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Full Length Research Paper

Investigation of ethanol productivity of cassava crop as a sustainable source of biofuel in tropical countries

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The ethanol productivity of cassava crop was investigated 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 ml of N-hexane (C_6H_{14}). 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. Quantitative relationships were obtained to relate the masses of cassava used to the masses and volumes of ethanol produced. These were used to relate known production values of cassava from tropical countries to ethanol that can be potentially produced. The ethanol had boiling point of 78.5°C and relative density of 0.791. The dried mash was found to contain 61.8 calories of food energy per 100 g. 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 is recommended in the cassava-growing tropical countries of the world.

Key words: Cassava, ethanol, fermentation.

INTRODUCTION

Scientific interest and efforts in researching into renewable energy technologies are still relevant, especially in view of the often very high costs of conventional energy supply worldwide. Another reason for their relevance is the fact that the rampant use of firewood for domestic and industrial heating in low income countries invariably necessitates the destruction of forests and this is harmful to the environment. Renewable technologies rely principally on plant and animal materials as their feedstock, of which the most dominant among the plant materials are the energy crops.

An energy crop is a plant grown at a low cost and low maintenance harvest used to make biofuels, or directly exploited for its energy content. Conventional energy crops include Barbados nut (*Jatropha curcas*), sunflower (*Helianthus annus*), sugarcane (*Saccharum officinarum*), soyabean (*Glycine max*), and maize (*Zea mays*). Cassava is yet to gain global recognition as an energy crop, although its importance in this regard is known in several places. Efforts reported in this paper, point at its capability as a potent source of ethanol and its potential to gain a recognizable presence in global energy economics. While research interest into the use of agricultural biomass to produce biofuel is increasing, largely due to the global awareness of the inadequacies of the almost total reliance on fossil fuels as energy sources, it is important to investigate the ethanol productivity of such an important tropical crop as cassava. Finding such an important use for cassava crop would help to reduce the current almost total reliance on wood and expensive fossil fuels as industrial energy sources in tropical countries. 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 (NPC, 2008). Other countries which grow Significant quantities of the crop include Brazil, Congo Democratic Republic, Thailand and Indonesia. A handful of others also grow the crop but at much lower production quantities. The present annual global production of the crop is estimated at about 160 million tonnes.

Ethanol fuel is ethanol (ethyl alcohol), the same type of alcohol found in alcoholic beverages. It can be used as fuel, mainly as a biofuel alternative to gasoline, and is widely used by flex-fuel light vehicles in Brazil, and as an oxygenate to gasoline in the United States. Together, both countries were responsible for 89% of the world's ethanol production in 2008 (Litcht, 2009). This is because it is easy to manufacture and process and can be made from common crops such as sugar and maize. In several countries, ethanol is increasingly being blended as gasohol or used as an oxygenate in gasoline. As noted by Blume (2007), the following are the key reasons for which ethanol is attractive as a substitute to gasoline: Ethanol is 98% pollution free; biodegradable; renewable; there is no carbon left when ethanol burns in cars; ethanol does not cause climate change; and all the by-products in the production of ethanol are edible and non-toxic, providing a very good source for animal feedstock. Using the U.S.A. experience in particular, Lovins et al. (2005) identified some further advantages that ethanol brings to the global energy sourcing solution to include the following: (i) Sound ethanol production practices would not hamper food and fiber production or cause water or environmental problems, (ii) ethanol improves urban air quality, and can reduce CO_2 emissions by 68% for cellulosic ethanol. (iii) properly grown feedstocks can even reverse CO_2 emissions by taking carbon out of the air and sequestering it in enriched top soil whose improved tilth can boost agronomic yields, (iv) using ethanol as a vehicle for better farm, range, and forest practices can also help to achieve other goals such as reduced soil erosion and improved water quality, and can dramatically improve the economies of rural areas, and (v) fuel ethanol production can lead to increased agriculture employment since there is pungent need to raise farm production levels to meet demand.

