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Integration of Biogas Technology into Farming System of the three Northern Regions of Ghana

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Abstract

This article takes a look at the possible integration of biogas technology into farming system of the three northern regions of Ghana. The nexus between animal husbandry and crop production is a key to improving agricultural productivity in the study areas. The research involves a thorough study of the farming system in the three northern regions and an extensive review of literature on biogas technology. During the research, it was revealed that the three northern regions which have the largest concentration of livestock hardly use the enormous manure generated by these livestock efficiently to improve the condition of their soils which lack basic nutrients such as Nitrogen (N), Phosphorous (P) and Potassium (K) needed for high crop yield. Farmers in the regions thus depend largely on chemical fertilizers. The research compares the use of digested slurry and raw manure, nutritional values of different animals' slurry and outlines the efficiencies of biogas in different equipment. The paper discusses the processes in biogas production as a source of energy in farming communities, outlines the basic farming systems in the three northern regions, the composition and application of biogas and the digested slurry, and summarizes the micro and macro benefits of the biogas technology. It was concluded with some recommendations.

Key words: biogas production, slurry application, eco-farming, livestock and chemical fertilizer

1.0 Introduction

There are various renewable energy sources such as hydro, solar, wind, and biomass that have the potential for exploitation in Ghana. There are also numerous technologies for harnessing these inexhaustible renewable energy resources. This study looks at the possibility of integrating biogas technology in our farming systems using animal and agricultural wastes to generate energy (biogas) for agricultural production. Biogas is one of the most important bio-energy in the world today which can be used in place of natural gas (Hobson et al. 1981). As the world yearns for the use of renewable energy in place of fossil fuels, coal and nuclear energy due to their environmental consequences, the use of biogas energy in agriculture to boost food production cannot be downplayed. Developing countries having the world largest population, high population growth, low standard of living, low technological advancement, and low energy use have the arduous responsibility to produce more energy for their economic growth. Renewable energy such as biogas could therefore be the best way forward especially for rural farming communities.

Biogas can be produced from simple organic raw materials such as animal dung, food wastes, agricultural residues, municipal waste materials and human wastes. The biogas generated from these materials could be used for electricity and heat generation, pressurized for use in public transport and as a fuel for cooking in homes - a substitute for natural gas. The issue of waste disposal, sanitation and environmental problems coupled with the high cost of fossil fuel make biogas production a better choice. Many of the farming communities are far away from the national grid and cannot even dream of getting connected thus the use of biogas technology in these communities could address their energy challenges. Already agriculture is known to contribute significantly to the global climate change; nevertheless, the transformation of animal wastes and other agricultural wastes will reduce the impact agriculture has on the environment. The issue of climate change with its concomitant challenges due to increasing CO_2 in the atmosphere could be addressed by the use of renewable energy resources such as biogas. The world today is experiencing global warming due to the use of fossil fuel and wood fuel but the use of biogas do not contribute to global warming neither does the methane produced has any effect on the atmosphere. The integration of biogas technology into agriculture popularly called biological or ecological farming will improve the income levels of farmers and facilitate the achievement of effective and low-cost productivity in our agricultural system. Biogas technology can provide the link between animal husbandry and crop farming thus playing an important role in self-sustaining eco-farming.

1.2 Problem statement

The Idea of renewable energy resources in Ghana started some years ago, however its exploitation has far been left behind. Renewable energy is now seen as the way forward for energy supply especially in rural communities. Agricultural communities in rural areas produces a chunk of the food for the nation yet lack the energy needed to process and add value to the food they produce. The main source of energy for the rural dwellers is wood fuel and charcoal which increases deforestation leading to the degradation of the environment. It was estimated that Ghana used about 18million tonnes of wood fuel in 2000 and the total energy consumption of Ghana during 1999 was 7,108 metric tons of which 5,196 metric tons were from traditional sources (Trossero, 2002).

The bulk of wood fuels amounting to 90 percent are obtained directly from the natural forest and approximately 60 percent of the world's total wood removals from forest and outside forests are used for energy purposes. The developed countries use only 30 percent of wood produced for energy whiles the developing countries use about 80 percent for the same purpose (ibid). It was estimated that 6.5 million hectares of forest in Ghana have been deforested at an alarming rate of 22,000 hectares per annum and the rest is being encroached upon. As at 1985, 12,000,000 m^3 of fuel wood and charcoal were consumed, forming about 70% of the country's energy consumption (Okoth-Ogendo & Ojwang, 1985). According to Aprovecho Institute (1984), developed countries use 155,000,000m3 of wood as firewood of which 0.4% of all energy used is equivalent to 10% of total wood used while developing countries use 1.2billion cubic metres of wood for firewood of which 25% of all energy use of firewood is equivalent to 90% of total wood used.

