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The potential of elephant grass (*Pennisetum Purperum S.)* as a promising bioenergy feedstock for cellulosic ethanol production in the six Geo-political zones of Nigeria

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Abstract

Energy is a domestic necessity but poses serious threat to human health and ecosystem. Oil and gas effects is currently high in Nigeria, being the sixth and eighth largest producer and exporter of crude oil globally with a proven reserve of over 37 billion barrels. This has contributed to unabating greenhouse gas (GHG) emissions globally resulting in climate change effects. This research aims to find a more sustainable alternative energy resources to reduce GHG emissions. Studies have identified biofuels as potential technology to address the global concerns of GHG emissions as well as promote energy security. Results of elephant grass specie show a clear potential to minimize the problems of climate change associated with the oil and gas activities in Nigeria. The theoretical ethanol yield at the zonal basis after excluding livestock areas to achieve food security showed that the SW zone would account about 2.2 billion litres of elephant grass-based ethanol. This amount could feed about 40 large-scale biorefineries. Results also showed the NC zone possess the highest potential with 1.8 billion litres and 32 large-scale processing facilities. Although *Miscanthus x giganteus* is an acclaimed potential feedstock, it is not in this work, where elephant grass was evaluated and recommended to policy makers as the best feedstocks for cellulosic bioethanol production particularly in Nigeria. Therefore, considering Nigerian Government's 10% blending target, the study showed that elephant grass can contribute about 7.1 billion litres of cellulosic bioethanol per annum at 41% land utilization to totally satisfy the county's PMS consumption.

1. Introduction

Energy plays a central role in national development [1]. It is a domestic necessity and a major factor which dictates the price of other goods [2]. The Nigerian energy sector is dominated by oil and gas [3]. They contribute about 80% of the total value of exports [4], but there are significant environmental impacts associated with it. Effects such as air pollution affects both human and ecosystem health, and greenhouse gas emission. Other impacts of oil exploration activities since its discovery in the 1950s includes the frequent inter-ethnic crises and fuel scarcity which had severally paralysed all economic activities in the country [5]. The diminishing rate of crude oil reserves [6] coupled with the desire to achieve energy security [7] also constitutes the key drivers for biofuel development in Nigeria [8]. Nigeria is the largest crude oil producer in Africa [9], and the sixth and eighth largest producer and exporter of crude oil globally with a proven reserve of over 37 billion barrels [10]. In 2005, Nigeria recorded a total oil production of 919 million barrels which surpassed the 911 million produced in 2004 by 0.9% [11]. Table 1 shows the evolution of the crude oil production between 2005 and 2015. The unstable production over the years has indicated significant adverse effects on the country's economic growth.

To help address the lingering issue of fuel scarcity in the country, Nigeria established major refining companies in Port Harcourt, Kaduna and Warri [11]. The essence of establishing these refining facilities was to meet the increasing demand and fulfil the dual role of supplying both the domestic and export market [12], but they performed well below their installation capacities [11], with the output capacities of 20%, 39% and only 18% for the Kaduna, Warri and the two Port Harcourt refineries (Table 2). Based on the constraints surrounding oil production and the poor refining capacity of the four refineries to attain its domestic demand for petroleum products [12], Nigeria is currently importing the bulk of its petroleum products. In 2015 the country imports accounted for about 7.4 million MT, the increasing rates of petroleum product imports over the years were attributed to the drop in domestic refining capacities [11, 13-22]. In order to address these problems associated with liquid transportation fuels, the Nigerian government decided to support and promote investments into biofuel [23], but the criticism and concerns over the sustainability of many first-generation biofuels like, for example, the 'food-versus-fuel' conflict, have led nations to seek potential alternative feedstocks otherwise known as second-generation biofuels [24]. Second generation bioethanol production has the potential to employ a range of non-edible feedstock sources such as forestry waste, agricultural wastes as well as purposely grown bioenergy crops, such as miscanthus and switchgrass. These feedstocks would help address the food versus fuel conflict, minimize land use competition and environmental impacts associated with first generation biofuel technology [25].

According to Iye and Bilsborrow [26, 27], Nigeria has considerable potential for agricultural residues as an attractive option for cellulosic bioethanol production. This is basically due to their relatively low cost and do not imply a food versus fuel conflict, which is a major barrier for first generation biofuels feedstock. Nigeria has high potential for agricultural residues with as much as 7556 km^3 per annum to meet its bioethanol target, but the challenges associated with the collection and transportation to processing facilities remains uncertain [26]. This was therefore the basis for adopting elephant grass for this study.

