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Research Article

Potential Cellulosic Ethanol Production from Organic Residues of Agro-Based Industries in Nepal

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With the objective of exploring the potential of bioethanol production from lignocellulosic wastes from major agro-based industries in Nepal, four types of major industries using raw materials from agriculture are selected as sources of lignocellulosic residues. They include a sugar industry, a paper industry, a tobacco industry, and a beer industry. Data from secondary/primary sources were used to record organic residues from these industries and estimates were made of potential production of bioethanol from them. About 494892.263 tons of dry bagasse could be produced if the total production of sugarcane in Nepal is taken to the sugar industry which means that about 138569.833 KL of bioethanol could be produced (in the year 2011/12). Similarly, the dry biomass residue produced from the paper mill is 86.668 ton/year that could produce 24.267 KL of bioethanol. The lignocellulosic residue from tobacco field in Nepal is approximately 18.826 ton/year that has potential to produce 5.836 KL of bioethanol. The dry biomass residue produced in beer industry amounts to 155.0596 ton/year that can yield about 63.5744 KL of bioethanol. It is estimated that about 57,841.3754 KL of bioethanol could be produced when these residues are fully utilized in producing bioethanol. If E10 is used in total import of petrol, about 20246.7 KL of bioethanol could be utilized, and the rest 37,594.6754 KL of bioethanol could be utilized for many other purposes.

1. Introduction

The world's economy today highly depends on fossil energy sources of which crude oils have been the major resource to meet the increased energy demand [1]. The utilization of these depletable sources in the long run is not considered to be sustainable. So, many countries around the world are shifting their focus toward renewable alternative sources for power production [2]. One renewable solution concerning the depletion of fossil fuels and the atmospheric pollution derived from their combustion is the use of biomass (bioenergy). The conversion of biomass into biofuels represents an important option for both the exploitation of an alternative source of energy and the reduction of polluting gases, mainly carbon dioxide [3, 4]. A variety of fuels can be produced from biomass resources that also include liquid fuels such as ethanol and methanol [5]. Liquid biofuels have several advantages [6]. Growing environmental concerns over the use and depletion of nonrenewable fuel sources, together with the increasing price of oil and instability in the oil market, have recently stimulated interest in optimizing fermentation process for large scale production of alternative fuels such as bioethanol [7].

The major biofuels include bioethanol and biodiesel and their major feedstocks are sugarcane or corn and oil seed, respectively. Bioethanol is petrol additive/substitute which can be blended in petrol at about 10–20% (E10-20) without modification of engine. Production of bioethanol from food crops such as maize and wheat by developed countries like the USA cannot solve the energy crisis but will further aggravate the food security and therefore has been opposed from most parts of the world. To avoid conflict between human food use and industrial use of crops, the wasted crops including lignocellulosic biomass as crop residues and sugarcane bagasse are included as feedstock for bioethanol production [8]. Production of bioethanol from the organic wastes comes in handy both from the environmental point of view and from the point of view of ensuring food security

[9, 10]. Extensive research has been carried out on ethanol production from lignocellulosic residues in the past two decades [11]. There is an estimate of 73.9 Tg of dry wasted crops in the world that could potentially produce about 49.1 GL year^{-1} of bioethanol [12]. Moreover, about 1.5 Pg year^{-1} of dry lignocellulosic biomass can be available from major food crops for conversion to bioethanol. Lignocellulosic biomass could produce up to 442 GL year^{-1} of bioethanol. Rice straw is the most favourable bioethanol feedstock followed by wheat straw, corn stover, and sugarcane bagasse. But current approaches require that the sugars contained in them to be separated before they can be turned into useful form for fermentation [9, 10]. Asia is the largest potential producer of bioethanol from crop residues. At present, Brazil and the US are major producers of bioethanol from sugarcane and corn, respectively. Nevertheless, progress has been made in utilizing lignocellulosic biomass for bioethanol [12]. Several microorganisms have been tested for converting cellulosic feedstock to ethanol via biological processing on the industrial scale, of which *Saccharomyces cerevisiae* and *Zymomonas mobilis* have shown promising results in terms of ethanol yield in bioconversion of lignocellulosic biomass in different conditions [13].

