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Assessment of by-products of bioenergy systems (anaerobic digestion and gasification) as potential crop nutrient

Sampriti Kataki [a], Samarendra Hazarika [b], D.C. Baruah [a,*]

[a] Energy Conservation Laboratory, Department of Energy, Tezpur University, Assam, India
[b] ICAR Research Complex for North Eastern Hill Region, Umium, Meghalaya, India

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ABSTRACT

Alternative fertilizer resources have drawn attention in recent times in order to cope up with ever increasing demand for fertilizer. By-products of bioenergy system are considered favourable as organic fertilizer due to their ability to recycle plant nutrients. Present study evaluates fertilizer suitability of by-products of two bioenergy systems *viz.* 3 types of anaerobic digestion by-products (digestate) from local surplus biomass such as cowdung, *Ipomoea carnea*:cowdung (60:40) and ricestraw:green gram stover:cowdung (30:30:40) and one gasification by-product (biochar) from rice husk. Digestates were assessed considering 4 different application options of each *viz.* whole, solid, liquid and ash from solid digestates. Digestate characteristics (organic matter, macronutrients, micronutrients and heavy metal content) were found to be a function of feedstock and processing (solid liquid separation and ashing). *Ipomoea carnea* based digestates in all application options showed comparatively higher N, P, K, NH_4^+-N, Ca, Mg, S and micro nutrient content than other digestates. Separation concentrated plant nutrients and organic matter in solid digestates, making these suitable both as organic amendments and fertilizer. Separated liquid digestate shared larger fraction of ammonium nitrogen (61–91% of total content), indicating their suitability as readily available N source. However, fertilizer application of liquid digestate may not match crop requirements due to lower total nutrient concentration. Higher electrical conductivity of the liquid digestates (3.4–9.3 mS cm^{-1}) than solid digestates (1.5–2 mS cm^{-1}) may impart phyto-toxic effect upon fertilization due to salinity. In case of by-products with unstable organic fraction i.e. whole and solid digestates of rice straw:green gram stover:cowdung digestates (Humification index 0.7), further processing (stabilization, composting) may be required to maximize their fertilizer benefit. Heavy metal contents of the by-products were found to be within the permitted range specified for organic fertilizer (vermicompost) in India. However, higher Al content of the digestates in whole, solid and ash phase (0.06–16.97g kg^{-1} fresh matter) can be a concern in acid soil which may cause Al toxicity.

Understanding on agrochemical characteristics of bioenergy by-products with varying feedstock and application option is expected to promote their valorization opportunities considering user specific requirements. In the context of agriculturally dominant but energy deficient rural Indian scenario, integrated production of bioenergy and by-product based fertilizer could be very significant to meet the critical additional requirement of both energy and fertilizer.

1. Introduction

Intensification of agricultural sector is imperative to ensure food security for growing population which is projected to reach 9.7 billion by 2050 (UN, 2015). To meet the associated global food demand, a necessary rise of 60% in current agricultural production by 2050 has been estimated by Food and Agriculture Organization of United Nations (FAO, 2013). For achieving such agricultural intensification, supplementation of external nutrient input to replenish soil is vitally important which is primarily done through chemical fertilizer. However, the prospect of organic fertilizer for enhancing crop production and sustaining soil health has also been realized. In this context, by-products of bioenergy systems could also be considered as prospective organic fertilizers, as it retains nutrients from input raw materials (Salminen et al., 2001; Gell et al., 2011). Furthermore, unpredictable cost dynamics and harmful impact of prolonged use linked with chemical fertilizer have

* Corresponding author.
E-mail addresses: sam_kat@tezu.ernet.in (S. Kataki), baruahd@tezu.ernet.in (D.C. Baruah).

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also led to consideration of recycling of these organic residues to land as a practice of nutrient conservation and management.

Bioenergy by-products (BEBPs) such as (i) digestate from anaerobic digestion (AD) that produces biogas and (ii) biochar from biomass gasification (BG) that produces producer gas are inevitable commodities of bioenergy conversion process (Taheripour et al., 2010; Galvez et al., 2012). Consideration and management of these residues along with main energy output are essentially required for comprehensive assessment and sustainability of bioenergy system (Taheripour et al., 2010; Wang et al., 2011; Galvez et al., 2012; Dahlin et al., 2015). With faster expansion of anaerobic digestion and gasification technologies empowering rural areas of developing countries, it is expected that, there will also be simultaneous increase in the by-products generated. Depending upon the feedstock, about 5–80% of input feedstock is generated as residue in energy conversion process (Moller and Müller, 2012). Thus, major portion of residue remains to be handled in bioenergy production process, calling for their proper management.

