switchgrass yield response to nitrogen on four soil types in West Tennessee. <http://www.beag.ag.utk.edu/present/sungrant/Presentation6a.pdf> (accessed March 15, 2014).
- Bracmort, A. 2013. Biochar: Examination of an emerging concept to sequester carbon. p. 79-104. *In* W.A. Green and L.G. Wayman (eds.), *Carbon Considerations:*

Biochar, Biomass, Biopower, and Sequestration. Nova Science Publishers, Inc. New York, USA.

- Briggs C.M., J.M. Breiner, and R.C. Graham. 2005. Contributions of pinus ponderosa charcoal to soil chemical and physical properties. *Pinus Ponderosa Charcoal*. pp. 1-13.
- Brown, R. 2009. Biochar production technology. *In* Lehmann, J. and S. Joseph (eds.). *Biochar for Environmental Management - Science and Technology*. London, Earthscan. pp. 127-128.
- Bruun, E.W., C. T. Petersen, E. Hansen, J. K. Holm, and H. Hauggaard-Nielsen. 2014. Biochar amendment to coarse sandy subsoil improves root growth and increases water retention. *Soil Use and Management* 30(1):109–118. doi: 10.1111/sum.12102
- Carter, S., S. Shackley, S. Sohi, T.B. Suy, and S. Haefele. 2013. The impact of biochar application on soil properties and plant growth of pot grown lettuce (*Lactuca sativa*) and cabbage (*Brassica chinensis*). *Agronomy Journal* 3:404-418. doi:10.3390/agronomy3020404
- Chan, K. Y., L. Van Zwieten, I. Meszaros, A. Downie, and S. Joseph. 2007. Agronomic values of greenwaste biochar as a soil amendment. *Australian Journal of Soil Research* 45(8):629-634.
- Chan, K. Y., L. Van Zwieten, I. Meszaros, A. Downie, and S. Joseph. 2008. Using poultry litter biochars as soil amendments. *Australian Journal of Soil Research* 46(5):437-444.
- Covell, P., G. Gammie, S. Hunt, L. Brunjes, F. Ng, and D. Nees. 2011. Advancing biochar in the chesapeake: A strategy to reduce pollution from poultry litter—forest trends/katoomba incubator, carbon war room, forest trends/chesapeake fund. http://www.forest-trends.org/documents/files/doc_2891.pdf (Accessed June 04, 2014).
- David, K. and A.J. Ragauskas. 2010. Switchgrass as an energy crop for biofuel production: A review of its ligno-cellulosic chemical properties. *Energy and Environmental Science* 3:1182–1190. DOI: 10.1039/b926617h.
- Filiberto, D.M. and J.L. Gaunt. 2013. Practicality of biochar additions to enhance soil and crop productivity. *Agriculture* 3:715-725. doi:10.3390/agriculture3040715
- Gaskin, J.W., R.A. Speir, K. Harris, K.C. Das, R.D. Lee, L.A. Morris, and D.S. Fisher. 2010. Effect of peanut hull and pine chip biochar on soil nutrients, corn nutrient status, and yield. *Agronomy Journal* 102(2):623-633.

- Glaser, B., J. Lehmann, and W. Zech. 2002. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal – A review. *Biology and Fertility of Soils* 35:219–230. DOI 10.1007/s00374-002-0466-4.
- International Energy Outlook. 2013. <http://www.eia.gov/forecasts/ieo/index.cfm> (Accessed May 30, 2014).
- Laird, D.A. 2008. The charcoal vision: A win–win–win scenario for simultaneously producing bioenergy, permanently sequestering carbon, while improving soil and water quality. *Agronomy Journal* 100(1):178-181.
- Laird, D.A., P. Fleming, D.D. Davis, R. Horton, B. Wang, and D. L. Karlen. 2010a. Impact of biochar amendments on the quality of a typical Midwestern agricultural soil. *Geoderma* 158:443–449.
- Laird, D.A., N.P. Rogovska, M. Garcia-Perez, H. P. Collins, J.D. Streubel, R.M. Smith, R. 2011. Pyrolysis and Biochar – Opportunities for Distributed Production and Soil Quality Enhancement. *In* Braun, R., D.L. Karlen, and D. Johnson. (eds.). Sustainable Alternative Fuel Feedstock Opportunities, Challenges and Roadmaps for Six U.S. Regions. Proceedings of the Sustainable Feedstocks for Advanced Biofuel Workshop. SWCS publisher. www.swcs.org/roadmap/ (Accessed June 01, 2014).
- Laird, D.A., P. Fleming, B. Wang, R. Horton, and D.L. Karlen. 2010b. Biochar impact on nutrient leaching from a Midwestern agricultural soil. *Geoderma* 158:436–442.
- Laufer, J. and T. Tomlinson. 2013. Biochar field studies: An IBI research summary. <http://biochar-international.org/>. (Accessed May 30, 2014).
- Lee, D.K., E.D. Nafziger, F. Fernández, E. Adey, S.A. Ebelhar, L.E. Paul, L. Deal, and M. Vose. 2009. Nitrogen fertility management of switchgrass for sustainable bioenergy feedstock production in Illinois. Illinois Fertilizer Conference Proceedings. <http://frec.ifca.com/2010/report12/> (Accessed May 27, 2014).
- Lehmann, J. 2007. Bio-energy in the black. *Frontiers in Ecology and the Environment* 5(7):381–387.
- Lehmann, J., J.P. da Silva Jr, C. Steiner, T. Nehls, W. Zech, and B. Glaser. 2003. Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: fertilizer, manure and charcoal amendments. *Plant and Soil* 249:343–357.
- Lehmann, J. and S. Joseph (eds.). 2009. Stability of biochar in the soil. *In* Biochar for Environmental Management - Science and Technology. London, Earthscan. pp 1-2.

- Lemus, R., D.J. Parrish, and O. Abaye. 2008. Nitrogen use dynamics in switchgrass grown for biomass. *Bioenergy Research* 1:153–162. DOI 10.1007/s12155-008-9014-x
- Major, J., M. Rondon, D. Molina, S. J. Riha, and J. Lehmann. 2010. Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol. *Plant and Soil* 333:117–128. DOI 10.1007/s11104-010-0327-0
- McLaughlin, S., J. Bouton, D. Bransby, B. Conger, W. Ocumpaugh, D. Parrish, C. Taliaferro, K. Vogel, and S. Wullschleger. 1999. Developing switchgrass as a bioenergy crop. *In* J. Janick (ed.), *Perspectives on new crops and new uses*. ASHS Press, Alexandria, VA. pp 282-299.
- Mike, O. 2011. Plant fact sheet for Indian grass (*Sorghastrum nutans* [L.] Nash). USDA-Natural Resources Conservation Service, Jimmy Carter PMC Americus, Georgia 31719.
- Muir, J.P., M.A. Sanderson, W.R. Ocumpaugh, R.M. Jones, and R.L. Reed. 2001. Biomass production of ‘Alamo’ switchgrass in response to nitrogen, phosphorus, and row spacing. *Agronomy Journal* 93:896–901.
- Mulkey, V.R., V.N. Owens, and D.K. Lee. 2006. Management of switchgrass-dominated conservation reserve program lands for biomass production in South Dakota. *Crop Science* 46:712–720. doi:10.2135/cropsci2005.04-0007
- Natural Resources Defense Council 2014. Renewable energy for America. Harvesting the benefits of homegrown, Renewable energy. <http://www.nrdc.org/energy/renewables/missouri.asp>
- Owens, V.N., D.R. Viands, H.S. Mayton, J.H. Fike, R. Farris, E. Heaton, D.I. Bransby, and C.O. Hong. 2013. Nitrogen use in switchgrass grown for bioenergy across the USA. *Biomass and Bioenergy* 58:286-293.
- Pedroso, G.M., R.B. Hutmacher, D. Putnam, S.D. Wright, J. Six, C. Kessel, and B.A. Linquist. 2013. Yield and nitrogen management of irrigated switchgrass systems in diverse eco-regions. *Agronomy Journal* 105:311–320. doi:10.2134/agronj2012.0354.
- Rajkovich, S., A. Enders, K. Hanley, C. Hyland, A.R. Zimmerman, and J. Lehmann. 2012. Corn growth and nitrogen nutrition after additions of biochars with varying properties to a temperate soil. *Biology and Fertility of Soils* 48:271–284. DOI 10.1007/s00374-011-0624-7
- Rinehart, L. 2006. Switchgrass as a bioenergy crop. A Publication of ATTRA - National Sustainable Agriculture Information Service. 1-800-346-9140. pp 1-10.
- Rondon, M.A., J. Lehmann, J. Ramírez, and M. Hurtado. 2007. Biological nitrogen fixation by common beans (*Phaseolus vulgaris* L.) increases with bio-char

- additions. *Biology and Fertility of Soils* 43:699–708. DOI 10.1007/s00374-006-0152-z.
- Schmer, M.R., K.P. Vogel, R.B., Mitchell, and R.K. Perrin. 2008. Net energy of cellulosic ethanol from switchgrass. *Proceedings of the National Academy of Science* 105(2):464–469.
- Singh, B., B.P. Singh, and A.L. Cowie. 2010. Characterisation and evaluation of biochars for their application as a soil amendment. *Australian Journal of Soil Research* 48:516–525.
- Solaiman, Z.M., P. Blackwell, L.K. Abbott, and P. Storer. 2010. Direct and residual effect of biochar application on mycorrhizal root colonisation, growth and nutrition of wheat. *Australian Journal of Soil Research* 48:546–554.
- Steiner, C., M.R. de Arruda, M.R., W.G. Teixeira, W. Zech. 2007. Soil respiration curves as soil fertility indicators in perennial central Amazonian plantations treated with charcoal, and mineral or organic fertilizers. *Tropical Science* 47:218-230.
- Stevenson, F.J. 1982. *Humus chemistry: genesis, composition, reactions*. A Wiley-Interscience Publication, John Wiley and Sons, New York, USA.
- Tammeorg, P., A. Simojoki, P. Mäkelä, F.L. Stoddard, L. Alakukku, and J. Helenius. 2014b. Biochar application to a fertile sandy clay loam in boreal conditions: effects on soil properties and yield formation of wheat, turnip rape and faba bean. *Plant and Soil* 374:89–107. DOI 10.1007/s11104-013-1851-5
- Tammeorga, P., A. Simojokib, P. Mäkelä, F. L. Stoddarda, L. Alakukkuc, and J. Heleniusa. 2014a. Short-term effects of biochar on soil properties and wheat yield formation with meat bone meal and inorganic fertilizer on a boreal loamy sand. *Agriculture, Ecosystems and Environment*. Article in press.
- U.S. Department of Energy. 2011. *U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry*. R.D. Perlack and B.J. Stokes (Leads), ORNL/TM-2011/224. Oak Ridge National Laboratory, Oak Ridge, TN. 227p.
- U.S. Energy Information Administration. 2014. http://www.eia.gov/kids/energy.cfm?page=biomass_home (Accessed May 30, 2014).
- Ulyett, J., R. Sakrabani, M. Kibblewhite, and M. Hann. 2014. Impact of biochar addition on water retention, nitrification and carbon dioxide evolution from two sandy loam soils. *European Journal of Soil Science* 65: 96–104. doi: 10.1111/ejss.12081.
- USDA-NRCS. Jimmy Carter Plant Materials Center. 2011. Plant fact sheet for switchgrass (*Panicum virgatum* L.). USDA-Natural Resources Conservation Service.

