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Bioenergy Potentials of Elephant Grass, *Pennisetum purpureum* Schumach

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Authors' contributions

This work was carried out in collaboration between all authors. Author EIO designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors PK and RESN edited the manuscript. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

Aim: Wild strains of elephant grass, *Pennisetum purpureum*, occur as invasive weed especially in disturbed freshwater swamps of Bayelsa State, Nigeria. A study was undertaken to assess the productivity and bioenergy potentials of the grass.
Study Design: A completely randomized experimental design was used.
Place and Duration of Study: Wilberforce Island, Bayelsa State, Nigeria and January–May 2012.
Methodology: Triplicate samples of the wild elephant grass were randomly collected at ten different locations from Wilberforce Island, Bayelsa State. Liquid extract were recovered from the grass, while the resulting bagasse was dried.
Results: The grass was found to have a biomass productivity of 7-11t/ha. The liquid extract was analyzed and was found to have the following characteristics; pH (5.55–5.98), electrical conductivity (14,610-48,214 µS/cm), specific gravity (1.56–1.60), sugars (2.59–4.47%), and ethanol (1.36–2.85%), while the gross calorific heating value of the bagasse ranged from 15.76–17.07 MJ/kg.
Conclusion: With these properties, the liquid extracts of elephant grass could be used as

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alternative feedstock for sugar and ethanol production, while the bagasse could be used as fuel for power generation via conventional steam turbine cycle.

Keywords: Bioenergy; bioethanol; biofuel; calorific; combustion; gasification; heating value; pyrolysis; sugar.

1. INTRODUCTION

Biomass is the only alternative energy source that has been demonstrated to be able to supply liquid, solid and gaseous fuels, for the replacement of fossil fuels. Solid and gaseous biofuels have been used for space heating, cooking and power generation, while liquid biofuels have also been used for power generation and more importantly for the substitution of liquid transportation fuels. One such example is that ethanol produced from biomass (bioethanol) can be used as automotive fuel in various forms; low level blend with gasoline (≤ 20%), high level blends for flex vehicle (≥ 85%) and neat (100% hydrous ethanol) [1]. Typically, 1.2 litres of hydrated ethanol can replace 1 litre of gasoline in the neat (pure) alcohol vehicles [2]. The advantages of ethanol fuel over gasoline have long been recognized to include higher compression ratios, higher heat of vaporization, the possibility of using leaner air fuel mixtures and greater power is obtained per unit with ethanol fuels, hence requiring smaller engine sizes [2]. In addition, ethanol fuels generate lesser emissions compared to gasoline and are generally considered as carbon-neutral. Biomass fuels generate more employment than any other fuel sources of equivalent energy content [3]. The sugarcane industry in Brazil generates about 1.3 million direct jobs, of which 54% are directly related to ethanol production [4]. Bioenergy could increase income for farmers, possibilities to expand agriculture and create more employment [5].

Notwithstanding the numerous advantages of ethanol, there are several challenges such as food versus fuel conflicts, forest destruction and conversion, negative energy balance, large volume of water consumption and stillage generation, shortage of feedstock etc [6-13]. But on the contrary Farrell et al. [13] reported that ethanol can contribute to energy and environmental goals. Five crops have emerged as dominant feedstocks for ethanol production in different countries; sugarcane (Brazil), corn (USA), sugar beets (Europe), cassava (Nigeria, China, Thailand) and sorghum (India, Philippines) [14]. Most of these crops are food crops in the various countries; for instance, cassava is a staple food to more than 70% of Nigerians, while maize is a staple food in Africa generally [5]. However, the utilization of cellulosic ethanol tends to minimize the negative aspects of biofuel while significantly increasing the benefits. Cellulosic ethanol, often referred to as a secondary biofuel, is produced from non-food sources such as municipal solid wastes, wood wastes, short rotation crops, grasses etc. Lynd [1] reported that cellulosic ethanol is one of the most promising technological options available to reduce transportation sector greenhouse gas emissions. Grasses, particularly the C4 species are now increasingly being considered for cellulosic ethanol production due to their more efficient photosynthetic pathway, high water use efficiency (WUE), and low nutrient requirements. For instance in Europe and America, the following grasses have been tested for ethanol production: switch grass (*Panicum virgatum*), *Miscanthus sp*., giant reed (*Arundo donax*) and reed canary grass (*Phalaris arundinacea*) [15].

