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Review Article

Alligator Grass (Alternanthera Philoxeroides), A Nuisance Aquatic Plant but a Potential Feedstock for Biofuels Production

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2. Keywords

Alligator grass; Biofuels feedstock; Energy conversion; Renewable biofuel

1. Abstract

Alligator grass (*Alternanthera philoxeroides*) is considered a nuisance aquatic plant. This biomass however has prolific growth and hence a potential feedstock for biofuels production. This biomass resource is considered an invasive species but will not compete with agricultural food or feed production. It can generate more than 7.85 tonnes of biomass per hectare (dry) and produces biomass continuously though out the year. Alligator grass can be harvested in 45 days rotation under good sunshine to provide biomass resource continuously and thereby improving logistical issues of harvest and transport. This biomass resource is more of an aquatic plant rather than terrestrial biomass and thus more suited for the production of methane gas via anaerobic digestion while converting the sludge into other biofuels via thermo-chemical conversion processes such as pyrolysis and gasification. This feedstock can be processed using readily available equipment. Common grass/hay harvesting equipment may be used for harvesting the material. The high moisture content (87%) of the freshly harvested material makes it an ideal feedstock for anaerobic digestion processes for the production of biogas (CH_4+CO_2).

Initial chemical and physical analysis of alligator grass indicated that this resource has relatively high energy content of 15 MJ/kg (6,500 Btu/lb as received), moderate ash content (15%) and can be processed readily via bio-chemical energy conversion. The methane production is as high as 4.4 L/kg of biomass via anaerobic digestion. The retention time was found to be approximately 17 days following a batch experiment. A 1,000 hectare of alligator grass plot is able to generate an average of 34.5 million L of biogas with a theoretical power equivalent of 1.6 MW.

3. Introduction

Alligator grass (*Alternanthera philoxeroides*) is a prolific South American aquatic weed having grasslike leaves and short spikes of white flowers (Figure 1) and is now abundant in the United States. It is very difficult to eradicate and several herbicides have been recommended to terminate its growth. It is said to have the ability to adjust to whatever new physical or chemical methods of eradication procedures used and tend to have a better competitive advantage over desired species [1]. It is a high producing biomass species and normally clogs waterways with dense floating masses. It is now considered a serious weed in America. It is also a weed of lowland rice (Oryza sativa L.) and studies in China reported an annual estimated loss of $75 million US dollars due to the invasiveness of the plant [2]. In addition, this weed is a host for one of the most important insect pest in rice, the rice water weevil (*Lissorhoptrus oryzophilus Kuschel*) in the United States [3]. This biomass is not a suitable dairy cattle feed material primarily because it can cause photosensitization and liver damage [4]. When these plants are decomposed, it is supposed to create breeding areas for mosquito and snail thereby enhancing environment and water pollution [5]. Perhaps instead of spending millions of research dollars in finding suitable physical and chemical eradication procedures for this weed species, the weed could be used as potential feedstock for biofuels production (**Figure 1**).

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Figure 1: Picture of the fresh alligator samples used in this study.

Eradication of this weed by mechanical or chemical means are not very effective due to the following reasons:

a) Most herbicides (chemical control) destroy leaves and shoots but do not cause direct mortality to the roots, thereby leaving the materials to regrow through its roots [6],

b) Excavating the material (mechanical control) seldom removes all propagules (stem nodes and roots) and thus, the plant simply recolonize in areas where the stems and roots are left to regrow [7],

c) Herbicides have no long term impact on root biomass and would not be effective after 6 weeks [1], and

d) The weed stores large amounts of carbohydrates in below ground material and is used to replace shoots and leaves once the aboveground material is severed [8].

Several areas where alligator weed grows abundantly include abandoned mining areas, marshland and abandoned gravel and sand excavation areas. In abandoned mining or gravel and sand excavation areas, the plants grow well on depressions filled with water during rainy months. However, during dry seasons, the weed also grows well in upland terrestrial conditions [9]. In managed marshland, the quality of wetland habitats have been affected negatively by the rapid growth of this weed and competing with important native plants [10]. Perhaps this rapid growth rate including persistence to herbicides makes this an ideal feedstock for biofuels production. The criteria of not having to compete with food supply and with very minimal or zero input (no fertilizer, marginal land and etc) makes this an ideal candidate for biofuels production. This study came about when several reports [9,10] commented on the proliferation of this weed in abandoned excavation areas. Eradication had been futile and thus, one logical way is to harvest the material and design ways to utilize this for biofuels production. There are several ways to convert this material into fuel as follows:

(a) Anaerobic digestion to produce methane and

(b) Thermal conversion to produce bio-oil, char and synthesis gas (or)

(c) Gasification to produce heat and synthesis gas for power production

This study was designed to evaluate the physical and chemical properties of the alligator grass and conduct controlled anaerobic digestion studies to evaluate the potential for methane production. Likewise, this study investigates the physical and chemical properties of processed alligator grass as potential fuel for biofuels production.