Considering the above trend of wood consumption, it is important to consider a cheap but reliable alternative source of energy such as biogas. It is worth noting that most of the wood fuel is used in rural communities as energy for cooking. Farmers in the rural communities also engage in charcoal production especially during the lean season which is transported to the cities for consumption. Integration of biogas technology into the farming system will reduce the use of firewood for cooking and reduce the involvement of farmers in charcoal production as they are likely to be busy on their farms. It is estimated that about 70% of Ghana's population are rural dwellers that use wood fuel as their main source of energy for their domestic and commercial activities. Farming communities in the three northern regions namely; Northern, Upper East and Upper West Regions cannot boast of basic energy on their farms to process their crops. Lack of basic energy coupled with the use of wood fuel and charcoal call for the need to integrate biogas technology into the farming systems to meet those challenges.

1.3 Perspective of Agriculture in the three Northern Regions

The major employment and economic activities in the region is agriculture. About 70% of the northerners are employed in the agriculture sector alone. The three regions cannot boast of any industry apart from the cotton industry which is now defunct. They therefore mainly depend on agriculture for their survival. Livestock rearing is an integral part of the farming system in the three northern regions. Most households keep some animals, mainly cattle, poultry, pigs, sheep and goats (Otchere *et al.* 1997b). The northern regions have a relatively high concentration of livestock: 75% of the countries cattle and 50% of its small ruminants are found in the regions. Smallholders use animals to supplement family diet and to generate occasional cash income (Atengdem & Dery, 1998).

The two forms of farming systems in the three northern regions are compound and bush farming. The main source of organic matter for soil improvement is animal dung from kraals and pens. Compost, pit garbage and crop residues are seldom used (Antwi *et. al*. 1996 and Adolph *et. al*. 1993). Compound farms are dominant in communities with limited croplands and fairly large, dispersed settlements (Adolph *et. al*. 1993). On the other hand bush farms are larger and further away from the houses than compound farms. Animal traction and other labour saving devices are used on the bush farms. In some villages, however, the use of hoe for tillage is still very common (Atengdem & Dery 1998 and Antwi *et. al*. 1996). Soil fertility is a major constraint for agricultural production in the three northern regions (Runge-Metzger & Diehl, 1993).

Organic matter content in the surface soil horizons is very low due to the high temperatures and annual grass burning. The nutrients status such as Phosphorus (P), Potassium (K) and Nitrogen (N) of the soils is therefore low. The high intensity of rainfall within a 4 to 5 month period coupled with sparse grass cover results in considerable sheet erosion and leaching of the soil. Chemical fertilizer use is therefore very common in the regions.

2.0 Overview of biogas production and slurry application

2.1 Microbiology and Biochemistry of Anaerobic Digestion

The process involved in the anaerobic degradation of organic materials is both biologically and chemically complicated as it involves so many possible intermediate of reactions. The accomplishment of microbiological breakdown of organic material in an anaerobic environment can only be done by micro-organisms (bacteria), which ultimately result in biogas production. These bacteria are aerobic bacteria, facultative anaerobic bacteria and anaerobic bacteria, which are responsible for the production of the biogas. The aerobic bacteria grows in the presence of oxygen, the facultative anaerobic bacteria metabolizes and grows with or without oxygen while the latter grows only in the absence of oxygen (Hobson *et al*. 1981).
The process is divided into three stages namely Hydrolysis, Acid formation and Methane producing stages (GTZ-GATE).

2.1.1 Hydrolysis or Liquidation Stage

Fats, which are also called lipids, are found in most digester feed stocks, as they are constituents not only of animal matter but also of organic materials. The lipids in a digester feedstock are mainly compounds of glycerol and long-chain fatty acids while others contain more complex molecules. The long-chain fatty acids can be in saturated or unsaturated forms. Irrespective of the number of chains, there is a breakdown of complex long chains organic molecules into simpler shorter molecules by the action of extra cellular enzymes. There are specific enzymes involved in the breakdown of these organic molecules. For instance, starch and glycogen, which are carbohydrates, are hydrolyzed to a disaccharide by the action of amylase – one of the enzymes.