Nepal is one of the countries with no any conventional fuel sources and is entirely dependent on imported fuel. Search for biofuel in Nepal was started recently and it focused mainly on the diesel plant, *Jatropha* [14–17]. Other than this, molasses has been the major feedstock for ethanol production. However, it is not justifiable that single feedstock (molasses) can fulfill all the needs of alternative fuel. Therefore, other possible nonfood based alternative resources must be explored and introduced. Among several possibilities, production of bioethanol from the nonfood based lignocellulosic wastes from agro-based industries can be potential source of bioethanol production. To this end, an estimation of the availability at present is the prerequisite of any further planning in this direction. The present study aims to assess the prospect of bioethanol production in Nepal. The questions we intend to address in this study are (i) how much organic wastes are produced from the agro-based industries? and (ii) what is the potential of bioethanol production from that lignocellulosic biomass?

2. Materials and Methods

2.1. Sampling. Sampling was done at four leading agro-based industries in Nepal (Table 1). Information about issues related to cultivation of crops as raw materials for these industries and generation of biomass residues was taken from farmers and relevant stakeholders. Samples from industries were taken for three times during the month of Falgun (Feb-Mar, 2012) whereas crop growers were contacted for once except for tobacco growers (they were sampled thrice). Data were collected from both primary and secondary sources.

2.2. Data Collection. The total biomass (lignocellulosic residue) was estimated on the dry weight basis. For this, fresh samples from the target industry sources were brought to the laboratory. The types of residues both from industrial sources and agricultural fields are given in Table 2. Five samples were taken from each source at every sampling time. Each sample contained 100 g of the residues both from industry and from agricultural field for sugarcane; from industries for paper and beer; and from agricultural field for tobacco. Samples were carried in closed plastic bags to the laboratory. Each sample was placed in hot air oven at about 70°C. These dried samples were then weighed and their mass was recorded until there was a constant reading. The information about organic residues was also collected from different stakeholders such as industry owners, key informants (technicians in the industries).

2.3. Estimation of Potential Bioethanol Production from Organic Residues. To estimate potential bioethanol production from these organic residues, dry biomass of the residues was used. The dry biomass was converted to ethanol following Kim and Dale [12]. Although there is no direct estimation of bioethanol production from dry biomass of tobacco, a US company based in Virginia is using genetically modified tobacco as a feedstock to produce both ethanol and biodiesel. It claims that one acre of tobacco can replace between eight and 12 acres of corn and soy (http://www.thebioenergysite.com/news/8706/producing-ethanol-and-biodiesel-from-tobacco, accessed on June 8, 2013). If we use corn stover, compared to tobacco, it contains 0.29 L ethanol/kg dry biomass [12]. It means that tobacco can yield 0.31 L of ethanol per kg of dry biomass (8% of 0.29 = 0.023; therefore, yield is 0.29 + 0.023 = 0.313 L/kg dry mass).

2.4. Data Analysis. Data obtained from various sources were processed and were presented in appropriate tabular/graphical forms. Comparison of results from different sources was made using one-way analysis of variance (ANOVA) test. All analyses were performed by using SPSS for Windows (16.0.0, SPSS Inc., USA).

3. Results

In order to estimate the dry biomass of residues coming from industries and/or from agricultural fields, samples were processed in the laboratory and the averaged dry biomass was used to estimate the total dry residues produced from that agro-based industry that can be used to produce bioethanol.

3.1. Organic Residues from Sugar Industry. The average dry biomass of residues produced from sugar industry and sugarcane field is shown in Figure 1. Although the values ranged from 51.00 to 52.50 g/100 g, there is significant difference ($P < 0.05$) among the average dry biomass of three sampling times in case of residues (bagasse) from sugar factory. On the other hand, the average dry biomass for residues from sugarcane field was much lower and ranged between 36.08 and 39.01 g/100 g and was significantly different ($P < 0.01$) among three sampling times.

On averaging all samples, the mean dry biomass of residues from sugar factory comes to be 51.97 g/100 g and that

Table 1: Studied industries and their location in Nepal.

S. N.	Name of industry	Location
(1)	Indu Shankar Sugar Mill Pvt. Ltd.	Hariwan, Sarlahi.
(2)	Everest Paper Mill Pvt. Ltd.	Mahendranagar, Dhanusha.
(3)	Surya Nepal Pvt. Ltd.	Simara, Bara.
(4)	Himalayan Brewery Pvt. Ltd.	Godawari, Lalitpur.