The specific objectives are as follows:

a. Determine the heating value and ultimate and proximate analysis of the fresh alligator grass samples,

b. Determine the potential biogas production from batch digestion of alligator grass with some amounts of animal manure,

c. Compare the biogas potential with other feedstock reported in literature, and

d. Propose a potential biofuels production scheme utilizing this invasive plant.

4. Methodology

4.1 Biomass Estimates

A biomass collection test area was marked off and fresh alligator weed samples were taken from La Grange, Texas [9]. The freshly harvested material was drained of water for three and half hours and weighed before fresh samples were sent for analysis. This procedure is done several times within a given time frame to generate an average fresh weight numbers including moisture content. Every 45 days, fresh new samples were harvested following sample collection outlined earlier. The fresh and dried samples were weighed and packaged for analysis to the Biomass Testing and Analysis Lab (http://betalab.tamu.edu) at Texas A&M University in College Station, Texas. Most of the samples were spread clean on thin aluminum trays to dry by sunlight and air dried until the moisture content is close to 10% on wet basis. The test site had an area of 167 m2 (1800 ft2). The data to be derived following this procedure include the following:

(a) Fresh and dried weight of material to report tonnes/ha (tons/acre) of freshly harvested and dried samples

(b) If feedstock is harvested every 45-days, how much tonnes/ha (tons/acre) can be harvested throughout the year.

(c) The length of time for the materials to be dried during summer and for other seasons in the year.

4.2 Heating Value and Proximate Analysis

ASTM Method E 870-82 (Reapproved 2006), the standard method for analysis of wood fuels was used to analyze the proximate and ultimate analysis for this feedstock. For moisture content (MC), Method E 871 was used and Test Method E 872 was used to measure volatile combustible matter (VCM). Briefly, MC is measured by placing a sample (at least 50g) in the oven set for 103oC for at least 16 hours. At the end of the period, the sample is cooled and weighed until the final weight is constant. This will become the dry weight of the material and the moisture content is easily calculated. The VCM is measured by placing the pre-weighed and bone dried sample in a platinum crucible with cap inside a tube furnace. The furnace is set at 950oC (+20oC) and the material is lowed and the volatiles are driven off in 7 minutes. The material is cooled and weighed to provide the VCM value. ASTM Method D 1102 was used for ash content while the fixed carbon (FC) is a calculated value. The material with the volatiles removed is then placed in a muffle furnace set at 600oC for at least 30 minutes or when the cooled sample achieved its constant weight. This final weight will be the ash content of the sample. The FC is calculated by the difference between the %VCM and the %ash content. The heating value was measured following Test method E 711. The equipment used for the heating value analysis was the Parr Oxygen Bomb Calorimeter Model 6300 (Parr Instrument Co., Moline, Illinois).

4.3 Ultimate and Ash Analysis

Samples were sent to Huffman Lab (Golden, CO) for the ultimate analysis (C, H. O, N and S). The ultimate analysis is important in determining the approximate "chemical formula" for the biomass feedstock in preparation for thermal conversion. ASTM Method E 870-82, the standard method for analysis of wood fuels was also used to analyze the ultimate analysis for this feedstock. For moisture content (MC), Method E 871 was similarly used. The loss on drying was determined in air at 105 degrees C overnight and is reported on an as received sample basis. The samples were ground prior to all other analysis.

4.4 Biogas Production Runs

Biogas production runs were made by designing a batch 5-gallon anaerobic digestion reactor (**Figure 2**). The experiments were done in triplicate. Finely ground (< 3mm mesh) samples of dried alligator grass were mixed with equal amounts of fresh dairy manure by weight and placed in sealed container. The slurry mixture is adjusted so that there is an equal amount of liquid and solids (solids to liquid ratio of 1:1) and carbon to nitrogen ratio of close to 30:1. This is done by comparing the ultimate analysis for manure and alligator grass and adjusting the carbon and nitrogen components accordingly. Daily methane production was measured via water displacement method. Methane gas concentration is measured using a portable gas chromatograph (SRI GC Model 8610C, Torrance, California) with TCD detector. The GC operating parameters are similar to those used in other similar studies [17]. The retention time (RT) or the biogas digestion was determined when the methane gas volume peaked. The RT will be used for the design of full scale anaerobic digestion reactors (**Figure 2**).

