Harvest timing and inorganic-nitrogen alternatives impact on lignocellulosic characteristics and yield under an intensified climate

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Introduction

Switchgrass (*Panicum virgatum* cv. Alamo [SG]) and guinea grass (*Panicum maximum* cv. Mombaza [GG]) have been proposed as sustainable alternatives to fossil fuels although conventional production requires non-renewable inputs. As interest increases in biofuel feedstocks, so do questions surrounding their long-term sustainability.

Synthetic nitrogen (N) inputs are manufactured from fossil fuels and are linked to negative environmental effects. Intercropping N_2-fixing legumes may provide an alternative to inorganic-N sources. Furthermore, biochar applications may increase carbon sequestration and plant nutrient retention, thereby decreasing chemical fertilizer inputs and enhancing the sustainability of production.

Objectives

Evaluate: 1) The effects of biochar (1 and 2 Mg ha^{-1}), two intercropped legumes [sunn hemp (*Crotalaria juncea* cv. Tropic Sun: SH) and pigeon pea (*Cajanus cajan* cv. Mandarim: PiP) intercrops] versus inorganic-N [67 kg ha^{-1} and 0 kg ha^{-1} (control)] on desired feedstock characteristics, yield, and soil characteristics;

2) Feedstock characteristics of SG and GG over three harvest dates.

3) Switchgrass adaptation to more extreme (tropical) growing conditions.

Materials and Methods

- The experiment took place in St. Croix, U.S. Virgin Islands (USVI) at the University of the Virgin Islands, Agricultural Experiment Station from 2012 to 2014. St. Croix lies in the eastern Caribbean at 17º 43' N latitude and 64º 48' W longitude.
- The experiment consisted of a factorally arranged randomized complete block design with three blocks. SG and GG plots were planted by hand on 60-cm plot centers on November 1st, 2012. Plot sizes for SG and GG were 1.8 x 6.1 m and 1.8 x 7.6 m, respectively.

Factor 1

- Biochar and inorganic-N treatments applied concurrent with legume interseeding (18 and 24 kg PLS ha^{-1} for PiP and SH, respectively) when feedstock heights were approximately 30 cm tall. Legumes were treated with cow-pea type inoculant (*Bradyrhizobium* spp.) then hand-seeded (13th July 2013, and again on 31st November 2013). Inorganic-N applied annually as ammonium nitrate (67 kg ha^{-1}), biochar was mixed in a slurry (20% water by volume) to avoid loss by wind erosion. No macro-nutrients were applied.

Factor 2

- Harvest treatments included: one baseline harvest (July, 2013), two dry season harvests (March and November, 2013) and one during the onset of the rainy season (July, 2014).

Sampling

- Baseline soil samples were collected in 2010 on a per plot basis to 0-15 cm depths to determine pH, cation exchange capacity (CEC, meg 100g^{-1}), organic matter (OM, %) base saturation (BS, %), nitrate (NO_3-, ppm), P, K, Mg and Ca concentrations. Soil sampling was repeated in July 2013 and 2014 to track elemental fluxes. Samples were analyzed with a Mehlich-3 extractant by A&L Laboratory (Memphis, TN).
- Biomass samples were hand clipped (1-2 kg), from two central rows totaling 2m^{-2}. Post sampling, plots were cut to a 20.3 cm stubble height. Samples were weighed, dried (49ºC for 48-72 hours), then reweighed to determine moisture content. Biomass tissue was ground for analysis with near-infrared spetroscopy (NIRS) using a LabSpec® Pro Spectrometer, for total N and minerals (P, K, Ca, Mg), acid detergent fiber (ADF), neutral detergent fiber (NDF), NDF digestibility (NDFD), lignin, cellulose, hemicellulose, sugars, fructans, and ash content.