The first-generation biofuels are those made from sugar, starch, vegetable oil, or animal fats using conventional technology (FAO, 2008). The basic feedstocks for the production of first generation biofuels are often seeds or grains such as wheat, which yields starch that is fermented into bioethanol, or sunflower seeds, which are pressed to yield vegetable oil that, can be converted into biodiesel. These feedstocks could instead enter the animal or human food chain, and with the rise of global population, their use in producing biofuels has been criticized for diverting food away from the human food chain, supposedly leading to food shortages and price increments. What is sometimes overlooked however is that the creation of a competing need most times motivates producers to raise production levels of the product in order to satisfy the higher demand. The other point is that competition necessitates the judicious absorption of any existing excess production as well as the plugging of avenues for wastes of all kinds. With the increased use of grains and tubers for ethanol production, it is anticipated that increased efficiencies in production will be brought to bear on agriculture and these advantages will then be of benefit. Several researchers have reported biofuel production from various agricultural materials including biogas from mixtures of cassava peels and livestock wastes (Adelekan and Bamgboye, 2009a), 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 livestock wastes (Adelekan and Bamgboye, 2009b).

There are two common strategies of producing liquid and gaseous agrofuels. One is to grow crops high in sugar (sugar cane, sugar beet, and sweet sorghum) or starch (maize, cassava, yam), and then make use of yeast fermentation to produce ethyl alcohol (ethanol) (ICRISAT, 2009). The second is to grow plants that contain high amounts of vegetable oil, such as oil palm, groundnut, soybean, castor oil, algae, jatropha, or *pongamia pinnata*. When these oils are heated, their viscosity is reduced, and they can be burned directly in a diesel engine, or they can be chemically processed to produce fuels such as biodiesel. The chemistry of the process basically involves the fermentation of sugars into ethyl alcohol, carbon dioxide and the production of heat as shown in the equation

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 + \text{heat}$$

The basic steps for large scale production of ethanol are: microbial (yeast) fermentation of sugars, distillation, dehydration and denaturing (optional) to render the ethanol unsuitable for human consumption. Enzymes are used to convert starch into sugar (Green Car Congress, 2005). Ethanol is produced by microbial fermentation of the sugar. For the ethanol to be usable as fuel, water must be removed. Most of the water is removed by distillation, but the purity is limited to 95 - 96% due to the formation of a low-boiling water-ethanol azeotrope. The 95.6% m/m (96.5% v/v) ethanol, 4.4% m/m (3.5% v/v) water mixture may be used as fuel alone, but unlike anhydrous ethanol, is immiscible in petrol (gasoline), so the water fraction is typically removed by further treatment in order to burn in combination with petrol in engines. Ethanol is most commonly used to power cars, although it may be used to power other vehicles, such as farm tractors and airplanes. Consumption of 100% ethanol (that is, E100) in an engine is approximately 51% higher than that of petrol since the energy per unit volume of ethanol is 34% lower than that of petrol (McCarl and Schneider, 1999). However, the higher compression ratios in an ethanol-only engine allow for increased power output and better fuel economy than could be obtained with lower compression ratios (University of Washington, 2008). For maximum use of ethanol's benefits, a much higher compression ratio should be used (Stauffer, 2006) which would render the engine unsuitable for petrol use. When ethanol fuel availability allows high-compression ethanol-only vehicles to be practical, the fuel efficiency of such engines should be equal or greater than current petrol engines. The mileage (miles-per-gallon) is therefore usually 20-30% higher than petrol-only engine (Hybridcars, 2009).

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 (that is, E85) filling stations and in France 131 E85 service stations with 550 more under construction (EUBIA, 2007). Since 1989, there have also been ethanol engines based on the diesel principle operating in Sweden (Scania Press Info, 2007). They are used primarily in city buses, distribution trucks and waste collectors also use this technology. The engines have a modified compression ratio, and the fuel (known as ED95) used is a mix of 93.6% ethanol, 3.6% ignition improver, and 2.8% denaturants (Warshaw, 2008). China is promoting ethanol-based fuel on a pilot basis in 5 cities in its central and northeastern region, a move designed to create a new market for its surplus grain and reduce consumption of petroleum. The cities include Zhengzhou, Luoyang and Nanyang in central China's Henan province, and Harbin and Zhaodong in Heilongjiang province, northeast China. Under the program, Henan will promote ethanol-based fuel across the province. Officials say the move is of great importance in helping to stabilize grain prices, raise farmers' income and reduce petrol-induced air pollution (China News, 2009).