Table 2: Types of residues and their sources.

S. N.	Residue	Source Industries	Agricultural field
(1)	Sugarcane bagasse	Indu Shankar Sugar Mill, Hariwan, Sarlahi	
(2)	Green and dried leaves of sugarcane	—	Hariwan-9, Sarlahi
(3)	Solid wet residues of paper	Everest Paper mill, Mahendranagar, Dhanusa	—
(4)	Green stems of tobacco	—	Viruwaguthi-1, Parsa
(5)	Fresh biomass (beaten barley)	Himalayan Brewery, Godawari, Lalitpur	—

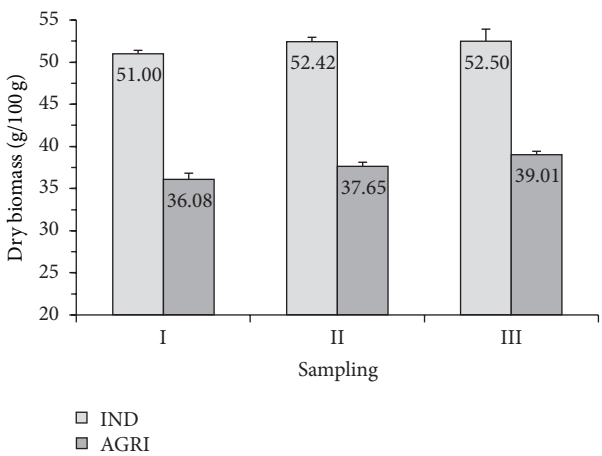

Figure 1: Estimated dry biomass of lignocellulosic residues from sugar industry (IND) and agricultural field (AGRI) for I, II, and III samplings. Columns represent average values with vertical bars as SD of the means ($n = 5$).

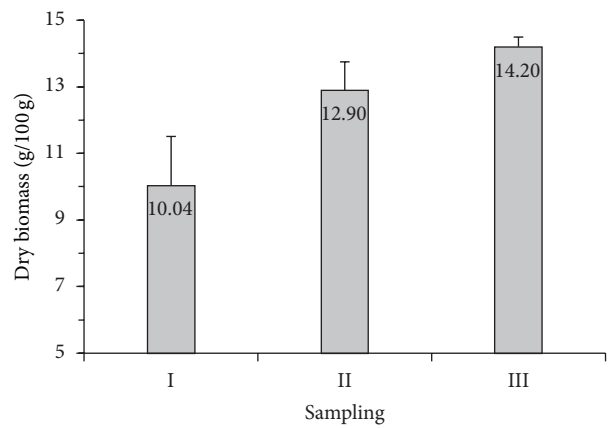

Figure 2: Estimated dry biomass of lignocellulosic residues from paper industry for I, II, and III samplings. Columns represent average values with vertical bars as SD of the means ($n = 5$).

from sugarcane field is 37.47 g/100 g. These values were used to estimate the potential bioethanol production.

3.2. Organic Residues from Paper Industry. The amount of dry biomass residues produced from the paper industry ranged between 10.04 and 14.20 g/100 g of the fresh residues (Figure 2). The average values differed significantly ($P < 0.01$) for the three samplings. On averaging all samples, the mean value of dry biomass residue comes to be 12.38 g/100 g of the fresh residue.

3.3. Organic Residues from Cigarette (Tobacco) Industry. The average values of dry biomass residues produced from the harvested tobacco crop varied from 12.68 to 17.73 g/100 g of the fresh residues (Figure 3). Higher dry biomass was obtained for the III sampling ($P < 0.01$) of the tree samplings. The average dry biomass of all samples is 15.095 g/100 g of the fresh residues which is used in the calculation of potential bioethanol production.

Important is the fact that fresh residues could not be obtained from Surya Nepal Pvt. Ltd. and therefore, dry biomass residues could not be calculated. Hence, estimation of potential bioethanol production from the residues was not calculated.

3.4. Organic Residues from Beer Industry. The average dry biomass residues produced at the beer industry range from 17.03 to 18.62 g/100 g of the fresh residues (Figure 4). However, there is no significant variation ($P > 0.05$) in the dry biomass produced in this case over the sampling period. For all the samplings, the average dry biomass residues produced was 17.897 g/100 g, the value used for estimation of potential bioethanol production.

Table 3: Estimated bioethanol production from different sources.