Lipases and esterases hydrolyze fats and lipids (oil) and these enzymes are specific in their reaction. The enzyme trypsin is specific for bonds involving the amino acids (Fruton & Simmonds, 1959). The enzymes are also responsible for the conversion of proteins into peptides and amino acids so is the conversion of polysaccharides to monosaccharides.

2.1.2 Acid Formation Stage

This second stage involved the conversion of the fermented intermediate materials into acetic acid (CH_3COOH), Hydrogen (H_2) and Carbon Dioxide (CO_2) by bacteria, which react in acidic medium. The bacteria (acidogenic and acetogenic) use up all the oxygen present creating an anaerobic environment for the methane-producing micro-organisms to react afterwards. They also reduce the compounds with a low molecular weight into alcohols, organic acids, amino acids, carbon dioxide, hydrogen, sulphide and traces of methane. The removal of the oxygen is characterized by extremely small changes in energy per unit substrate decomposed (McCarty, 1971).

2.1.3 Methane Formation

The final stage of the process is the methane producing stage, which involves methane-producing bacteria called methanogenic bacteria. Methane forming bacteria are sensitive to pH and conditions should be mildly acidic (pH 6.6-7.0) and certainly not below pH 6.2 (Twidell & Weir, 1986). These bacteria convert the compounds formed during the second stage into a low molecular weight such as methane and carbon dioxide in the absence of oxygen. Both acidogenic and acetogenic bacteria and the methanogenic bacteria act in support of one another in that the anaerobic condition created could be poisonous to those bacteria if not used up by other bacteria while the methanogenic bacteria could not also operate without such an environment. The reaction is as shown below:

$$\text{Organic matter} = \frac{\text{anaerobic}}{\text{Microorganisms}} = CH_4 + CO_2 + H_2 + H_2S$$ (Price & Cheremisinoff, 1981)

2.2 Factors that Affect Biogas Production

There are many factors that affect biogas production and these factors may have either positive or negative impacts on the biogas production. The optimum level of each of the following factors will form the best environment for an efficient and reliable performance of the biogas plant. These factors affect the bacteria at the various stages differently. Biogas digestion is a microbial process, and for that matter requires the maintenance of suitable growth conditions for biogas producing bacteria. The common factors involved in microbiological methanation are:

Temperature

There are three main temperature mediums for the production of biogas in the digester which are **Psychrophilic**, **Mesophilic** and **Thermophilic** temperatures.

Nutrients Availability

The waste to be fed into the digester must contain a reasonable amount of nutrient suitable for the growth of the organisms.

Retention time (flow-through time)

The retention time depends on the material and the temperature present. Two methods of determining the retention time are batch or continue type facility. Batch method is the best way to measure retention time but continue type method will only give an approximation or mean retention time which is given by

$$\frac{\text{Digester volume}}{\text{Daily feed rate}}$$

Level of pH

An appropriate pH level is very important for an effective performance of the methanogenic bacteria. The optimum pH for the methanogenic bacteria is 7 or about 7.2 (Ghosh & Klaus, 1978). The ideal pH value for methane formation lies within 6.5-7.5. Animal dung and night soil have normally this ideal range of pH value (Moulik, 1990).

Nitrogen inhibition and C/N ratio

Nitrogen and carbon are basic ingredients needed by microorganisms for their metabolic activities. The optimum level of C/N ratio for the perfect operation of the methanogenic bacteria is approximately 8 – 20 and this value varies from one case to another.

Others are inhibitory factors such as detergent in sewage sludge, heavy metals, moisture content and cations which may also affect the production of biogas. According to Sasse, 1988, the substrate - water ratio is 1:3, which depends on the material input.