2. Methodology

Python software was embedded within ArcGIS to carry out the various estimations.

To allow this estimation, equation 1, with glucose contents of elephant grass specie (Fig. 1) extracted from literature were used to determine the potential ethanol yields (Table 3) was used;

Ethanol yield (L) = Biomass resource amount (kg) X Glucose content
X Fermentation efficiency (85%)
X Theoretical ethanol yield (51%)
X Process recovery (90%)/ Specific gravity of ethanol 0.79 (kg/l) ……1
[26].

The ethanol yield and number of processing facilities (biorefineries) were determined based on the estimated biomass production (Table 4). Since an ideal large commercial biorefinery was indicated to possess at least 5000 tonnes/day [28], potential biorefineries was determined by dividing crop productivity by plant input capacity.

Fig. 1. Elephant grass (***Pennisetum Purperum S.***)

Table 1. Crude oil production in Nigeria (Million barrels) [29].

Year	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Quantity	919	869	803	769	780	896	866	853	800	799	774

Table 2. Capacity utilization of the Nigerian oil refineries from 1997 to 2008 (%).

Plants	**Year commissioned**	**capacity (10^3 bbl/d)**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Refinery & Petrochemical Company.	1980	110	22.7	31.4	35	15.9	26	33.1	8.3	0.0	19.6
Port Harcourt Refinery Company.	1966 (old)	50	31	60.7	52.2	41.9	31	42.2	50.3	24.9	17.8
Port Harcourt Refinery Company.	1989 (new)	160	31	60.7	51.4	50.5	30.7	38.1	45.7	23.8	48.5
Warri Refinery & Petrochemical Company.	1978	125	5.0	48.3	55.5	14.3	9.1	54.9	3.8	0.0	38.5

Table 3. Glucose composition (%) of some bioenergy crop (elephant grass and *Miscanthus x giganteus* for cellulosic bioethanol estimation.

Component (%)	**Glucose 1**	**Glucose 2**	**Average glucose %**	**Reference**
Miscanthus x giganteus	48.4	49.5	49.0	[30, 31]
Elephant grass	57.8	50.3	50.6	[32, 33]

3. Results and Discussion

3.1 Results

The results are presented in Tables 4 – 8.

Table 4. Evaluating the potential of promising bioenergy crops in Nigeria based on 100% utilization of the country's suitable grassland and shrub land.

Specie	Ethanol yield (Bl)	No of Processing facilities
Miscanthus x giganteus (MG)	236	534
Elephant grass (EG)	338	735

Table 5. Estimation of cellulosic bioethanol production (Billion litres) from *Miscanthus x giganteus* (MG) and Elephant grass (EG) and number of processing facilities required in each zone.

Zone	EG (000 tonne)	Ethanol yield (Bl)	N° of processing facilities	MG (000 tonne)	Ethanol yield (Bl)	N° of processing facilities
NW	268000	68	147	188000	45	103
NE	322000	81	176	300000	73	164
NC	390000	98	214	254000	61	139
SW	180000	45	99	89754	22	49
SS	139000	35	76	113000	27	62
SE	43140	11	24	29672	7	16

3.2 Discussion

The Nigerian government introduced the country's Biofuel Policy and Incentives in 2007 [10]. This was aimed to reduce the nation's dependence on imported gasoline, reduce environmental pollution while at the same time creating a commercially viable industry that can support sustainable domestic jobs. To achieve these, the Nigerian National Petroleum Corporation (NNPC) was mandated to blend gasoline and diesel with 10% bioethanol and 20% biodiesel known as the E10 and B20 blends. A 10% blend ratio with fuel ethanol was indicated to require 1.3 billion litres of bioethanol with an estimated increase to about 2 billion litres by 2020. The Biofuel Policy also aspired to achieve 100% domestic production of biofuels consumed in the country by 2020. Most commercial bioethanol production occurs from first generation feedstocks, i.e. sugar cane in Brazil, maize in the US and wheat in Europe. Many of the Nigerian biofuel projects have been designed to use cassava which is the country's major staple food. However, the use of first generation feedstocks in Nigeria would cause major issues with respect to food security at a time when the population of the country is increasing. The sustainability of first generation biofuels has also been criticised especially in recent years over competition with food crops [34, 35], hence, there is an urgent need to develop a more sustainable feedstock that would not compete with food.

