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Potentials of Selected Tropical Crops and Manure as Sources of Biofuels

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1. Introduction

The chapter presents comprehensive and up-to-date knowledge on the themes of biogas, bioethanol, biodiesel as obtained from cassava, cocoyam, jatropha, grasses and manure. The author's research findings as well as those reported by other researchers are used for the discussion. Recommendations as regards how to benefit much more from these biofuels derived from selected tropical crops are presented. It is anticipated that these recommendations will be of immense help to academics and industry specialists working in such areas.

2. Contemporary focus on renewable energy

In contemporary times, a great deal of interest has been generated worldwide regarding the use of biofuels namely biogas, bioethanol and biodiesel for energy supply. The most ambitious goal thus far in respect of the development and exploitation of renewable energy sources appear to be that articulated by the European Renewable Energy Council. According to European Renewable Energy Council EREC (2010) in March 2007, the Heads of States and Governments of the 27 EU Member States adopted a binding target of 20% renewable energy in final energy consumption by 2020 and 100% by 2050. Combined with the commitment to improve energy efficiency by 20% until 2020 and to reduce greenhouse gas emissions by 20% (or respectively 30% in case of a new international climate agreement) against the 1990 level, Europe's political leaders paved the way for a more sustainable energy future for the European Union and for the next generations. In order to reach the binding overall target of at least 20% renewable energy by 2020, the development of all existing renewable energy sources as well as a balanced deployment in the heating and cooling, electricity and transport sectors is needed. According to estimates of the European renewable energy industry around 40% of electricity demand will be generated with renewable energy sources by 2020 (EREC, 2010). Furthermore, the new Renewable Energy Directive (RED) will undoubtedly stimulate the renewable energy heating and cooling market, and according to EREC's projections, up to 25% of heating and cooling consumption can come from renewable energy by 2020. Similar kind of awareness is evident in other regions of the world and cogent efforts are being made to increase the renewable energy share of the energy profile and reduce overdependence on fossil fuels.

For about 3 decades, Brazil has been in the forefront of using renewable energy in the form of bioethanol derived mainly from sugarcane to power fuel-flex vehicles or as oxygenate to gasoline and has made a remarkable success of it. Likewise, the USA has also to some extent used bioethanol to power vehicles. Bioethanol is the biofuel most widely used for transportation worldwide. The global annual production of fuel ethanol is around 40 to 50 billion litres, of which 90 percent is produced by the USA and Brazil from maize and sugarcane respectively (World Bank, 2008). Global ethanol production has seen steady growth since the search for alternatives to petroleum was prompted by the oil crisis of 1973/1974. The USA is now the largest consumer of bioethanol, followed by Brazil. Together they consume 30 billion litres, or three quarters of global production (Licht, 2005). The Economist (2005) reported that as at that time Germany was raising its output of biodiesel by 50% per year; USA was boosting its ethanol production by 30% per year; France aimed to triple its output of biodiesel and ethanol by 2007; China had just built the largest ethanol plant in the world; and also that Brazil was producing around 4 billion litres of ethanol per year, and hoped to export 8 billion litres per year by 2010. China's Ministry of Science and Technology plans that the country would attain 12 million tonnes of biodiesel production by the year 2020 (GTZ, 2006).

According to OECD (2008), the global ethanol and biodiesel production in 2007 is given in Table 1. Certainly, successes recorded as regards exploitation and use of other biomass for energy supply, will further enhance global energy security. Some of the themes involved in this are discussed in this chapter.

Country	Ethanol	Biodiesel
USA	26,500	1,688
Canada	1,000	97
European Union	2,253	6,109
Brazil	19,000	227
China	1,840	114
India	400	45
Indonesia	0	409
Malaysia	0	330
Others	1,017	1,186
World	52,009	10,204

Source: OECD (2008)

Table 1. Global Ethanol and Biodiesel Production for 2007 (in million litres)

3. History of anaerobic biodigestion

Sparse evidence suggests that biogas was known to the Assyrians and Persians centuries before Jesus Christ was born. Further evidence is traceable to count Alessandro Volta who in 1776 concluded that there was a direct link between the amount of decaying organic matter and the amount of flammable gas produced. Sir Humphrey Davy determined in 1808 that methane was present in the gasses produced during the anaerobic decomposition of cattle manure. Helmont recorded the emanation of an inflammable gas from decaying organic matter in the 17th century (Brakel, 1980). It was not until towards the end of the 19th century that methanogenesis was found to be connected to microbial activity. In 1868, Bechamp named the organism responsible for methane production from ethanol. This organism could more accurately be described as a mixed population. Bechamp was able to show that, depending on the substrate different fermentation products were formed. Zehnder et al (1982) stated that it was in 1876 when Herter reported that acetate in sewage was converted to equal amounts of methane and carbon dioxide. Meynell (1976) noted that the first anaerobic digestion plant was built in Bombay, India in 1859. The first notable use of biogas in England occurred in 1859 when gas derived from a sewage treatment facility was used to fuel street lamps in Exeter (McCabe and Eckenfelder, 1957). Then in 1904, Travis put into operation a new two-stage process in which the suspended material was separated from the wastewater and allowed to pass into a separate 'hydrolyzing' chamber (Carcelon and Clark, 2002). Buswell and Hatfield (1936) and some other researchers in the 1930s identified anaerobic bacteria and the conditions that promote the production of methane. Their works also explained such issues as the fate of nitrogen in the anaerobic digestion process, stoichiometry of the reactions, as well as the production of energy from farm and industrial wastes through the anaerobic digestion process. Regarding anaerobic technology, farm–based facilities are the most common. In contemporary times low–technology biogas digesters have been most extensively used in China and India. Bui-Xuan (2004) pointed out that low cost biogas technology has been well received by small holder farms in many developing countries for producing a clean fuel to replace firewood, within the recent ten years. Stating that more than twenty thousand digesters have been installed in Vietnam, mainly paid for by the farmers; however biodigesters are still not fully integrated into the farming system as there is only limited use of by-products (effluent) as fertilizer for vegetables, fruit trees, fish pond and water plants. The paper further stated that the use of effluent from digester can be studied as a resource for small scale farmers. Interest in the technology is increasing in several other parts of the world.

4. Overview of biogas production

Biomass is basically used as fuel, fertilizer, and feed. One fact which is evident in the literature is that the use of biomass, particularly livestock manure as fertilizer and feed has not grown with the continuously increasing rate of production of the manure itself. For instance, Wadman et al., (1987) pointed out that in the Netherlands, the total production of manure from housed cattle (during the winter period only) pigs, poultry, and fattening calves increased from 10 tonnes/ha in 1950 to 26 tonnes/ha in 1982. Neeteson and Wadman (1990) observed that within that same period however in the same country, the need to use animal manures as fertilizers decreased due to the widespread adoption of cheap inorganic fertilizers. These inorganic fertilizers have a number of advantages over manure namely; their composition is known, they are easier to store, transport, and apply and have a more predictive effect on crop growth than manures. Therefore, livestock manure was increasingly regarded as a waste product rather than a fertilizer.

The situation reported for the United Kingdom is another example. Using agricultural census data, Smith and Chambers (1993) estimated that around 190 million tonnes of livestock excreta per year are produced on U.K farms. Some 80 million tonnes of this is collected in buildings and yards where they are stored and hopefully applied to land later. However, land application of all the collected manure has not always been possible over the years. Chalmers (2001) in a review of fertilizer, lime and organic manure use on farms in Great Britain noted that the proportion of UK land receiving organic manures remained at 16% for tillage cropping but increased slightly for grassland, from a mean of 40% in 1983-1987 to 44% in 1993–1997. Just as in the case of the Netherlands referred to previously, livestock manure produced on UK farms constituted a burden since land application of all of it was increasingly impossible. Against the background that Netherlands used as an example has 5, 95, and 14 millions of cattle, poultry, birds, and pigs respectively, implications for other countries which have higher livestock populations are quite significant.

The option of using livestock manure as fuel merits closer investigations for its evident biogas–generation potential. Heltberg et al., (1985) pointed out that biomass could potentially contribute about 3.2 billion GJ to the United states energy resources, which is roughly the amount of energy expected to be supplied from nuclear and hydroelectric power plants in the USA as at that time. Within the USA itself, some projects are already operational. Thomas (1990) reported the case of a commercial project in California which was generating about 17.5 MW of electricity from cattle manure. Biogas typically refers to methane produced by fermentation of manure or other biomass under anaerobic conditions. Mata-Alvarezi (2002) focused on the state of research on the subject in Europe and noted that the process is popular in the rural areas, particularly in the Netherlands and Denmark because it provides a convenient way of turning waste into electricity. The use of biogas is encouraged because methane burns with a clean flame and produces little pollution or no pollution.

The use of manure to produce biogas for energy supply also has attractive prospects in developing countries. According to Akinbami et al., (2001), Nigeria produced about 227,500 tons of fresh animal waste daily. The paper noted that since 1kg of fresh animal waste produces about 0.03 m^3 of biogas, then Nigeria can produce about 6.9 million m^3 of biogas everyday. In addition to all this, 20kg per capita of municipal solid waste (MSW) has been estimated to be generated in the country annually. Going by the census figures 140 million inhabitants, the total generated MSW would be at least 2.8 million tonnes every year. With increasing urbanization and industrialization, the annual MSW generated will continue to increase. Biogas production can therefore be a profitable means of reducing or even eliminating the menace and nuisance of urban waste in many cities by recycling them; while at the same time contributing towards providing adequate solution to the seemingly intractable problem of energy security. In the case of Nigeria, a few small scale biogas plants have been constructed by the Sokoto Energy Research center (SERC) and the Federal Institute of Industrial Research (FIIRO) Oshodi, Lagos. As of now contributions of these small - scale biogas plants to aggregate energy supply are yet to become significant (Energy Commission of Nigeria, 1998). Similar potential as this exists in many countries across the developing world.