The Nigerian experience as regards to the adoption and use of ethanol in local energy supply is also of interest. In August 2005, under the directive of the former President of the Federal Republic of Nigeria, Chief Olusegun O. Obasanjo, the Nigerian National Petroleum Corporation (NNPC) inaugurated its Renewable Energy Department (RED). This department was given the mandate to develop the biofuels industry in Nigeria. In essence, the Nigerian biofuels program seeks to produce ethanol and diesel using agricultural base materials (Odusote, 2008). There has been a strong desire in this program to establish a synergistic connection between the energy and agricultural sectors. The desire had been very rightly placed because up till this time, the level of performance of the energy sector of the country had been very poor. The country's renewable energy program was set up as a catalyst to improve performance in these sectors. Although it had been planned to produce ethanol and diesel under this program, efforts so far made have concentrated on the production of ethanol (to achieve a first blending phase of 90% petrol with 10% ethanol), making the initiative known for now as the Nigerian E-10 Policy.

Advantages exist in the production and use of bioethanol. Studies conducted in Belgium at Flemish Institute for Technological Research and in Germany at Stuttgart, Heidelberg and Bochum Universities for the life-cycle assessment (LCA) of biofuels proved that the net environmental impact of biofuels is sure to be advantageous in supporting sustainable agriculture and sustainable development, provided the feedstock of biofuels is produced under appropriate agricultural and climatic conditions (Energy Facts, 2008). In addition, the production and use of all biomass goes through at least some of the following steps: (1) It needs to be grown, (2) collected, (3) dried, (4) fermented, and (5) burned. All of these steps require resources and an infrastructure. The total amount of energy input into the process compared to the energy released by burning the resulting ethanol fuel is known as the energy balance (or Net energy gain). Figures compiled by reference (Bourne and Clark, 2007) point to modest results for corn ethanol produced in the United States: One (1) unit of fossil-fuel energy is required to create 1.34 energy units from the resulting ethanol. The energy balance for sugarcane ethanol produced in Brazil is more favourable, viz, 1:8. A separate survey reports that production of ethanol from sugarcane, which requires a tropical climate to grow productively, returns from 8 to 9 units of energy for each unit expended, as compared to corn which only returns about 1.34 units of fuel energy for each unit of energy expended (IEA, 2004). Carbon dioxide, a greenhouse gas, is emitted during fermentation and combustion. However, this is canceled out by the greater uptake of carbon dioxide by the plants as they grow to produce the biomass (Biomass Energy Homepage, 2005). When compared to petrol, depending on the production method, ethanol releases less greenhouse gases (Wang et al., 1999; Wang, 2002).

As regards to disadvantages, a study by atmospheric scientists at Stanford University found that E85 fuel would relatively increase the risk of air pollution deaths to that of petrol (San Francisco Chronicle, 2007). Ozone levels are significantly increased, thereby increasing photochemical smog and aggravating medical problems such as asthma (EST, 2009; Jacobson, 2009). Habibah (2009) noted that the demand for biofuels may create a huge demand for cereals, sugar and oilseeds which may result in an increase in food price, greater food insecurity and higher level of poverty. A negative impact on the environment resulting from deforestation, intensive tillage and cultivation practices may also occur. In other words, biofuel is competing for arable land that would have been used for growing food crops but is now being used to grow energy crops. Given these possibilities, it would be desirable to find more energy efficient biofuel sources and produce them under appropriate agricultural and climatic conditions thereby supporting sustainable agriculture and sustainable development. One of such sources of interest is cassava and the efforts made in this regard are reported in this paper.

MATERIALS AND METHODS

The experiments were carried out at the Institute of Agricultural Research and Training (IAR&T), Moor Plantation, Ibadan, Nigeria.

Table 1. Cassava production from tropical countries.