Table 6: Estimated cellulosic ethanol yield (million litres) and the number of large biorefineries in each zone based on number of cattle, goats and sheep in Nigeria.

Feedstock	Zone	Suitable area (ha)	Area for livestock production (ha)	Area available for biofuel production (ha)	yield based on livestock area (tonnes)	Ethanol yield (Million litres)	Number of processing plants
Elephant grass	NC	10,631,484	7,234,665	3,396,819	58,663,067	1,803.47	32
	NE	11,133,846	8,221,748	2,912,098	37,711,671	1,159.36	21
	NW	8,009,550	4,062,785	3,946,765	49,966,045	1,536.10	27
	SE	1,636,353	1,121,863	514,490	7,799,676	239.78	4
	SS	4,887,279	1,316,325	3,570,954	63,277,300	1,945.32	35
	SW	5,513,625	2,490,776	3,022,849	72,669,282	2,234.06	40
		41,812,137		17,363,975	290,087,040	7,115	159
Miscanthus x giganteus	NC	10,680,921	7,234,665	3,446,256	38,666,994	1,188.73	21
	NE	11,483,514	8,221,748	3,261,766	35,748,957	1,099.02	20
	NW	8,009,550	4,062,785	3,946,765	35,007,806	1,076.24	19
	SE	1,636,434	1,121,863	514,571	6,972,443	214.35	4
	SS	4,924,080	1,316,325	3,607,755	45,277,322	1,391.95	25
	SW	5,513,625	2,490,776	3,022,849	42,440,795	1,304.75	23
		42,248,124		17,799,962	204,114,317	6,275	112

Table 7: Population of livestock (cattle, sheep and goat) in each zone.

Zone	Population of sheep	Population of goat	Population of cattle	Total population	area for small ruminant	area for cattle	Area for livestock
NW	23,129,581	24,111,781	10067851	57,309,213	25,321,561	1,677,975	26,999,536
NE	6,603,820	8,134,410	5270614	20,008844	7,343,312	878,436	8,221,748
NC	5,702,809	6,716,436	5527623	17,946,868	6,313,394	921,271	7,234,665
SE	708,978	4,512,678	15849	5,237,504	1,119,221	2,641	1,121,863
SS	856,966	4,772,850	152782	5,782,598	1,290,862	25,464	1,316,325
SW	1,524644	10,371,584	139568	12,035,796	2,467,515	23,261	2,490,776
Country	Overall total			118,320,823			47,384,913

Table 8: Sensitivity analysis of the estimated cellulosic ethanol yield (billion litres; Bl) in each of the six geopolitical zone.

Specie	Zone	Yield (000 tonne)	20% increase of glucose composition (%)	20% decrease of glucose composition (%)	20% increase ethanol	20% decrease ethanol	Ethanol Original
Elephant grass	NW	268000	0.61	0.40	80.74	52.94	67.50
	NE	322000	0.61	0.40	97.00	63.61	81.10
	NC	390000	0.61	0.40	117.49	77.04	98.23
	SW	180000	0.61	0.40	54.23	35.56	45.34
	SS	139000	0.61	0.40	41.87	27.46	35.01
	SE	43140	0.61	0.40	13.00	8.52	10.87
Miscanthus x giganteus	NW	188000	0.59	0.39	54.78	36.21	45.49
	NE	300000	0.59	0.39	87.41	57.78	72.60
	NC	254000	0.59	0.39	74.01	48.92	61.47
	SW	89754	0.59	0.39	26.15	17.29	21.72
	SS	113000	0.59	0.39	32.93	21.76	27.35
	SE	29672	0.59	0.39	8.65	5.72	7.18

To meet the 10% replacement as mandated in the Nigerian Biofuels Policy was suggested to require about 1 million hectares out of the 34 million hectares currently under cultivation [34]. With problems arising from the use of food crops and agricultural land, Iye and Bilsborrow [26, 27] evaluated the potential of agricultural residues for bioethanol production. The study looked at both field and processing residues and estimated a production potential of 7.6 billion litres per annum, but again these feedstocks had transport logistics problem. This therefore motivated further research to look at the potential of some local bioenergy crop. This study evaluated the production potential of elephant grass, as a second-generation feedstock with the highest potential to produce cellulosic ethanol across the six geo-political zones of Nigeria.