In the tropical world, one of the grasses exhibiting good traits for biofuel production is elephant grass, *Pennisetum purpureum* Schumach. Elephant grass is also called Napier grass in some literature [16-18] but different from the Asian elephant grass Miscauthus [18]. There are about 140 species of the genus *Pennisetum L*. (Rich) in the grass family *Poaceae* (gramineae) [17,19,20]. About 60% of all C4 species belong to the *Poaceae* family [21,22]. Vermerris [23] reported that C4 photosynthesis is common in grasses adapted to tropical/subtropical climates including maize (*Zeaa mays L.),* sweet sorghum (*Sorghum bicolour (L*), Moench) sugar cane (*Saccharum spp*), Miscanthus and switchgrass. The physiology of C3 and C4 grasses can be found in [22,23]. However, C4 plants have key advantages over C3 because of their higher nitrogen utilization efficiency (NUE) and WUE [18,22,24,25]. Elephant grass is a tetraploid (2n=28) and a perennial tropical grass primarily used as forage or fodder owing to its high forage yield [16,17]. Elephant grass possesses several advantages that make it suitable as bioenergy crop; elephant grass is perennial, it can be vegetatively propagated and it can withstand repeated cutting/harvesting and regenerates [17,26]. Due to its highly efficient CO_2 fixation, elephant grass is capable of producing 60 tonnes/ha/yr of dry biomass under optimal condition [27,28,29] and 30 tonnes/ha/yr of dry biomass under sub-optimal condition [30]. The ability of elephant grass to produce adequate biomass under limited nitrogen levels is linked to the occurrence of diazotrophic nitrogen fixing bacteria with the grass, which augment the nitrogen requirement of the plant by fixing atmospheric nitrogen [27,28,29]. Other features that made elephant grass suitable for bioenergy purposes include the possibility of multiple harvest per year [17,28,30]; high levels of fiber and lignin and low levels of nitrogen and ash [31,32]. When burned in a biomass power plant, elephant grass can generate 25 times as much energy as the amount of fossil fuel input, which is several orders higher than the energy ratios of US corn ethanol (1:1) and Brazilian sugar cane ethanol (8:1) [33] but comparable to Miscanthus (22–50:1) [18]. Like other cellulosic feedstocks, elephant grass has high cellulose (28%), hemicelluloses and lignin (12%), low ash (2.6–3%) [30] and is considered adequate for power generation. Like sugarcane bagasse, elephant grass bagasse can be practically combusted in furnaces and boilers to produce steam for a Rankine cycle (steam cycle) for power generation [34-37]. Because of the lower content of sulphur in biomass, they are considered easier to gasify than coal [38].

A variety of energy carriers can be produced from biomass via gasification including syngas, FT diesel, FT gasoline, kerosene, ethanol, methanol, MTBE, ether [39] and power via the gas cycle. Bio-oil can be produced from elephant grass via pyrolysis [34,40]. Elephant grass has other bioenergy applications including the production of ethanol, pellets, and briquettes. The bagasse has been considered as possible replacement of coal for iron and steel processing [33]. Like many other lignocellulosic biomass crops, elephant grass bagasse can undergo pretreatment for the production of cellulosic ethanol [41-43]. Some C4 grasses including Switchgrass and Bahia grass are currently being used to co-fire power plants in the US [44]. Despite the potential relevance of elephant grass for bioenergy application, little genetic improvements have been carried out on the plant as compared to other grasses like Switchgrass and Miscanthus. In fact, the few genetic improvement studies carried out on elephant grass was for forage yields and palatability [16,17,45-47], which could be inappropriate for bioenergy application where low protein and high fiber is preferable [28]. Utilization of wild elephant grass for bioenergy applications is more environmentally and energy friendly than using cultivated species because of no energy and agrochemical input during cultivation. Elephant grass has been used for the phyto-remediation of crude oil polluted sites [48].