Weighing samples for yield determination

Collecting samples for tissue analysis

Initial Planting (Nov. 1st, 2012 (top) and 30 days after planting (bottom)

Sampling of GG (top) and SG (bottom) March 2013

GG and SG harvest November 2013

SH intercropped in SG (top) and PP intercropped GG (bottom) pre-harvest July 2014

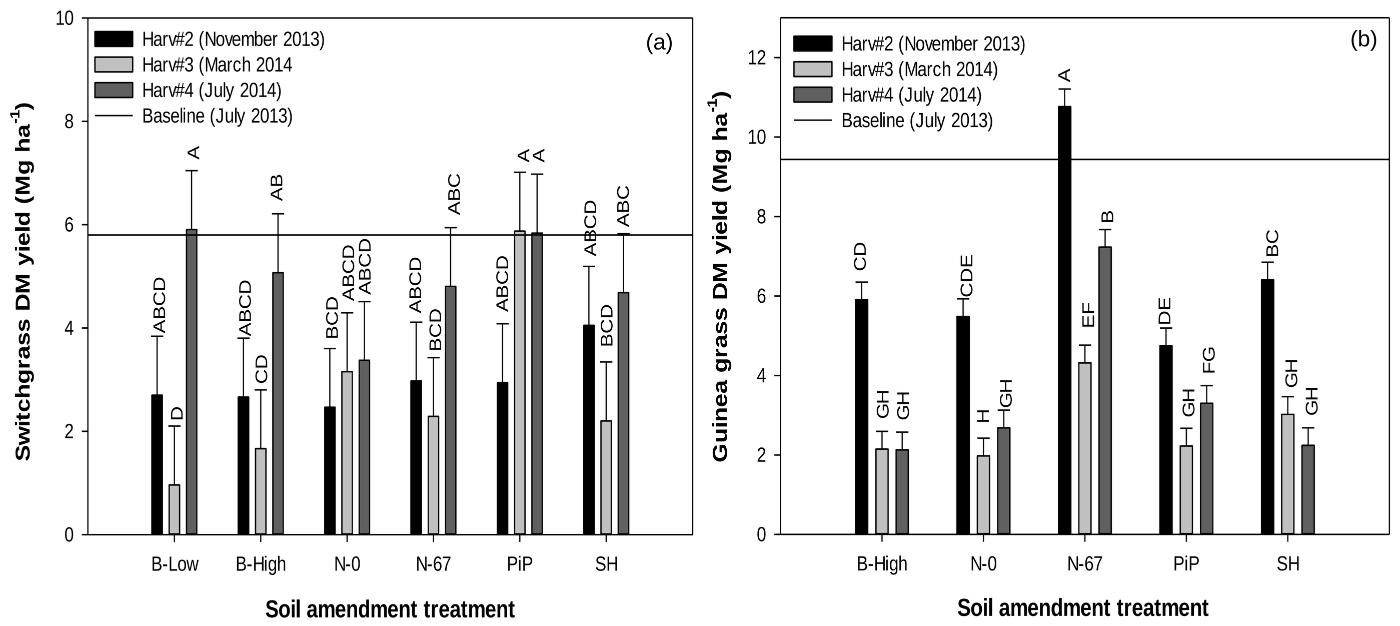

Figure 1. SG (a) and GG (b) dry matter (DM) yield based on harvest timing [baseline (pre-treatment; July, 2013), harvest#2 (Nov., 2013, harvest#3 (March, 2014), and harvest#4 (July, 2014)] per soil amendment treatments. Different letters indicate a significant difference with the LSD procedure at the *P*<0.05 level. (Soil amendment treatments include: B-high=biochar 2 Mg ha^{-1}; N-0=0 kg N ha^{-1}; N-67= 67 kg N ha^{-1}; PiP=pigeon pea; and, SH=sun hemp).