3.2.1 Evaluating the potential of Elephant grass based on 100% land utilization.

Elephant grass accounted for the highest potential nationally based on 100% land utilization with 338 billion litres per annum and 735 processing facilities, while *Miscanthus x giganteus* the second most potential specie with 236 billion litres per annum and 534 processing facilities (Table 4). Results of the evaluation based on zonal level showed that the NC zone was predicted to have the highest potential followed by the NE with 98 and 81 billion litres of cellulosic bioethanol per annum. In the Southern region, the SW zone could produce 45 billion litres of ethanol per annum, followed by SS zone with 35 billion litres while the SE has the least potential across Nigeria (Table 5).

In terms of the evaluation of potential feedstocks based on current livestock numbers in Nigeria. Considering the high number of livestock production in the North with a total of 95 million compared to the South with only 23 million head, the NW zone with over 50% of the total country's livestock population was not recommended for biofuel development due to requirement for sufficient area. To this effect, the NC zone was identified with the potential to produce about 1.2 billion litres of ethanol to feed 32 facilities and produce (Table 6). The SW zone was identified to have the highest potential for bioethanol production from elephant grass. The zone could produce 2.2 billion litres of ethanol to feed 40 processing facilities while the SE the lowest potential zone across the country requiring 5 facilities to produce 240 million litres of cellulosic ethanol (Table 6).

3.2.2 Evaluating the production potential of elephant grass in Nigeria based on the country's current livestock population.

Though, it is interesting to note that Nigeria stands the chance to meet her domestic energy demand and still have in excess biofuels available for export. But the possible problem that would arise from the 100% utilization of the national grazing land would be a case of feed versus fuel conflict and displacing current livestock activities. Therefore, the second scenario was investigated, which looked at the current livestock population in Nigeria at 41% free land for biofuel production after the deduction of the livestock areas (Table 6 & 7). Based on this evaluation, the SW zone still accounted the highest potential with 2.2 billion litres from elephant grass and 40 large scale processing facilities, the SS zone is second with 2.0 billion litres of cellulosic ethanol and 35 large scale facilities while the SE zone has the lowest potential with 240 million litres of cellulosic ethanol and 2 large processing facilities. The NC zone was the third highest potential with 1.8 billion litres of ethanol and 32 large scale processing facilities (Table 6).

Based on the 10% blending target and considering the current (2015) PMS [21, 22] consumption at 49 million litres per day, it was indicated that the country's biofuel potential at 41% utilization of the free land for the feedstock production would account for 7.1 billion litres of cellulosic bioethanol per annum. This amount was far much greater than the 10% blending target by the Federal Government of Nigeria at 1.8 billion litres per annum.

Conclusion

In conclusion, transportation logistics of feedstock production to various processing facilities is the key issue confronting second generation biofuel production especially when dealing with high volume low density materials. However, as with agricultural residues, the delivery to central collection points before it's conveyed to the bio-refineries remains a key limitation. Hence the search for the potential of herbaceous energy crop to contribute towards biofuel production in Nigeria. The study showed that at 41% of the country area, the South has higher potential for biofuels compared with the North, where the SW zone was identified to possess the highest potential for biofuel production while the NW zone not recommended for this purpose due to the high livestock population in the region.

Meanwhile, considering the current PMS consumption at 49 million litres per day, it was indicated that the country would potentially account for 7.1 billion litres of cellulosic bioethanol per annum. This amount is far much greater than the 10% blending target by the Federal Government of Nigeria at 1.8 billion litres per annum, and would have the potential to totally satisfy Nigeria's PMS consumption.

The study further advised that decision makers should reconsider the Nigerian biofuel policy to be in line with the UN policy statement, ''that Policies promoting biofuels must be consistent to maintain food security and achieve sustainable development goals." However, the study recommends that there is need for appropriate laboratory experiments, basically by fermentation of reducing sugars to determine the actual cellulosic bioethanol yield of each bioenergy crop, to help validate the results since the ethanol productivity of this specie was based on estimation of the theoretical yield.

Sensitivity analysis of ethanol yield potential

In terms of the sensitivity analysis carried out on ethanol productivity at ±20% of the model parameter, results of the analysis showed a significant change in the ethanol productivity of elephant grass biomass in the six geopolitical zones (Table 8). It was also gathered that elephant grass would have significant effect to the ethanol productivity in the zones, if further adjustments are made on the model parameters. For instance, the SW zone was identified to increase by 11 and 16 million litres respectively on increasing the yield parameters by ±20% (Table 8).

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