- Uzoma, K.C., M. Inoue, H. Andry, H. Fujimaki, A. Zahoor, and E. Nishihara. 2011. Effect of cow manure biochar on maize productivity under sandy soil condition. *Soil Use and Management* 27:205–212.
- Van Zwieten, L., S. Kimber, A. Downie, S. Morris, S. Petty, J. Rust, and K.Y. Chan. 2010. A glasshouse study on the interaction of low mineral ash biochar with nitrogen in a sandy soil. *Australian Journal of Soil Research* 48:569-576.
- Varvel, G.E., K.P. Vogel, R.B. Mitchell, R.N. Follett, and J.M. Kimble. 2008. Comparison of corn and switchgrass on marginal soils for bioenergy. *Biomass and Bioenergy* 32(1):18–21.
- Vogel, K.P., J.J. Brejda, D.T. Walters, and D.R. Buxton. 2002. Switchgrass Biomass Production in the Midwest USA: Harvest and Nitrogen Management. *Agronomy Journal* 94:413–420.
- Wennerberg, S. 2006. Plant fact sheet for big bluestem, USDA-Natural Resources Conservation Service, USDA-NRCS National Plant Data Center, Baton Rouge, Louisiana.
- Wright, L. and A. Turhollow. 2010. Switchgrass selection as a “model” bioenergy crop: A history of the process. *Biomass and Bioenergy* 34:851–868.
- Yamato, M., Y. Okimori, I.F. Wibowo, S. Ashori, and M. Ogawa. 2006. Effects of the application of charred bark of *Acacia mangium* on the yield of maize, cowpea and peanut, and soil chemical properties in South Sumatra, Indonesia. *Soil Science and Plant Nutrition* 52:489–495. doi:10.1111/j.1747-0765.2006.00065.x
- Zhao, X., S. Wang, and G. Xing. 2014. Nitrification, acidification, and nitrogen leaching from subtropical cropland soils as affected by rice straw-based biochar: laboratory incubation and column leaching studies. *Journal of Soils and Sediments* 14:47–482. DOI 10.1007/s11368-013-0803-2.

CHAPTER 3

EFFECTS OF BIOCHAR ON YIELD AND NITROGEN NUTRITION OF WARM-SEASON BIOMASS GRASSES

Abstract

Switchgrass, big bluestem, and Indian grass are perennial (C₄) warm-season grasses native to North America, and desirable as biomass energy crops. They are highly adapted to growing under diverse growing conditions, particularly on marginal lands. Improving water holding capacity and soil fertility of marginal lands could potentially increase biomass yield of energy crops on marginal lands. Biochar is a carbon-rich solid material produced by thermal decomposition of biomass under limited supply of oxygen (O₂), and at relatively low temperatures (<700 °C) that can be applied as an organic soil amendment on such lands. The hypothesis tested was biochar application with N fertilizers to soils with low-fertility will increase biomass production for switchgrass, big bluestem, and Indian grass. I conducted two greenhouse experiments, in 2014 and 2015 summer, to evaluate the effects of biochar amendments with different N rates on biomass production of switchgrass, Indian grass, and big bluestem and determine the biochar effect on water holding capacity of the potting media. The experimental design was a randomized complete block design (RCBD) with four blocks. In the first study, potting media was prepared by homogenously mixing Promix[®] starter mix and sand 3:1 by volume and 0, 5, 20, 35 Mg ha⁻¹ rates of biochar. In the second study, the potting mix and sand (1:9 by volume) were mixed to create sandy marginal soils found along floodplains of major rivers. Four nitrogen (NH₄NO₃ fertilizer) application rates (0, 60,

120, 180 kg N ha⁻¹) were used in both trials. Above and belowground biomass yield, net photosynthetic rate, and water holding capacity of the potting media were measured. Biochar by nitrogen interaction was significant for belowground biomass yield of switchgrass in 2014 study where 20 Mg ha⁻¹ biochar and 60 kg N ha⁻¹ resulted the highest belowground biomass. However, the interaction effect was not significant with related to aboveground biomass yield and photosynthetic rate for any of the species in both years. Root:shoot ratio of both switchgrass and Indian grass was significantly declined with increasing N rates in 2015. There was a positive trend observed with increasing biochar rates in the medium with 90% sand for volumetric water content at field capacity. Further studies should include field experimentation in marginal sandy soils in long-term to explore the sustainability of using biochar for herbaceous biomass crop production.

Key words: Big bluestem, biomass energy, Indian grass, marginal sandy soils, switchgrass

Introduction

Majority of the global energy supply depends on the fossil fuel sources such as petroleum, coal, and natural gas. However, significant environmental impacts including air and water pollution, global warming, and environmental degradation are associated with this energy production (Bassam, 2010). In the United States, the search for cleaner burning fuels has drawn the attention of researchers due to several factors such as issues of high dependency on imported oil and the environmental costs associated with mining, processing and combustion of fossil fuels (McLaughlin et al., 1999).

Renewable energy is being produced from the natural sources that are sustainably replaced. Solar energy, wind energy, biomass energy, hydroelectric power, geothermal energy, and ocean energy are the sources from which renewable energy can be produced (Natural Resources Defense Council, 2014). Renewable energy provides several environmental, economic, and health benefits so it is beneficial in different ways. Since those are clean sources of energy they improve the air quality by reducing the effects of burning of fossil fuels.

Bioenergy has been identified as a form of renewable energy and it is produced from the plant and animal based materials which are called as biomass feedstocks (Bracmort, 2013). Cellulosic feedstocks have been identified as the principle raw material in the bioenergy production (U.S. Department of Energy, 2006). Trees, perennial grasses, and some annual crops are grown as biomass crops because they are capable of producing uniform yield and quality feedstocks in large quantities for biofuel and bio-power production (U.S. Department of Energy, 2011).

Switchgrass (*Panicum virgatum* L.), big bluestem (*Andropogon gerardii* Vitman), and Indian grass (*Sorghastrum nutans* (L.) Nash) are perennial warm-season grasses with C₄ photosynthetic system that are indigenous to most areas of North America (U.S. Department of Energy, 2011). Switchgrass has been identified as the model herbaceous bioenergy crop in early 1990s, according to the screening trials funded by U.S. Department of Energy (Wright and Turhollow, 2010). High cellulosic content in the switchgrass is desirable for cellulosic ethanol production which will help in reducing the fossil fuel usage (Rinehart, 2006). Furthermore switchgrass is important in carbon

sequestration because of its deep root system and efficiency in water use (Ma et al., 2000).

Nitrogen (N) is the most limiting soil nutrient for switchgrass management systems that are grown for biomass feedstocks, which affects their biomass productivity and yield (Lemus et al., 2008; Lee et al., 2009; Anderson et al., 2013; Owens et al., 2013; Pedroso et al., 2013). However, the factors such as cultivar, harvest management, biomass yield, and soil and weather conditions may affect switchgrass response to N fertilization (Lee et al., 2009; Owens et al., 2013).

Biochar is a carbon-rich solid material which is produced during pyrolysis, by thermal degradation of biomass under limited supply of oxygen and at relatively low temperatures (Lehmann and Joseph, 2009; Laufer and Tomlinson, 2013). It can be used as a soil amendment for increasing the agronomic productivity in the low potential soils. Furthermore it is identified as a soil conditioner, as biochar does not contain high levels of nutrients (Glaser et al., 2002). Biochar can be produced using a wide range of biomass sources including woody materials, agricultural wastes such as coconut husks, green waste, and animal manure. Application of biochar to soil improves soil quality parameters such as soil pH, CEC, total C, total N, available P, water holding capacity, exchangeable cations, nutrient cycling and attract more beneficial fungi and microbes (Yamato et al., 2006; Chan et al., 2007, 2008; Laird et al., 2010). Furthermore, biochar is beneficial in decreasing available soil Al, soil strength, and soil bulk density as well (Major et al., 2010; Van Zwieten et al., 2010; Filiberto and Gaunt, 2013). These beneficial effects of biochar are important in agricultural practices in order to increase biomass yield and crops yield under variable soil and fertile conditions (Filiberto and

Gaunt, 2013). Furthermore, some studies have demonstrated these agronomic benefits on marginal and degraded soils (Jeffery et al., 2011; Spokas et al., 2012; Liu et al., 2013). According to Ippolito et al. (2012a), application of biochar into degraded or sandy soils where low nutrient or water holding capacity seems to be more beneficial compared to addition of biochar into highly productive soils. However, the fundamental mechanisms which affect crop growth and productivity by biochar are not adequately understood (Sohi et al., 2010).

Studies have demonstrated that, there are positive interactions when N fertilizer and biochar were applied together (Chan et al., 2007, 2008). Biochar amendments can enhance the retention of N fertilizer in the soil compared to non-amended soil (Steiner et al., 2007). Furthermore reduction of N leaching, enhanced N adsorption, and improved nitrification by addition of biochar are important for maximizing N fertilizer usage (Chan et al., 2007; Ulyett et al., 2014; Zhao et al., 2014). Abbasi and Anwar (2015) reported that application of biochar alone or mixed with N fertilizer will increase the growth and biomass production of maize and wheat.