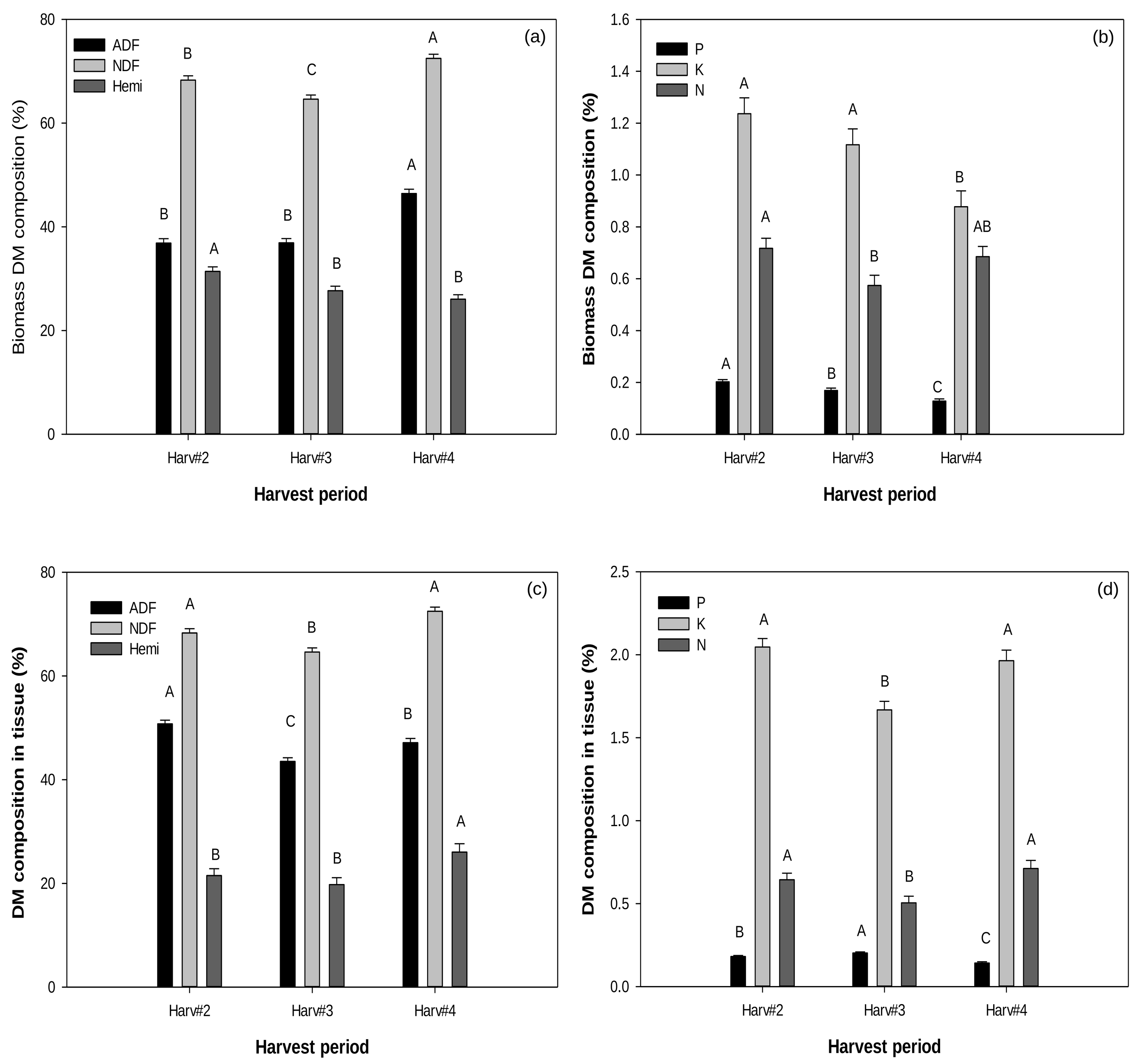

Figure 2. SG (a, b) and GG (c, d) dry matter (DM) feedstock characterization based on harvest timing [baseline (pre-treatment; July, 2013), harvest#2 (Nov., 2013, harvest#3 (March, 2014), and harvest#4 (July, 2014)] averaged across soil amendment treatments. Different letters indicate a significant difference with the LSD procedure at the *P*<0.05 level within a given component across harvests. (Acid detergent fiber=ADF; neutral detergent fiber=NDF; hemicellulose=hemi.).