Monospecific stands of wild elephant grass grew luxuriantly in Bayelsa and Rivers states even without irrigation, pesticides and fertilizer application. They grow especially in farms and other areas where the natural vegetation had been disturbed. The weed is typically cut down and burnt during land preparation at the beginning of the planting season. This practice, in addition to releasing smoke, carbon dioxide and other greenhouse gases into the atmosphere, results in the loss of useful energy. Meanwhile, there is an impending energy crisis in Nigeria due to fuel shortages and power instability [49-51]. Only 40% of the population is connected to the national grid and electricity generation in Nigeria is of poor quality and very unstable with blackouts occurring frequently. Liquid transportation fuel (gasoline and diesel) and cooking fuel (kerosene and LPG) are in short supply [52-55]. Hence, this study is focused on the generation of useful energy carriers such as ethanol (for vehicle and household cooking fuels) and bagasse (for power generation in steam turbine via steam cycle) from elephant grass in order to solve the twin problems of weed control and energy generation within a sustainable development perspective

2. MATERIALS AND METHODS/EXPERIMENTAL DETAILS/METHODOLOGY

2.1 Field Sampling

Ten plots having mono specific stands of matured elephant grasses of height about 1.5m tall were randomly selected at Wilberforce Island, Bayelsa State, Nigeria. At each site, a 1x1m2 quadrant was launched thrice and all the elephant grass biomass within the quadrant was harvested to ground level and packaged in jute bags.

2.2 Productivity

The wet weight of the grasses in each plot was measured using weighing balance (Spring Dial). The grass content of each bag was cut into smaller pieces of about 10cm using machete and quantitatively re-packaged in the bag. A hydraulic jack was used to express the liquid (elephant grass extract) from the grass, thus leaving a solid wet residue called elephant grass bagasse. In order to determine the dry matter content, the wet bagasse was oven-dried at 80℃ to a constant weight according to the methods of the Association of Official Analytical Chemist [56]. The percentage dry matter was calculated by multiplying the ratio of dry matter to fresh weight by 100 [17]. From these, the productivity in tones/ha was calculated.

2.3 Determination of Gross Calorific Value

The gross calorific value (GCV) of the oven dried elephant grass bagasse was determined using E2K Bomb Calorimeter (Digital Data System (Pty) Limited, Gauteng, South Africa) using the method described by Erakhrumen [57]. The bagasse was milled and screened through a mesh size of <3.5 mm, pelleted, from which 1.0g was taken for analysis. The bagasse was completely burnt in excess of oxygen at the steel compartment of the calorimeter and the GCV was obtained.

2.4 Elephant Grass Extract Physicochemistry

The volume of extracts obtained from the grass was measured using volumetric cylinder. The following physicochemical parameters were determined, pH, specific gravity, conductivity, sugar and alcohol content.

The specific gravity (SG) of the samples was determined with the use of specific gravity bottles [58,59]. The specific gravity bottles with the glass stoppers were filled to the brim (i.e.

overflowing with the various fractions of the palm wine products). All spillage on the body of the bottle was cleaned after the bottle had been stopped with the glass stopper. The weight of the bottle was measured with analytical balance (Metler Toledo) and the SG was calculated using the formula

$$SG = \frac{\text{Mass of SG bottle + samples} - \text{Mass of the empty bottle}}{\text{Volume of SG bottle}}$$

The percentage alcohol content of the various samples was determined with the $K_2Cr_2O_7$ method [60]. An alcohol standard curve was prepared by diluting a 98%-100% absolute ethanol, to give a series of standards, 20%-80%. From each of these standard solutions, 1ml of alcohol was added into a test tube and 5ml of 0.1M $K_2Cr_2O_7$ was added and incubated for 30minutes at room temperature. The spectrophotometer (Jenway 650 UV/VIS) was set up at a wavelength of 540nm. The blank used in this case was 1ml of distilled water in a test tube and 5ml of 0.1M $K_2Cr_2O_7$ added and incubated at room temperature for 30 minutes. This was used to zero the spectrophotometer, and absorption values were then taken, the curve obtained was linear. The samples were also treated in the same manner and their absorbances were measured. A standard graph of absorbance versus alcohol percentage was drawn, and alcohol percentage values were calculated by extrapolation from the curve.