In this study, the hypothesis was application of biochar with N fertilizer would have positive interactions by enhancing water and nutrient retention. Therefore, the objectives of this study were to evaluate the effects of biochar and N fertilizer on above and belowground biomass production of switchgrass, big bluestem, and Indian grass under greenhouse conditions, and determine the impact of biochar addition on the water holding capacity of potting medium mixed with high and low levels of sand.

Materials and Methods

Location

Two different greenhouse experiments were conducted as one with a soil mix with low levels of sand and another with high levels of sand. The first study was carried out at the University of Missouri-Columbia green house complex (38.9453 °N, 92.3288 °W) from May to September in 2014. Microclimatic conditions (light and temperature) at the green house were 45% sun light and 18 – 27 °C temperature. Second study was carried out at the Horticulture and Agroforestry Research Center (HARC) green house, New Franklin, Missouri (39.0161 °N, 92.7383 °W) from May to September in 2015. The greenhouse conditions were, 60% sun light and 21 – 30 °C temperature.

Planting Materials

Two month-old ‘Alamo’ switchgrass, ‘Rountree’ big bluestem, and ‘Rumsey’ Indian grass plants were used as the planting materials for the first experiment. Only switchgrass and Indian grass were used for the second experiment. The age of the seedlings and cultivar were same in both experiments.

Polyethylene pots with volumes of 11 L (25.5 cm diameter and 23 cm depth) and 19 L (27 cm diameter and 28 cm depth) were used for planting the seedlings in the first and second studies respectively. Potting media was prepared using peat-based Promix[®] (all-purpose growing mix) and river sand. The components of the Promix[®] were Canadian sphagnum peat moss (75-85% by volume), perlite, limestone (for pH adjustment), and a wetting agent.

Biochar produced from oak wood shavings was obtained from a producer at Boonville, Missouri. The pyrolysis temperature of the biochar was about 450 – 500 °C.

Biochar was incorporated with Suma Grow[®] organic biostimulant and SeaAgri SEA-90[®] sea mineral solids. Biostimulant contained humic acid derived from Leonardite Ore 8% as a carrier for proprietary and microbial blend inert ingredients 92%. The composition of sea minerals is listed in Table 3.1. The same type of biochar was used in both years. The physical and chemical properties of the biochar used are provided in the Table 3.2.

The potting media was prepared by homogenously mixing Promix[®] and river sand. The ratio of Promix[®] to sand by volume was 3:1 in 2014, and 1:9 in 2015 respectively. Biochar was also mixed homogenously at the relevant rates with the potting mixture. Mixing was done using an electric rotating drum mix. Prepared media were filled into the pots evenly as four replicates for one treatment. The physical and chemical properties of potting media used in both years are given in the Tables 3.3 and 3.4.

Experimental Design and Measurements

Biochar and N fertilizer treatments were applied for all grass species as shown in the Table 3.5. Biochar rates were calculated on volume basis by assuming soil depth as 20 cm and bulk density as 1.3 g cm^{-3} . Ammonium nitrate (NH_4NO_3) was used as the N fertilizer source. The treatments were arranged in a randomized complete block design (RCBD) with four blocks. One bench in the greenhouse was considered as one block. Since the amount of sunlight received into the greenhouse varies depending on the time of day, it was used as the blocking factor.

The pots were arranged on the tables in the greenhouse. The seedlings were planted at the depth of about 8 – 9 cm in each pot, as one plant per pot. The relevant rates of NH_4NO_3 were applied after 10 days of planting. All pots were watered evenly when the plants were exhibiting stress signs such as wilting and rolling of leaves. The

procedure was similar in both years. Biochar and mixed potting media were analyzed for different parameters as described in Table 3.6.

Photosynthetic gas exchange ($\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) was measured one month, two months, and three months after planting to determine if treatments have affected the plant physiological functions. Photosynthetic rate of the most recent fully expanded leaf blade on two tillers from two plants (two replicates per treatment) were measured with a LI-6400 portable photosynthesis system (LI-COR, Lincoln, Nebraska, USA) equipped with CO_2 and temperature control modules calibrated to deliver saturating light conditions of $1500 \mu\text{mol m}^{-2} \text{ s}^{-1}$ PAR (photosynthetically active radiation) and ambient CO_2 (380 ppm) with a leaf temperature of 27–30 °C (Sanderson and Reed, 2000; Barney et al., 2009).

The aboveground biomass was harvested at the termination of the greenhouse trial (14 weeks after planting). Harvesting was accomplished by cutting the aboveground biomass at the base of the plant approximately 3–5 cm above the pot (Warren, 2012). Belowground root biomass within each pot was separated manually from the potting media and washed off the medium with biochar particles from the roots. Then biomass was dried in a forced air oven at 60 °C for 48 h (Mulkey et al., 2006), and aboveground yield and belowground root biomass were reported as dried biomass (g pot^{-1}) (Warren, 2012).

Furthermore, water holding capacity of the potting media mixed with biochar was determined on volumetric basis using pressure plate method. Water holding capacity of the media was determined using two separate laboratory tests at pressures of 33 kPa and 1500 kPa. Field capacity water content was measured at 33 kPa and wilting point water

content (amount of water the soil holds when it is so dry that plant roots can no longer remove water) was measured at 1500 kPa. As the first step, the porous ceramic plates with required bubbling pressures (1 bar HF and 15 bar) were saturated with distilled water for 24 hours. Large flexible rings were placed around the plate to allow water to be ponded on the plate. Then excess water was drained from the porous plates and placed the small rubber rings. Potting media samples were placed into the rings on the place as four replicates for one biochar rate and separately for two pressures. After that, samples were saturated with distilled water and allowed them to equilibrate for 24 hours. Then most of the water was drained from porous plate and removed the flexible rings. Next, the plates with samples were placed into the pressure chambers separately for 33 kPa and 1500 kPa and applied desired pressure as about 5 psi for field capacity water content and about 225 psi for wilting point water content. The samples were kept in the chambers for five days and transferred the media samples to moisture cans. Then moist weight of samples with can (Mws) were weighted and dried in the oven for approximately 48 h at 105 °C to obtain the mass of oven dry samples (Mos) with moisture can, and obtained the tare measurements of moisture cans ($Tare$). Gravimetric water content (w) was calculated by following equation.

$$w = \frac{Mws - Mos}{Mos - Tare}$$

After that, volumetric water content (θ) was estimated using the equation given below.

$$\theta (\%) = w \times \frac{Db}{\rho w} \times 100\%$$

where D_b is the density of each potting media and ρ_w (density of water) which is considered 1.00 g cm^{-3} .

Finally plant available water was determined using following equation.

$$\text{Plant available water} = \text{Field capacity water content} - \text{wilting point water content}$$

Statistical analysis

The data were analyzed by PROC GLM procedure using SAS version 9.4 (Cary, NC) to determine the main effects and the interaction effects between the treatment variables ($\alpha = 0.05$). The hypothesis tested was biochar by nitrogen treatments have an effect on aboveground and belowground biomass and net photosynthetic rate of warm-season grasses. Tukey's range test was used as the mean separation procedure to test for difference among treatment means if there were no interactions.

Results and Discussion

Aboveground biomass yield

No biochar by nitrogen interactions were found with this investigation related to aboveground biomass yield. In both years aboveground yield increased with N applications. 180 kg N ha^{-1} produced the highest biomass yield of switchgrass ($P = 0.0145$ in 2014 and $P < 0.0001$ in 2015) while 120 kg N ha^{-1} showed the highest biomass yield for Indian grass ($P = 0.0041$ in 2014 and $P < 0.0001$ in 2015) for both years (Fig. 3.1A and Fig. 3.2A). The biomass yields for switchgrass at 180 kg N ha^{-1} were 104 and 57 dry weight g pot^{-1} in 2014 and 2015 respectively. The yield of Indian grass at 120 kg N ha^{-1} were 30 and 27 dry weight g pot^{-1} for two years respectively. The values in two years were not compared since they were two different populations with entirely different

greenhouse conditions. However the values were numerically greater in 2014 than in 2015. It is because of the favorable growing conditions in the potting media where it contained 75% of commercial potting mix in 2014. It was 90% sand in 2015 where it was marginal growing conditions for plants. In contrast to nitrogen, biochar effect was not significant on biomass yield of any grass species in both studies (Fig. 3.1B and Fig. 3.2B) where $P = 0.7998$ and $P = 0.3763$ for switchgrass and $P = 0.8181$ and $P = 0.6004$ for Indian grass respectively.

Nitrogen fertilizer inputs are important for optimizing the biomass yield and maintaining sustainable stands (Vogel et al., 2002). Boyer et al. (2012) reported that annual N fertilizer applications are necessary to produce higher switchgrass biomass yields for economically viable lignocellulosic biomass production. Muir et al. (2001) reported that, spring application of 168 kg N ha^{-1} maximized the switchgrass biomass production by nearly $13.4 \text{ Mg ha}^{-1} \text{ yr}^{-1}$ on average in TX, USA. Pedroso et al. (2013) observed a switchgrass biomass yield increase of $9.7 - 13 \text{ Mg ha}^{-1} \text{ yr}^{-1}$ on average across four ecoregions in California in 2009 and 2010, with the N fertilization rate of $300 \text{ kg N ha}^{-1} \text{ yr}^{-1}$. The same trend was observed in my study where N fertilizer had a significant effect on warm-season grass biomass yield.

In contrast to my observations of no effect of biochar, Allaire et al. (2015) observed 10% aboveground yield improvement during the establishment year of switchgrass in Quebec, Canada. The short cropping period, lack of microbial activities in the media as they were grown in the greenhouse conditions, and sufficient soil moisture for the grasses may be factors responsible for a lack of biochar effect in my study.

Biochar is reported to increase soil water holding capacity (Liu et al., 2013; Novak et al., 2012), but with frequent watering of the pots, drought stress was not imposed severely in this study.

Belowground biomass yield

A significant biochar by nitrogen interaction effect was observed for belowground biomass of switchgrass in 2014 ($P = 0.0409$). The highest belowground biomass (178 dry weight g pot⁻¹, Fig. 3.3) was observed in the 20 Mg ha⁻¹ biochar with 60 kg N ha⁻¹ treatment. However, interaction effect was not significant for belowground biomass of big bluestem ($P = 0.9694$) and Indian grass ($P = 0.7799$).

Biochar and nitrogen interaction effect was not significant for belowground biomass yield in 2015. Rate of N was significant for belowground biomass of both switchgrass ($P = 0.3985$) and Indian grass ($P = 0.3633$) in this study (Fig. 3.4). The lowest values were observed for 0 kg N ha⁻¹ while other rates were not significantly different from each other. However, biochar effect was not significant for any species ($P = 0.3719$ for switchgrass and $P = 0.8791$ for Indian grass).

