Annals of Agricultural & Crop Sciences

Open Access

Austin Publishing Group

Special Article - Biomass Production

Agriculture Residue: A Potential Source for Biogas Production

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Received: April 19, 2021; **Accepted:** May 11, 2021; **Published:** May 18, 2021

Abstract

To achieve energy security and to address energy related environmental issues attempts have been made to find out such energy resources that are economically viable and environmentally friendly. Biogas appears as a sustainable, renewable and carbon neutral energy source, a substitute to reduce the global fossil fuels dependency. Agricultural activities generate huge amounts of organic residues annually worldwide. Microbial conversion of agriculture residue and organic wastes to produce biogas offers an attractive way for energy supply, resource recovery and waste treatment. Energy generated is renewable can have positive impact on environment, replacing fossil fuels and mitigating greenhouse gases emissions. In addition to a clean and cost effective energy source, it improves the management of manure and organic wastes and replaces inorganic fertilizer. Biogas production in the agricultural sector is a fast growing market particularly in many European countries. This article is aimed to review and investigate the potential contribution of biogas from agricultural residues. Techniques for quantitative assessment of the residue from different crops that can be recovered sustainably as a potential resource for biogas production are discussed.

Keywords: Agricultural residue; Crop yields; Biogas; Renewable energy; Environment

Introduction

Continued growth in population worldwide needs consistent increase in food stock and energy supply. Current energy needs are mostly met by fossil fuels that accounts for about 80% of the world's primary energy supply [1,2]. Extensive use of conventional energy sources (coal, oil, natural gas, etc.) gives rise to two major issues - energy deficit and insecurity due to limited reserves of fossil fuels, high depletion rate and at the same aggravating environmental challenges [3,4]. Replacing fossil fuels with renewable energy alternatives for sustainable development has become a major global issue of the 21st century [3]. An important component to get independence from fossil-based resources is to produce energy from renewable resources such as agriculture crop residue [5].

Agriculture practices produce high proportion of crop and huge amounts of organic residues annually worldwide [6]. The activity spreads over half of the world's habitable land [7] and there is continued expansion and intensification in agriculture. The expansion in agriculture is inevitable for meeting the urgent food and nutritional needs of rapidly growing population and their energy need. Potential household, especially in rural areas of developing countries uses agricultural residues for domestic cooking and heating [8]. Biomass has played a dominant role in the energy need of the continued world growing population contributing towards sustainable development in energy security.

Agriculture crop residues are the part of plants that are not commonly used as food by people, such as stalks, roots, and leaves. These residues are waste stream with a high-untapped potential for energy generation and greenhouse gas mitigation. The residue (biomass) bears significance being an important source of energy [5]. It can be used directly or converted into liquid biofuels (biodiesel and ethanol), or gaseous biofuels i.e. biogas and hydrogen gas [6]. The use of biomass as solid biofuels is not yet well developed but is renewable energy source widely used today, supplying 10-15% of total world energy supply. Liquid biofuels (e.g. ethanol and biodiesel) and biogas contribute only a small portion of biomass energy [2]. Combustion process is inefficient and produces a large amount of greenhouse gas.

Biogas has become a well-established energy resource technically viable. Since the 1950's, biogas production from manure and/or crops has continued to develop in many countries worldwide [2]. According to the International Renewable Energy Agency [9], the biogas production has been more than doubled in the world from 2009 to 2018 [4]. The European countries account for 70-74 % of the world biogas production, Germany leading with over half (50-53%) of the total European biogas produced [4]. USA is the second-largest biogas producer while Italy third, in the world in 2018. Germany is driving up much faster than other countries. Family size biogas plants are very common in Asian countries and in some countries the number of operational plants is very high, such as China (12 million), India (3.7 million) and Nepal (140 thousand) [10].

The use of agriculture residue for energy production *via* anaerobic digestion is one of the most promising and sustainable alternative source for renewable energy. It has great potentials and is sustainable energy providing a practical approach to reduce the local energy deficit [11]. Biogas can be considered not only an attractive option to reduce GHG emissions and mitigate environmental contamination but avoids undesirable effects in the environment

Citation: Raja IA. Agriculture Residue: A Potential Source for Biogas Production. Ann Agric Crop Sci. 2021; 6(3): 1081.

derived from other uses of crop residue e.g. combustion in thermal power plants, domestic cooking and heating. It has great economic and environmental relevance and can be used to close material source and energy cycles, to preserve environments, recover resources and reduce the impacts and the quantity of waste [12].

Biogas is an attractive form for low cost energy production in term of resources availability, simple conversion techniques into the secondary energy carriers, a substitute to fossil fuels addressing energy security, environment and socially sensitive issues of fossil fuel dependence. The present review article aims to highlight various agriculture residue and their potentials focusing on biogas production. Estimation of the resources, opportunities and challenges of using agriculture residues are also discussed.