The Percentage of sugar content in various samples was determined with the use of potassium ferricyanatein the presence of NaOH [58]. 1 ml of the filtered sample was put into a test tube followed by the addition of 5 ml of 0.1, potassium ferricyanate solution and 1ml of 2M NaOH solution. The test tubes were then placed in a water bath at 100OC and incubated for 10–15 min until the greenish yellow colour developed. A standard 100% sugar solution was prepared as the stock sugar solution from D-glucose crystals by weighing 100g of glucose into 100ml volumetric flask and making up to the mark with distilled water. By using the M1 V1=M2 V2 relationship, various dilutions ranging from 20%-80% were created. Using the same procedure as that of the samples, the standard glucose solution was treated. The spectrophotometer was set at 420nm after incubation. Absorbance values were taken and a calibration curve was drawn. The percentage of sugar was determined by extrapolation from the standard curve.

The pH was determined in-situ according to the scheme of Ademoroti [61], using pH meter (HANNA HI 9820).

The conductivity was measured in-situ with the aid of conductivity meter (HANNA HI 9820) as described by [61].

Yeast counts and identification: Serially diluted elephant grass extract was plated on Sabouraud dextrose agar containing 0.05 mg/ml chloramphenicol for yeast counts. The yeast was identified with morphological, cultural, and biochemical tests [62].

2.5 Statistical Analysis

The data were subjected to descriptive statistics (mean and standard error) and analysis of variance (ANOVA), while Fisher's Least Significant Differences (LSD) was used to determine the source of the differences at p=0.05. SPSS version 17 (IBM-SPSS, US) was used for statistical analysis.

3. RESULTS AND DISCUSSIONS

The dry matter yield of the wild elephant grass at first cut (harvest) ranged from 7.00–11.33tonnes/ha, which is significantly different (P<0.05) among the different plots (Table 1). This value is significantly lower than what has been reported by other authors (in tonnes dry matter/ha/year); 22.0–31.0 [15], 31.0–43.0 [63], 45.0–67.0 [28]. Most of these studies did not indicate the number of harvest resulting to this level of productivity except de Morais et al. [28] that recorded 24.9–27.7, 18.9–22.9 and 8.4–11.2 tonnes/ha during first, second and third cuts, respectively. Other authors have reported other values of elephant grass productivity including 22–31 tonnes/ha/yr [15], 31–43 tonnes/ha/yr [28], 30–40 tonnes/ha/yr [33]. But even under suboptimal conditions of limited nutrients in poor nitrogen soils, a biomass productivity of 30tonnes/ha/yr was recorded [30], which was not significantly different from the results of some other authors under optimal conditions.

Table 1. Elephant grass productivity

Plot #	Wet Weight, tonnes/ha	Dry Weight, tonnes/ha	% Dry Weight	Grass Extract Volume, litres/ha	GCV, MJ/kg
1	65.33±2.60ab	7.00±0.58a	10.68±0.46a	6.57±0.13a	16.89±0.18c
2	55.67±4.67a	7.00±0.58a	12.60±0.59b	6.07±0.52a	16.94±0.04c
3	63.00±2.89ab	7.33±0.33ab	11.65±0.28ab	6.37±0.09a	16.95±0.07c
4	71.00±6.08bc	10.33±1.33cd	14.49±0.87c	5.73±0.12a	16.43±0.10abc
5	63.67±2.40ab	7.33±0.33ab	11.52±0.38ab	5.87±0.17a	16.14±0.09ab
6	73.33±5.24bcd	9.67±0.88bcd	13.15±0.46bc	9.10±0.76c	17.07±0.45c
7	67.00±3.00ab	8.00±0.58abc	11.92±0.47ab	5.63±0.20a	16.99±0.19c
8	75.33±4.84bcd	11.00±1.00d	14.55±0.37c	9.30±0.74c	15.76±0.24a
9	81.67±3.93cd	10.67±0.33d	13.08±0.25bc	6.77±0.54ab	16.62±0.25bc
10	86.67±6.39d	11.33±1.20d	13.01±0.51bc	8.17±0.73bc	16.77±0.25bc