Source of residues		Dry biomass produced (ton/year)	Ethanol content (L/kg) in dry biomass [12]	Estimated bioethanol that can be produced (KL)
Industry	Cultivated land			
Indu Shankar Sugar Mill Pvt., Ltd.	—	65,029.965	0.28	18,208.390
—	Sugarcane field from whole Nepal	141,211.815	0.28	39,539.308
Everest Paper Mill Pvt., Ltd.	—	86.668	0.28	24.2670
Surya Nepal Pvt., Ltd.	—	NA		NA
—	Tobacco field residue from whole Nepal	18.826	0.31*	5.836
Himalayan Brewery Pvt., Ltd.	—	155.0596	0.41	63.5744
Bioethanol that could be produced from the dry bagasse produced from whole Nepal in the year 2011/12 (includes that from Indu Shankar Sugar Mill)		494,892.263	0.28	138,569.833
Total		636,264.974		178,202.8184

NA: not available; *as stated in the calculation of ethanol from dry biomass in Section 3.

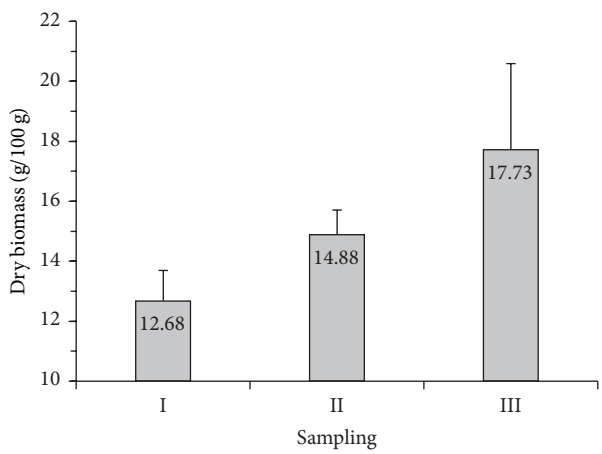

Figure 3: Estimated dry biomass of lignocellulosic residues from harvested tobacco crop for I, II, and III samplings. Columns represent average values with vertical bars as SD of the means (n = 5).

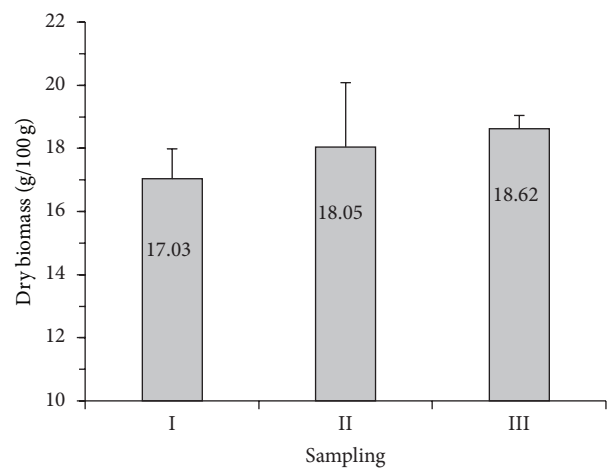

Figure 4: Estimated dry biomass of lignocellulosic residues from beer industry for I, II, and III samplings. Columns represent average values with vertical bars as SD of the means (n = 5).

The amount of dry biomass residue (lignocellulosic biomass) and potential ethanol production from them is given in Table 3. Total dry biomass produced from the sugar industry is appx. 65029.965 ton/year that has the potential of producing 18,208.390 KL/year of bioethanol. On the other hand, total dry biomass residue produced from sugarcane cultivated land for Nepal is 141211.815 ton/year and has potential of producing 39539.308 KL of bioethanol per year.

Similarly, the dry biomass residue produced from the paper mill is 86.668 ton/year which has potential of producing 24.267 KL of bioethanol. The estimate of lignocellulosic residues produced from tobacco field shows that dry biomass residues from tobacco field in Nepal is appx. 18.826 tons/year that has potential to produce 5.836 KL of bioethanol per year. In case of beer industry, the dry biomass residues produced amount to 155.0596 ton/year. This can yield about 63.5744 KL/yr of bioethanol. The total import of petrol and required amount of bioethanol for blending are given in Table 4. When E-10 blending is considered, the amount of bioethaol required comes to be 20246.70 KL.