3.0 Composition and Characteristics of Biogas

Biogas has almost the same characteristics as natural gas. It is pressure and temperature dependent and also affected by moisture content. Biogas has a heat value of 6kWh/m^3 which is equivalent to 21,600kJ/m^3 whiles that of natural gas is 11kWh/m^3 . It is also a clean and odourless combustible gas (like natural gas) which is produced when organic matter from plant and animal wastes are anaerobically fermented or digested by methanogenic bacteria (Pokharel & Yadav, 1991). The dominant gases are CH_4 and CO_2. It burns with a clear blue flame with no smoke, has a flame temperature of about 800 ^{0}C with a calorific value of 5650 Kcal /m^3 of gas (Pokharel & Yadav, 1991). The gas is almost 20% lighter than air and has an ignition temperature of 650 – 750 ^{0}C (Moulik, 1990). The major drawback of biogas is its lower energy content compared to natural gas due to the varying amount of CO_2 and other trace gases. Nonetheless, the liquefaction of biogas can be performed successfully, if the raw biogas is cleaned up and the methane content improved. However, the presence of Hydrogen Sulphide (H_2S) and moisture in the biogas forms corrosive acids which may lead to corrosion and wear on engines, burners and lamps thus the need to remove them. The presence of H_2S can be identified using lead acetate paper that turns black upon exposure to the biogas. H_2S is poisonous, smell like a rotten egg and form weak acid with water, and explode with air. Nevertheless there are various methods for removing H_2S. Among these are the use of iron oxide filters, dry desulphurization using ferrous substance and quicklime or slaked lime is also used in removing the presence of H_2S especially in small-scale production. Air can also be doped into the gasholder, which will reduce about 80% of the H_2S into elementary sulphur that is deposited within the plant (Klaus, 1988). The reaction is as shown below: $FeO + H_2S = FeS + H_2O$; $2FeS + O2 = 2FeO + 2S$ (Sasse, 1988). The chemical composition and efficiency of biogas in different equipment are indicated on table 1 and figure 1 respectively in the appendix.

3.1 Slurry as by-product from biogas production

Besides the biogas produced, the slurry which is a byproduct is a very good source of fertilizer for crop production. Its advantages far outweigh the raw manure and chemical fertilizers in term of quality and crop yield. According to

Ames (1976), the slurry contains excellent nutrients such as N, P, K, Ca, Mg, Fe, S and other trace elements. The short-term fertilizer worth of the slurry is doubled while the long-term effects are reduced to half after digestion. The chemical composition of the slurry of some animal manure is presented in table 2 in the appendix.

Pantastico (1976) also made relevant analysis of the organic nutrients in slurry and came out with the following estimation that waste from animals, plants, and humans could supply developing countries with six to eight time more nutrients than they derive from chemicals fertilizers. Comparism of slurry from digester and the raw manure has also been made and in table 3 in the appendix.

Besides the gas generated from the digester, the byproduct also provide a better alternative for crop production thus given a double benefit of the manure. Using sludge from anaerobic digester poses fewer problems if any at all than using aerobically treated wastes because the smaller amount of bacteria matter minimizes both smells and insect development. Integrating livestock production into our farming system will help farmers to maximize profits in their farming business. Farmers can produce organic food products which are of quality and have better prices thus improving their income levels. The biogas produced can also be fed into biogas generators to provide lights and run other equipments on the farm.

Many writers and authors have come to the conclusion that the use of recycled organic nutrients or digested slurry represents a better alternative to the use of chemical inputs for soil improvement and crop yield. Increase in nutrient value of the slurry has improved the physical and chemical properties of the soil, hence boosting crop production. However, studies have shown that about 16% of the nitrogen present in the digester sludge is present as dissolved ammonia, which evaporates on standing (Idnani & Varadarajan 1974). It is therefore suggested that the slurry should be covered from the direct sun in order to preserve its fertilizer quality. Proper storage and application method should therefore be observed to minimize volatilization losses. The digester slurry must be kept moist or buried under soil to preserve its nutritional value.

3.2 Macro and Micro benefits of biogas production

There are two main ways of evaluating biogas technology; macro and micro economic analyses. The former compares cost of the programme to the benefits for the country or society. For instance, improvement in the standard of living of rural dwellers, preservation of the forest and clean environment (sanitation) while the micro-economic analysis looks at a single investment at a specific location and within a definite set of macro-conditions. It also judges the profitability of the programme from the point of view of the user. For instance, sanitation and hygiene, high crop yields and energy supply. The direct relationship between them is that micro economic conditions provide information for the macro conditions. Barnett *et al*. (1978) suggested that the evaluation of biogas technology should be treated or handled initially at the micro level. The benefits of biogas technology can be classified broadly under the following: Social and Economic, Ecological, Heath and Sanitary, and Environmental benefits.