The extensive root system of switchgrass and other perennial grasses are effective in reducing erosion, reduction of nutrient loss, and sequestering carbon (Ma et al., 2000; Wayman et al., 2014). Allaire et al. (2015) reported that biochar improved root biomass of switchgrass by 40% during the first year of establishment, which is similar to my study where biochar and nitrogen interaction was significant in 2014. While the reasons for biochar effect on root biomass is not clear, it is possible that the retention of water and nutrients by biochar created favorable conditions for root growth (Allaire et al., 2015). In

contrast, the effect of biochar was not significant for belowground biomass of both switchgrass and Indian grass in 2015. This may be due to the restriction of root growth by the pots and short duration of the cropping period. According to a greenhouse study conducted by Lemus (2004), root biomass of switchgrass was increased with increasing supply of N up to 115 kg N ha⁻¹, where result was similar to my observations as N effect was significant for root biomass of switchgrass and Indian grass in 2015.

Root:shoot ratio

Biochar by nitrogen interaction effect was not significant for root:shoot ratio for any of the species evaluated in both studies. Furthermore, biochar effect was also not significant in both years. Although N effect was not significant in 2014, there was a significant N fertilizer effect in 2015 for root-to-shoot ratio of both switchgrass ($P = 0.001$) and Indian grass ($P < 0.001$). The highest ratio was observed for 0 kg N ha⁻¹ where the lowest ratio was with 180 kg N ha⁻¹ in both species (Fig. 3.5).

Root-to-shoot ratio is an indicator of partitioning of biomass within belowground and aboveground plant parts. Although N fertilization on switchgrass aboveground biomass production has been widely studied (Muir et al., 2001; Vogel et al., 2002; Lemus et al., 2008), the N fertilization effect on root chemistry and belowground biomass is less studied (Ma et al., 2000; Sanderson and Reed, 2000; Garten et al., 2011). Similar to my results, Ma et al. (2001) observed a reduction of root:shoot ratios of 4-year old switchgrass with 224 kg N ha⁻¹ fertilization compared to the control stands (0 kg N ha⁻¹). Heggenstaller et al. (2009) found that root:shoot ratios declined in 3 to 4 year old stands of switchgrass in Iowa at higher fertilization rates (200 kg N ha⁻¹). Furthermore, Garten

et al. (2011) reported that root:shoot ratios of 5-year old 'Alamo' switchgrass grown in West Tennessee reduced significantly at the highest nitrogen treatment of 202 kg N ha⁻¹.

Net photosynthetic rate of switchgrass

Net photosynthetic rates in switchgrass were not significantly different for interaction effect of biochar and nitrogen in both years ($P = 0.0720$ in 2014 and $P = 0.4572$ in 2015). Furthermore, it was not significant for biochar or nitrogen effect in 2014. However, nitrogen effect was significant on switchgrass photosynthetic rate in 2015 ($P < 0.0001$) as 0 kg N ha⁻¹ had the lowest photosynthetic rate of 4.2 $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ while highest of 17.6 $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ was observed at 120 kg N ha⁻¹ (Fig. 3.6).

Photosynthesis is the key physiological process where plants assimilate carbon for their growth. However little research has been conducted to evaluate the physiological responses of plants that are grown on biochar amended soils (Baronti et al., 2014; Kammann et al., 2011; Uzoma et al., 2011). Biochar induced changes in soil may affect plant photosynthesis by altering leaf N and other nutrient states such as P (Kammann et al., 2011; Vassilev et al., 2013). Xu et al. (2014) reported that there was a significant improvement of leaf photosynthesis and capacity on biochar amended red ferrosol soils, which they attributed to increased leaf N and soil available N. However, my results showed that there was no significant effect of biochar on photosynthesis in 2014, most likely because of neither N nor water was limiting in any of the treatments. Nitrogen effect was however significant on rate of photosynthesis in 2015, when plants were grown in the sandier potting mix. Nitrogen is a critical nutrient for photosynthesis, and increased supply will stimulate the plant growth, productivity, and single leaf photosynthetic capacity due to increased amount of stromal and thylakoid proteins in

leaves (Panković et al., 2000). Similar results were observed by Stroup et al. (2003) as single leaf photosynthesis of switchgrass was increased under high N conditions. Zhu et al. (2014) evaluated nitrogen deficiency on switchgrass seedling growth under hydroponic conditions and reported that transpiration, stomatal conductance, and net photosynthetic rate of switchgrass were affected by N deficiency treatments. Under N stress conditions, there was a deficient supply of N for chloroplast protein synthesis, and lower photosynthesis resulted due to reduction in chlorophyll content and rubisco activity.

Plant available water content of potting media

Plant available water content was not significantly different for biochar rates in both potting mixtures which contained 25% sand ($P = 0.9473$) and 90% sand ($P = 0.0566$; Fig. 3.7). However, volumetric water content at field capacity (33 kPa) was significantly different for 2015 media ($P = 0.0012$) which contained 90% sand (Table 3.7). The lowest water retention was observed for control treatment. Then water retention was gradually increased with increasing biochar rates. Conversely, water content at wilting point (1500 kPa) was not significant for 2015 media ($P = 0.2216$). In contrast, volumetric water contents at both 33 kPa ($P = 0.8732$) and 1500 kPa ($P = 0.8209$) were not significantly different for the 2014 media which had 25% sand. This may be due to the higher percentage of commercial potting mix in the media which masked the biochar effect.

Biochar is identified as an organic soil amendment which has ability to increase water holding capacity of many loams and sandy soils (Mulcahy et al., 2013). Studies have demonstrated that porous physical structure of biochar induces a greater sorption

capacity for soil moisture conservation and nutrient retention (Novak et al., 2012; Laird et al., 2010; Lehmann et al., 2003). Similar results were found in other studies where biochar addition has increased the water retention of soil. Ippolito et al. (2012b) reported that addition of 2% biochar on weight basis increased the moisture content of two aridisols by 3–7% in comparison to the control soils. According to Ulyett et al. (2014), water retention at field capacity was increased with addition of 60 Mg ha⁻¹ into two differently managed soils as 1.3% soil moisture increase in organically managed soil and 0.3% increment in conventionally managed soil. Yu et al. (2013) mentioned that water holding capacity of a loamy sand soil was increased around 1.7% by mass for each 1% addition of biochar. The increase of water retention with biochar addition could reduce plant moisture stress and may have positive effects on plant productivity under water deficit conditions (Mulcahy et al., 2013).

Conclusions

This study was conducted to evaluate the effect of biochar on nitrogen nutrition for the growth, physiology, and water retention in marginal sandy soils for warm-season biomass production. I expected that N fertilization with biochar application would increase the biomass yield; however, biochar effect was not significant for most of the measured parameters. The study was conducted for 14 weeks and the duration may be not enough for obtaining positive effects of biochar since most of the biochar studies are being conducted as long term studies. Furthermore, plants were grown in the green house under favorable growing conditions especially with adequate supply of water, therefore did not mimic the potential positive impacts as they had been grown under stress conditions. Nitrogen fertilizer effect was significant on aboveground biomass,

belowground biomass, root:shoot ratio and photosynthetic rate of these warm-season grass species. Because N is one of the major essential nutrient in warm-season biomass production.

In conclusion, carrying out similar but long-term studies in field scale while examining the spatial and temporal changes in soil physical, chemical, and biological parameters are necessary for making long-term management plans in warm-season biomass grass production on marginal landscapes.

Acknowledgements

I would like to thank Mr. Phil Blom for providing biochar for this project. My special thanks goes to Dr. Steve Anderson, Department of Soil, Environmental, and Atmospheric Sciences, University of Missouri, Columbia for his valuable support in conducting the water holding capacity measurements.

References

- Abbasi, M.K., and A.A. Anwar. 2015. Ameliorating Effects of Biochar Derived from Poultry Manure and White Clover Residues on Soil Nutrient Status and Plant growth Promotion-Greenhouse Experiments. *PLoS one* 10(6): e0131592.
- Allaire S.E., F.S. Lange, L.D. Smith, and others. 2015. Carbon dynamics in a biochar-amended loamy soil under switchgrass. *Canadian Journal of Soil Science* Available at <http://pubs.aic.ca/doi/10.4141/cjss-2014-042> (verified 14 October 2015).
- Anderson, E.K., A.S. Parrish, T.B. Voigt, V.N. Owens, C.H. Hong, and D.K. Lee. 2013. Nitrogen fertility and harvest management of switchgrass for sustainable bioenergy feedstock production in Illinois. *Industrial Crops and Products* 48:19-27.
- Antweiler, R.C., C.J. Patton, and H.E. Taylor. 1996. Automated, colorimetric methods for determination of nitrate plus nitrite, nitrite, ammonium and orthophosphate ions in natural water samples. U.S. Geological survey. Open-File Report 93-638. Denver, Colorado, USA.