Processes for the conversion of biomass to biogas may be classified into two categories namely thermal processes (as in biomass gasification), and biological processes (as in anaerobic digestion). As observed by Chynoweth and Isaacson (1987), the major advantage of thermal processes is their ability to effect total conversion of organic matter at rapid rates.

The major disadvantage however is that they produce a mixture of gaseous products that must be upgraded to methane and are only economic at larger scales. Biological processes on the other hand, have the major advantages of producing biogas composed primarily of methane and carbon dioxide with traces of hydrogen sulfide, and are also low – temperature processes which are economical at a variety of scales. Biomass gasification is a process in which solid fuels are broken down by the use of heat to produce a combustible gas (Foley and Barnard, 1985). Fuels that can be gasified include wood, charcoal, coal, and a variety of other organic materials. In the sense used in this chapter, gasification should be distinguished from biogas production which uses wet organic feed stock and works by means of microbial action. Biological processes of biogas production may be aerobic (Evans and Svoboda, 1985) or anaerobic (Voermans, 1985). However, because of the high cost of aerobic processes particularly as regards the provision of energy to sustain the processes, anaerobic processes are preferred. As noted by Voermans (1985) biogas is the main purpose of anaerobic digestion and it comprises ± 55–70% CH_4; 30–45% CO_2, water vapor, and 0.0–0.5% H_2S Anaerobic digestion is brought about in anaerobic digesters.

5. Biofuels for the production of energy

Biomass represents a continuously renewable potential source of biogas and other biofuels and thus is certainly an option to inevitable fossil fuel depletion. Biogas can be economically converted to methane at facilities ranging from smallholder utility equipments to large scale plants and therefore can be tailored to supply rural and urban gas needs as well as meet regional and nationwide energy demands. According to Shoemaker and Visser (2000), the composition of biogas produced by anaerobic digestion as compared to natural gas is given in Table 2. It is readily seen from the table that overall, biogas is of a better quality than natural gas and possesses much less potential for polluting the environment. Biogas therefore constitutes a good alternative to natural gas.

Component	Natural gas (%)	Biogas (%)
CH_4	85	50-80
CO_2	0.89	20-45
C_2H_6	2.85	-
C_3H_8	0.37	-
C_4H_{10}	0.14	-
N_2	14.32	-
O_2	<0.5	-
H_2S	<0.5	0-1.5
NH_3	-	0-0.45

Table 2. Compositions of Natural Gas and Biogas by Volume

However, the present potential of biofuels to enhance energy security is limited. Globally, the huge volume of biofuels required to substitute for fossil fuels is beyond the present overall capacity of global agriculture. For example in the year 2006/2007, the United States used 20 percent of its maize harvest for ethanol production, which replaced only three percent of its petrol consumption (World Bank, 2008). The possibility of more significant displacement of fossil fuels should be possible with second and third generation biofuels.

Theoretically, biomass includes every material of plant or animal origin. However, the focus of research and use of biomass in practical terms is on those materials from which biogas, ethanol and biodiesel may be derived at economic scales. Earlier researchers reported successes which have been advanced by more recent works. Hill (1984) conducted experiments to investigate methane productivity of some animal waste types at low temperatures and very low volatile solids concentrations. Results indicated that there are large differences between the waste types and that poultry waste produced the highest biogas yield for animal live weight (LW) while dairy waste was the least productive on a LW and total solids (TS) basis. This result corroborates those of Huang and Shin (1981), Huang et al., (1982), and Shih (1984). These studies evaluated the potential of methane generation from chicken manure and also assessed the performance of poultry waste digesters. Of further interest is the finding of the last paper, which showed that a high rate of gas produced at 4.5 v/v/day (methane 3.0 v/v/day) can be reached at 5^0C, 4–day retention time (RT) and 6% volatile solids (VS) concentration. Shih (1984) further pointed out that if this potential can be obtained on a poultry farm, the process of anaerobic digestion for waste treatment and energy production would be economically attractive. The potentials of other kinds of livestock waste for biogas production have also been investigated for example dairy manure (Lindley and Haughen, 1985), beef cattle manure (Hamiton et al., 1985) and pig manure (Fedler and Day, 1985). A common result however, is that these particular livestock waste types did not produce biogas as much as poultry manure in the experiments conducted. In experiments conducted on a digester (Ghederim et al., 1985) gas yields related to the organic matter fed to the digester were 0.5 to $0.6m^3/kg$ for pig farm sludge and 0.2 to $0.3m^3/kg$ in the case of beef cattle waste. Methane content varied between 60 and 70%.

The possibility of manure–straw mixtures producing more gas than manure alone continues to engage the interests of researchers. Jantrania and White (1985) found that high–solids anaerobic fermentation of poultry manure mixed with corn stover at 30% to 35% initial total solids produced biogas quantitatively comparable to slurry type anaerobic fermentation. However, the retention time of the process was much longer than required in the conventional process. Hills and Roberts (1979) had earlier reported a substantial increase of methane produced from rice–straw manure and barley–straw manure mixtures compared to manure alone. In a comparative study of pig manure and pig manure–corn stover, Fujita et al (1980) concluded that the mixtures produced more methane than manure alone. In a pit–scale study of wheat straw–manure mixture, Hashimoto and Robinson (1985) found a methane production of $0.25m^3\,CH_4/kg$ of volatile solids (VS).

In more contemporary papers, several researchers have recently reported improvements in biofuel production from various agricultural materials including biogas from mixtures of cassava peels and livestock wastes (Adelekan and Bamgboye, 2009a), biogas from pretreated water hyacinth (Ofuefule et al., 2009), methanol from cow dung (Ajayi, 2009) fuel from indigenous biomass wastes (Saptoadi et al., 2009), ethanol from non-edible plant parts (Inderlwildi and King, 2009), as well as biogas from various livestock wastes (Adelekan and Bamgboye, 2009b). Adelekan (2012) showed that cassava, an often neglected but sturdy crop is a potent energy crop for the production of methane and ethanol, and presented production estimates for these biofuels based on cassava yield from the tropical countries. It has been discovered that, under aerobic conditions, living plants also produce methane which is significantly larger in volume than that produced by dead plants. Although this does not increase global warming because of the carbon cycle (Keppler et al., 2006), it is not readily recoverable for economic purposes. However, the methane which is recoverable for the direct production of energy is from dead plants and other dead biomass under anaerobic conditions.

Prasad et al., (2007) observed that with world reserves of petroleum fast depleting, ethanol has in recent years emerged as the most important alternative resource for liquid fuel and has generated a great deal of research interest in ethanol fermentation. The paper noted that research on improving ethanol production has been accelerating for both ecological and economic reasons, primarily for its use as an alternative to petroleum-based fuels. Based on their genetic diversity, climatic adaptation, biomass and sugar production, field crops have the best potential as large scale fuel sources. Lignocellulosic biomass is the most abundant organic raw material in the world. As observed further, the production of ethanol from renewable lignocellulosic resources will improve energy availability, reduce dependence on petroleum based fuels, decrease air pollution, and diminish atmospheric CO_2 accumulation. Using the by-products of crop processing for ethanol production will also reduce waste disposal problems and lower the risks of polluting the environment.

Adelekan (2011) in laboratory experiments compared the ethanol productivity of selected varieties of cassava, sorghum and maize crops widely grown in West Africa by correlating volumes and masses of ethanol produced to the masses of samples used. The rate of ethanol production were found to be 145 l/tonne, 135 l/tonne and 346 l/tonne for cassava (variety TMS 30555), sorghum and maize respectively. In terms of ethanol productivity, the order observed in the study was maize > cassava > sorghum. The dried mash produced from the process was analysed for its nutritive quality and that from cassava was found to contain 61.8 calories of food energy per 100g; that from maize and sorghum; 59.5 and 58.1 calories respectively, making them good materials for livestock feed composition. Overall, the ethanol produced from these tropical crop varieties is of a good quality. The key advantage is that the ethanol is being produced from renewable sources which are also sustainable. The production and use of ethanol from cassava, sorghum and maize crop is recommended particularly in West African countries which often suffer crucial problems in respect of sourcing and delivery of fossil fuels and also in other tropical countries where these crop varieties are grown. In such places, ethanol can be blended with gasoline. The key production process used is fermentation and this being a natural process is very efficient, safe and not destructive to the environment.

6. Conditions for anaerobic biodigestion

Chynoweth and Isaacson (1987) observed that in any anaerobic digestion process that is not inhibited or kinetically limited, two major factors affecting methane yields are feedstock composition and inoculum characteristics. The composition of the biodegradable organic compounds can influence methane yield in that reduced compounds such as fats and proteins produce a higher percentage of methane than oxidized compounds such as sugars. Ultimate methane yields are however, influenced principally by the biodegradability of the organic components. The same paper noted further that each anaerobic environment may differ in the types of bacteria involved in the methanogenesis, depending on differing factors such as substrate, retention time, temperature, pH, and fluctuations in environmental parameter. Although certain general properties are common from one environment to another, each environment may have its own unique population of bacteria, and associated microbial activities. Key operating factors which have a direct influence on the level and efficiency of biogas include volatile solids loading rate, digester temperature hydraulic retention time, pH and carbon: nitrogen ratio (Vetter et al., 1990).