Region/country	Area (mil. Ha)	Yield (tonnes/ha)	Production (mil. tonnes)
Africa			
Nigeria	2.70	11.3	30.41
Congo Dem. Rep.	2.20	7.5	16.5
Ghana	0.63	11.4	7.17
Tanzania	0.69	8.9	6.19
Mozambique	1.02	5.6	5.64
Uganda	0.34	6.7	2.28
Asia			
Thailand	1.12	14.3	15.96
Indonesia	1.20	12.2	14.73
India	0.25	24.0	5.87
China	0.23	15.6	3.60
Vietnam	0.23	7.7	1.78
Latin America			
Brazil	1.58	12.4	19.81
Paraguay	0.24	13.9	3.30
Others			1.0
TOTAL			134.24

Source: FAO (2001).

Table 2. Volumes and masses of ethanol produced.

Sample (3 replicates)	Mean mass of Cassava samples (kg)	Ethanol Produced (mean values)	
		Mass (kg)	Volume (l)
Sample 1	5	0.25	0.31
Sample 2	15	0.76	0.96
Sample 3	25	1.27	1.61
Sample 4	35	1.75	2.21

Cassava variety TMS 30555 was obtained at the cassava unit of the International Institute for Tropical Agriculture (IITA), Ibadan, Nigeria. The cassava tubers were peeled and rinsed in clean water. 5, 15, 25 and 35 kg samples of the tubers were then weighed on a laboratory scale in three replicates. Afterwards the weighed cassava was soaked in clean water for 24 h to dilute any impurities that may be present in it. Then the cassava tubers were placed on a clean tray in the laboratory and allowed to dry naturally for 4 h. After this de-watering process, the cassava tubers were cut and the pieces transferred to a mortar where they were mashed using a pestle to attain sufficient size reduction. This ensures the creation of sufficient surface area for the material to aid the process of fermentation. The mash was then transferred into a plastic bucket. 500 ml of N-hexane (C_6H_{14}) was added to it to aid fermentation.

The mash was thoroughly stirred to achieve an even mixture with the hexane. It was then covered and left undisturbed in the laboratory at room temperature for 8 days. Afterwards, the now fermented mash was poured onto a 0.6 mm aperture size sieve placed over a clean plastic bowl. This cassava mash was then completely squeezed to dryness while the liquid filtered through the sieve. The filtered liquid was afterwards transferred to the soxhlet machine for removal of N-hexane that may still be present in it. The collected liquid was poured into a glass dish and then gradually heated at 79°C for a total of 10 h (at intervals of 2 h heating followed by 1 h cooling) to ensure complete evaporation of any trapped H_2O or CO_2 remaining in it. Afterwards the final liquid (ethanol) was allowed to cool normally in the lab and its mass, volume and other properties were determined. The properties of the ethanol produced were determined and compared to the known properties of ethanol. Temperature was measured with a thermometer. Relative density was measured with a pictometer. The squeezed mash was placed on trays in the lab and allowed to air dry normally. The eventual caked mash was analyzed for its nutritive properties.

RESULTS

From the literature, the given cassava production from tropical countries are shown in Table 1. From this experiment, the volumes and masses of ethanol produced which corresponded to the mean mass of cassava samples used are shown in Table 2. The values shown in Table 2 were plotted to produce Figure 1, the relationship between