- Barney, J.N., J.J. Mann, G.B. Kyser, E. Blumwald, A. Van Deynze, and J.M. DiTomaso. 2009. Tolerance of switchgrass to extreme soil moisture stress: ecological implications. *Plant Science* 177(6): 724–732.
- Baronti, S., F.P. Vaccari, F. Miglietta, C. Calzolari, E. Lugato, S. Orlandini, R. Pini, C. Zulian, and L. Genesio. 2014. Impact of biochar application on plant water relations in *Vitis vinifera* (L.). *European Journal of Agronomy* 53: 38–44.
- Bassam, N.E. 2010. *Handbook of Bioenergy Crops: A Complete Reference to Species, Development and Applications*.
http://books.google.com/books/about/Handbook_of_Bioenergy_Crops.html?id=zRW3_QwQhTIC (accessed March 16, 2014).
- Boyer, C.N., R.K. Roberts, J.A. Larson, B.C. English, D.D. Tyler, and V. Zhou. 2012. Switchgrass yield response to nitrogen on four soil types in West Tennessee. <http://www.beag.ag.utk.edu/present/sungrant/Presentation6a.pdf> (accessed March 15, 2014).
- Bracmort, A. 2013. Biochar: Examination of an emerging concept to sequester carbon. p. 79-104. *In* W.A. Green and L.G. Wayman (eds.), *Carbon Considerations: Biochar, Biomass, Biopower, and Sequestration*. Nova Science Publishers, Inc. New York, USA.
- Chan, K. Y., L. Van Zwieten, I. Meszaros, A. Downie, and S. Joseph. 2007. Agronomic values of green waste biochar as a soil amendment. *Australian Journal of Soil Research* 45(8):629-634.
- Chan, K. Y., L. Van Zwieten, I. Meszaros, A. Downie, and S. Joseph. 2008. Using poultry litter biochars as soil amendments. *Australian Journal of Soil Research* 46(5):437-444.
- David, K. and A.J. Ragauskas. 2010. Switchgrass as an energy crop for biofuel production: A review of its ligno-cellulosic chemical properties. *Energy and Environmental Science* 3:1182–1190. DOI: 10.1039/b926617h
- Filiberto, D.M. and J.L. Gaunt. 2013. Practicality of biochar additions to enhance soil and crop productivity. *Agriculture* 3:715-725. doi:10.3390/agriculture3040715
- Garten, C.T., D.J. Brice, H.F. Castro, R.L. Graham, M.A. Mayes, J.R. Phillips, W.M. Post, C.W. Schadt, S.D. Wullschleger, D.D. Tyler, and others. 2011. Response of “Alamo” switchgrass tissue chemistry and biomass to nitrogen fertilization in West Tennessee, USA. *Agriculture, ecosystems & environment* 140(1): 289–297.
- Gelderman, R.H. and D. Beegle. 1998. Nitrate-Nitrogen, p. 17-18. *In*: *Recommended Chemical Soil Test Procedures for the North Central Region*. NCR Publication No. 221. Missouri Agricultural Experiment Station. Columbia, MO, USA.

- Glaser, B., J. Lehmann, and W. Zech. 2002. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal – A review. *Biology and Fertility of Soils* 35:219–230. DOI 10.1007/s00374-002-0466-4.
- Heggenstaller, A.H., K.J. Moore, M. Liebman, and R.P. Anex. 2009. Nitrogen influences biomass and nutrient partitioning by perennial, warm-season grasses. *Agronomy Journal* 101, 1363–1371.
- Ippolito, J.A., D.A. Laird, and W.J. Busscher. 2012a. Environmental benefits of biochar. *Journal of Environmental Quality* 41:967-972. doi:10.2134/jeq2012.0151
- Ippolito, J.A., J.M. Novak, W.J. Busscher, M. Ahmedna, D. Rehrach, and D.W. Watts. 2012b. Switchgrass biochar affects two Aridisols. *Journal of environmental quality* 41(4): 1123–1130.
- Jeffery, S., F.G.A. Verheijen, M. Van Der Velde, and A.C. Bastos. 2011. A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. *Agriculture, ecosystems & environment* 144(1): 175–187.
- Kammann, C.I., S. Linsel, J.W. Gößling, and H.W. Koyro. 2011. Influence of biochar on drought tolerance of *Chenopodium quinoa* Willd and on soil–plant relations. *Plant and Soil* 345(1-2): 195–210.
- Laird, D.A., P. Flemming, D.D. Davis, R. Horton, B. Wang, and D.L. Karlen. 2010. Impact of biochar amendments on the quality of a typical Midwestern agricultural soil. *Geoderma* 158:443–449. doi:10.1016/j.geoderma.2010.05.013
- Laufer, J. and T. Tomlinson. 2013. Biochar field studies: An IBI research summary. <http://biochar-international.org/>. (Accessed May 30, 2014).
- Lee, D.K., E.D. Nafziger, F. Fernández, E. Adee, S.A. Ebelhar, L.E. Paul, L. Deal, and M. Vose. 2009. Nitrogen fertility management of switchgrass for sustainable bioenergy feedstock production in Illinois. *Illinois Fertilizer Conference Proceedings*. <http://frec.ifca.com/2010/report12/> (Accessed May 27, 2014).
- Lehmann, J., J.P. Silva, Jr., C. Steiner, T. Nehls, W. Zech, and B. Glaser. 2003. Nutrient availability and leaching in an archeological Anthrosol and Ferralsol of the central Amazon basin: Fertilizer, manure and charcoal amendments. *Plant Soil* 249:343–357. doi:10.1023/A:1022833116184
- Lehmann, J. and S. Joseph (eds.). 2009. Stability of biochar in the soil. *In Biochar for Environmental Management - Science and Technology*. London, Earthscan. pp 1-2.
- Lemus, R., D.J. Parrish, and O. Abaye. 2008. Nitrogen use dynamics in switchgrass grown for biomass. *Bioenergy Research* 1:153–162. DOI 10.1007/s12155-008-9014-x

- Lemus, R.W. 2004. Switchgrass as an energy crop: fertilization, cultivar, and cutting management. Available at http://www.researchgate.net/profile/Marcus_Alley2/publication/267196428_SWITCHGRASS_AS_AN_ENERGY_CROP_FERTILIZATION_CULTIVAR_AND_CUTTING_MANAGEMENT/links/54fa30900cf23e66f031172c.pdf (verified 14 October 2015).
- Liu, X., A. Zhang, C. Ji, S. Joseph, R. Bian, L. Li, G. Pan, and J. Paz-Ferreiro. 2013. Biochar's effect on crop productivity and the dependence on experimental conditions—a meta-analysis of literature data. *Plant and soil* 373(1-2): 583–594.
- Ma, Z., C.W. Wood, and D.I. Bransby. 2000. Impacts of soil management on root characteristics of switchgrass. *Biomass Bioenergy* 18: 105–112.
- Major, J., M. Rondon, D. Molina, S. J. Riha, and J. Lehmann. 2010. Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol. *Plant and Soil* 333:117–128. DOI 10.1007/s11104-010-0327-0
- McLaughlin, S., J. Bouton, D. Bransby, B. Conger, W. Ocumpaugh, D. Parrish, C. Taliaferro, K. Vogel, and S. Wullschleger. 1999. Developing switchgrass as a bioenergy crop. *In* J. Janick (ed.), *Perspectives on new crops and new uses*. ASHS Press, Alexandria, VA. pp 282-299.
- Muir, J.P., M.A. Sanderson, W.R. Ocumpaugh, R.M. Jones, and R.L. Reed. 2001. Biomass production of 'Alamo' switchgrass in response to nitrogen, phosphorus, and row spacing. *Agron. J.* 93:896–901.
- Mulcahy, D.N., D.L. Mulcahy, and D. Dietz. 2013. Biochar soil amendment increases tomato seedling resistance to drought in sandy soils. *Journal of Arid Environments* 88: 222–225.
- Mulkey, V.R., V.N. Owens, and D.K. Lee. 2006. Management of switchgrass-dominated conservation reserve program lands for biomass production in South Dakota. *Crop Sci.* 46:712–720. doi:10.2135/cropsci2005.04-0007
- Natural Resources Defense Council 2014. Renewable energy for America. Harvesting the benefits of homegrown, Renewable energy. <http://www.nrdc.org/energy/renewables/missouri.asp>
- Novak, J.M., W.J. Busscher, D.W. Watts, J.E. Amonette, J.A. Ippolito, I.M. Lima, J. Gaskin, K.C. Das, C. Steiner, M. Ahmedna, and others. 2012. Biochars impact on soil-moisture storage in an ultisol and two aridisols. *Soil Science* 177(5): 310–320.
- Owens, V.N., D.R. Viands, H.S. Mayton, J.H. Fike, R. Farris, E. Heaton, D.I. Bransby, and C.O. Hong. 2013. Nitrogen use in switchgrass grown for bioenergy across the USA. *Biomass and Bioenergy* 58:286-293.

- Panković, D., M. Plesničar, I. Arsenijević-Maksimović, N. Petrović, Z. Sakač, and R. Kastori. 2000. Effects of nitrogen nutrition on photosynthesis in Cd-treated sunflower plants. *Annals of Botany* 86(4): 841–847.
- Pedroso, G.M., R.B. Hutmacher, D. Putnam, S.D. Wright, J. Six, C. Kessel, and B.A. Linquist. 2013. Yield and nitrogen management of irrigated switchgrass systems in diverse eco-regions. *Agronomy Journal* 105:311–320. doi:10.2134/agronj2012.0354.
- Pella, E. 1990. Elemental organic analysis. Part 1. *Am. Lab* 22: 116-125.
- Rinehart, L. 2006. Switchgrass as a bioenergy crop. A Publication of ATTRA - National Sustainable Agriculture Information Service. 1-800-346-9140. pp 1-10.
- Sanderson, M.A. and R.L. Reed. 2000. Switchgrass growth and development: Water, nitrogen, and plant density effects. *J. Range Manage.* 53(2): 221-227.
- Sohi, S.P., E. Krull, E. Lopez-Capel, and R. Bol. 2010. A review of biochar and its use and function in soil. *Advances in agronomy* 105: 47–82.
- Spokas, K.A., K.B. Cantrell, J.M. Novak, D.W. Archer, J.A. Ippolito, H.P. Collins, A.A. Boateng, I.M. Lima, M.C. Lamb, A.J. McAloon, and others. 2012. Biochar: a synthesis of its agronomic impact beyond carbon sequestration. *Journal of Environmental Quality* 41(4): 973–989.
- Steiner, C., M.R. de Arruda, M.R., W.G. Teixeira, W. Zech. 2007. Soil respiration curves as soil fertility indicators in perennial central Amazonian plantations treated with charcoal, and mineral or organic fertilizers. *Tropical Science* 47:218-230.
- Stroup, J.A., M.A. Sanderson, J.P. Muir, M.J. McFarland, and R.L. Reed. 2003. Comparison of growth and performance in upland and lowland switchgrass types to water and nitrogen stress. *Bioresource Technology* 86(1): 65–72.
- U.S. Department of Energy. 2006. Breaking the biological barriers to cellulosic ethanol: A joint research agenda. DOE/SC-0095. US Department of Energy, Office of Science and Office of Energy Efficiency and Renewable Energy.
- U.S. Department of Energy. 2011. U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry. R.D. Perlack and B.J. Stokes (Leads), ORNL/TM-2011/224. Oak Ridge National Laboratory, Oak Ridge, TN. 227p.
- Ulyett, J., R. Sakrabani, M. Kibblewhite, and M. Hann. 2014. Impact of biochar addition on water retention, nitrification and carbon dioxide evolution from two sandy loam soils. *European Journal of Soil Science* 65: 96–104. doi: 10.1111/ejss.12081
- Uzoma, K.C., M. Inoue, H. Andry, H. Fujimaki, A. Zahoor, and E. Nishihara. 2011. Effect of cow manure biochar on maize productivity under sandy soil condition. *Soil use and management* 27(2): 205–212.