6.1 Digester temperature

Marchaim (1992) noted that there is a close relationship between the biogas fermentation process and the temperature of the reactor. The higher the temperature, the more biogas is produced but when the temperature is too high, this can cause metabolic process to decline. Hobson et al., (1981) found biogas production to be greatest when the digester temperature was in the range of 32 to 40^{0}C. Hill (1982) also stated that digestion temperatures for optimum design all occur in the mesophilic range of 32^{0}C to 40^0 C. This work suggested that temperature beyond 40^{0}C has little effect on digester performance since the higher volumetric methane productivity is offset by the smaller digestion volume. As observed by the paper these lower temperatures also represent major savings in energy requirements when compared to thermophilic digestion (i.e. 60^{0}C). During the process of anaerobic biodigesiton in order to reach optimum operating temperatures (30–37^{0}C or 85–100^{0}F), some measures must be taken to insulate the digester, especially in high altitudes or cold climates (VITA, 1980). Straw or shredded tree bark can be used around the outside of the digester to provide insulation. According to Carcelon and Clark (2002), anaerobic bacteria communities can endure temperatures ranging from below freezing to above 57.2^{0}C (135^0 F), but they thrive best at temperatures of about 36.7 ^{0}C (98^0 F) (mesophilic) and 54.4^{0}C (130^0 F) thermophilic. Bacteria activity, and thus biogas production falls off significantly between about 39.4^{0}C and 51.7^{0}C (103 ^{0}F and 125 ^{0}F) and gradually from 35 ^{0}C to 0^0 (95 ^{0}F to 32 ^{0}F). To optimize the digestion process, the digester must be kept at a consistent temperature as rapid changes will upset bacterial activity.

The potential of thermophilic digester operating temperatures ($\geq$ 55^{0}C) for anaerobic biogestion of livestock waste has been investigated by several researchers (Converse et. al., 1977; Hashimoto, et. al., 1979; Hashimoto, 1983; Hashimoto, 1984; Hill, 1985; Hill and Bolte, 1985; Hill et. al., 1986) with the technical feasibility being decided in favour of the process. Hill (1990) identified the advantages of thermophilic digestion over conventional mesophilic digestion as reduced hydraulic retention time (HTR), increased loading rate, and smaller physical reactors for identical waste amounts. The major disadvantage identified is the increased use of energy required to heat the feedstock and maintain digester operating temperature. Chen and Hashimoto (1981) however suggested that the development of heat exchangers to recover energy in the effluent somewhat alleviated this advantage.

In cold climates, or during cold weather, optimal temperatures become very expensive to maintain, thus reducing the economic feasibility of the process of anaerobic biodigestion (Cullimore et al., 1985). In view of this, investigations have been conducted into the feasibility of anaerobic biodigesiton at lower temperatures. Stevens and Schulte (1979) thoroughly reviewed the literature regarding low–temperature digestion and found that methanogenesis occurs at temperatures as low as 4^{0}C, and that an increase in temperature from 4^{0}C to 25^{0}C dramatically increased the rate of methanogenesis. Cullimore (1982) reported results which indicated that as digester temperature was reduced from optimal levels, biogas production decreased linearly to extinction at between 0 and 8^{0}C. Ke–Xin and Nian–Guo (1980) successfully ran several rural digesters at ambient winter temperatures of 12 to 13^{0}C, and obtained gas yields which were 23 to 40 percent that of the optimal temperature production. Pos et al., (1985) suggested that if the anaerobic digestion process was found to function efficiently at lower temperatures, the use of large digestion units at longer retention times and without heating might be considered. It might then be possible to run full scale digesters at less than optimal temperature in order to increase their economic feasibility.

Safley Jr and Westerman (1990) reported satisfactory digester performance for both winter and summer conditions. However, biogas production was found to fluctuate seasonally with reduced biogas production being noted during the winter. Mean methane yield was found to be 0.34 m^3 CH_4 kg of volatile solids (VS) added. Mean biogas concentration was 69.5% CH_4 and 26.8% CO_2. The loading rate during the 17–month period of study was 0.12 kg VS/m^3–day. Typically, anaerobic digesters are designed to operate in either in the mesophilic (20^{0}C – 45^{0}C) or thermophilic (45^{0}C – 60^{0}C) temperature ranges. However, as pointed out by Safely Jr and Westerman (1990) the production of methane (called methanogenesis) has been observed at temperatures approaching 0^{O}C. The anaerobic decomposition of organic matter at low temperature (< 20^{0}C) is referred to as psychrophilic anaerobic digestion.

6.2 Suitable pH

According to San Thy et al., (2003) biogas fermentation requires an environment with neutral pH and when the value is below 6 or above 8 the process will be inhibited or even cease to produce gas because of toxic effect on the methanogen population. The optimum for biogas production is when the pH value of the input in the digester is between 6 and 7. Increasing the amount of feedstock or a change in the fermentation material is likely to acidify the fermentation system because of the accumulation of volatile fatty acids (VFA). In this way pH can be used to indicate if the system is being overloaded. In the initial period of fermentation, as large amounts of organic acids are produced by the acid-forming bacteria, the pH in the digester may fall below 5 causing inhibition of the growth of the methanogenic bacteria and hence reduced gas generation (Da Silva, 1979). Acetate and fatty acids produced during digestion tend to lower the pH of the digester liquid (Marchaim, 1991). Hansen et al., (1998) stated that acetate-utilizing methanogens are responsible for 70% of the methane produced in biogas reactors.

Buren (1983) pointed out that the micro–organisms involved in anaerobic biodigestion require a neutral or mildly alkaline environment, as a too acidic or too alkaline environment will be detrimental. The work stated that a pH between 7 and 8.5 is best for biodigestion and normal gas production. The pH value for a digester depends on the ratio of acidity and alkalinity and the carbon dioxide content in the digester, the determining factor being the density of the acids. Buren (1983) noted further that for the normal process of digestion, the concentration of volatile acid measured by acetic acid should be below 2000 ppm, as too high a concentration will greatly inhibit the action of the methanogenic micro–organisms. Results of a study by Jantrania and White (1985) further confirm the foregoing. The study compared the performance of a number of digesters processing poultry wastes and found that the pH of the residue from digesters that failed were between 6.1 and 6.7, while the pH from the successful digester was 7.5. The digesters which stopped producing any appreciable amount of gas after 54 days had higher hydrogen sulfide content (over 200 ppm) than the successful digester.

6.3 Volatile solids

The solids concentration of the influent into the biodigester affects the rate of fermentation (Marchaim, 1992). In a reported experiment conducted in China, which is mostly located in the temperate latitudes, the optimum concentration of solids was considered to be 6% in summer but between 10 and 20% in winter and spring. When temperatures are low and materials take longer to decompose; it is better to have a higher total solids concentration, although this might cause a problem with impeded flows through the digesters (San Thy et al., 2003). The loading rate is defined as the amount of volatile solids (fermentable solids) per unit of active biodigester volume per day. Typical values of loading rates are between 0.2 and 2 kg VS/m^3/day. This assumes that total solids (TS) are 17% of the fresh weight of the manure and that the volatile solids content (VS) is 77% (Fulford, 1988). The methane content of the gas can indicate overloading but it is more difficult to measure unless the right equipment is available. If the digester is being overloaded, the gas production will rise up initially and then fall after a while when inhibition occurs. The CH_4 content of the gas will fall while the CO_2 content will rise, because CO_2 is not used by the hydrogen consuming bacteria or because the methanogenic bacteria are inhibited.

The feedstock concentration of volatile solids (VS), the detention time, and the operating temperature are the major design factors, which determine the maximum total daily methane production (Hill, 1982). In a study by Vetter et al., (1990), daily biogas production was determined to be directly proportional to the volatile solids loading rate, given that other factors such as digester temperature and pH stayed relatively the same. Hill (1982) found that maximum VS reduction based on developed kinetic data was 75, 56, 30 and 62 percent for pig, beef, dairy, and poultry waste respectively. No significant increase in VS destruction will occur at temperature greater than approximately 45^{0}C.

6.4 Concentrations of methanogenic microorganisms

Biogas production is not possible without a sufficient quantity of anaerobic bacteria. In fresh manure, the concentration of these is low. Taking some effluent (10 to 30% of daily input) and putting it back into the digester is a way of inoculating the fresh manure with active microbial flora. This inoculation of fresh manure can increase gas production up to 30% and it is very important in a plug flow digester as there is almost no mixing between old and fresh slurry. The main nutrients required by microorganisms involved in anaerobic biodigestion are carbon, nitrogen, and inorganic salts. According to Buren (1983), a specific ratio of carbon to nitrogen must be maintained between 20:1 and 25:1, but this ratio will vary for different raw materials and sometime even for the same ones. The main source of nitrogen is human and animal excrement, while the polymers in crop stalks are the main source of carbon. Buren (1983) noted further that in order to maintain a proper ratio of carbon to nitrogen, there must be proper mixing of excrements with polymer sources. Since there are few common materials with a suitable ratio of carbon to nitrogen, production will generally not go well with only one source of material.

6.5 Retention (or detention) time

The amount of gas produced depends on the slurry in the digester volume (Fulford, 1988). The digester volume is also related to the retention time measured in days and the loading rate, in terms of manure solids per unit liquid volume (San Thy et al., 2003). According to experiences in China, 97% of the total yield of gas from fermenting cattle manure will be produced in a period of 50 days at 35^0C. The hydraulic retention time (HTR) in anaerobic digesters is determined by calculating the number of days required for displacement of the fluid volume of the culture. At a given organic loading rate, the HTR is lower when using high water – content feeds than when using those containing less water (Fannin and Biljetina, 1987). The detention time is dependent on all the factors discussed above. Generally a retention time of between 30 and 45 days and in some cases 60 days is enough for substantial gas production (Clanton et al., 1985; Carcelon and Clark, 2002). A study by Hill (1982) found that detention times for digesters designed to produce maximum daily methane volume varied from 7.9 days for dairy waste to 14.8 days for poultry, and similar wide variations in loading rates existed between the two wastes.