Quesada [64] reported 30tonnes/ha/yr from two harvests. The productivity reported in this study is only comparable to the third harvest 8.4–11.2 tonnes/ha reported by de Morais et al. [28]. For forage purposes, elephant grass can be harvested after every 50–60 days of re-growth [17,65], whereas for bioenergy purposes 2-3 harvests/year is possible [28]. Hence, the productivity of wild elephant grass in Bayelsa could increase significantly if multiple harvests are done. Besides, being wild, they grew in degraded lands where other crops/weeds failed to establish. The energy ratio of these wild elephant grasses could be very high because no external energy was applied for their cultivation in the form of land preparation (clearing, and ploughing), irrigation, fertilizer or pesticides application. Wild elephant grass is ecologically friendly because it does not cause the disturbance of the site during land preparation or environmental pollution resulting from fertilizer and pesticides application. Additionally, it provides habitats for wildlife unlike other biofuel crops that destroy wildlife habitats e.g. oil palm plantations in Malaysia and Indonesia destroying orangutan habitats [66].

The productivity of the wild strain of elephant grass recorded in this study is comparable to that of other perennial rhizomatous grasses screened as energy crops in the US and Europe (tonnes/ha/year); 6.8–11.9 big blue stem *Andropogon gerardii* vitaman [67], 3.1–8.0 eastern gamma grass, *Tripsacum dactyloides* L. [68], 1.6–12.2 reed canary grass, *Phalaris* *aru*ndinecea L [69], 1.6–6.0 Timothy home grass, *Phleum pretense* L. [70,71], 3.3–6.7 smooth home grass, *Bromu sinermis* Leyss [71], 3.6–11.0 tall festue, *Festuca arundinacea* Schreb [70,71], 8–10 cockstoot grass, *Dactylis glomerta* L. [73], 9 giant cord grass, *Spartina cynosuroides* L. [74] and 9 – 13 common reed, *Phragmites communis Trin.* [75].

The gross calorific value of the elephant grass bagasse ranged from 15.76–17.07MJ/kg (Table 1), which is comparable to values recorded by authors for other biomass. The heating values reported are 16.46–18.10MJ/kg for sugarcane bagasse [76,77], 14.65–21.63 MJ/kg for agro forestry wood [57], and for other hard wood reported by various authors in Nigeria 10.17 MJ/kg [78], 17.46 MJ/kg [79], 18MJ/kg [80], and 20.66–22.03 MJ/kg [79]. The heating value reported for the wild elephant grass is also comparable to that of oil palm processing residues (empty fruit bunch, fibre, shell,) are 16.970–18.537 MJ/kg, 16.472–21.037 MJ/kg and 19.378–21.614MJ/kg, respectively [55]. Wahid [81] reported calorific values of 19.1 MJ/Kg, 18.8 MJ/kg and 20.1 MJ/kg, while Sumathi et al*.* [82] reported 18.84 MJ/kg, 19.07 MJ/kg and 4.95 MJ/kg for empty fruit bunch, fiber, shell respectively. These oil palm biomass wastes are traditionally used as solid fuel for oil palm processing activities, particularly boiling for cooking of palm fruit, generation of process heat and electricity [59]. The heating value recorded in this study for elephant grass bagasse is, therefore, adequate for the generation of electricity via direct biomass combustion. Other useful energy carriers can also be obtained from the bagasse via gasification and pyrolysis [34,39,40,83,84]. More so, that de Morais et al. [28] recorded low values of residual ash (2–3%), which is considered to be lower than the 5% critical level reported by [31].