- Van Zwieten, L., S. Kimber, A. Downie, S. Morris, S. Petty, J. Rust, and K.Y. Chan. 2010. A glasshouse study on the interaction of low mineral ash biochar with nitrogen in a sandy soil. *Australian Journal of Soil Research* 48:569-576.
- Vassilev, N., E. Martos, G. Mendes, V. Martos, and M. Vassileva. 2013. Biochar of animal origin: a sustainable solution to the global problem of high-grade rock phosphate scarcity? *Journal of the Science of Food and Agriculture* 93(8): 1799–1804.
- Vogel, K.P., J.J. Brejda, D.T. Walters, D.R. Buxton. 2002. Switchgrass biomass production in the mid-west USA: harvest and nitrogen management. *Agronomy Journal* 94, 413–420.
- Warncke, D. and J.R. Brown. 1998. Potassium and other basic cations, p. 31-33. *In* Recommended Chemical Soil Test Procedures for the North Central Region. NCR Publication No. 221. Missouri Agricultural Experiment Station, Columbia, MO, USA.
- Warren, E.C. 2012. The effects of biochar amendment to soil on bioenergy crop yield and biomass composition. Master's Thesis, University of Tennessee, 2012. http://trace.tennessee.edu/utk_gradthes/1150 (Accessed March 24, 2014)
- Wayman, S., R.D. Bowden, and R.B. Mitchell. 2014. Seasonal changes in shoot and root nitrogen distribution in switchgrass (*Panicum virgatum*). *Bioenergy Research* 7(1): 243–252.
- Whitney, D.A. 1998. Soil salinity. p. 59-60. *In* Recommended Chemical Soil Test Procedures for the North Central Region. NCR Publication No. 221. Missouri Agricultural Experiment Station, Columbia, MO, USA.
- Wright, L. and A. Turhollow. 2010. Switchgrass selection as a “model” bioenergy crop: A history of the process. *Biomass and Bioenergy* 34:851–868.
- Xu, C.Y., S. Hosseini-Bai, Y. Hao, R.C. Rachaputi, H. Wang, Z. Xu, and H. Wallace. 2014. Effect of biochar amendment on yield and photosynthesis of peanut on two types of soils. *Environmental Science and Pollution Research* 22(8): 6112–6125.
- Yamato, M., Y. Okimori, I.F. Wibowo, S. Ashori, and M. Ogawa. 2006. Effects of the application of charred bark of *Acacia mangium* on the yield of maize, cowpea and peanut, and soil chemical properties in South Sumatra, Indonesia. *Soil Science and Plant Nutrition* 52:489–495. doi:10.1111/j.1747-0765.2006.00065.x
- Yu, O.-Y., B. Raichle, and S. Sink. 2013. Impact of biochar on the water holding capacity of loamy sand soil. *International Journal of Energy and Environmental Engineering* 4(1): 1–9.
- Zhao, X., S. Wang, and G. Xing. 2014. Nitrification, acidification, and nitrogen leaching from subtropical cropland soils as affected by rice straw-based biochar: laboratory

incubation and column leaching studies. *Journal of Soils and Sediments* 14:47–482. DOI 10.1007/s11368-013-0803-2

Zhu, Y., X. Fan, X. Hou, J. Wu, and T. Wang. 2014. Effect of different levels of nitrogen deficiency on switchgrass seedling growth. *The Crop Journal* 2(4): 223–234.

Table 3.1. Elemental analysis of SEA-90®

Element	Symbol	Concentration (ppm)
Lithium	Li	0.7
Berellium	Be	0.007
Boron	Be	3.3
Sodium	Na	35
Magnesium	Mg	5158
Aluminum	Al	188
Silicon	Si	165
Phosphorous	P	12.28
Potassium	K	1276
Calcium	Ca	3139
Scandium	Sc	0.105
Titanium	Ti	16.5
Vanadium	V	1.15
Chromium	Cr	0.21
Manganese	Mn	7.1
Iron	Fe	72.7
Cobalt	Co	0.064
Nickel	Ni	0.32
Copper	Cu	0.21
Zinc	Zn	1.89
Gold	Au	56.45
Thorium	Th	0.105
Arsenic	As	1.05
Selenium	Se	0.84
Bromine	Br	709
Rubidium	Rb	0.5
Strontium	Sr	134
Yttrium	Y	<0.01
Zirconium	Zr	0.105
Iodine	I	0.095
Molybdenum	Mo	0.027

Source: New SEA-90 product fact sheet (2014).

<http://www.seaagri.com/applications.htm>

Table 3.2. Chemical and physical properties of biochar

Parameter	Units	Results
pH		7.31
E. C. - Saturation Paste	mmho/cm	0.19
Moisture	%	58.9
C/N Ratio		366
Total Nitrogen (N)	%	0.073
Total Phosphorus (P)	%	0.003
Total Potassium (K)	%	0.056
Total Calcium (Ca)	%	0.154
Total Magnesium (Mg)	%	0.020
Total Zinc (Zn)	ppm	4
Total Iron (Fe)	ppm	28
Total Manganese (Mn)	ppm	50
Total Copper (Cu)	ppm	2
Total Carbon (C)	%	27

Table 3.3. Chemical and physical properties of potting media with 25% sand and different rates of biochar

Parameter	Units	Biochar rates (Mg ha ⁻¹)			
		0	5	20	35
pH		6.75	6.35	6.26	6.18
E. C. - Saturation Paste	mmho/cm	0.209	2.373	2.27	4.91
Total Nitrogen (N)	%	0.173	0.173	0.176	0.177
Total Phosphorus (P)	%	0.012	0.011	0.011	0.017
Total Potassium (K)	%	0.308	0.322	0.316	0.325
Total Calcium (Ca)	%	0.354	0.391	0.389	0.395
Total Magnesium (Mg)	%	0.046	0.051	0.053	0.053
Total Zinc (Zn)	ppm	2	2	3	4
Total Iron (Fe)	ppm	179	153	198	157
Total Manganese (Mn)	ppm	145	171	152	150
Total Copper (Cu)	ppm	4	21	5	13

Table 3.4. Chemical and physical properties of potting media with 90% sand and different rates of biochar

Parameter	Units	Biochar rates (Mg ha ⁻¹)			
		0	5	20	35
pH		8.06	7.77	8.04	7.65
E. C. - Saturation Paste	mmho/cm	0.308	0.337	0.25	0.017
Total Nitrogen (N)	%	0.153	0.175	0.13	0.105
Total Phosphorus (P)	ppm	0.6	0.8	0.4	0.9
Total Potassium (K)	ppm	14	17	12	21
Total Calcium (Ca)	ppm	23	22	20	24
Total Magnesium (Mg)	ppm	5	6	4	7
Total Zinc (Zn)	ppm	0.01	0.018	0.013	0.017
Total Iron (Fe)	ppm	1.108	0.767	0.309	0.543
Total Manganese (Mn)	ppm	0.052	0.02	0.01	0.015
Total Copper (Cu)	ppm	0.019	0.009	0.008	0.013

Table 3.5. Treatment combinations applied in the experiment

Level of N kg ha ⁻¹	Rate of Biochar (Mg ha ⁻¹)			
	0	5	20	35
0	×	×	×	×
60	×	×	×	×
120	×	×	×	×
180	×	×	×	×

Table 3.6. Analytical methods for biochar and potting media mixtures

Test	Method
pH	pH was measured in solution after mixing 10 g of material in 200 mL of DI water using a pH meter.
Total N	Combustion method (Pella, 1990).
EC	EC was measured using 1:1 (w/w) soil-to-water extract method. 20 g of sample was scooped into a large test tube, 20 mL of distilled water was added, then periodically stirred the suspension and allowed it to equilibrate for 15 to 20 minutes. The conductivity cell calibrated with the 0.01 M KCl into the suspension was inserted and read the conductivity (Whitney, 1998).
Ammonium and nitrate N	These were analyzed by extracting the sample with 2 M KCl (Gelderman and Beegle, 1998). Ammonium and nitrate in the extractant was determined colorimetrically with an automated continuous flow analyzer (Antweiler et al., 1996).
Mehlich 3 extractable nutrients of P, Ca, Mg, K, Na, Mn, Fe and Zn	Mehlich 3 extractable nutrients were measured using following procedure. 2 g of potting media sample was measured into an extraction tube and 20 mL of Mehlich 3 (0.2 N CH ₃ COOH+0.25 N NH ₄ NO ₃ +0.015 N NH ₄ F+0.013 N HNO ₃ +0.001 M EDTA [(HOOCH ₂) ₂ NCH ₂ NCCH ₂ COOH] ₂) extractant was added. The samples were shaken for 5 minutes on the shaker at 200 rpm. Filtered the suspensions through Whatman No. 2 or equivalent filter paper and

elements in filtrate were measured by inductivity coupled plasma – optical emission spectroscopy (ICP-OES) (Warncke and Brown, 1998).

Table 3.7. Volumetric water content of potting media at field capacity and permeant wilting point

Rate of biochar (Mg ha ⁻¹)	Mean volumetric water content (%)			
	Media with 25% sand		Media with 90% sand	
	33 kPa	1500 kPa	33 kPa	1500 kPa
0	11.59 ^a	5.26 ^a	3.22 ^b	2.64 ^a
5	12.06 ^a	5.64 ^a	4.31 ^a	3.32 ^a
20	12.13 ^a	5.67 ^a	5.04 ^a	3.50 ^a
35	11.81 ^a	5.35 ^a	4.90 ^a	3.37 ^a

Data followed by the same letter within a column were not significantly different at $\alpha \leq 0.05$.

