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Evaluation of treatment options for garden biomass with specific reference to reduction in greenhouse gases

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Abstract

Garden biomass (GB) is generally differentiated from other types of biomass, and it is defined as low density and heterogeneous waste fraction of garden rubbish like grass clippings, pruning, flowers, branches, weeds, roots. Open burning, dumping, and composting are the common place disposal methods adopted in India. These methods are typically associated with Green House Gas (GHG) generation and inefficient energy and resource recovery. The major concern about the management of garden biomass is the lack of authentic scientific information on quantity, composition, and technicalities of various processing options. This paper deals with the evaluation of various treatment options for garden biomass and correlating these options to GHG emissions. Anaerobic Digestion (AD) seems to be the most appropriate process for GB treatment, as it recovers maximum energy and reduces GHG emissions. The reduction in GHG emission is compared with other treatment options.

Keywords: Garden biomass, Greenhouse Gases, Anaerobic digestion, Pre-treatment, Energy

1. Introduction

India is blessed with huge land cover, relatively high population density with substantial landmass left undeveloped. Many cities, large or small, have developed many gardens and recreational parks and contribute to the sizable quantum of garden biomass (GB) generation. Garden biomass is defined as low density and heterogeneous waste fraction of garden rubbish like grass clippings, pruning, flowers, branches, weeds, roots that can rot down relatively easily. Consequently, maintenance of green areas produces a significant amount of waste and it is a major constituent of solid waste^[1, 2]. The total annual production of leafy biomass in India is estimated to be of the order of 1130 million tons^[3]. The main components of GB are carbohydrates (approximately 75%, dry weight) and lignin (approximately 25%, dry weight), which can vary with plant type. The carbohydrates are mainly cellulose or hemicellulose fibers, which impart strength to the plant structure, and lignin, which holds the fibers together. Some plants also store starch and fats as sources of energy, mainly in seeds and roots^[4]. The general characterization of garden biomass is given in Table 1.

Table 1: Characterization of garden biomass^[5, 6]

Parameter	Leaves	Grass	Branches	Yard Waste
Total organic carbon(% dry weight)	30.1	40.6	40.4	36.2
C/N Ratio	21.6	17.5	13.1	18.7
Fats/lipids(% dry weight)	2.59	2.41	1.04	2.49
Cellulose(% dry weight)	9.48	39.67	14.71	27.20
Hemicellulose(% dry weight)	3.24	16.89	12.87	11.25
Lignin/humus(% dry weight)	33.88	17.63	42.89	24.34
Volatile Solids(% dry weight)	63.3	81.7	81.7	73.8
Cellulose/lignin ratio	0.28	2.25	0.34	1.12

Source: (Haug *et al.*, 2001; Komilis and Hamb, 2003)

In India, common methods adopted for the disposal of biomass are open burning, dumping and composting, which neither recover energy nor recycle resources efficiently.

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In addition, these treatment options also lead to the generation of GHG emissions. Also, the Municipal Solid Waste-Handling and Management rules, 2000, Government of India, (Commonly referred as MSW 2000 rules) do not permit open burning of the biomass [7]. The greenhouse gases that are making the largest contribution to global warming are carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O). All three are produced during the management and disposal of organic wastes. Also, due consideration was given to GHG emissions associated with various activities in MSW management and their potential for environmental pollution. In such an exercise, GHG emissions associated with non-fossil carbon are counted alongside those from fossil sources. The climate responds no differently to fossil or non-fossil CO₂, and thus it is important to include all emissions on a like-for-like basis [8].

The major concern about the management of garden biomass is the lack of authentic information on quantity, composition, and technicalities of various processing options. The high moisture content of GB is advantageous for AD process. Otherwise also, from the environmental point of view AD is the only process which reduces GHG emissions and yielding energy, besides recycling the organic content and nutrients of GB back to the soil in the form of residues. Hence, in the major focus of this study was to evaluate AD process for GB with an aim of studying its influence on GHG emission potential.