Table 1. Soil characterization of baseline [yr1 (2013)] and final year (yr2 (2014)]- results (averaged from on a per treatment basis) for SG and GG, based on soil amendment inputs at the St. Croix, USVI, Agricultural Experiment Station. Soil test results from Mehlich-3 extractant.

Species and year	Soil amendment	pH	P	K	Ca	Mg	NO_3^-	CEC†	OM
			---------------kg ha^{-1}-------------				ppm	Meq 100 g soil^{-1}	%
SG-1‡	B-High§	7.9a¶	5.3a	269.7a	12646a	280.3a	5.7a	52.9a	5.2a
	B-Low	7.9a	7.7a	312.7a	12220a	302.0a	5.3a	51.5a	4.9a
	N-0	7.9a	5.7a	273.0a	12522a	287.7a	4.3a	52.7a	5.1a
	N-67††	7.7a	24.0a	254.7a	10470a	281.3a	5.3a	44.4a	5.3a
	PP‡ ‡	7.9a	11.0a	313.7a	12355a	307.3a	6.0a	52.2a	5.2a
	SH	8.1a	6.0a	303.0a	12497a	307.7a	4.0a	52.6a	5.1a
SG-2	B-High	7.8a	8.0a	307.7a	13572a	345.3a	2.7a	57.2a	5.2a
	B-Low	7.7a	8.3a	327.3a	12674a	332.3a	2.0a	53.6a	5.5a
	N-0	7.8a	6.7a	279.0a	14195a	322.3a	2.0a	59.4a	5.1a
	N-67	7.8a	9.3a	282.3a	12581a	337.7a	3.3a	53.2a	4.9a
	PP4	7.5a	8.3a	317.0a	13724a	343.7a	2.0a	57.8a	5.0a
	SH	7.8a	7.3a	294.0a	13631a	336.7a	3.7a	57.3a	5.2a
GG-1	B-High	8.3a	4.7a	183.3a	12313a	220.7a	2.0a	50.9a	5.3a
	N-0	8.2a	4.6a	182.0a	13221a	215.3a	2.1a	54.5a	4.9a
	N-67	8.3a	6.3a	207.7a	15405a	242.0a	4.0a	63.4a	4.7a
	PP	8.2a	7.3a	218.7a	13393a	214.3a	2.3a	55.2a	4.7a
	SH	8.2a	5.3a	209.3a	14132a	228.0a	2.3a	58.2a	4.9a
GG-2	B-High	7.8a	6.0a	187.3a	18392a	275.7a	2.0a	75.4a	4.9a
	N-0	7.6a	6.0a	179.8a	17729a	263.3a	2.0a	72.7a	5.3a
	N-67	7.5a	7.0a	185.0a	18973a	280.3a	2.0a	77.7a	4.9a
	PP	7.6a	7.7a	228.3a	18472a	278.3a	2.0a	75.8a	4.9a
	SH	7.9a	7.0a	179.3a	16899a	278.7a	2.0a	69.6a	4.8a

‡ By experiment (i.e. species SG=switchgrass; GG=guinea grass) and sampling period (1=baseline and 2= yr2).

§ Swtichgrass biochar rates: B-high (2 Mg ha^{-1}) and B-low (1 Mg ha^{-1}) applied each spring.

¶Different letters indicate a significant difference within a given species (experiment), sampling period, and analyte with the LSD procedure at the *P*<0.05 level.

††kg N ha^{-1}

†CEC: cation exchange capacity; OM: organic matter.

Table 2. Outline of switchgrass weed index (SGWI) categories to determine adaptability to a tropical environment. [Adapted from Linares et al., 2010].