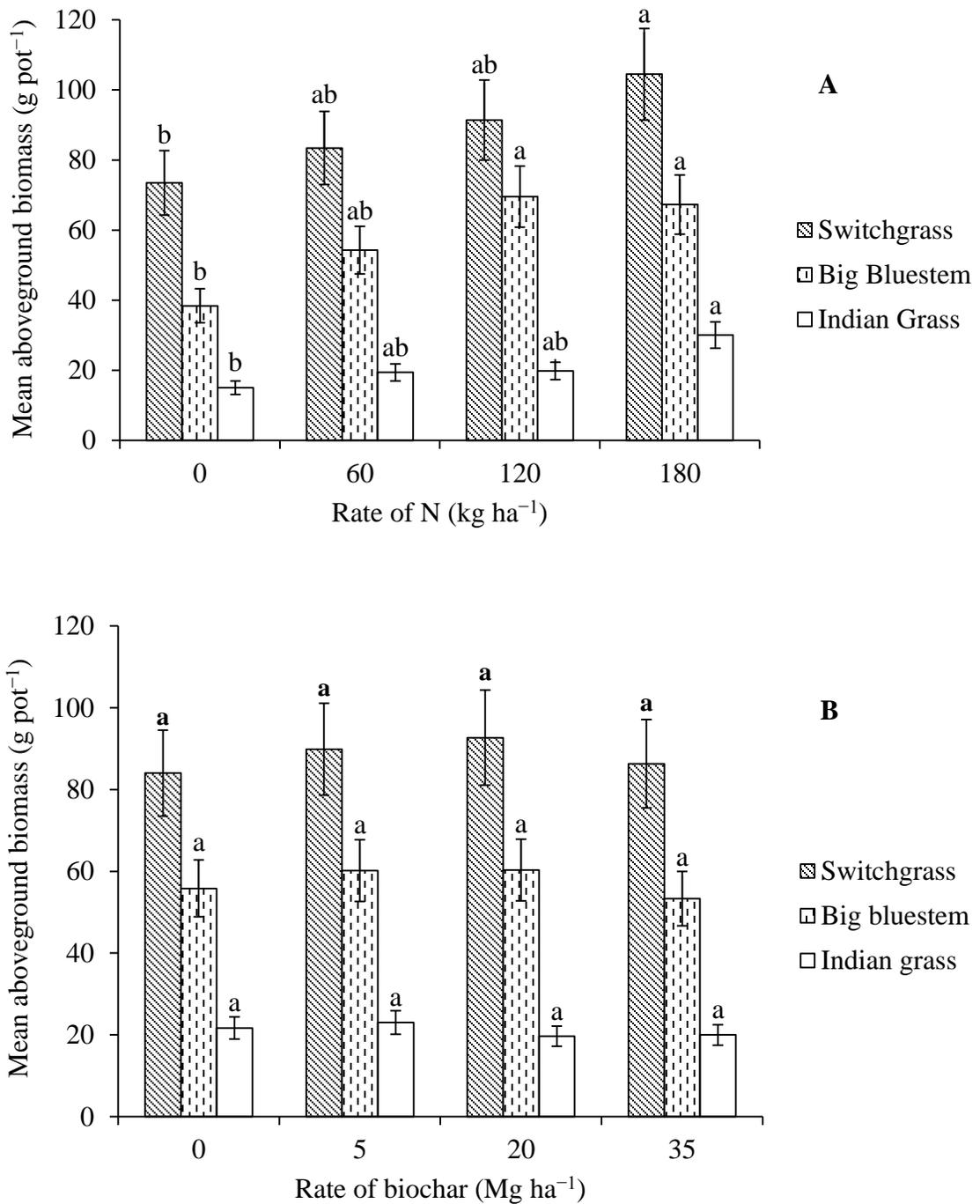


Figure 3.1. Mean aboveground biomass of switchgrass, big bluestem, and Indian grass with different rates of N (A) and biochar (B) in 2014. Bars with different letters denote significant differences among treatments at $\alpha \leq 0.05$.

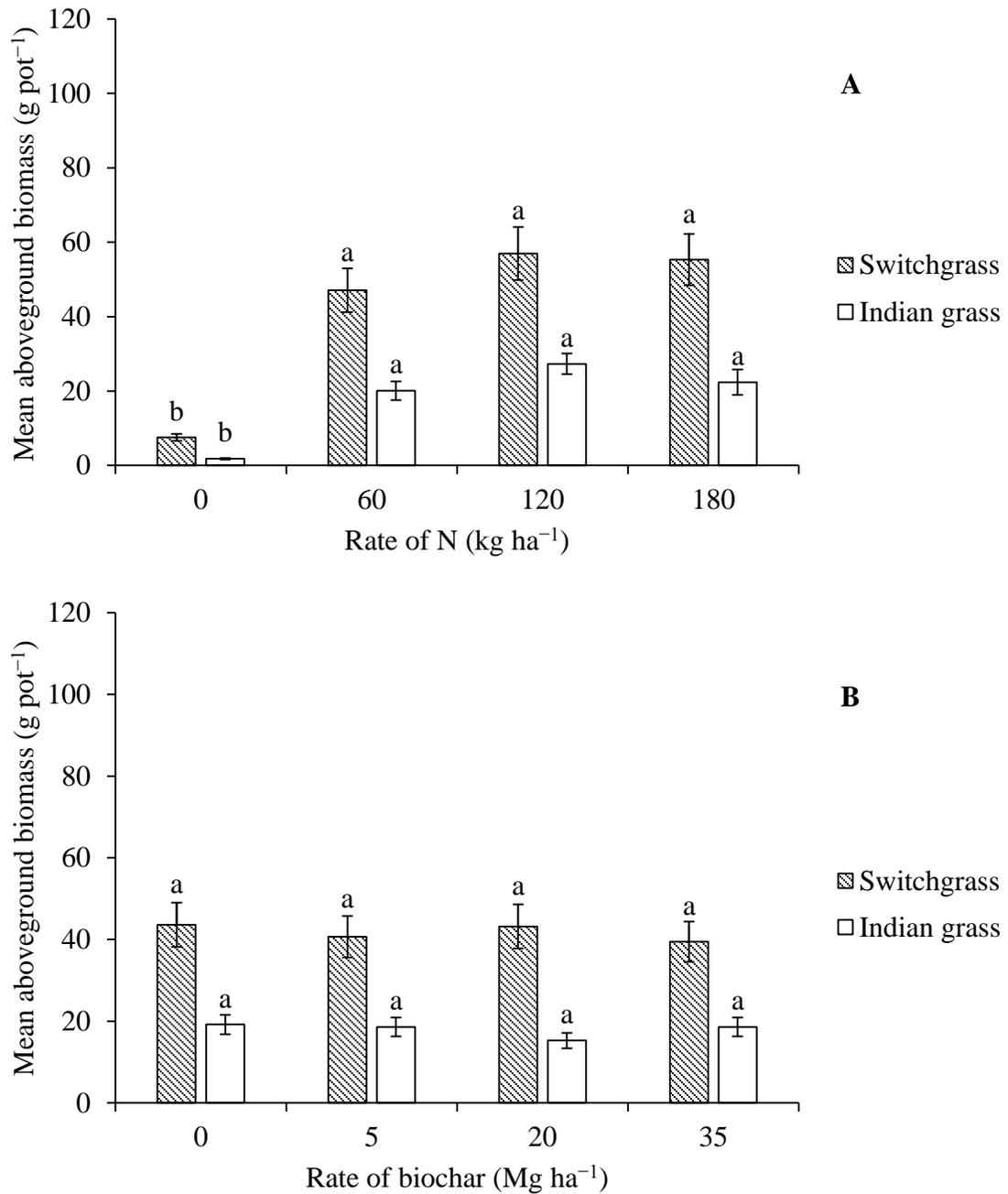


Figure 3.2. Mean aboveground biomass of switchgrass and Indian grass with different rates of N (A) and biochar (B) in 2015. Bars with different letters denote significant differences among treatments at $\alpha \leq 0.05$.

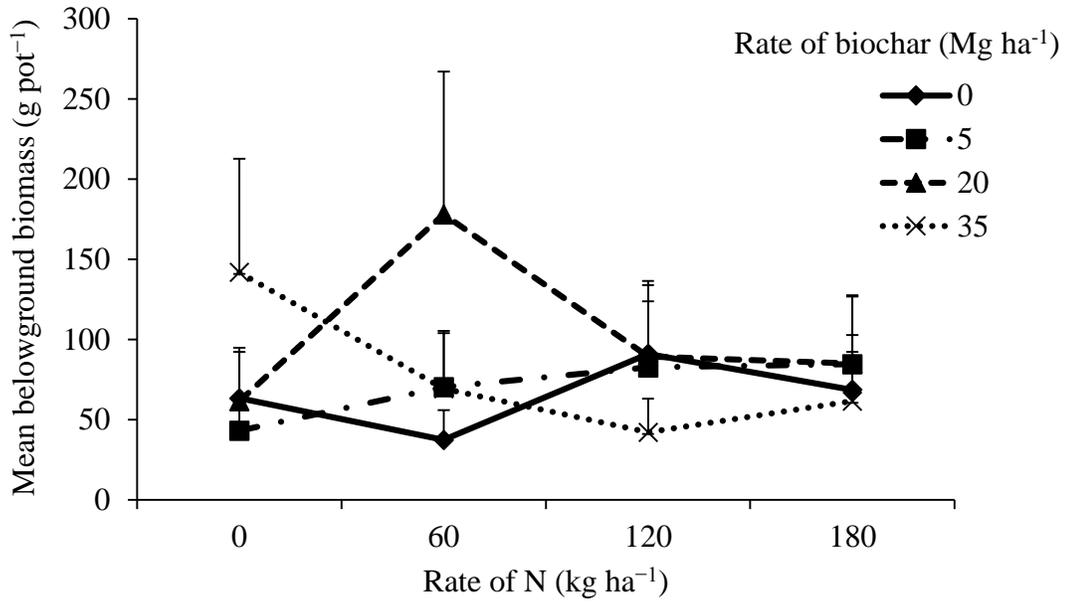


Figure 3.3. Mean belowground biomass of switchgrass with different N and biochar rates in 2014. Error bars denote significant differences among treatments at $\alpha \leq 0.05$.