2. Materials and Methods

2.1 Collection and processing of Garden Biomass

Garden biomass consisting of grass cuttings, fallen leaves, flowers, roots, twigs etc. were collected from the garden area of National Environmental Engineering Research Institute (NEERI), Nagpur. After initial screening, GB was pulverized using a pulveriser to a size of 1 to 5 mm and stored in an air tight container for further experiments.

2.2 Pretreatment of GB

5 kg of GB was taken and soaked in 50 l of approximately 0.5% (w/w) H₂SO₄ solution for 30 min. The contents were mixed well and kept in an autoclave for heating. The temperature of the autoclave was set at 121 °C with a pressure of 15 lbs and the contents were autoclaved for 30 min.

2.3 Anaerobic digestion of GB

The pre-treated samples were transferred to a container and washed repeatedly for maintaining the pH about 5.5 to 6.5. The washed biomass was collected and used as a feed for anaerobic digester. In all these experiments, nutrients were added according to Gupta *et al.*, 2012; Hu and Yu, 2005 [9, 10]. A glass bottle of 2.5 l capacity was used as an anaerobic reactor. Approximately 10% (w/w) cow dung slurry was added as seed material and was properly mixed. The biogas formed was measured by volume displacement method. Temperature was maintained at 37°C and percent methane in biogas produced was measured by GC (Shimadzu-GC 2010). Methane yield from various garden biomasses using AD was collected from literature and was compared with our results.

2.4 Chemical Analysis

The dried sample of GB was ground to powder for chemical analysis. The organic carbon content and volatile solids (VS) of GB was estimated by combustion method according to Nelson & Sommers, 1982 [11]. Known quantity (mg) of substrate (GB) and its hydrolysed residue after pre-treatment was taken and analysed for cellulose by HNO₃-ethanol method. Lignin content of samples was estimated by 72% (w/w) H₂SO₄ method and hemicellulose by Liu method [12]. The total nitrogen (TN) content of the sample was estimated using LECO Protein-Nitrogen Analyzer (Model FP528).

3. Results and Discussion

3.1 Chemical Characterization of GB

The results of chemical characterization of GB showed that it contained 94.10% (w/w) of total organic matter, 49.12% (w/w) of organic carbon, 1.65%(w/w) of nitrogen, 38.54%(w/w) of cellulose, 25.68%(w/w) of lignin and 26.24%(w/w) of hemicellulose.

3.2 Anaerobic Digestion of Garden Biomass

It was found that mild acid pre-treated garden biomass produced more and consistent biogas than control which was not pre-treated. Table 2 shows methane/biogas yield from various garden biomass samples or components of garden waste. The results are summarised for the yield of methane (%) as reported in literature. Similar trends of methane production were observed by others under different conditions. However, direct comparisons of methane yield with those reported in literature are not possible because of the significant differences in the substrates and inoculums used, and the experimental conditions. During 30 days of batch reactor operation, the biogas yield ranged between 610–900 ml. After 30 days of batch reactor operation, the biogas yield was 173 ml/g of VS with a methane yield of 125 ml/g VS.

Liew *et al.* (2011) also evaluated methane production from fallen leaves wherein the highest methane yield (82 l/kg VS) was obtained at NaOH loading rate of 3.5% with a substrate-to-inoculum (S/I) ratio of 4.1 [13]. Lehtomaki *et al.* (2008) conducted anaerobic digestion of grass silage in batch leach bed processes for methane productions, with and without a second stage up flow UASB. 66% of the methane potential in grass was obtained within the 55 days solids retention time in the leach bed-UASB process without pH adjustment, whereas in the one-stage leach bed process 20% of the methane potential in grass was extracted. The methane potential of the digestates varied from 0.141 to 0.204 m³ CH₄/kg added volatile solids [14].