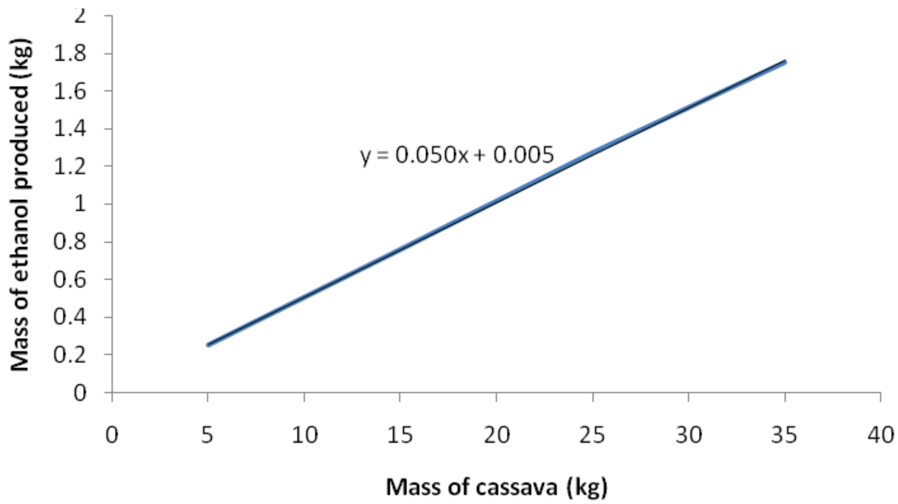

Figure 1. Production of ethanol from cassava on mass basis

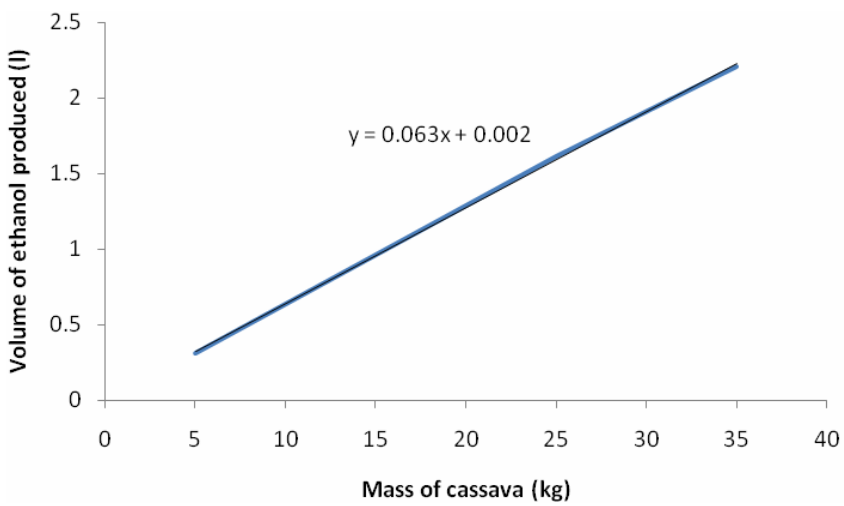

Figure 2. Production of ethanol from cassava on volume basis.

the mass of cassava samples used and the mass of ethanol produced was given as:

$$y = 0.050x + 0.005$$

Where, y = mass of cassava samples; x = mass of ethanol produced.

The values shown in Table 2 were plotted to produce Figure 2, the relationship between the mass of cassava samples used and the volume of ethanol produced was as:

$$y = 0.063x + 0.002$$

Where, y = mass of cassava samples; x = volume of ethanol produced.

The properties of the ethanol produced were measured and are shown in Table 3. There was no equipment available on ground to measure the freezing point of ethanol. The nutritive properties of the dried mash were determined and are shown in Table 4. Based on the data in Tables 1 and 2 as well as equations derived in Figures 1 and 2, the projected production of ethanol from cassava producing nations is shown in Table 5. They can serve as guideline values under which the assumption that the variety of the crop used for this experiment is grown.

DISCUSSION

Rao (2000) pointed out that 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. Table 6 shows the com-

Table 3. Properties of ethanol produced.

Fuel	Melting point (°C)	Boiling point (°C)	Relative density (at 20°C)
Standard ethanol	-114.1	78.5	0.789
Ethanol produced		78.5	0.791

Table 4. Nutritive properties of dried cassava mash (per 100 g portion).

Nutrient	Quantity
Food Energy (calories)	61.8
Water (g)	2.5
Carbohydrates (g)	14.4
Proteins (g)	1.2
Fat (g)	0.1
Calcium (mg)	153
Iron (mg)	0.5

parison of ethanol yield produced from different energy crops. Cassava has the highest ethanol yield of 6,000 kg/ha/yr and highest conversion rate of 150 L/ton of all the energy crops. Though sugar cane and carrot have higher produce yield of 70 and 45 tons/ha/yr respectively, 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. The value of 145 litres per tonne obtained in this present study is comparable to this.