6.6 Air-tightness

None of the biological activities of anaerobic microorganisms, including their development, breeding and metabolism, requires oxygen. In fact, they are very sensitive to the presence of oxygen. The breakdown of organic materials in the presence of oxygen will produce carbon dioxide; in airless conditions, it produces methane (Buren, 1983; Voermans, 1985). Ferguson and Mah (1987) pointed out that methane–producing bacteria carry out the terminal step in the formation of biogas from the anaerobic decomposition of biomass. Methane is the final product of mineralizing the organic material in digesters and most anaerobic freshwater habitats. Most of the chemical energy in the starting materials (substrates) actually ends up in the methane released by these anaerobic bacteria. Ferguson and Mah (1987) noted further that in direct contrast, aerobic bacterial metabolism releases most of the chemical energy in the starting substrates by oxidizing them to carbon dioxide and water. Buren (1983) noted that if the digester is not sealed to ensure the absence of air. The action of the microorganisms and the production of biogas will be inhibited and some will escape. It is therefore crucial that the biogas digester be airtight and watertight.

6.7 Moisture content

There must be suitable moisture content of the feedstock as the microorganisms' excretive and other metabolic processes require water. The moisture content should normally be around 90% of the mass of the total contents (Buren 1983). Both too much and too little water are harmful, with too much water the rate of production per unit volume in the digester will fall, preventing optimum use of the digester. If the moisture content is too low, acetic acids will accumulate inhibiting the digestion process and hence production. Furthermore, a rather thick scum will form on the surface of the substrate. This scum may prevent effective mixing of the charge in the digester.

6.8 Carbon: Nitrogen ratio

The carbon:nitrogen (C/N) ratio expresses the relationship between the quantity of carbon and nitrogen present in organic materials. Materials with different C/N ratios differ widely in their yield of biogas. The ideal C/N ratio for anaerobic biodigesiton is between 20:1 and 30:1 (Marchaim, 1992). If C/N ratio is higher than that range, biogas production will be low. This is because the nitrogen will be consumed rapidly by methanogenic bacteria for meeting their protein requirements and will no longer react on the left over carbon remaining in the material. In such case of high C/N ratio, the gas production can be improved by adding nitrogen in farm cattle urine or by fitting latrine to the plant (Fulford, 1988). Materials with high C/N ratio typically are residues of agricultural plants. Conversely if C/N ratio is very low, that is outside the ideal range stated above, nitrogen will be liberated and it will accumulate in the form of ammonia. Ammonia will raise the pH value of the slurry in the digester. A pH value which is higher than 8.5, will be toxic to the methanogenic bacteria in the slurry. The cumulative effect of this is also reduced biogas production. Materials having low C/N ratio could be mixed with those having high C/N ratios so as to bring the average C/N ratio of the mixture to a desirable level. Human excreta, duck dung, chicken dung, and goat dung are some of the materials which typically have low C/N ratios.

According to Karki and Dixit (1984), typical C/N ratios of common organic materials are as shown in Table 3.

#	Organic Materials	C/N ratios
1	Duck dung	8
2	Human excreta	8
3	Chicken dung	10
4	Goat dung	12
5	Pig dung	18
6	Sheep dung	19
7	Cow dung	24
8	Buffalo dung	24
9	Water hyacinth	25
10	Elephant dung	43
11	Maize straw	60
12	Rice straw	70
13	Wheat straw	90
14	Saw dust	200

Source: Karki and Dixit (1984)

Table 3. C/N Ratios of some Organic Materials

7. Cassava (*Manihot* species) as a biofuel

In contemporary times, cassava is being recognized as an important source of biofuel. Research efforts aimed at investigating the potential of this sturdy crop for the production of biogas and bioethanol are currently in progress.

7.1 Global production of cassava

As observed by Adelekan (2012), Cassava (*Manihot esculenta* Cranz) is a very important crop grown for food and industrial purposes in several parts of the tropics. Nigeria, with a 2006 production of 49 million tonnes of cassava is the largest producer of the crop in the world

(National Planning Commission, 2009). Other countries which grow significant quantities of the crop include Brazil, Congo Democratic Republic, Thailand, Indonesia, Ghana and China. A handful of other countries also grow the crop but at much lower production quantities. According to IFAD/FAO (2000) report, cassava is the fourth most important staple crop in the world after rice, wheat and maize. The present annual global production of cassava is estimated at 160 million tonnes. This huge production also results into the discharge of significant cassava–derived solid wastes and liquid wastes into the environment especially during processing. Cassava peels constitute 10–20% by mass of each tuber. Cassava tuber contains 25–30% dry matter by mass, the major portion of which is made up of carbohydrates in the form of starch and sugars. The tuber also contains 70–75% moisture. The ongoing encouragement of cassava cultivation by Governments in Nigeria, Thailand, China and other countries is gradually raising the profile of the crop as a significant cash crop. With increased crop production is also an associated increased production of peels and other cassava-derived wastes. This constitutes an enhanced risk of pollution of the environment. There is therefore a pungent need to find an alternative productive use of the peels. One area of possibility is to investigate the potential of cassava peels for the production of biogas. Finding such an important use for the peel would make it less burdensome on the environment as a pollutant and contribute towards enhancing energy security in the cassava-producing regions.

7.2 Biogas production from cassava waste

Adelekan and Bamgboye (2009a) investigated biogas productivity of cassava peels, mixed with poultry, piggery and cattle waste types in ratios 1:1, 2:1, 3:1 and 4:1 by mass, using 12 Nos. 220l batch type anaerobic digesters in a 3 x 4 factorial experiment using a retention period of 30 days and within the mesophilic temperature range. Biogas yield was significantly ($P \leq 0.05$) influenced by the different mixing ratios of livestock waste with cassava peels. The cumulative average biogas yield from digested cassava peels was 0.6 l/kg-TS. The average cumulative biogas yield increased to 13.7, 12.3, 10.4 and 9.0 l/kg-TS respectively for 1:1, 2:1, 3:1 and 4:1 mixing ratios when cassava peel was mixed with poultry waste. On mixing with piggery waste, the average cumulative biogas yield increased to 35.0, 26.5, 17.1 and 9.3 l/kg-TS respectively for 1:1, 2:1, 3:1 and 4:1 mixing ratios. In the case of mixing with cattle waste, the average cumulative biogas yield increased to 21.3, 19.5, 15.8 and 11.2 l/kg-TS respectively for 1:1, 2:1, 3:1 and 4:1 mixing ratios. Results show that for all livestock waste types, mixing with peels in the ratio 1:1 by mass produced the highest biogas volumes, and highest in piggery waste. Cassava peels have high value of organic carbon and low value of total nitrogen, and this result in a particularly high C/N ratio. According to Karki et al. (1994) high C/N ratio is indicative of the fact that the material is not good for biogas production and will not appreciably yield biogas. However, the work points out that such a material could be mixed with another with a much lower C/N ratio to stabilize the ratio to an optimal value between 22 and 30. Biogas yield was significantly ($P \leq 0.05$) influenced by cassava peels used. The cumulative average biogas yield from digested cassava peels was 0.6 l/kg- TS. This value is low compared with values obtained by Bamgboye (1994) from other lignocellulosic materials such as chopped substrate (1.85 - 3.95 l/kg-TS) and ground water hyacinth substrate (4.01 - 5.55 l/kg-TS). Since cassava peel is a material with a high C/N ratio, it will not yield much biogas. As the paper showed however biogas production from cassava peels was enhanced by mixing with manure.

Bolarinwa and Ugoji (2010) studied biogas production by anaerobic microbial digestion of starchy wastes of *Dioscorea rotundata* (yam) and *Manihot esculenta* (cassava) aided by abattoir liquid effluent using a laboratory digester. The volume of the gas produced at 12hr intervals by feedstock varied for the 72hr of study. The cassava substrate mixture produced the highest daily average volume of gas (397ml), mixture of cassava and effluent 310.4ml; mixture of cassava, yam and effluent 259ml; mixture of cassava and yam produced 243.6ml; yam 238ml; mixture of yam and effluent 169.4ml while abattoir effluent produced the lowest volume of gas (144.4ml). The average pH of digester varied between 5.6 and 6.7 while the temperature varied between 32.3^{0}C and 33.3^{0}C. The microbial load of digester samples was determined at 12hr-intervals. Two groups of bacteria were isolated. Acid-formers isolated included *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Bacillus subtilis*, *Escherichia coli*, *Serratia liquefaciens*, *Micrococcus pyogenes* and *Streptococcus pyogenes* while the methane-formers were *Methanobacterium* sp. and *Methanococcus* sp. This study concluded that spoilt yam and cassava, which are otherwise of no apparent use, could provide a cheap source of renewable energy for domestic use.

7.3 Bioethanol production from cassava

Cassava is the best energy crop used to produce ethanol. This is because the ethanol yield of cassava per unit land area is the highest among all known energy crops. The comparison of ethanol yield produced from different energy crops shows that cassava has the highest ethanol yield of 6,000 kg/ha/yr and highest conversion rate of 150 L/tonne of all the energy crops. Though sugar cane and carrot have higher crop yield of 70 and 45 tonnes/ha/yr respectively compared to 20 tonnes/ha/yr for cassava, the huge quantities of water which they require during their growth periods is a strong limitation when compared to cassava which can actually grow under much drier conditions. Kuiper et al., (2007) noted that a tonne of fresh cassava tubers yields about 150 litres of ethanol.