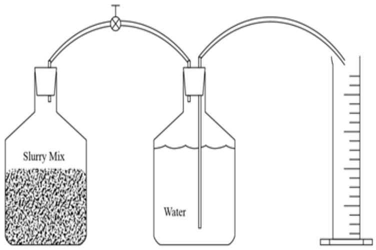

Figure 2: Schematic of the anaerobic digestion experiments.

5. Results and Discussions

5.1 Biomass Estimates

Data for the moisture content of freshly harvested alligator grass is shown in Table 1 with a mean of about 86.4% on wet basis. Freshly harvested alligator grass normally weighs about 14 metric tons per hectare (6.2 tons/acre) based on the field trials for this study. At an average moisture content of 86%, the dry material weighs 1.96 tonnes/hectare (0.9 ton/acre). If the material is to be harvested every 45 days, the yield per harvest will decrease and on the average the estimate was found to be around 7.85 dry tonnes/ha/yr. The study by [1] showed a potential of more than 78 tonnes/ha/yr (wet) or about 11.7 tonnes (dry)/ha/yr. These values are near the average yield for switchgrass (7.4 dry tonnes/hectare) grown in Illinois [11]. This yield value is lower than most other dedicated high biomass feedstocks being developed for biofuels production. However, these yield figures are generated without the use of fertilizer input and other associated production cost. The high biomass sorghum feedstock being developed at Texas A&M University reported a yield of 23.8 dry tonnes/ha with fertilization rates of 120 kg N/ha [12] (**Table 1**).

Tabke 1: Data for freshly harvested alligator grass.

Sample	% Moisture Content (wet basis)
1	86.64
2	85.87
3	86.50
Mean	86.34 $\pm$ 0.41

5.2 Heating Value and Proximate Analysis

The average heating value of air dried samples of alligator grass with 8.32% moisture content (weight basis) was 14.82 + 0.07 MJ/kg (6,372 + 30 Btu/lb) close to 15 MJ/kg (6,500 Btu/lb). This is shown in Table 2. This is a typical heating value of biomass from agricultural residue and wastes. The heating value is slightly lower than the 15.2 MJ/kg heating value of rice straw [13] and but higher than the heating value on a dry ash free basis for animal manure of around 8,500 Btu/lb [14]. The proximate analysis results are shown in Table 3. The average moisture content of dried samples was 8.32%, the VCM was 28.06%, the FC was 52.9% while the ash content was 19.04% (**Table 2** and **3**).

5.3 Ultimate and Ash Analysis

Table 4 shows the ultimate and ash analysis of the alligator grass samples. The values are typical of biomass residues and wastes with the carbon content of around 39% and oxygen content of 34%. The ash analysis allows one to evaluate slagging and fouling indexes when the materials is used in a thermal conversion system [13]. More than half of the ash content of the alligator grass was potassium (K as K2O), hence, not ideal for thermal conversion as raw material [15] (**Table 4**).

Tabke 2: Heating value and proximate analysis of alligator grass samples.

Sample	Heating Value (Btu/lb) (As received)	Heating Value (MJ/kg) (As received)	Heating Value (Btu/lb) (DAF)	Heating Value (MJ/kg) (DAF)
1	6,340	14.75	8,707	20.25
2	6,375	14.83	8,796	20.46
3	6,400	14.89	8,812	20.50
Mean	6372 ± 30	14.82 ± 0.07	8,772 ± 56	20.40 ± 0.13

Tabke 3: Proximate analysis of air dried alligator weed samples.

Sample	Moisture (%)	VCM (%)	Fixed Carbon (%)	Ash (%)
1	8.40	27.65	53.56	18.79
2	8.34	27.77	53.04	19.19
3	8.23	28.76	52.09	19.15
Mean	8.32 ± 0.09	28.06 ± 0.61	52.90 ± 0.75	19.04 ± 0.22

Tabke 4: Ultimate and ash analysis of alligator grass samples.