SGWI value	Switchgrass adaptability	Weed pressure	Weed control
<0.5	SG not competitive	Weeds predominate	Very poor (>70% weeds)
0.5–1	SG coexist	Weeds coexist	Poor
1–3	SG starts prevailing	Weeds prevail in certain niches	Moderate
3–5	SG prevails	Weeds fail to predominate	Adequate
5–15	SG predominate (70% to 90%)	<10% to 30% weeds	Excellent
>15	SG completely predominates	<5% weeds	Outstanding

Applying Biochar November 2013

Results and Discussion

Biomass Yield

- SG yield was impacted by harvest timing (*P* = 0.003) but not soil amendments, or soil amendment x harvest timing (*P* ≥0.05) . Harvest 4 yields were greater than harvest 2 and 3 [2.96 and 2.69 Mg ha^{-1}, respectively; Fig.1 (a)].
- GG yield was affected by soil amendment (*P* <0.0001), harvest period (*P* <0.0001), and their interactions (*P* = 0.002). Yields were greatest for harvest 2 (6.4 Mg ha^{-1}) while harvest 3 and 4 did not differ (2.59 and 3.37 Mg ha^{-1}, respectively).
- SH intercrop and the high-biochar rate (2 Mg ha^{-1}) during the 2nd harvest were not different (*P*<0.05) than the current recommended inorganic-N rate (67 kg ha^{-1}) [Fig. 1 (b)].

Feedstock Characteristics

- SG cell wall characteristics were impacted by harvest period (*P* <0.05), whereas only P levels were impacted by soil amendments (*P* = 0.04).
- ADF and P were impacted by harvest period x soil amendment treatments (*P* <0.05).
- ADF levels for low biochar (1 Mg ha^{-1}) and inorganic-N treatments were similar and were the highest, suggesting greater availability of digestible 5 and 6 carbon sugars.
- Harvest 2 resulted in the greatest hemicellulose, N, P, and K tissue levels [Fig. 2 (a, b)].
- GG cell wall composition was affected by harvest period, not by soil amendments [Fig. 2 (c, d)]. The only important feedstock characteristic impacted by harvest timing and amendment x harvest interaction was NDF (*P* = 0.02); PiP and high biochar treatments were the greatest (75.9 and 75.6%, respectively) during harvest 2.
- Harvest 2 also had the greatest K removal from the high biochar treatment, which was not different than the low biochar treatment (harvest period x amendment; *P* = 0.04). The 4th GG harvest had the greatest NDF and ADF levels.

Influence of Climate on SG

- SG adaptation based on SGWI indicated varying weed competition (5-30%), likely due to photoperiod sensitivity and lack of biochemical adaptations.
- Rapid anthesis resulted in reduced vegetative growth and consequently, higher weed yields than that of GG due to lack of canopy cover (0.70 vs. 0.04 Mg ha^{-1}, respectively).
- During the 3rd harvest period, SGWI increased to 18.4-19.2, suggesting SG was dominant with <5% weed cover (Table 2).
- During the final harvest, SGWI decreased to 5.4-6.4, with 10-30% weed presence due to the competitive growth habit of many tropical weeds (e.g. desmodium (*Desmodium intortum* (Mill.) with climbing tendrils).

Conclusion

- PiP and SH inter-crops and biochar may supply analogous-N as synthetic fertilizers.
- No initial or final soil characteristic differences were observed for either SG or GG as a result of experimental treatments (*P* >0.05; Table 2).
- Neither inter-crops nor biochar added or removed/chelated soil macro-nutrients, despite non-senesced tissue being harvested.
- Biochar has the potential to provide a 'closed-loop' system, considering the feedstock co-product can be applied to the bioenergy crop the following season, however, further research to determine proper application rates are needed.
- SG may be produced in the tropics and even under an intensified climate, however more aggressive weed measures and photoperiod insensitive varieties would be required.
- When SGWI was averaged across all harvest periods, 'excellent' weed control was observed (Table 2; SGWI = 9.2).

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USDA United States Department of Agriculture National Institute of Food and Agriculture