Adelekan (2010) investigated ethanol productivity of cassava crop in a laboratory experiment by correlating volumes and masses of ethanol produced to the masses of samples used. Cassava tubers (variety TMS 30555) were peeled, cut and washed. 5, 15, 25 and 35 kg samples of the tubers were weighed in three replicates, soaked in water for a period of a day, after which each sample was dried, crushed and the mash mixed with 500, 650, 800, and 950 ml of N-hexane (C_6H_{14}) respectively. This crushed mash was then allowed to ferment for a period of 8 days and afterwards pressed on a 0.6 mm aperture size and sieved to yield the alcohol contained in it. The alcohol was heated at 79°C for 10 h at intervals of 2 h followed by an h cooling. Ethanol yield was at average volumes of 0.31, 0.96, 1.61 and 2.21 litres, respectively, for the selected masses of cassava samples. This study found that a total of 6.77 million tonnes or 1338.77 million gallons of ethanol are available from total cassava production from tropical countries. The production and use of ethanol from cassava crop in the cassava-growing tropical countries of the world certain holds much promise for energy security and is therefore recommended.

Some benefits of using ethanol are that it is not poisonous and neither causes pollution nor any environmental hazard. It does not contribute to the greenhouse effect. It has a higher octane value than gasoline and is therefore an octane booster and anti-knock agent. It reduces a country's dependence on petroleum and it is an excellent raw material for synthetic chemicals. The main crops presently being used for ethanol production are maize, sugarcane and cassava, and among these, cassava has a competitive advantage because of its lower cost of raw material and a simpler ethanol processing technology. Nguyen and Gheewala (2008) conducted a well-to-wheel analysis for cassava-based ethanol in Thailand. The aim of the analysis was to assess the potentials of cassava-based ethanol in the form of gasohol E10 for promoting energy security and reducing environmental impacts in comparison with conventional gasoline. The results showed that cassava-based ethanol in the form of E10, along its whole life cycle, reduced certain environmental loads compared to conventional gasoline. The percentage reductions relative to conventional gasoline are 6.1% for fossil energy use, 6.0% for global warming potential, 6.8% for acidification, and 12.2% for nutrient enrichment. The paper concluded that using biomass in place of fossil fuels for process energy in the manufacture of ethanol leads to improved overall life cycle energy and environmental performance of ethanol blends relative to conventional gasoline.

8. Cocoyam (*Colocasia* and *Xanthosoma* species) as a biofuel

Over the recent past, cocoyam has received inadequate attraction from researchers. Relatively few works reported on considered principally as a food crop. However, as will be seen in this subsection, some papers are beginning to point out the potentials of this crop as a source of biofuel.

8.1 Global production of cocoyam

The world has focused entirely on a comparatively small number of crops to meet the various needs for food and industrial fiber; the total number of economic crops of significance to global trade hovering just above one hundred. The consequence is that thousands of plant species with a considerably larger number of varieties fall into the category of underutilised or neglected crops. These crops are marginalized by agricultural, nutritional and industrial research (Global Forum for Underutilized Species, 2009). One of such neglected crops is cocoyam which over the years has received minimal attention from researchers and other stakeholders of interest. Cocoyam (*Colocasia* and *Xanthosoma* species), a member of the Aracea family of plants, is one of the oldest crops known. It is grown largely in the tropics, for its edible corms and leaves and as an ornamental plant. On a global scale, it ranks 14th as a vegetable crop going by annual production figures of 10 million tonnes (FAO, 2005). Its production estimates vary. However, one study points out that Africa accounts for at least 60% of world production and most of the remaining 40% is from Asia and Pacific regions (Mitra et al., 2007). Another study opines that coastal West Africa accounts for 90% of the global output of the crop with Nigeria accounting for 50% of this (Opata and Nweze, 2009). Cocoyam thrives in infertile or difficult terrains that are not well suited for large scale commercial agriculture for growing most conventional staple crops. As observed by Williams and Haq (2002), since the poor are frequently the main occupants of such areas, cultivation of neglected crops such as cocoyam constitute practical alternatives for them to augment their meagre incomes. The crop's supposed association with the poor may be a reason while conventional agricultural research has not bothered much to take a closer look at it.

8.2 Biogas production from cocoyam

Adelekan (2011) produced methane from cocoyam corms and related the volumes and masses obtained to the masses of corms used; derived guiding numerical relationships for the processes and extrapolated these values using production quantities of the crop reported globally and finally submitted workable estimates as regards biogas which is derivable from aggregate global production of the crop. The scientific innovation and relevance of the work reported lies in the fact that the fermentation and anaerobic digestion methods used are applicable across countries and regions irrespective of available degree of industrialization and climate. A new vista is opened in the use of this neglected crop as a cheap renewable source of energy in view of the rapid depletion, environmental pollution and high costs of fossil fuels. Results show that the 10 million tonnes annual global production of cocoyam is potentially able to produce 39.5 million cubic metres of methane which on burning would produce 179.3×10^7 MJ of enerrgy. The mash obtained as byproduct of the processes is capable of supplying 59 calories of food energy per 100g which is an excellent feedstock for livestock. The use of cocoyam (*Colocasia* and *Xanthosoma* species) as a renewable source of energy for the production of biogas poses no threat to the environment or food supply and is therefore recommended. Furthermore, doing so helps to enhance energy security.

Adeyosoye et al., (2010) studied biogas yield of peels of sweet potato (SPP) and wild cocoyam (WCP). Buffered and sieved goat's rumen liquor was added to 200 mg of dried and milled SPP and WCP in 100 ml syringes supplied with CO_2 under anaerobic condition and incubated for 24 hr. Total biogas produced was measured at 3 hr intervals till the 24th hr when the fermentation was terminated. The inoculum was also incubated separately. The proximate composition of SPP and WCP were similar except for the higher EE content (12%) of SPP. The SPP and WCP used contained 26.81 and 26.97% DM, 3.06 and 3.83% CP, and 78.94 and 79.17% carbohydrate respectively. Both samples had the same crude fibre (7.00%) content. Total biogas produced from SPP, WCP and the inoculum varied from 13.0, 11.0 and 5.0 ml respectively at the 3rd hr through 66.5, 61.5 and 18.0 ml at the 18th hr to 77.5, 72.0 and 30.0 ml at the 24th hr respectively. The differences in biogas production across the treatments were significant ($p < 0.05$). There were no significant differences ($p > 0.05$) in the volumes of methane produced from SPP (42.5 ml) and WCP (39.5 ml) which were significantly ($p < 0.05$) higher than 20.0 ml produced by the inoculum. The study pointed out that peels of sweet potato and cocoyam wastes can produce significant quantities of biogas for domestic applications. The foregoing studies confirm that ultimate methane yields from biomass are influenced principally by the biodegradability of the organic components. The more putrescible the biomass, the higher is the gas yield from the system (Wis, 2009).

8.3 Bioethanol production from cocoyam

Climate change, crop failures, unpredictable commodity prices, wars, political unrest and other forms of dislocations in the established pattern of global affairs, variously show that overreliance on just a few crops is risky to the world. However, bringing those crop species with underexploited potentials out of the shadows into the mainstream would help to spread this risk and enhance the utility of marginal lands on which many of them are cultivated. Most of the comparatively few number of studies reported in respect of cocoyam have focused largely on enhancing its value as a food crop, principally to supply carbohydrates and starch; a role which it already shares with so many competing crops. However, the paper by Adelekan (2011) looked at cocoyam as an energy crop for the supply of ethanol and biogas; a role which if fully developed can raise the profile of this crop in global energy economics. Points in favour of this research are the fact that it is in line with ongoing global research efforts at discovering more energy crops and developing other sources of renewable energy. Some progress has been reported in the use of cassava (another neglected tropical crop) for the production of ethanol as a sustainable source of biofuel in tropical countries Adelekan (2010). Cocoyam also has similar potential for this, most particularly in the tropical and subtropical countries. According to Adelekan (2011) which investigated the global potential of cocoyam as an energy crop, the yield of bioethanol from cocoyam is 139 L/tonne. This compares very favourably with 145 L/tone obtained for cassava (Adelekan, 2010), 100L/tonne for carrot and 70L/tone for sugar cane. Given a global annual production quantity of cocoyam to be 10million tonnes, 331 million gallons of ethanol is potentially available from this.

The question always arises, with a growing demand for ethanol produced from cocoyam, is there a threat to food security in respect of the crop? The answer to this question is twofold. Firstly, the yield of cocoyam, presently about 30 tonnes per hectare (Ekwe et al., 2009) can be tremendously improved through scientific research directed at producing higher yielding varieties. With success in this area, there may not be a need to cultivate more land to increase production of the crop. The present global cultivated total hectares of the crop can still sustain higher improvements in yield. The second part of the answer hzas to do with the need to husband the crop more efficiently to plug avenues for waste. In many parts of the developing world, between the farm and the consumers, 25 to 50% losses still occur to harvested crops because of poor preservation techniques, inadequate storage facilities, deficient transportation infrastructure, weak market structures and other factors. Therefore there is a pungent need to continue to research options which will enhance preservation and lengthen the storage life of cocoyam. Improvements in the area of preservation of the crop will also increase its supply, making its use as an energy crop less potentially deleterious on its use as a food crop and thereby enhancing food security.

Lee (1997) stated that the biological process of bioethanol production utilizing lignocellulosic biomass as substrate requires: 1) delignification to liberate cellulose and hemicelluloses from their complex with lignin, 2) depolymerization of the carbohydrate polymers (cellulose and hemicelluloses) to produce free sugars, and 3) fermentation of mixed hexose and pentose sugars to produce ethanol. In Europe the consumption of bioethanol is largest in Germany, Sweden, France and Spain. Europe produced 90% of its consumption in 2006. Germany produced about 70% of its consumption, Spain 60% and Sweden 50% in the same year. In 2006, in Sweden, there were 792, 85% ethanol (i.e E85) filling stations and in France 131 E85 service stations with 550 more under construction (European Biomass Association 2007).