Component	Ultimate Analysis		Component	Ash Analysis
Drying Loss (%)	11.73		Al as Al_2O_3	1.02
Carbon (%)	39.02		Ca as CaO	4.98
Hydrogen (%)	5.25		Fe as Fe_2O_3	0.44
Nitrogen (%)	2.81		Mg as MgO	3.39
Oxygen (%)	34.09		Mn as MnO	0.04
Sulfur (%)	0.57		P as P_2O_5	2.66
Ash (%)	18.27		K as K_2O	52.54
			Si as SiO_2	3.91
			Na as Na_2O	0.40
			S as SO_3	0.14
			Ti as TiO_2	0.04

5.4 Biogas Production Runs

Figure 3 shows the daily methane production for the anaerobic digestion of alligator grass and pure animal manure (control). Gas yield for the mixture is higher than pure manure by about 15%. The average biogas composition include 60% CH_4 and 40% CO_2 for both runs. The retention time is approximately 17 days for alligator grass mixture and 21 days for pure manure. The preliminary results showed the potential methane generation from this feedstock of around 4.4 L of CH_4 per kg of substrate. The typical value for methane generation from dairy manure is around 34 L/kg [16]. The average heating value of the biogas was 24 MJ/m3, typical value for most biogas output. The amount of sludge left after anaerobic digestion process was around 80% by mass. This sludge may be used for further processing into biofuels via thermal conversion such as pyrolysis (**Figure 3**).

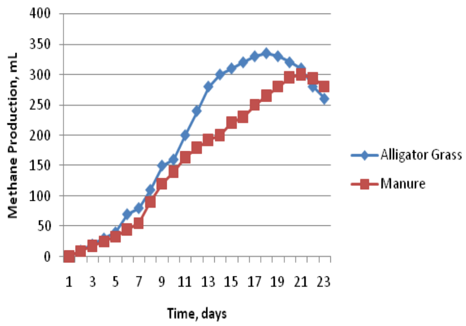

Figure 3: Plots of biogas production with time during anaerobic digestion experiments.

5.5 Potential for Biofuels Production

This section summarizes the potential products and by-products produced from conversion of alligator grass into biofuel via anaerobic digestion of fresh samples and succeeding pyrolysis of the sludge. The assumed area for the projection is 1,000 hectares (2,470 acres) and the harvest period is done every 45 days. Table 4 shows the results of this initial estimates based on the values determined from the study. Harvesting the material continuously throughout the year would generate 4 times more energy output than one time harvest as shown. Over 34 million liters of biogas may be produced with a power equivalent of 1.6 MW(**Table 5**).

Table 5: Summary of results when translated into a 1,000 hectare plot.

Item	Mass Output Per Year	Energy Output Per Year	Other Equivalent Units
One Time Harvest			
Fresh harvest weight	14,000 metric tons	32,340,000 MJ/yr	1 MW
Dry weight	1,960 metric tons	32,340,000 MJ/yr	1 MW
45-day harvest (8x a year) total			
Fresh weight	56,071 metric tons	129,524,010 MJ/yr	4.1 MW
Dry weight	7,850 metric tons	129,524,010 MJ/yr	4.1 MW
Anaerobic Digestion Tests			
Biogas Production	34.5 Million Liters	834,846 MJ/yr	1.6 MW

Thermal Conversion Processes

The sludge resulting from anaerobic digestion process may in turn be converted into additional biofuels via pyrolysis (assumed weight yield of 80%). The following data were generated from such analysis.

The scaled up study (1,000 acres and harvest period of 45 days) showed the following output:

(a) The alligator grass has the ability to generate 15.7 dry tons of biomass per acre per year similar to high yielding biomass resources such as high tonnage sorghum biomass

(b) When pyrolyzed [15,17], the bio-oil yield is approximately 785,000 gallons per year. If this is sold for $1/gallon, a significant revenue ($785,000) can be derived.

(c)Approximately 6,280 tons of bio-char may be recycled as soil enhancement material per year. If valued at $100/ton, an additional revenue of $628,000 is possible.

(d) The synthesis gas may be used to maintain the operating temperature of the pyrolyzer. Hence, additional external heating of the pyrolyzer is minimized.

6. Conclusions

Alligator grass was evaluated as a potential feedstock for biofuels production. The heating value was about 15 MJ/kg (6,500 Btu/lb) typical of various agricultural wastes and residues. The ash content was 20% and higher than most agricultural residues and thus, not appropriate for thermal conversion. This conclusion was also validated by eutectic point analysis having very high potassium content. Because of the high moisture content of the alligator grass at harvest (above 85%), the most logical biofuel production pathway is to generate methane through anaerobic digestion followed by pyrolysis of sludge. Results of the anaerobic digestion studies shown that there is potential to generate 4.4 liters of biogas (65% CH_4 and 35% CO_2) per kg of this feedstock or about 34.5 million liters per year for 1,000 hectare plot. The power equivalent is around 1.6 MW. The retention time for the batch digestion process was found to be approximately 17 days using batch systems. The sludge from the anaerobic digestion may be used for further production of energy via pyrolysis and generate additional potential revenue from the bio-oil and bio-char as soil amendment.

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