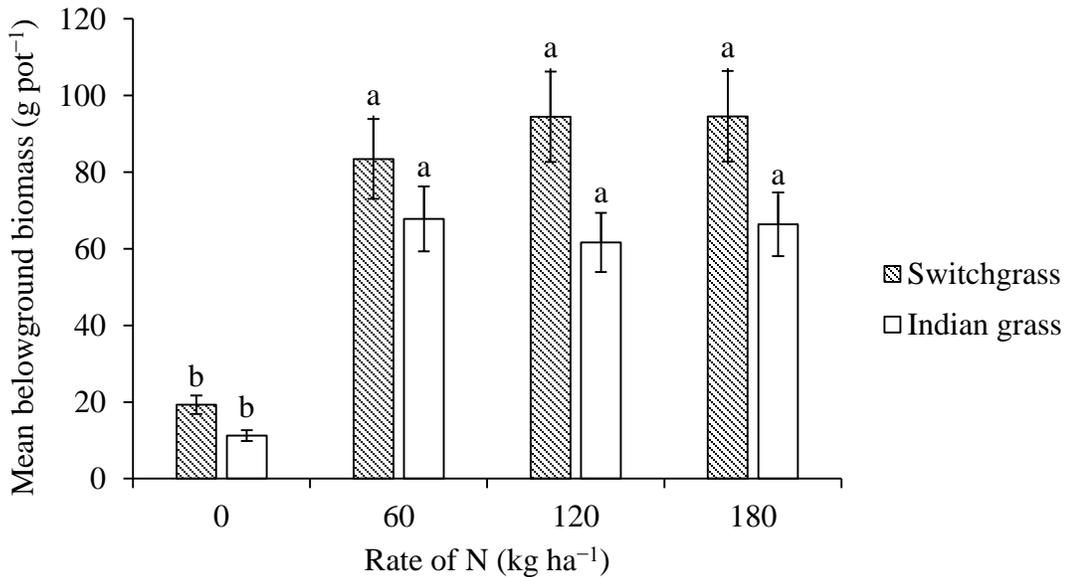


Figure 3.4. Mean belowground biomass of switchgrass with different N rates in 2015. Bars with different letters denote significant differences among treatments at $\alpha \leq 0.05$.

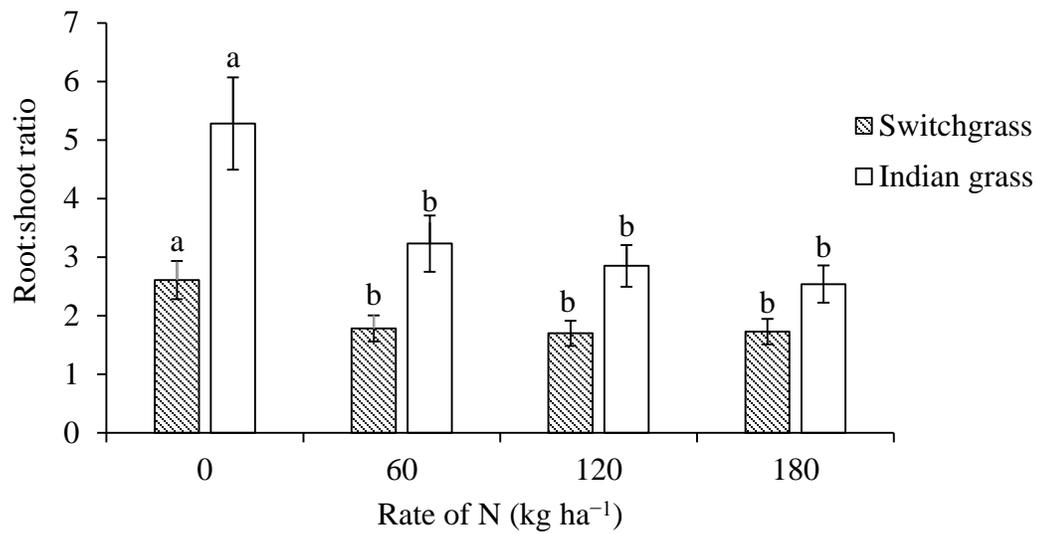


Figure 3.5. Root:shoot ratio of switchgrass and Indian grass with different rates of N in 2015. Bars with different letters denote significant differences among treatments at $\alpha \leq 0.05$.

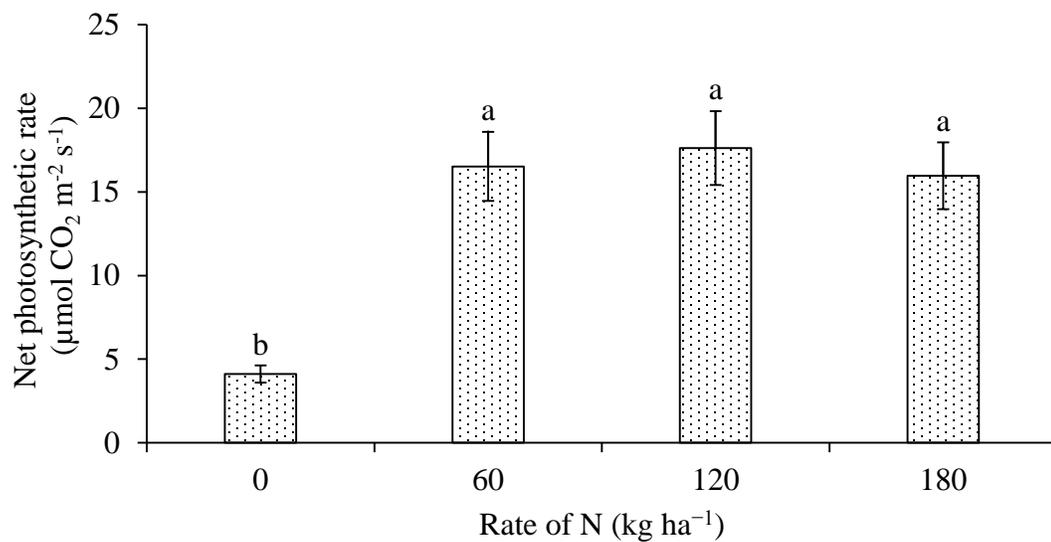


Figure 3.6. Net photosynthetic rate of switchgrass with different N rates in 2015. Bars with different letters denote significant differences among treatments at $\alpha \leq 0.05$.

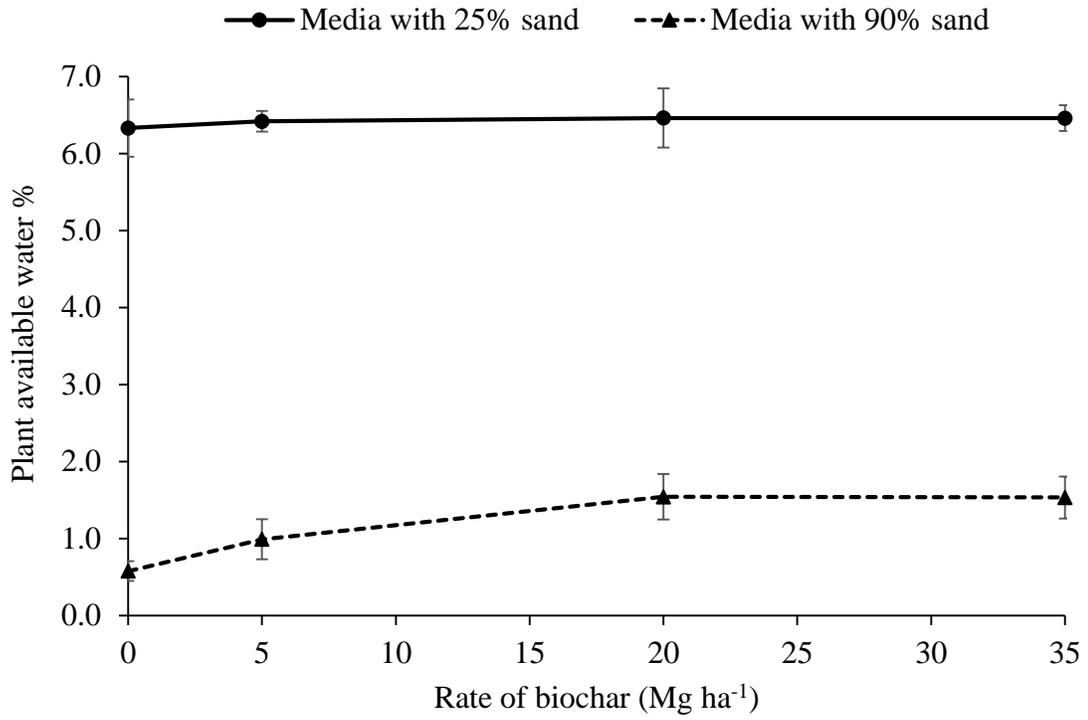


Figure 3.7. Plant available water content of potting media of 25% and 90% sand with different biochar rates.

CHAPTER 4

CONCLUSIONS

This study was conducted to evaluate the effects of biochar with N fertilizer for growth, physiology, and impact of biochar for water retention on marginal sandy soils for biomass production of warm-season grasses. The study was conducted in 2014 and 2015 as pot experiments under greenhouse conditions. Potting media in the first study contained commercial potting mix and relevant rates of biochar with 10% sand while it contained 90% sand by volume in the second study. The experimental duration was 14 weeks in both years. Aboveground biomass, belowground biomass, and net photosynthetic rate were measured as plant parameters.

According to the observations, biochar by nitrogen interaction was not significant on any measured parameters except for belowground biomass of switchgrass in 2014. The hypothesis tested was that N fertilization with biochar application would increase the biomass yield. However biochar effect was not significant for above and belowground biomass and photosynthetic rate. The experimental duration may not be long enough for the positive impacts of biochar to become apparent or significant, since biochar is well known for producing long-term benefits. Furthermore, the greenhouse conditions such as adequate soil moisture were favorable for growth of the grasses and positive impacts can be expected if they were grown under moisture stress conditions.

Nitrogen is one of the essential nutrient for higher biomass production of warm-season grasses. Nitrogen fertilizer effect was significant on aboveground biomass, belowground biomass, and photosynthesis rate in this study. However the results suggest

that biochar may be effective in increasing soil moisture retention particularly in marginal sandy soil, since there was a trend for increasing volumetric water content at field capacity with increasing biochar rates in the medium with 90% sand.

A few studies have been conducted to evaluate the impact of biochar on warm-season grass biomass production, particularly on switchgrass. However, information on biochar impact on yield of other warm-season grass species grown as bioenergy feedstock such as big bluestem and Indian grass is not available to the author's knowledge. Contrary to the hypothesis, a substantial increase in aboveground biomass with respect to biochar treatments was not observed. The type of potting mix, duration of the study, source of biochar may all have contributed to the observed results.

Hence, future studies are needed to determine the long-term effect of biochar for warm-season biomass production in marginal sandy soils at field and regional scales. Furthermore, it is important to evaluate the soil and plant response of biochar produced from different feedstocks and production temperatures.