The determined properties for the ethanol produced from cassava in this study are shown in Table 3. The liquid had a boiling point of at 78.5°C and a relative density of 0.791. The liquid was clear, colourless and fully miscible in water. It had a very sharp alcoholic taste, as well as the typical ethanol odour. When tested on a blue piece of cloth, it readily bleached it to almost white colour. These values and attributes compared favourably with those provided by Paul and Kemnitz (2006) which reported that the ethanol produced from their research had a relative density of 0.79 and a viscosity of 1.5mm^2/s. The boiling point was also quite comparable to the value of 78.4°C reported by Rutz and Janssen (2007) which investigated ethanol production from potato. The paper further reported that the by-product of ethanol production from potato was suitable for animal feed. This assertion was further corroborated by Liimatainen et al. (2004). In a bid to determine the situation as regards cassava crop, this present research also investigated the suitability of the by-product of ethanol production from cassava as animal feed. The nutritive analysis of the dried cassava mash shown in Table 4 revealed that the mash contained 61.8 calories of food energy and 14.4 g of carbohydrate, 1.2 g of protein, 0.1 g of fat, 153 mg of calcium and 0.5 mg of iron per 100 g of mash. Kuiper et al. (2007) reported that raw cassava tuber contains 62 g of water, 35 g of carbohydrate, 2 g of protein and 0.3 g of fat for every 100 g. This showed that the by-product of ethanol production from cassava also contains useful nutrients not much different from its initial state, making it suitable for composition in the feed rations of livestock. If this possibility is further investigated, it may well mean that the material can attain some level of significance as a concentrated material in livestock feeding.

From the foregoing, it is seen that the overall ethanol production of cassava is of good quality. A total of 6.77 million tonnes or 1338.77 million gallons of ethanol are available from total cassava production from tropical countries. The cassava crop is a readily renewable resource unlike the hydrocarbon fuels. The tropical countries where this crop is grown have to develop the capacity for the conversion of the crop into ethanol and this can be used as fuel. By doing this, it will help to mitigate their dependence on fossil fuels. Concerns about the possible health consequences of using ethanol as transport fuel have been raised. These concerns mainly include the inhalation of ethanol vapours when using pure or blended ethanol in transport applications. Nevertheless, as observed by Armstrong (1999), it is highly unlikely that exposure to airborne ethanol associated with gasoline use could produce toxic effects. The reasons for this are the ethanol that might be received is in tiny doses and the body's rapid capability in eliminating them.

Conclusion

The solution to the energy problem lies in the integration of several options and technologies from diversified fields, viz, biomass, biofuel, biogas, solar energy, wind energy, hydropower and other reasonably ecofriendly options. No particular option may be regarded as the panacea. Different nations and respective areas of the world would have to decide and choose on the combination of options which suit them the best giving cognizance to their resource base, technology level, and available manpower to operate the various systems as well as economic, environmental and political considerations. For the tropical countries, one of the options should look in the direction of cultivation of cassava (an often neglected but sturdy crop) as a sustainable source in the production of ethanol fuel for the supply of energy. The production and use of the ethanol from cassava is recommended particularly in the tropical regions of the world.

Table 5. Projected ethanol production from cassava.

Region/country	Production (mil. tonnes)	Projected ethanol production (mil. tonnes)	Projected ethanol production (mil. gallons)
Africa			
Nigeria	30.41	1.52	300.58
Congo Dem. Rep.	16.5	0.83	164.13
Ghana	7.17	0.36	71.19
Tanzania	6.19	0.31	61.30
Mozambique	5.64	0.29	57.35
Uganda	2.28	0.15	29.66
Asia			
Thailand	15.96	0.80	158.2
Indonesia	14.73	0.74	146.33
India	5.87	0.29	57.35
China	3.60	0.18	35.60
Vietnam	1.78	0.09	17.80
Latin America			
Brazil	19.81	0.99	195.77
Paraguay	3.30	0.17	33.62
Others	1.0	0.05	9.89
TOTAL	134.24	6.77	1338.77

Table 6. Comparison of ethanol yield produced from different energy crops.

Crops	Yield (tons/ha/yr)	Conversion rate to ethanol (L/ton)	Ethanol yield (kg/ha/yr)
Sugar cane	70	70	4,900
Cassava	40	150	6,000
Carrot	45	100	4,500
Sweet sorghum	35	80	2,800
Maize	5	410	2,050
Wheat	4	390	1,560
Rice	5	450	2,250

Source: Rao (2000).

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