4. Discussion

Results indicate that the most suitable raw material among the industries in present study is sugarcane bagasse, both in terms of quantity and quality in producing bioethanol. It is evident that about 18208.390 KL/yr of bioethanol can be produced from dry bagasse of Indu Shankar Sugar Mill Pvt. Ltd. alone. But when bagasse produced from all sugar mills in Nepal is taken into consideration, it comes to be many fold suitable feedstock for bioethanol production (138,569.833 KL/yr). Globally, about 180 Tg of dry sugarcane bagasse is produced which is when utilized could produce

Table 4: Blending percentage and required amount of bioethanol in total import of petrol in Nepal.

Total import of petrol in the year 2011/12 (KL)	Blending amount of bioethanol (%)	Bioethanol required (KL)
202467	5	10123.35
	10	20246.70
	15	30370.05
	20	40493.40

about 51 GL of bioethanol per year [12]. Furthermore, dry biomass of lignocelluosic residues is available from that of sugarcane field which is potentially a huge feedstock that can produce more bioethanol.

Residues from sugar industries (at sugarcane fields and sugarcane bagasse) are utilized for many other purposes. Bagasse is used for electricity generation in the sugar industry through steam production, used as a raw material for paper industry, used to make board, and also used as fuel for brick industry. The residues of sugarcane field are utilized for cattle feedings and are also left in the field as organic manure so that the nutrient is recycled to the soil after decomposition and maintains the soil fertility [18]. To some extent, it is also used as fuel for cooking. Each year a large portion of field residues is burnt which directly affect nutrient cycling pattern in the crop field and also add to the global warming [3]. Extensive research has been carried out on ethanol production from these agricultural residues which can prevent the loss of these resources and reduce global warming [11]. Hence, bioethanol production can be one of the effective ways of its sustainable utilization.

Paper is manufactured from organic residues and the major raw material is rice straw; sugarcane bagasse and husk of wheat are also used. The damaged papers are again recycled to make paper, so, the least residue is produced from paper industry as compared to sugar industry. Therefore, estimated bioethanol production from the residues of paper industry has been lower than sugar industry (24.2670 KL/year of bioethanol). In case of tobacco industry, the potential of bioethanol production is much low (5.836 KL/yr) owing to the fact that factory residues are least produced. In case of beer industry, the residues produced from the factory could produce 63.5744 KL/year bioethanol.

With Brazil and the USA as global leaders in the production of biofuels from corn, sugarcane, and lignocellulosic crops, countries in Asia are also emerging as players in the biofuel market. Among them, China produces an enormous amount of agricultural residue suitable for biofuel production, with ethanol blended fossil fuel comprising 20% of total Chinese petroleum consumption. In India, first generation biofuel technology is more mature than second generation technologies, with India supporting its bioethanol production with sugarcane molasses and biodiesel from *Jatropha* [19]. So, production of bioethanol has increased year after year because of being renewable energy. Hence, Nepal cannot keep away itself from this scenario since there are no proven fossil fuel deposits available in the country and total petroleum products are imported.

Being as a developing country, the energy consumption rate increases in Nepal as the country steps forward in development; the demand for fuels increases accordingly. But because of rapid fluctuations of fossil fuel prices in the world market and the political instability in the country, shortage of petroleum products has become very common experience [20]. The total import of petrol in Nepal in fiscal year 2011/12 is 202467 KL. If implemented, bioethanol blending to petrol in Nepal could reduce Nepal's fuel import which could save substantial money and could also minimize the environmental pollution. From the present study, it is estimated that about 57,841.3754 KL of bioethanol could be produced from the four industries when the residues are fully utilized in producing bioethanol. If E10 is used in total import of petrol, about 20246.7KL of bioethanol could be utilized, and the rest 37,594.6754 KL of bioethanol could be utilized for many other purposes. When the total potential ethanol production is taken into account, the surplus could be incredibly large.

In conclusion, although limited in its scope and scale, the study highlights the fact that Nepal has great potential to produce lignocellulosic-based ethanol and to use it as part of a blend in gasoline-run vehicles. The increased use of biofuels not only reduces dependency on fossil fuels but also reduces the greenhouse gas (GHG) emissions and local air pollution caused by vehicular emissions. In addition, the production of biofuels can serve as a driver for improvements in employment generation and agriculture sector.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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