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The utilisation potential of urban greening waste: Tartu case study

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ABSTRACT

In light of climate change and the increasingly limited availability of energy resources, any form of renewable raw materials that can be used for energy production should be accounted for. One of the most promising renewable sources is considered to be that of lignocellulosic feedstock. In urban forestry and greening, millions of tons of lignocellulosic waste is produced every year but that biomass mostly goes unused. The aim of this research project was to investigate the utilisation potential of this very form of waste biomass using a medium-sized town as a sample for the work (Tartu in Estonia, with a population *circa* 100,000). Woody and non-woody vegetation representing greening waste from different seasons was investigated: spring and autumn leaves, and mixed waste from urban greening which contained grass, twigs, and leaves. BMP assays were conducted to estimate the biogas production potential and the three step bio-ethanol production process was used to estimate the bio-ethanol production potential. In the bio-ethanol production process, an N_2 explosion pre-treatment was used, followed by enzymatic hydrolysis and fermentation. Map analysis was used to assess the area that was manageable by urban forestry and greening in the city of Tartu in order to estimate the amount of greening and forestry waste that was available for bioconversion and the volumes of biofuel that could be produced.

1. Introduction

The EU is committed to reducing greenhouse gas (GHG) emissions when compared to their 1990 levels by a figure of 20% by the year 2020, and by 80–95% by 2050 (Commission, 2011). Currently, energy industries and the transport sector are responsible for 35% and 30% of CO_2 emissions respectively (EuroStat, 2011). GHG emissions from the transportation sector can be reduced with the use of fuels from renewable energy sources (Haberl et al., 2011; Silvestrini et al., 2010), and with the use of energy efficient technologies. Currently, biofuels are the only direct substitute for petrol and diesel in road transportation (Sims et al., 2010; Slade and Bauen, 2013). This means that the conversion of biomass to alternative and renewable fuels has the attractive potential of replacing fossil-fuel-derived fuels (Abdoulmoumine et al., 2012; de Almeida et al., 2013).

One of the under-utilised lignocellulosic biomass resources, which is dramatically increasing with rapid urbanisation worldwide, is waste from urban forestry and greening (Shi et al., 2013). This form of renewable biomass is composed of various plant structures, including tree branches, hedge cuttings, grass clippings, small branches, leaves, and other plant debris (Wang et al., 2014). Forestry and greening waste in urban areas annually offers substantial and continuous volumes of biomass (Shi et al., 2013). Additional benefits are lower feedstock costs and the ability to turn waste products into a useful commodity (Abdoulmoumine et al., 2012) which could contribute significantly to regional bio energy system (Shi et al., 2013) and reduce greenhouse gas emmissions (Wang et al., 2014). Lignocellulosic biomass could be used for the production of liquid biofuels such as ethanol, or converted to biogas by anaerobic digestion.

Liquid biofuels are classified into 'First Generation' and 'Second Generation' biofuels (Nigam and Singh, 2011; Demirbas, 2011). The primary distinction between them is in the feedstock used (Nigam and Singh, 2011). The first generation liquid biofuels are those types of liquid fuels that are generally produced from food crops such as sugar, starch, or oil cultures (Sims et al., 2010; Nigam and Singh, 2011; Phitsuwan et al., 2013; Haghighi Mood et al., 2013; Agbor et al., 2011), and this is the least complex method used to produce the finished fuel product. Second generation liquid biofuels, however, are produced from lignocellulosic biomass, which are either non-edible residues of food crop production or non-edible whole plant biomass (Nigam and Singh, 2011), which makes up the majority of the cheap and abundant non-food materials that are available from plants (Phitsuwan et al., 2013; Naik et al., 2010). The main advantage of the production of second generation biofuels from non-edible feedstock is that it limits the direct food-versus-fuel

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Table 1
The results of biomass analysis for cellulose, lignin, and hemicellulose.

Sample	Hemicellulose (%)	Cellulose (%)	Lignin (%)
Spring leaves	NA	22.32	27.29
Waste from urban greening	3.79	16.87	16.32
Autumn leaves	5.96	18.12	13.75

competition that is normally associated with first generation biofuels (Nigam and Singh, 2011; Demirbas, 2011; Haghighi Mood et al., 2013; Naik et al., 2010).

Biogas, which can be produced by anaerobic digestion from biomass materials of different origins, is another source that can be used as vehicle fuel, as well as for the production of heating or electricity (Nallathambi Gunaseelan, 1997; Frigon and Guiot, 2010). It primarily consists of methane and carbon dioxide. These days, biogas is mainly utilised in combined heating and power plants; however, upgrading and utilisation as renewable vehicle fuel or as an injection into the natural gas grid is of increasing interest when it comes to using biogas in a more efficient way (Weiland, 2010). It is also important that products which are created by anaerobic digestion have valuable usages and no waste is produced.