9. Barbados nut (*Jatropha curcas*) as a biofuel

9.1 Global production of Jatropha

Jatropha is a shrub, belonging to the Euphorbiaceae family, thriving in various environments and across a wide range of ecosystems. It is a plant that can survive several months with minimal water and can actually live up to 40 years or more. It is not edible to human beings or animals. The jatropha industry is in its very early stages, covering a global area estimated at some 900,000 ha. More than 85 percent of jatropha plantings are in Asia, chiefly Myanmar, India, China and Indonesia. Africa accounts for around 12 percent or approximately 120,000 ha, mostly in Madagascar and Zambia, but also in Tanzania and Mozambique. The West African nations of Mali, Ghana and Senegal have also established lofty production targets for Jatropha notably; to cultivate 320,000 ha of *Jatropha curcas* in Senegal by 2012 and 1 million ha in Ghana in the medium term (OECD, 2008). Latin America has approximately 20,000 ha of jatropha, mostly in Brazil. The area planted with jatropha was projected to grow to 4.72 million ha by 2010 and 12.8 million ha by 2015. By then, Indonesia is expected to be the largest producer in Asia with 5.2 million ha, Ghana and Madagascar together will have the largest area in Africa with 1.1 million ha, and Brazil is projected to be the largest producer in Latin America with 1.3 million ha. Total biogas generation potential from *Jatropha curcas* cakes in India has been estimated as 2,550 million m^3 from 10.2 lakh metric ton of *J. curcas* oil seed cakes.

Jatropha curcas contains about 30% oil leaving behind presscake (75% including about 5% losses of oil in extraction process in the mechanical expeller) with residual oil. The oil is used for preparing bio-diesel (Achten et al., 2008) and in soap preparation. The press cake is rich in organic matter (Abreu, 2009). It can be used as manure, as feedstock for biogas production, animal feed and so forth. (Agarwal, 2007). Also, *Jatropha* oil cake is used for enriching the soil (Reyadh, 1997). Envis (2004) observed that *Jatropha* oil cake is an organic fertilizer that is superior to cattle manure and it is in great demand by farmers.

9.2 Biogas production from Jatropha

Ali et al., (2010), studied the use of *Jatropha curcas* defatted waste as an alternative feed in biogas plant for its bio-methanisation. The paper observed that as it remains as defatted cake after the extraction of non-edible oil from *Jatropha* seeds, it cannot be used directly for any purpose due to presence of toxic substance called 'curcin'. This toxin renders it unsafe for the animal feed and other purposes. It contains 5.73% nitrogen, 1.5% phosphorus and about 1% potassium. On the basis of its chemical composition, its application as substrate to the biogas plant can be a sustainable alternative as compared to the other applications of *Jatropha* press cake. The study was conducted on a floating drum type biogas plant. The study observed that the biogas plant, initially charged with pure cattle dung, when gradually replaced with *Jatropha* oil cake (0 - 100%), increased the biogas production up to approximately 25% in reasonable time duration. A significant increase in the percentage of nitrogen, phosphorus and potassium during the biofermentation process invokes the use of the effluent slurry as organic manure. Simultaneous reduction in the amount of the oil (5.67 to 3.95%) sustains the possibility of degradation of oil during methanisation. The plant has showed higher biogas yields at low temperatures also. Therefore, *Jatropha* defatted waste can successfully be used as an addition as well as substrate in already running cattle dung based biogas plant to get higher yield of biogas in comparison to cattle dung feed.

A laboratory experiment was conducted to find out the biogas production potential of dried, powdered Jatropha cake mixed with buffalo dung at 6% total solids (Prateek, 2009). The experiment was run on daily feeding basis in 5-litre capacity glass digesters for 180 days, while biogas production was recorded at 24 hr interval. Quality of biogas and nutritive value of effluent slurry was also determined. Results show significantly higher (139.20%) biogas production in test (Jatropha cake + Buffalo dung) over control (Buffalo dung only) digesters with methane content of 71.74%. Nutritive value of effluent slurry of test digester was significantly higher in terms of available nitrogen and potassium; calcium; magnesium and carbonate contents than that of control digesters. This co-digestion resulted in 92.94% decrease in chemical oxygen demand.

Dhanya et al., (2009) researched the biogas production potential of Jatropha (*Jatropha curcas*, L) Fruit Coat (JFC) alone and in combination with cattle dung (CD) in various proportions at 15 per cent total solids by batch phase anaerobic digestion for a period of ten weeks HRT (Hydraulic Retention Time) under a temperature of 35^0C+1^0C. The maximum biogas production was noticed in cattle dung and Jatropha Fruit Coat in 2:1 ratio with 403.84 L/kg dry matter followed by 3:1,1:2, 1:1 and 1:3 having 329.66, 219.77, 217.79, 203.64 L/kg dry matter respectively as compared to 178.49 L/kg dry matter in CD alone. The JFC alone was found to produce 91% of total biogas of that obtained from cattle dung. The per cent methane content of the biogas in all the treatments was found on par with cattle dung.

9.3 Biodiesel production from Jatropha

Ways and means have been sought for many years to be able to produce oil-substitute fuel. Biodiesel extracted from fresh or used vegetable oil whether edible or not, is one such renewable alternative under consideration. Merits of biodiesel are that it can be directly used in engines with little or no modifications; contains little or no sulphur; no aromatics; has a higher cetane number and contains about 10% built-in oxygen and these properties help it burn fully with the result of having less carbon monoxide production, less unburnt carbon and less particulate matter residues. The production of biodiesel would be cheap as it could preferably be extracted from non edible oil sources. *Jatropha curcas* (Linaeus), a non-edible oil-bearing and drought-hardy shrub with ecological advantages, belonging to the *Euphorbiaceae* family, has been found to be the most appropriate renewable alternative source of biodiesel. Presently, the procedure for biodiesel production from jatropha seeds starts with harvesting whole ripe fruits. These fruits are then opened to remove the typically 3 or 4 seeds contained in each fruit. (A matured plant produces about 20kg of seeds in a year). These seeds are then sundried and afterwards stones, sticks, mouldy or damaged seeds and other foreign materials are handpicked from the batch of dried seeds. Next, this cleaned batch of seeds is crushed in an oil extraction machine to free the oil. This extracted oil is then filtered to remove impediments and the oil is poured in air-tight containers for storage. The extracted and filtered vegetable oil can be used directly as a fuel in suitable diesel engines without undergoing the trans-esterification process (Achten et al., 2008). However, to make it more useful in many engines, this Jatropha oil has to undergo a trans-esterification process of the triglyceride molecules in fats and oils with light weight alcohols like ethanol and methanol in a reactor in order to convert it to biodiesel. After being put into the reactor, the Jatropha oil settles; it is washed and purified by evaporation, and the liquid produced is biodiesel. Under optimal conditions, *Jatropha curcas* produces a higher oil yield per hectare compared to peanuts (*Arachis hypogea*), sunflower (*Helianthus annus*), soyabean (*Glycine max*), maize (*Zea mays*) and cotton (*Gossypium* species) (Kaushik et al., 2007). Biodiesel is a promising alternative because it is a renewable liquid fuel source that can be used alone and alternatively blended with petroleum-based diesel.

Jatropha's potential as a new energy source comes at time when interest in biofuel production is at an all-time high. As observed by Parwira (2010), biofuel production could potentially position developing nations to become net exporters of fuel which could greatly advance their objectives of economic independence. The paper noted further that many international corporations in Scandinavia, China, and Europe are purchasing tracts of land in developing countries (especially African countries) in an attempt to capitalize on this growth industry. New uses are being found for biofuel continually and this creates an impetus to strengthen efforts to produce them. In fact, several wireless communication companies have constructed cellular network base stations that are powered by *Jatropha*-based biofuel (Katembo and Gray, 2007). Presently, corn ethanol has a yield of 3100–4000 L/ha. This is still much higher than *Jatropha curcas* which is approximately 460-680 L/Ha of oil (Dar 2007). However, the production of Jatropha biodiesel is still very attractive largely due to its excellent fuel properties.

Kywe and Oo (2009) obtained a biodiesel yield of 30 gallons/day from a pilot plant which produced oil from Jatropha. The biodiesel demonstrated excellent fuel properties and it was found to be of very good quality. Tomomatsu and Swallow (2007) studied the economics and potential value of *Jatropha curcas* biodiesel production in Kenya and noted that in recent years, the production of *Jatropha curcas* has been widely promoted by private enterprises, non-governmental organizations and development agencies as one of the most viable candidates for biodiesel feedstock in Africa. While multiple benefits of jatropha production such as a petroleum product substitute, greenhouse gas mitigation and rural development are emphasized, the viability of production at farm level is questioned. The study revealed that the profitability of jatropha production for smallholder farmers is expected to be minimal unless farm-level production is accompanied by significant investments and policies targeted at enhancing production of the crop. However another economic study which took place in Mali showed that when all uses of Jatropha were taken into consideration, a rate of return of 135% could be achieved (Dinh et al., 2009).