4.0 Discussions, Conclusion and Recommendations

4.1 Discussions

4.1.1 Slurry from the anaerobic digester

It has been proved that biogas technology is indeed a reliable source of energy that can improve farming activities and increase the income of farmers. The comparism made by Chengdu (1980) and cited by Sasse (1988) clearly indicate that the slurry has more nutritional value and improve crop yield than the normal manure. It also improves the physical and chemical conditions of the soil, creates conducive environment for the micro- organisms in the soil and reduces insect infestation. It is worth noting that, the slurry will provide better alternative for food production. The use of slurry could also promote organic farming which is the preferred option. The slurry also contains excellent nutrients such as Nitrogen (N), Phosphorous (P), Potassium (K), Calcium (Ca), Magnesium (Mg) and other trace elements. The short-term fertilizer worth of the slurry is doubled while the long-term effects are reduced to half after digestion. As stated above, the use of slurry will help farmers than the raw manure which are hardly applied appropriately. The effects associated with raw manure are drastically reduced and this improves the quality of food produced.

Relevant analysis conducted on the organic nutrients (slurry) and chemical fertilizers by Pantastico (1976) indicated that organic matter will have six to eight times more nutrients than they derive from chemical fertilizers. The use of chemical fertilizer has dominated the agricultural sector of late. Despite the improvement in food production, the use of chemical fertilizer has many side effects such as water pollution and reduction of the quality of food produced. It has been established that the nutritional value of slurry far outweigh raw manure and chemical fertilizers.

It is already established that raw manure contains salts due to cattle ration thus heavy application to soils will increase the salinity which destroys the soil in the long run. Meanwhile, the digested slurry contains a small fraction of salt which is far lower than the raw manure making it an ideal fertilizer for plants growth. It is therefore imperative to encourage farmers to include livestock production into their farming systems and establish biogas technologies on their farms so that the slurry is used to increase food production.

4.1.2 Gas generated from the anaerobic digestion

Anaerobic digestion of agricultural waste produces biogas which could be used in gas generators to provide electricity for the farmers and their families. The presence of power will reduce boredom on the farm and increase night activities in farming communities especially in a farm stead. Students in those farming communities can study comfortably in the night like their counterparts in the cities. The gas could also be used for cooking instead of firewood and charcoal thus saving our forest from further degradation. Werner *et al*. (1989) estimated that a simple 8 - 10 m^3 biogas plant produces 1.5-2 m^3 and 1001 digested-slurry fertilizer per day using dung from 3-5 head of cattle or 8 - 12 pigs. With that much biogas, a family of 6 - 8 persons can cook 2-3 meals or operate one refrigerator all day and two lamps for 3 hours or operate a 3 kW motor generator for 1 hour. This implies that simple biogas plant could be planted in every farm of about seven or more cattle which in the long term promote eco-farming where husbandry is integrated into crop farming.

4.2 Conclusion

The nexus between animal husbandry and crop farming is very important to promote biogas technology in rural farming communities. It could be deduce for the above discussions that the application of biogas technology has enormous benefits and has the potential to change our agricultural system in Ghana and improve rural lives. Apart from the use of the gas to provide electricity and operate basic electrical appliances, the gas could run on generators to process food crops and as cooking fuel for the family; the slurry could also be used to improve crop yields which benefits supersede raw manure and chemical fertilizers.

Biogas technology also improves the environment, health and sanitation, the ecological environments and promotes social and economic lives of the rural folks. The three northern regions have suitable environment, raw materials in terms of livestock availability and the farming environment for biogas technology. It is therefore imperative for government and other relevant stakeholders to support and encourage the integration of biogas technology into the farming systems of the three northern regions.

4.3 Recommendations

The following recommendations are drawn for consideration.

1. Farmers should be given loans to increase their livestock capacity, build proper stables for the animals as well as available veterinary services.
2. Exemptions of tax on materials made purposely for biogas plants most especially generators that run on biogas and provide subsidies to farmers who practice eco-farming.
3. Since agricultural communities far from the national grid can hardly enjoy electricity, cheap and simple biogas designs should be made available to them at affordable prices.
4. Government or donor agencies should support renewable energy projects especially biogas and make it cheaper and affordable to the rural communities.
5. Trained extension agents should advice farmers to improve the breed of animals, disease control and prevention, vaccination, feeding to enhance the live weight and health of the animals.
6. Farmers should be assisted to establish intensive fodder plots and also to incorporate forage legumes into the farming systems to improve ruminant nutrition.