Agricultural Residues

Agriculture represents the largest sector of the economy, particularly in developing countries that generates highest number of employment and largest contributor to the Gross Domestic Product (GDP) [1]. Agriculture products, grains and cereals are essential part of the human diet and residues feed for animals and other living creatures on planet Earth. To maintain essential supplies, the crops need to be harvested freshly every year. Harvests varies around the world, every country grows the crops according its need and local climate to ensure the availability of a different types of crop residues abundantly.

Agriculture crop residues are the non-edible portion of plants i.e. those parts of plant, which are not normally eaten by human. According to the definitions [4,13], these are divided into two basic types as primary residue and secondary residue. Primary agricultural residues are the materials left over remain in fields as by-products after separation of edible product harvested e.g. cereal grain straws, wheat, barley, rice, corn stovers, stalks, leaves, etc. Secondary agriculture residues arise during processing of agriculture products for food such as bagasse, sunflower husks and so on [4]. Major proportion of primary residues are collected and stored while some remain on the fields following harvesting [4].

Residue Management

Recovering primary agriculture crop residue to maximum is neither possible nor desirable. There are several reasons that only a part of the crop residues are collected and sustainably utilized but at least two are significant [4,13]. Firstly, crop residues are an important source of soil organic matter, a part of the residue such as roots, stubbles etc.; is left in the field to maintain the soil quality. The roots hold the soil together, give soil structure and upon degradation add humus or carbon content to the soil. Secondly, the weather conditions - wet weather after harvest, generally degrade the quality of the residues and may not be available [4]. Depending on type of crop, it is estimated that 30-60% of crop residue can be sustainably recovered [14].

Crop residues are managed or utilized in many different ways, depending on the nature of crop, local agricultural practices and alternate uses of residues. Some of these practices are:

- Ploughing in [15]: a sustainable farming practice, roots and stubbles are ploughed in the field.

Table 1: Residue-to-crop production ratios (kernel/seed weight), Total (wet) weight of crop residues and reported production.

Agriculture Residue	Yield (m^3/wet tonne)
Maize silage 33% TS [44]	180-220
Whole crop (wheat) [44]	180-210
Grain (oats, rye, barley, wheat [44]	300-550
Whole crop(oats, rye, barley Maize) [44]	80-332
Grass Silage (cut to 6mm) [44]	120-215
Beet leaves, fresh grass [44]	39-70
Rapeseed [44]	550-650
Sugar beet [44]	235-380
Maize grain [44]	270
Sunflower [2]	154-400
Sorghum [2]	295-372
Potatoes [2]	276-400
Vegetables [44]	50-80

- Livestock feed [5]: collected and stored to feed livestock.
- Livestock bedding [5,15]: bedding for animal comfort, spent bedding treated with livestock manure.
- Incineration in field [5]: Quick and cheap way of clearing the field and killing weeds, insects for preparing the field for next harvest. Although the practice is banned in, most parts of the world but still continued illegally in some parts of Asia and Africa.
- Combustion for heat [2,5,15]: combustion in thermal power plants boilers or used as domestic fuel for cooking or heating, inefficient way, loss of nutrients and causes air pollution.
- Biofuels (Bio-oil) [5]: High-density liquid can be combusted directly in boilers, gas turbines and slow and medium speed diesels for heat, power transport applications.
- Mushroom cultivation [5,10] - quite small (less than 1% of the total production), can be reused.
- Industrial applications [10] - very marginal, around 1% of straw production.
- Anaerobic digestion [1,5]: a proven technology for biogas production but not widely implemented.

Agricultural Residues Assessment

In order to establish the potential for sustainable biogas production from different waste streams including crop residues, several studies have been made and reported for assessing the available resources and respective biogas yield over the last 20 years [4,5,15-20] Based on the fact that the quantity of residue produced and that can potentially be removed is directly related to the crop yield, a simple technique “residue-to-crop ratios”, has been proposed and is widely used [4,21-23] for estimating the agriculture crop residue. The residue-to-crop ratios of various crop residue are given in Table 1. The crop yield is multiplied by respective ratio to estimate of the available residues per unit of harvest. Data related to crop yield is widely available national and international economic surveys/ statistic. A useful document is produced by World Food and Agriculture Organization of United

Table 2: Global crop residues yield [24-32].

Crop residues (million tonnes)	Rice	Wheat	Maize	Rye	Barley	Oats	Rape seed	Sugar Beets	Sugar cane	Sorghum
Global Crop Yield estimate [22]	770	772	1,135	14	147	26	76	301	1,842	58
Harvest residue coeff. [24]	1.33	1.33	1.5	1.86	1.5	1.5	3	0	0.28	2.33
Process residue coeff. [25]	0.23	0.21	0.18	0.2	0.27	0.2	0.3	0.25	0.2	0.1
Recovery factor [26]	90	90	90	90	90	90	90	90	0	90
Total solids	96	90.15	89.6	86	86	86	80	11.6	76.7	94.5
Volatile Solids	79.4	93.55	93.2	94.4	93.7	93.5	94.3	85	86.3	94.2
Methane yield [27-31]	335.6	213.43	360	179	320	240	252	360	195	340

Nation “FAO”. Global crop yields of some relevant crops are given in Table 2 [24-32].

