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Technical analysis of crop residue biomass energy in an agricultural region of Ghana

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ABSTRACT

The aim of this study was to assess crop residue biomass potential for second generation biofuel production in the Lawra–Nandom district of Ghana. The methods used in this study included interviews, survey, field and laboratory experiments. The findings show that total annual crop residues production in the Lawra–Nandom district amounts to about 272,000 t. Among the major crops grown in the district, sorghum crop generates the largest quantity of residues, contributing 59% by weight of the total residues. Ethanol production potential could reach 40 million litres if 40% of the average residue generated between 2003 and 2012 were used for energy purposes. The net energy balance of the biofuel production process was 1718.7 MJ with a ratio of energy output to input being 1.31. Second generations biofuels are expensive compared to first generation and research efforts aimed at technology improvement and cost reduction must intensify in order to make the technology attractive to developing countries.

1. Introduction

Humans have three basic needs namely food, water and shelter. These needs cannot be met without energy. Energy is therefore viewed as the lifeblood of our society and economy (Smith, 2008). It is needed for mobility, lighting, heating and cooling. However, ensuring sustainable energy access has recently become an issue of public concern. Energy crisis is one of the most difficult challenges faced by humankind in the 21st century (Rajvanshi, 2010) as the world becomes increasingly dependent on fossil oil. Global energy consumption is projected to increase by 36% by 2030 (British Petroleum, 2013). In Africa, oil consumption could double in that time (GTZ/MOFA-Kenya, 2008). Since the transport sector relies almost entirely on oil supplies for fuel, countries will have to keenly compete for this limited supply of oil and this presents more challenging issues. Several other factors, such as energy price increases, increased market volatility, heavy dependence of many countries on imported oil, lingering debate about the ultimate size of remaining, recoverable fossil fuel reserves and the growing concern about the environmental impact of fossil fuel usage have provided impetus for the current strong interest in and support for alternative energy in many parts of the world (Mandil and Shihab-Eldin, 2010).

Efforts are being made globally to develop alternative energy sources, such as wind, solar, mini-hydro and biomass that would complement fossil fuel use and hopefully serve as replacement should fossil fuels run out one day. In sub-Saharan Africa, biomass is already a major source of energy for cooking and heating but it is presently used principally in traditional forms such as firewood and charcoal in largely inefficient stoves (Sielhorst et al., 2008). Inefficient use of biomass in traditional forms present major environmental and health concerns such as indoor air pollution caused by burning biomass and coal in residences (Zuzarte, 2007). Also, the unsustainable sourcing of firewood or wood for preparation of charcoal contributes to the degradation of the local environment. According to Chagwiza (2008), modern biomass energy is a promising long-term renewable energy source, which has the potential to address environmental impacts, rising fossil fuel prices as well as security concerns posed by current dependence on fossil fuels. Modern biomass energy could provide new income and employment opportunities for farmers.

Several African countries, including Ghana, have been considering biofuels as they seek to reduce dependence on imported oil. Ghana imports large quantities of crude oil from Nigeria and Equatorial Guinea at prices that ranged from US$ 120 to US$ 130 per barrel in 2012 (Energy Commission, 2012). According to Ghana's central bank monetary policy report (Bank of Ghana, 2014), the sharp rise in crude oil prices on the international market is

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increasing the depreciation of the local currency and may heighten inflation by causing manufacturing input prices upwards which could lead to slowdown in economic activities. There is therefore the need for the country to focus attention on domestically produced biofuels in order to reduce the challenges posed by oil importation. Ghana's Energy Commission, the agency in charge of energy planning in Ghana, posited that the development of biofuel will enable Ghana achieve its strategic energy objectives which include energy security, reducing oil bill and saving foreign exchange, climate change mitigation, poverty alleviation and wealth creation through employment generation. The Commission has set a target for Ghana to substitute national petroleum fuels consumption with biofuel by 10% by 2020 and 20% by 2030 (Energy Commission, 2010). The biofuels needed to meet the 10% target in 2020 is estimated at about 336 million litres (Antwi et al., 2010). Meeting this demand requires abundant information on feedstock sources.