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Appendix

Table 1: Chemical composition of biogas

Components (% vol.)	**Household waste**	**Wastewater treatment plants sludge**	**Agricultural wastes**	**Waste of agri-food industry**
Methane (CH_4)	50-60	60-75	60-75	68
Carbon Dioxide (CO_2)	38-34	33-19	33-19	26
Nitrogen (N_2)	5-0	1-0	1-0	-
Oxygen (O_2)	1-0	< 0,5	< 0,5	-
Water Vapour (H_2O)	6 (à 40 ° C)	6 (à 40 ° C)	6 (à 40 ° C)	6 (à 40 ° C)
Total	100	100	100	100
H_2S mg/m^3	100 - 900	1000 - 4000	3000 – 10 000	400
NH_3 mg/m^3	-	-	50 - 100	-

Source: http://www.biogas-renewable-energy.info/biogas_composition.html

Table 2: Chemical composition (%) some organic manure (slurry)

Animal manure	**Nitrogen (N)**	**Phosphorus (P)**	**Potassium (K)**
Cattle dung and urine mixed	0.60	0.15	0.45
Horse dung and urine mixed	0.70	0.25	0.55
Sheep dung and urine mixed	0.95	0.35	1.00
Human urine	1.0 – 1.2	0.1 – 0.2	0.2 – 0.3
Night soil	1.2 – 1.3	0.8 – 1.0	0.4 – 0.5
Settled sludge (dry)	2 – 2.5	1 – 1.2	0.4 – 0.5
Activated sludge (dry)	5 – 6	3 – 3.5	0.5 – 0.7

Source: Ames 1976

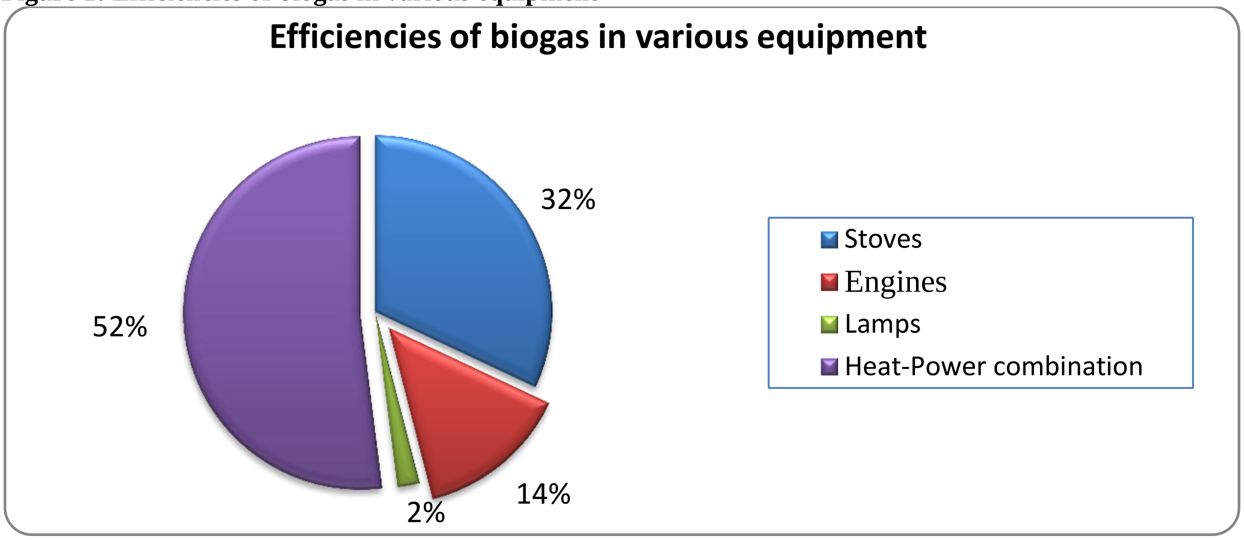
Table 3: Comparism of slurry from digester and raw manure

Tested plants	Quantity of slurry	Yield		Increase	(%)
		With slurry	With manure		
	m /ha	kg/ha	kg/ha	kg/ha	
Sweet potato	17	24,000	21,500	3,500	12
Rice	15	6,500	6,000	500	8
Corn (Maize)	22.5	5,000	4,600	400	9
Cotton	22.5	1,300	1,200	100	8

Source: (Chengdu, 1980) cited by Sasse, 1988

It is observed from the table 3 in annex 1 that there are 12, 9, and 8 percent increment of crop yield using the slurry from the biogas digester as compare to the raw manure.

Figure 1: Efficiencies of biogas in various equipment



Source: Sasse et al, 1991

It could be observed from the chart that the use of biogas in heat-power combination and stoves are the best options which farmers actually need. The heat-power combination will provide the farmer with light and energy for processing of food products. The stoves will also help the farmer to cook thus reducing the reliance on wood fuel and charcoal.