Sustainable Removal Rate of Residues

While quantity of residue produced is substantial, only a part of it can be collected for bioenergy and/or biogas use. The agriculture crop residues are an important source of soil organic matter, play significant role in soil conservation, animal feed, and have other applications. Therefore, while collecting the residues these applications should be considered. Also wet weather after harvest may be degrade quality of the residues and is not available. Thus, only a part of the crop residues can be sustainably utilized. Depending on soil type, climate, topography, other sources of soil organic matter, etc. the sustainable removal rates mostly is in the range 30-60 % [21].

Biogas from Agricultural Residues

Biogas systems operate by the fermentation of organic materials. Various types of biomass and waste are suitable for anaerobic digestion such as energy crops and agricultural residues, manure and sewage sludge, domestic and industrial waste [1-6]. Biogas comprises of methane (CH_4) 60-70 %, carbon dioxide (CO_2) 28-30 % and around 2% hydrogen sulphide (H_2S), nitrogen (N_2), and water vapour [1].

Agriculture residue, a primary source of biogas from anaerobic digestion that may be digested on their own (mono digestion) or co-digested with other waste stream. Some lignocellulose biomass has high lignin content which results in a slow and incomplete anaerobic digestion [34,37], requiring prolonged retention times, from several weeks to months. The process in dry digestion set up with retention time of 80-100 days under mesophilic process and 30-40 days under thermophilic conditions [37,38]. Plant residue may contain a high percentage of carbon giving rise too high C/N ratio [35]. Therefore, mono-digestion of crop residue is not favoured and the residues most often are co-digested with other substrates [35,37], like livestock manure. The biogas yield from various agriculture crops residue in Table 3.

Table 3: Relative biogas yields of feedstocks.

Agriculture Residue	Yield (m³/wet tonne)
Wheat [22]	0.9
Rye [22]	1.1
Barley [22]	0.7
Oats [22]	0.8
Rapeseed and turnip rape [22]	1.2
Maize [21]	1
Sugar beets [23]	0.6

Biogas technology generally has had good track record - treating a variety of farm, industrial, and municipal bio-wastes. Utilizing agriculture residue offers great potential to generate energy if co-digested with livestock manure from cattle, buffaloes and chickens were to be collected and anaerobically digested. Taking into account ploughing in and diversion to feeding animals, if all readily available and recoverable agriculture residues current global production of crops is used for anaerobic digestion, it has the potentials:

- World Electricity Demands - to meet the electricity needs of 393 to 500 million people or 5.2 to 6.5% of the world population [37, 39] by generating 3,080 to 3,920 TWh of energy globally.
- Gas Needs [40] - to meet the combined natural gas consumption of China and Japan110 producing 300 to 380bcm bio-methane per year.
- World Agriculture Energy Needs [41]- to meet 100% of all energy needs of world agriculture: 2,400TWh including electricity, coal, fuel oil, liquefied petroleum gas, motor gasoline, gas-diesel oil, and energy for power irrigation, significant contribution to the energy security at farms.
- Organic Fertilizer [42] - to be used as organic fertilizer or soil amendment, 10 billion tonnes of nutrient-rich digestate.
- Reduction in GHG Emission [42]- to reduce global GHG emissions by 930 to 1,260 Mt CO_2 eq. per year, about 13 to 18% of current emissions related to livestock or equivalent to the emissions of Germany [43].

Technology for Anaerobic Crop Digestion of Crops

A number of technical solutions are offered and documented based on the same basic principle. These are defined in four distinct steps for crop digestion processes [2]:

- Harvest, pre-processing and storage of crops
- Anaerobic process configuration and control
- Treatment, storage and use of digestate
- Treatment, storage and use of biogas

Conclusion

Agricultural activities generate huge amounts of organic residues annually worldwide. The residue include all nonedible parts left over after harvest such as straw, stalks, branches, leaves, roots. Agricultural crops residues are valuable resource that can be used biogas production. Anaerobic digestion represents a fascinating process for the recovery of nutrients and renewable energy from various agriculture residue and an important way for handling waste. The emphasis today is mainly on climate and environmental protection, conservation of natural resources and the development of a sustainable and secure energy supply. Biogas production from agriculture crop residue as a substitute for fossil fuels offers great potential to address today's two main issues energy security and environment protections by generating 3,080 to 3,920 TWh of energy globally it can reduce global GHG emissions by 930 to 1,260 Mt CO_2 eq. per year.

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