Veljkovic et al., (2006) noted that biodiesel, which is made from renewable sources, consists of the simple alkyl esters of fatty acids. As a future prospective fuel, biodiesel has to compete economically with petroleum diesel fuels. The use of the less expensive feedstock containing fatty acids such as inedible oils, animal fats, waste food oil and byproducts of the refining vegetables oils reduces the costs of producing biodiesel. Therefore the availability and sustainability of supplies of less expensive feedstock will be a crucial determinant in competitively delivering biodiesel to commercial fuel filling stations. Such less expensive feedstock can come from inedible vegetable oils, mostly produced by seed-bearing trees and shrubs such as Jatropha curcas, a plant which has no competing food uses and which grows widely in tropical and subtropical climates across the world (Openshaw, 2000). Berchmans and Hirata (2008) developed a technique to produce biodiesel from crude Jatropha curcas seed oil having high free fatty acids (15% FFA). The high FFA level of the oil was reduced to less than 1% by a two-step pretreatment process. The first step was carried out with 0.60 w/w methanol-to-oil ratio in the presence of 1% w/w H_2SO_4 as an acid catalyst in 1-hr reaction at 50^0C. After the reaction, the mixture was allowed to settle for 2 hr and the methanol–water mixture which separated at the top layer was removed. The second step involved trans esterification using 0.24 w/w methanol to oil and 1.4% w/w NaOH to oil as alkaline catalyst to produce biodiesel at 65^0C. The final yield for methyl esters of fatty acids was achieved for 90% in 2 hr.

Hawash et al., (2011) investigated the trans-esterification of *Jatropha curcas* oil (JCO) to biodiesel using CaO as a solid base catalyst by determining the effects of molar ratio of methanol to oil, water content, reaction time and mass ratio of catalyst to oil in laboratory experiments. Experimental results revealed that a 12:1 molar ratio of methanol to oil, addition of 1.5% (w/v) CaO catalyst, 70°C reaction temperature, 2% water content in the oil produced more than 95% biodiesel yield after 3 hours reaction time. Calcium oxide activated with ammonium carbonate was an efficient super base catalyst for a high yield transesterification reaction and the base strength of CaO was more than 26.5 after dipping in ammonium carbonate solution followed by calcinations. Transesterification of Jatropha oil using supercritical methanol was also studied under the range of temperature from 120°C to 250°C, and range of pressure from 5 - 37 bars using superbase catalyst CaO and acid catalyst. The reaction products were analyzed for their content of glycerol by high performance liquid chromatography (HPLC) and this revealed that the process of supercritical transesterification achieved a yield of more than 95% after 1 hour.

The typical fuel properties of *Jatropha curcas* L, oil are as shown in Table 4 below. These properties show that jatropha biodiesel is a good quality biofuel.

S/N	Property	Numerical quantity	Reference
1	Calorific value (MJkg^{-1})	39.77	Kumar and Sharma (2008)
2	Cetane number	51	Dinh et al., (2009)
3	Cloud point (^{0}C)	2	Achten et al., (2008)
4	Flash point (^{0}C)	235	Achten et al., (2008)
5	Kinematic viscosity at 40^{0}C (mm^{2}sec^{-1})	41.51	Kywe and Oo (2009)
6	Relationship C/H (%wt)	13.11	Abreu (2009)
7	Relative density	0.87	Kywe and Oo (2009)
8	Sulphur content (%wt)	0.04	Abreu (2009)
9	Carbon residue (%)	0.02	Dinh et al., (2009)

Table 4. Fuel Properties of *Jatropha curcas* oil

10. Common grasses as biofuels

10.1 Global availability of grasses and other wild plants

The grass family (gramineae or poaceae) is perhaps the most successful taxonomic group in the plant kingdom. Members of this group number about 9000 species distributed in about 635 genera and they grow in all ecosystems and agroclimatic zones. From economic and ecological standpoints, they are the most important species in the plant kingdom. The pea family (leguminosae or fabaceae) is the largest family of flowering plants and also contains a large number of species found flourishing in many ecosystems and agroclimatic zones. Both families of plants contain domesticated crops and wild plants which are being researched for their potentials as reliable sources of biofuels. These plants certainly have a significant role to play in an anticipated global scenario which is 100% dependent on bioenergy in the near future.

10.2 Biogas production from grasses and wild plants

A study by Sidibe and Hashimoto (1990) documented the fact that grass straw can be fermented to methane and the yield can be relatively high. This laboratory experiment showed that the ultimate methane yield of rye grass straw (341$\pm$ 5ml/g VS) and fescue grass straw (356±ml/g VS) are not significantly different but both grass straws had significantly higher yield ($p < 0.01$) than dairy cattle manure (288 ± 3 ml/g VS). The paper noted that nitrogen does not appear to be a limiting nutrient in the fermentation of grass straw to methane; the length of time between inocula feeding does not affect the ultimate methane yield of the straw, and longer acclimation may increase the ultimate methane yield of grass straw. Among plants themselves, differences exist regarding their potentials as feedstock for biogas production. For instance, De–Renzo (1997) reviewed anaerobic digestion of plant materials and concluded that aquatic plants such as algae and moss can be much better digested than terrestrial plants because of their toughness. Ordinarily, more digestion results in more biogas production. Akinbami et al (2001) noted that in the tropics, the identified feedstock substrates for an economically feasible biogas programme include water lettuce, water hyacinth, dung, cassava peelings, cassava leaves, urban refuse, solids (including industrial waste), agricultural residue and sewage.

Uzodinma and Ofoefule (2009) investigated the production of biogas from equal blending of field grass (F-G) with some animal wastes which include cow dung (G-C), poultry dung (G-P), swine dung (G-S) and rabbit dung (G-R). The wastes were fed into prototype metallic biodigesters of 50 L working volume on a batch basis for 30 days. They were operated at ambient temperature range of 26 to 32.8°C and prevailing atmospheric pressure conditions. Digester performance indicated that mean flammable biogas yield from the grass alone system was 2.46±2.28 L/total mass of slurry while the grass blended with rabbit dung, cow dung, swine dung and poultry dung gave average yield of 7.73±2.86, 7.53±3.84, 5.66±3.77 and 5.07±3.45 L/total mass of slurry of gas, respectively. The flash point of each of the systems took place at different times. The field grass alone became flammable after 21 days. The grass-swine (G-S) blend started producing flammable biogas on the 10th day, grass-cow (GC) and grass-poultry (G-P) blends after seven (7) days whereas grass-rabbit (G-R) blend sparked on the 6th day of the digestion period. The gross results showed fastest onset of gas flammability from the G-R followed by the G-C blends, while the highest average volume of gas production from G-R blend was 3 times higher than that of F-G alone. Overall, the results indicated that the biogas yield and onset of gas flammability of field grass can be significantly enhanced when combined with rabbit and cow dung.

Ofuefule et al., (2009) reported a comparative study of the effect of different pre-treatment methods on the biogas yield from Water Hyacinth (WH). The WH charged into metallic prototype digesters of 121 L capacity were pre-treated as: dried and chopped alone (WH-A), dried and treated with KOH (WH-T), dried and combined with cow dung (WH-C), while the fresh water Hyacinth (WH-F) served as control. They were all subjected to anaerobic digestion to produce biogas for a 32 day retention period within a mesophilic temperature range of 25 to 36°C. The results of the study showed highest cumulative biogas yield from the WH-C with yield of 356.3 L/Total mass of slurry (TMS) while the WH-T had the shortest onset of gas flammability of 6 days. The mean biogas yield of the fresh Water Hyacinth (WH-F) was 8.48 ± 3.77 L/TMS. When the water Hyacinth was dried and chopped alone (WH-A), dried and treated with KOH (50% w/v) (WH-T) and dried and combined with cow dung (WH-C), the mean biogas yield increased to 9.75 ± 3.40 L/TMS, 9.51 ± 5.01 L/TMS and 11.88 ± L/TMS respectively. Flammable biogas was produced by the WH-F from the 10th day of the digestion period whereas the WH-A, WH-T and WH-C commenced flammable gas production from the 9th, 6th and 11th day respectively. Gas analysis from WH-F shows

Methane (65.0%), CO_2 (34.94%). WH-A contained Methane (60.0%), CO2 (39.94%). WH-T contained Methane (71.0%), CO_2 (28.94%), while WH-C had Methane (64.0%) CO_2 (35.94%). The other gases were found in the same levels and in trace amounts in all the systems. The overall results showed that treating water Hyacinth with KOH did not have a significant improvement on the biogas yield. It also indicated that water Hyacinth is a very good biogas producer and the yield can be improved by drying and combining it with cow dung.

10.3 Ethanol production from common grasses

As pointed out by Barber et al., (2010) perennial grasses benefit the environment in numerous ways. They help to reduce climate change, increase energy efficiency and will constitute a sustainable energy resource for the world. Switchgrass, the most widely used perennial grass for biofuels, is also in such a manner, beneficial to both farmers as well as energy consumers in general. Perennial grasses are crucial to the ecosystem to create a sustainable energy resource for the world and also to limit the use of fossil fuels. These grasses are important because they can produce ethanol, an energy source that emits much less carbon dioxide than other fossil fuels. Reducing carbon dioxide emissions is important because carbon dioxide emissions in the atmosphere constitute one of the leading causes of climate change. Barry (2008) pointed out that 1 bale of switchgrass can yield up to about 50 gallons of ethanol. As reported by Rinehart (2006), researchers are using switchgrass as a biofuel so that they can successfully reduce carbon dioxide emissions. Switchgrass has a high energy in and out ratio because of lignin, the byproduct of the cellulose conversion that stores internal energy for its energy transformation process. Ethanol reduces carbon dioxide emissions by approximately ninety percent when compared to gasoline and consequently, carbon dioxide in the ozone layer of our atmosphere will slowly begin to deplete itself as biofuels created from switchgrass, other grasses and other ethanol sources are utilized. As a rule, all species of the grass family (poaceae) contain starch and should be able to yield ethanol.