Research on feedstock for biofuel production in Ghana is limited and most researchers focus their attention on first generation feedstocks such as sugar cane, cassava, oil palm and cereal grains for biofuels (see for example, Kemausuor et al., 2013; Osei et al., 2013; Afrane, 2012). However, producing biofuels from these first generation feedstocks present social challenges with respect to land grabbing that could potentially cause food supply shortages (Boamah, 2014a,b; Schoneveld et al., 2011). Also first generation biofuels may not be the answer to climate change mitigation as previously envisaged. Crop residues and biomass from other waste sources are more suited feedstocks for biofuels production with regards to social and environmental benefits and are envisioned as an attractive solution to the aforementioned problems associated with the production of first generation biofuels. According to Kumarappan (2011), biofuels produced from lignocellulosic biomass feedstocks offer a number of potential benefits and could serve the purpose of sustainability. The raw materials used are largely waste materials from agriculture, forestry or other non-food crops. The use of wastes overcomes the problems of using food and feed grains such as corn, for biofuel. Also, cellulosic biofuels help reduce greenhouse gas emissions relative to fossil fuels and other biofuels, such as corn ethanol. Research into second generation biofuels in Ghana has so far only considered feedstock availability and not much has gone into analysis of other important factors such as energy balance and economic analysis (Kemausuor et al., 2014a; Mohammed et al., 2013; Duku et al., 2011).

The main aim of this study is to provide an objective and comprehensive assessment of agricultural crop waste biomass potential for ethanol production using Lawra–Nandom district, one of the principal agricultural production areas in Ghana, as a case study. The specific objectives were to:

(i) estimate present and future crop residue biomass with corresponding second generation biofuel production potential in the Lawra–Nandom district of Ghana and compare with fuel demand and;
(ii) determine the energetic efficiency of ethanol production from crop residue biomass.

2. Methodology

2.1. Assessment of biomass residue and its ethanol potential

Ghana is divided into ten regions. The Lawra–Nandom district is located in the north western part of the country in a region known as Upper West Region (see Fig. 1), which is a principal food hub for the country. The total area of the district is 1051 square km with a 2010 population of 100,292 and a population growth rate of 1.7% (Ghana Statistical Service, 2012). The climate of the district is tropical continental type with the mean annual temperature ranging between 27 °C and 36 °C. The period between February and April is the hottest. The district lies within the Guinea Savannah Zone which is characterized by short grasses and few woody plants. Common trees in the district consist of drought and fire resistant trees such as *baobab* (*Adansonia gregorii*), *dawadawa* (*Parkia biglobosa*), *shea trees* (*Vitellaria paradoxa*) and *acacia* (*Acacia nilotica*). Agriculture accounts for 80% of the Lawra–Nandom district economy. Major crops cultivated in the district include maize, millet, sorghum, cowpea, groundnuts and soybean. In the animal sector, production and rearing of livestock include Cattle, sheep, goats, pigs and poultry.

To assess agricultural crop waste biomass (residues) potential in the district, data on crop production as well as the residue-to-product ratio (RPR) of major crop types were collected. Data on crop production was obtained from the district office of the Ministry of Food and Agriculture (MOFA). RPR values were determined in the field and the moisture content of each crop residue was determined at the Savanna Agricultural Research Institute (SARI), which is located in the Upper West regional capital, Wa.

2.1.1. Procedure for RPR determination

The following procedure was used in the determination of RPR values:

(1) Ten farms each of maize, sorghum, millet and groundnut were selected based on farmers' willingness to participate in the experiment.
(2) Four plots each of size 20 m by 20 m square were obtained by random sampling from each of the selected farms.
(3) Crops from the plots were harvested and the weight of both the food products and the residue were recorded.
(4) RPR of each residue type was determined using the weight of the food product and the residue (Eq. (1)).

$$\mathrm{RPR} = \frac{\text{Weight of residue from a food crop sample}}{\text{Weight of the food crop sample}} \tag{1}$$

The moisture content of each residue type was determined using the oven method (Zhang et al., 2012).

It is generally accepted that not all residues will be available for bioenergy production due to their scattered nature, technical constraints (complexities of harvesting and transporting), ecosystem functions (maintenance of soil fertility and erosion protection), possibility of getting consumed by bush fires, and other uses (such as for animal fodder, domestic heating and cooking). A recoverability fraction of 10% to 25% of the total available residues has been assumed in previous studies (OECD/IEA, 2010) for energy purposes. International Resource Group (2009) has suggested a recoverability fraction of 5%, 10% and 15% for biofuel production. Groode and Heywood (2008) suggested an allowable removal rate of 30–50%. This study assumes 10%, 25% and 40% availability of residues representing low scenario, medium scenario and high scenario, respectively.

To estimate the crop residue potential, the equation used by Lal (2005) and International Resource Group (2009) were adopted and modified as shown in Eq. (2).

$$W_B = \sum_{i}^{crop} CP_i \times RPR_i \times PR_i \tag{2}$$

where W_B is the weight of agricultural waste biomass (residues) produced (t), CP is the average crop production in (t), RPR is the residue-to-product ratio, PR is the percentage of residue available for biofuel production, $\sum_i^{crop}$ is the summation of all individual crop types.