Yu *et al.* (2002) reported an average of 0.15m³ of methane/kg of grass. The average methane concentration in the produced gas was 71% [15]. Jagadish *et al.* (1998) developed plug flow digesters for biogas generation from leaf biomass. Results show that during long term operation, such biogas plants have the ability to produce up to 0.5 m³ gas/m³ reactor/day (ambient conditions) at specific conversion rates ranging between 180 and 360 l biogas/kg TS at a 35 day retention time [16]. A summary of methane yield obtained from different forms of biomass is given in Table. 2

Table 2: Methane/Biogas yield from various garden biomasses tested with anaerobic digestion

Feedstock	Pretreatment	Methane /Biogas production	Methane %	Reference
Fallen Leaves	Alkaline	81.8 L methane/kg VS	-	[13]
Grass Silage	-	0.141 to 0.204 m ³ CH ₄ /kg VS	66	[14]
Grass	-	0.15 m ³ of Methane/kg of grass	71	[15]
Leaf Biomass	-	180 and 360 l biogas/kg TS	-	[16]
Gliricidia Leaves	-	165–180 ml CH ₄ /g VS	60-75	[17]
Pelleted Hay	Steam explosion	405 m ³ biogas /ton TS	52.3	[18]
<i>Miscanthus giganteus</i>	Fenton	13.6 Ndm ³ biogas/kg TS	75	[19]
Grass	-	209 L Methane/kg VS	-	[20]
Leaves	-	123 L Methane/kg VS	-	[20]
Branches	-	134 L Methane/kg VS	-	[20]
Blend Of Grass, Leaves And Branches	-	143 L Methane/kg VS	-	[20]
Hay	a) Ca(OH) ₂ b) (NH ₄) ₂ CO ₃ c) Maleic acid	230 -300 L Methane/kg VS	-	[21]
Straw	a) Ca(OH) ₂ b) (NH ₄) ₂ CO ₃ c) Maleic acid	150 – 320 L Methane/kg VS	-	[21]
Bracken	a) Ca(OH) ₂ b) (NH ₄) ₂ CO ₃ c) Maleic acid	90 - 170 L Methane/kg VS	-	[21]
Grass Silage Liquor	-	0.385 m ³ Methane kg ⁻¹ COD.	70-80	[22]
Garden Biomass	Mild acid pretreatment using autoclave	125 ml Methane/g VS	72	This Study

Gunaseelan (1988) studied anaerobic digestion of *gliricidia* leaves for biogas and organic manure. *Gliricidia maculata* is a tree grown in India for green leaf manure. Results indicate a gas yield of 165–180 ml CH₄/g VS added and a VS reduction of 37–39% [17]. Marousek (2012) evaluated cumulative biogas production of pelleted hay as 405 m³/ton TS (with 52.3% methane), Michalska *et al.* (2012) treated biomass from *Miscanthus giganteus* with Fenton's reagent for 2 hours under optimal conditions (pH of 3, mass ratio of [Fe²⁺]:[H₂O₂] equals 1:25). The biogas production for *Miscanthus* was (13.6 Ndm³/kg TS fed) with a 75% methane content [18, 19]. Owens and Chynoweth (1993) observed a value of 209 L methane/kg VS, 123 L methane/kg VS, 134 L methane/kg VS, 143 L methane/kg VS for grass, leaves, branches, blend of grass, leaves and branches respectively [20].

4. Comparison on GHG emission potential of different treatment options for GB

The greenhouse gases that are making the largest contribution to global warming are carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O). Once a molecule of CO₂ is in the atmosphere, its potential as GHG is the same regardless of its source [23]. The greenhouse gases emissions associated with the current treatment options i.e. burning, dumping and composting are calculated for representative 1 tonne of garden biomass on wet weight (ww) basis and accumulate the emissions that are expected for a 100-year period into a time integrated value.

The CO₂ emissions were calculated based on the total amount of waste combusted, according to the formula

proposed by IPCC and calculated value is 416.82 kg of CO₂ for 1 tonne of GB wet weight (ww) [24]. The Landfill gas generated from degradation of organic matter is assumed to be emitted directly to the atmosphere. The prime GHG from landfilling is methane generated by anaerobic degradation of the waste inside the landfill body. Based on the content of biogenic carbon (C, in kg tonne–1ww) and assuming that on a mass base 55% of the carbon becomes CH₄ and 45% becomes CO₂, the overall amount of methane and carbon dioxide generated within 100 years of degradation is calculated as 75.71 kg CH₄/tonne GB (ww) and 170.23 kg CO₂/tonne (ww) [25].