The volume of liquid extract from the elephant grass ranged from 5.63–9.10 litres/ha, being significantly different among the plots (Table 1). The results of the physicochemical properties of the extracted liquid are presented in Table 2.The liquid extract was analyzed and was found to have the following characteristics; pH (5.55–5.98), electrical conductivity (14,610-48,214 µS/cm), specific gravity (1.56–1.60), sugars (2.59–4.47%), and ethanol (1.36–2.85%). With these properties, the liquid extracts of elephant grass could be used as alternative feedstock for sugar and ethanol production.

These results show that some fraction of the initial sugar content in the extract has been converted to ethanol by yeast, *Saccharomyces cerevisiae,* that may have been spontaneously inoculated in the extract during processing. Studies have shown that the microbial infestation of sugary extracts, which promotes the proliferation of yeast and bacteria for the conversion of the extracts into ethanol can occur spontaneously [85,86]. The population of yeast found in the grass extracts were in the order of 10^6 cells/ml, which is comparable to what has been reported for fermented raffia palm sap [54].

The results also show that the elephant grass extract is a good substrate/feedstock for the production of sugar and bioethanol. Apart from the extracts, the elephant grass bagasse can be used as feedstock for the production of cellulosic ethanol. Lignocellulosic biomass has been reported to contain 30-60% cellulose, 20–40% hemicelluloses and 10–30% lignin [87,89]. Grasses generally have 25–40% cellulose, 25–50% hemicelluloses and 10-30% lignin [89]. De Morais et al. [28] reported 27.9–28.2% cellulose, 11.9–12.4% lignin and 2.2-2.6% ash for elephant grass bagasse. There are well established technology of pretreatment (hydrolysis and saccharification) and fermentation of lignocellulosic biomass for the production of ethanol [87-89].

Table 2. Physicochemical properties of elephant grass extract

Plot #	pH	SG	Electrical Conductivity, μS/cm	Sugar, %	Alcohol, %
1	5.67±0.03ab	1.57±0.02a	29291.00±615.61d	3.60±0.05cd	1.36±0.03a
2	5.63±0.04a	1.58±0.01a	43485.67±316.62f	3.09±0.10b	1.75±0.04b
3	5.78±0.06bc	1.60±0.00a	36184.00±609.02e	3.72±0.05d	2.37±0.02c
4	5.55±0.02a	1.57±0.02a	35138.67±494.27e	4.47±0.05e	2.85±0.07d
5	5.98±0.05f	1.57±0.02a	35793.33±251.95e	3.74±0.06d	2.51±0.07c
6	5.78±0.05bc	1.58±0.01a	35844.67±128.13e	2.59±0.13a	2.85±0.06d
7	5.98±0.06f	1.58±0.01a	24882.33±527.69c	3.39±0.13c	1.81±0.07b
8	5.81±0.02cd	1.56±0.03a	21850.00±571.77b	3.77±0.03d	2.35±0.04c
9	5.92±0.05ef	1.58±0.01a	14610.00±249.08a	3.53±0.05cd	1.78±0.14b
10	5.55±0.03a	1.56±0.02a	48214.67±683.01g	4.41±0.04e	2.41±0.08c

4. CONCLUSION

Weed control in Nigerian farms is done mostly manually and to a lesser extent by the use of herbicides. In Bayelsa and Riversstates, monospecific stands of elephant grass colonize farms and disturbed freshwater forests. Farmers spend huge amount of money, labour and herbicide to control the invading grasses. While herbicide is costly, their use could also contaminate the environment and impact non-target organisms. But the usual practice is to cut down and burn the grasses, which could release smoke, carbon dioxide and other greenhouse gases into the atmosphere, thus impacting on the local and regional environment and socio-economic condtions of the people. The open air combustion of elephant grass also results in the loss of useful energy into the atmosphere, even at a time when the country is suffering from shortage of energy including electricity, cooking and transportation fuel. The findings of this research could be beneficial to smallholder farmers, who instead of spending money to control the invading elephant grass, could earn money for the conversion of elephant grass to fuel ethanol and bagasse for power generation. This project will therefore have environmental, social and economic benefits especially to the rural people, hence it could become an agent of sustainable agriculture and rural development.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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