The aim of this study was to assess the potential of waste from urban forestry and greening as a substrate for bio-ethanol and biogas production using a small sized town as an example (Tartu in Estonia, which has a population of around 100,000). A novel N_2 explosion pre-treatment was applied to various biomass samples of different types, and the traditional three step ethanol production process was used for the analysis of bio-ethanol production efficiency. Additionally, BMP assays were used to estimate the biogas potential of urban greening waste as a substrate. Finally, a map analysis was used to assess the area that is manageable through urban forestry and greening in the city of Tartu and thereby estimate the amount of biomass that would be available and the biofuel production potential that could be drawn from that.

2. Materials and methods

2.1. Biomass

Three different kinds of biomass samples that are characteristic of three different seasons were collected in order to be able to investigate the suitability of waste from urban forestry and greening for bio-ethanol production. Mixed leaves from maple, oak, and bushes that were left outside over winter were collected to represent the biomass that is available in spring. Leaves that were collected in the autumn consisted mainly of maple leaves – the most common greening waste from that time of year, when abscission is occurring on the trees. In addition, waste that contained grass, twigs, and leaves was also investigated – material that is common urban greening waste for the summer season when, as well as normal biomass from forestry, lawns are being mowed and trees pruned. The samples were dried to a moisture content less than 10% and ground down with an SM 100 'Comfort' Cutting Mill (Retsch GmbH) and then processed through a ZM 200 Cutting Mill (Retsch GmbH) to a particle size of 3 mm or less. The biomass composition of all three samples, representing urban greening waste from three different seasons, was analysed and the fibre content of all samples is given in Table 1.

2.2. Chemical analysis

The percentage of lignin, Acid Detergent Fibre (ADF), and Neutral Detergent Fibre (NDF) in the dry mass (DM) of the biomass samples was determined in the Plant Biochemistry Laboratory of the Estonian University of Life Sciences (Tecator ASN 3430) (Van Soest et al., 1991; AOAC, 1990). The glucose and ethanol concentrations in the mixture were determined using an Analox GL6 analyser (Analox Instruments Ltd).

2.3. Pre-treatment

N_2 explosion pre-treatments were used to break the lignin seal and open up the structure of lignocellulosic material for enzymatic hydrolysis (Raud et al., 2016a, 2016c; Tutt et al., 2016).

In the N_2 explosion pre-treatment, 100 g of dried and milled biomass was diluted to 1,000 ml using distilled water. Samples were heated to temperatures of 125 °C, 150 °C, and 175 °C with a variance of ±3 °C, and a pressure of 30 bar was applied using compressed nitrogen gas. After reaching the target temperature, the mixture was cooled below boiling point and pressure was released in an explosive manner. After the explosion, samples were cooled to a temperature below 50 °C. The pH value of the samples did not require neutralisation since no chemicals were added.

2.4. Hydrolysis and fermentation

Enzymatic hydrolysis with enzyme complex Accellerase 1500 was used to convert cellulose in the biomass to glucose. An enzyme mixture was added to the samples at a ratio of 0.3 ml per gram of biomass. Hydrolysis lasted for 24 h at a temperature of 50 °C under conditions of constant stirring in a rotating shaker/incubator (Unimax 1010, Heidolph Instruments GmbH & Co KG). After the hydrolysis process had been completed, the glucose concentration in all samples was measured.

In order to start the fermentation process, 2.5 g of dry yeast, *Saccharomyces cerevisiae*, was added to all samples. The fermentation process was carried out at room temperature under low oxygen conditions in 1,000 ml glass bottles, sealed with a fermentation tube, and lasted for seven days after which the ethanol concentration was measured.

2.5. Biogas production

The biochemical methane potential test (BMP test) which was carried out in this study was based on a modified version of the guidelines described by Owen et al., 1979 (Owen et al., 1979). An averaged greening sample of all three different samples containing autumn and spring leaves, grass clippings, and twigs was used in BMP measurements. The experiments were carried out in triplicate using 575 ml plasma bottles filled with 200 g of inoculum and substrate mixture with a substrate-to-inoculum ratio of 0.3 on a volatile solids (VS) basis. Total solids and volatile solids for the substrate were determined beforehand. Total solids (TS) were found by heating the substrate samples at 105 °C for 24 h and volatile solids (VS) were measured as a loss of ignition at 550 °C for three hours. No additional nutrients were added to the BMP test. Before starting the experiment, the test bottles were flushed with N_2/CO_2 (80/20) to assure anaerobic conditions. Test bottles were incubated at 36 °C in a set of Mermet isothermal thermo-chambers during a span of 42 days. The blanks which contained inoculum alone were included in order to allow a measurement to be made of the biogas and methane production from the inoculum, which were later subtracted from that of the tests with substrate. Biogas production was determined by measuring pressure in the headspace of bottles with a pressure meter, a BMP-Testsystem WAL (WAL Mess- und Regelsysteme GmbH). The concentration of methane in biogas was analysed with a gas chromatograph (CP-4900 Micro-GC, Varian Inc).

The inoculum was collected from the anaerobic reactor at the municipal wastewater treatment plant in Tartu, Estonia. Before use the inoculum was sieved through 1 mm mesh and was pre-