Greenhouse gases are released from composting facilities due to degradation of organic matter [26]. In open technologies, composting is performed in outdoor facilities and the gaseous emissions are in general neither collected nor treated. The main gaseous emissions from composting are CO₂, CH₄ and N₂O. An overview of GHG emissions from open composting of garden biomass is 266 kg CO₂/tonne GB (ww), 0.05 kg CH₄/tonne GB (ww) and 25 kg N₂O/tonne GB (ww) [27-31].

Based on the experiment carried out on AD, biogas yield from GB was 173 l/kg VS and perusal of results shows that the concentration of volatile solids in GB is 94.10% that will yield approximately 163 l biogas/kg of GB. Consider that the biogas is composed of 72% CH₄ and 28% CO₂; the amounts of CH₄ and CO₂ are found to be 117 l CH₄ and 46 l CO₂ respectively. Assuming that the density of CH₄ and CO₂ is 0.662 and 1.83 kg/m³ respectively; then the amounts of CH₄ and CO₂ are found to be 0.0774 kg CH₄ and 0.0842 kg CO₂ respectively. Consider the hypothetical situation where the

biogas produced from AD is burnt under adequate combustion conditions, the total CO₂ emission will be 297 kg CO₂ from 1 tonne of dry GB. If we consider moisture content as 50.77% and calculated on wet weight (ww) basis it will be appx.148.5 kg CO₂ from 1 tonne of wet GB.

Theoretical calculations of GHG emission from conventional disposal options for GB are reported in Table 3 for comparison with GHG emission from AD.

Table 3: Summary of global warming potential of GB

Treatment	CO ₂ (kg CO ₂ -eq./tonne ww)	CH ₄ (kg CO ₂ -eq./tonne ww)	N ₂ O (kg CO ₂ -eq./tonne ww)
Burning	416.82	-	-
Dumping	170.23	1590	-
Open Composting	266	1.05-142.8	7750-55180
Anaerobic Digestion	148.5	-	-

Values are related to the treatment of 1tonne of GB (ww)

This clearly indicates that if GB was properly handled and treated by AD methods, there is substantial reduction in GHG emission as compared to conventional methods. It can be seen that process reduces GHG emissions. There may be differences in emissions from combustion of biogas, which are due to a variety of reason linked to the overall set-up and efficiency of the overall system. Biogas yields and the nature of the energy that this biogas use avoids play the most important role and will determine the ultimate savings. From the above analysis it is clear that burning of biogas produces energy with less impact on the environment than liberating the biogas freely to the atmosphere.

The higher value of moisture content shows that incineration will be not a proper option for processing of GB due to higher costs and unsuitable waste composition. Moreover the energy production is also not very lucrative as compared to the other options [32, 33]. Burning garden wastes can produce large amounts of harmful gases (such as nitrogen oxides), which pollute the atmosphere [34]. Gasification or pyrolysis is another option which can be thought of as an alternative to AD. However, gasification or pyrolysis is high temperature and high pressure processes which are potentially hazardous and difficult to operate. In addition management of residues from these processes is difficult. Thermo-chemical processes are cost efficient [35] but not applicable to the developing countries like India on account of the low calorific value and high organic content of waste [36, 37].

From environmental point of view AD is the only process which reduces GHG emissions, yields energy, and most importantly recycles the organic content and nutrients of GB back to the soil in terms of digested from AD. Thus, this process not only helps management of GB but also protect the soil quality. The use of digestate as a compost material for agriculture is a proven method to maintain or restore the quality of soils. In other options recycle of organic content and nutrients back to soil are not feasible. Therefore this research work strongly recommends AD of GB is environmentally most sound management practise.

5. Conclusion

The various treatment options for garden biomass processing were evaluated. Among all the techniques, anaerobic digestion seem to be the most appropriate process for GB treatment option as it yields maximum energy and reduces GHG emissions. Further, it was found that mild acid pre-

treatment using autoclave was facilitated the digestion of GB and subsequent yield of biogas and concentration of methane.

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