11. Manure as a biofuel

Manure has for a long time been recognised as a renewable source of energy. Earlier practices involved direct combustion of manure to produce heat energy; while latter practices involved gasification of manure, followed by combustion. The more recent practices involved anaerobic biodigestion of manure to produce biogas which is scrubbed to purer methane and then combusted.

11.1 On-farm availability of manure

Huge quantities of manure are produced on farms. In fact a cattle farming operation which has a herd size of 10,000 animals can on a daily basis generate wastes equal to that produced by a city of half a million residents. Considering cattle for instance reported values of daily manure production range from 10kg (VITA, 1980) to 60kg (Safley Jr, et al., 1985) per animal. Legg (1990) reports that the 8.5, 28, 6.9 and 104 million cattle, sheep, pigs and poultry reared in England and Wales produced 80, 11, 11, and 30 million tonnes of manure respectively for the year immediately preceding. Smith and Chambers (1998) noted that manure arising from dairy beef farming comprise the majority (73 million tonnes) of the 90 million tonnes annual animal production of livestock manure in the UK. Yet another estimate, Smith et al., (2001) reported that 4.4 million tonnes of poultry manure are produced annually in the UK; comprising about 2.2 million broiler litter, 0.3 million tonnes of turkey litter, 1.5 million tonnes of layers manure (i.e. from egg producing hens) and 0.4 million tonnes from other sources (mainly breeding hens, cocks, and ducks). Total manure production from pigs in England and Wales is estimated to be about 10.03 million tonnes per year with about 45% as slurry and 55% as farmyard manure (Smith et.al., 2001).

The yearly production of livestock wastes in the Netherlands is estimated to be about 10 million tonnes dry matter (De Boer, 1984). The paper noted that 75 to 80% of it is ruminant waste while the rest is attributed to manure from pig and poultry. Specifically in the case of Nigeria, reported values of animal waste production range from 144 million tonnes/year (Energy Commission of Nigeria, 1998) to 285.1 million tonnes/year (Adelekan, 2002). This huge production of manure from farms can constitute a threat to the environment since it may not be readily returned to or in fact absorbed by land for fertilization. The challenge is how to find effective uses for the livestock wastes out of which the production of biofuels is an attractive option.

11.2 Biogas production from manure

Manure continues to be a promising resource for biogas production. Chynoweth et al. (1993) suggested potential biogas production from cattle waste, buffalo waste, piggery waste, chicken waste and human excreta as 0.360, 0.540, 0.180, 0.011 and 0.028 $m^3 kg^{-1}$. The right mixing ratio of slurry can further increase the quantity of gas which can be produced from any particular feedstock. Adelekan and Bamgboye (2009b) investigated the effect of mixing ratio of slurry on biogas productivity of wastes from poultry birds, pigs and cattle. The investigation was carried out using 9 Nos. 220-litre batch type anaerobic digesters designed to remove CO_2, H_2S and other soluble gasses from the system. Freshly voided poultry, piggery, and cattle wastes were collected from livestock farms at the Institute of Agricultural Research and Training (IAR&T), Moor Plantation, Ibadan, Nigeria. After being totally freed of foreign matter, the samples were well stirred and digested in a 3x3 factorial experiment using a retention period of 30 days and within the mesophilic temperature range. The waste: water mixing ratios of slurry used were 1:1, 2:1 and 3:1 by mass. Three replicates were used for each ratio. Biogas yield was significantly ($p < 0.05$) influenced by the various factors of animal waste ($F=86.40$, $P< 0.05$), different water mixing rates ($F=212.76$, $P< 0.05$) and the interactions of both factors ($F=45.91$, $P< 0.05$). Therefore, biogas yield was influenced by variations in the mixing ratios as well as the waste types used. The 1:1 mixing ratio of slurry resulted in biogas productions of 20.8, 28.1, and 15.6 l/kgTS for poultry, piggery and cattle wastes respectively. The 2:1 ratio resulted in 40.3, 61.2 and 35.0l/kgTS while the 3:1 ratio produced 131.9, 117.0 and 29.8l/kgTS of biogas respectively. Therefore an increasing trend was observed in biogas production as mixing ratio changed from 1:1 to 3:1. For cattle waste however, production decreased from ratio 2:1 to ratio 3:1. The N, P, K values were highest for poultry waste (3.6, 2.1, and 1.4% respectively) and least for cattle waste (2.2, 0.6, 0.5% respectively). Organic carbon was highest for cattle waste (53.9%) and least for poultry waste (38.9%). Reduction in C/N ratio for each experiment ranged from 1.1 to 1.9%. This study found that for poultry and piggery wastes, slurries mixed in ratios 3:1 waste:water produced more biogas than those of 2:1 and 1:1 ratios. For cattle waste, the 2:1 mixing ratio produced the most biogas. The paper therefore recommended a livestock wastes: water mixing ratio of 3:1 for poultry and piggery slurries, and 2:1 for cattle slurry for maximum biogas production from methane-generating systems, given 30% TS content.

11.3 Potential of digested manure as a fertilizer

After the anaerobic digestion of manure to produce biogas, a nutrient-rich substrate which is still very beneficial to plants remains. This observation is supported by the findings of Thomsen (2000). These studies agree that only small differences of between 0.5 and 2.0% are usually measurable in the aggregate nutrient concentrations when digested manure is compared to the undigested form. Adelekan et al., (2010) did a comparative study of the effects of undigested and anaerobically digested poultry manure and conventional inorganic fertilizer on the growth characteristics and yield of maize at Ibadan, Nigeria. The pot experiment consisted of sixty (60) nursery bags, set out in the greenhouse. The treatments, thoroughly mixed with soil, were: control (untreated soil), inorganic fertilizer, (NPK 20:10:10) applied at the 120 kgN/ha; air-dried undigested and anaerobically digested manure applied at 12.5 g/pot, or 25.0 g/pot or 37.5 g/pot, and or 50.0 g/pot. Plant height, stem girth, leaf area, number of leaves at 2, 4, 6 and 8 weeks after planting (WAP) and stover mass and grain yield were measured. Analysis of variance (ANOVA) at $P \leq 0.05$ was used to further determine the relationships among the factors investigated. Generally, results in respect of plants treated with digested manure, were quite comparable with those treated with undigested manure and inorganic fertilizer, right from 2WAP to 6WAP. Stover yield was increased to as much as 1.58, 1.65 and 2.07 times by inorganic fertilizer, digested and undigested manure, respectively while grain yields were increased by only 200% with inorganic fertilizer, but by up to 812 and 933% by digested and undigested manure, respectively. The paper concluded that digested poultry manure enhanced the growth characteristics of the treated plants for the maize variety used. As observed, the order of grain yield was undigested manure > digested manure > inorganic fertilizer. These results agree with those reported by Agbede et al., (2008) for sorghum (*Sorghum vulgare*), Akanni (2005) for tomato (*Lycopersicon esculentum*) and Adenawoola and Adejoro (2005) for jute (*Corchorus olitorus* L).

Organic manures play a direct role in plant growth as a source of all necessary macro and micronutrients in available forms during mineralization. Thereby, they improve both the physical and physiological properties of soil (El Shakweer et al., 1998; Akanni, 2005), thus enhancing soil water holding capacity and aeration (Kingery et al., 1993; Abou el Magd et al., 2005; Agbede et al., 2008). Organic manures decompose to give organic matter which plays an important role in the chemical behavior of several metals in soil through the fulvic and humic acid contents which have the ability to retain metals in complex and chelate forms (Abou el Magd et al., 2006). They release nutrients rather slowly and steadily over a longer period and also improve soil fertility status by activating soil microbial biomass (Ayuso et al., 1996; Belay et al., 2001). They thus, ensure a longer residual effect (Sherma and Mittra, 1991), support better root development and this leads to higher crop yields (Abou el Magd et al., 2005). Improvement of environmental conditions and public health as well as the need to reduce cost of fertilizing crops are also important reasons for advocating increased use of organic manures (Seifritz, 1982). While the practice of anaerobic digestion of biomass for biogas production is increasing, the use of the digested manure for crop production should concurrently be encouraged, judging by its potential to enhance the growth and yield of crops.

12. Conclusions and recommendations on the use of tropical crops as biofuels

1. Biofuels such as biogas, bioethanol and biodiesel are reliable and renewable options for enhancing global energy security. In view of the on-going depletion of fossil duels, keener global research interest should be directed at developing known and new sources of these fuels.
2. Concerted efforts should be made by stakeholders worldwide to encourage the use of biofuels given their multifarious advantages of protecting the environment and mitigating climate change.
3. Research funds should be further directed at developing the potentials of known energy-yielding plants such as cassava, *Jatropha curcas,* common grasses and others to contribute towards ensuring global energy security.
4. Neglected tropical crops such as cocoyam and others identified should be researched for their energy yielding abilities and bring them to the main stream of interest of conventional agricultural research.
5. The potential of manure as a significant environmental pollutant can be lessened if more concerted efforts are made to produce biogas from it and this will also concurrently result in the production of nutrient-rich digested biomass which can be returned to land to enhance crop production.

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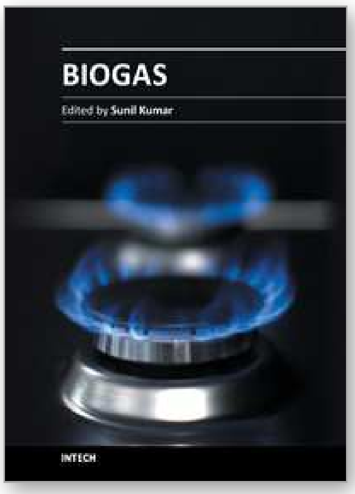

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