AD and BG processes have high adaptation to undertake a range of feedstock, which led to generation of by-products with varying physico-chemical characteristics (Abubaker and Risberg, 2012; Enders et al., 2012). The fertilizer potentials of digestates from poultry slaughterhouse waste (Salminen et al., 2001), municipal sludge (Tambone et al., 2010; Massaccesi et al., 2013), cowdung, human excreta, pig slurry (Gell et al., 2011), guinea pig manure (Garfi et al., 2011), farm and agro industrial residue (Alburquerque et al., 2012), cow dung and chicken droppings (Alfa et al., 2014), Maize silage (Nabel et al., 2014; Westphal et al., 2016), food waste co-digested with human excreta (Owamah et al., 2014); food waste (Chiew et al., 2015; Tampio et al., 2016), sugar beet pulp, fruit marc, maize silage (García-Sanchez et al., 2015) were shown to be a function of feedstock. These studies discussed various chemical and biological (macro and micro nutrient, heavy metal, organic content, pH, cation exchange capacity, chemical and biochemical oxygen demand, electrical conductivity, microbial mass, pathogenic content, phyto-toxicty) and physical indicators (dry matter, suspended solid, odour, dissolved solid) to evaluate quality of digestate as fertilizer. In general, digestates are reported to contain nutrients with enhanced bio-availability (60–80% of total nitrogen in mineralized form along with bioavailable phosphorus and potassium), making these a suitable consideration as soil applicant (Tambone et al., 2009; Garfi et al., 2011; Makadi et al., 2012).

Performance of digestates as soil applicant is found to be encouraging depending upon quality and nutritional status (Arthurson, 2009). Benefits of digestate application are reported as enhanced crop yield (Rivard et al., 1995; Kocar, 2008; Vaneeckhaute et al., 2013), plant nutrient uptake (Rubaek et al., 1996; de Boer, 2008; Terhoeven-Urselmans et al., 2009; Bachmann and Eichler-Löbermann, 2009; Andruschkewitsch et al., 2013; Koszel and Lorencowicz, 2015) and enhanced soil quality through higher available N and P, nitrogen mineralization capacity, soil respiration, increased microbial activity and diversity (Friedel et al., 1996; Odlare et al., 2008; Galvez et al., 2012; Sapp et al., 2015; García-Sanchez et al., 2015). Performance of digestate was reported to be at par with chemical fertilizer in terms of crop yield and soil properties by some other researchers (Adelekan et al., 2010; Loria et al., 2007; Chantigny et al., 2008; Abubaker and Risberg, 2012; Herrmann et al., 2013; Riva et al., 2016).

As seen from the above discussion, though the fertilizer value of digestate could be realized, however, there are some feedstock related and managerial issues that can limit their direct agricultural valorization. Application of some types of digestates are not encouraged due to increased soil salinity, soil heavy metal accumulation, introduction of contaminant, phyto toxicity, ecotoxicity that may arise from feedstock dependent digestate properties (WRAP, 2009; Govasmark et al., 2011; Massaccesi et al., 2013; Islam et al., 2014; Kupper et al., 2014; Chiew et al., 2015; Tigini et al., 2016). There are also some managerial issues such as problems of bulk handling, transportation that increase distribution cost (WRAP, 2013), nutrient leaching and pollution from emission (N_2O, CH_4) due to improper method of application and storage (Sharpley and Moyer, 2000; Eickenscheidt et al., 2014; Zeshan and Visvanathan, 2014; Riva et al., 2016), resulting in non-optimized utilization of digestate. To address these issues, some processing methods such as dewatering, solid liquid separation and stabilization (composting) have been proposed to obtain products suitable for different uses (Balsari et al., 2010; Teglia et al., 2011a). However, understanding on characterization and distribution of nutrients with respect to varied feedstock and processing are required for appropriate and selective use.

Similarly, application of biochar, a by-product of gasification was reported to increased crop productivity, soil organic carbon, total N, extractable P, K, Mg (Laird et al., 2010; Zhang et al., 2012; Galvez et al., 2012). Potential benefits of biochar as fertilizer are generally attributed to its capacity to enhance soil property through carbon sequestration and reduced GHG emission (Lehmann et al., 2006). Fertilizing effect of biochar depends upon input feedstock and method of application (Gell et al., 2011).

To summarize the above discussion, benefits of BEBP as crop nutrient have been almost conclusively evidenced from the previous works. The prospect of application of such alternative fertilizer resource is very significant in Indian context, as the critical additional requirement of both energy and fertilizer could be understood from Table 1. Particularly in North East India, where per capita energy availability (1221 MU) is lower than the national average (96,739 MU) and also chemical fertilizer input (66 kg ha^{-1}) in agriculture is far lower than the national average (128 kg ha^{-1}) (Table 1), integrated production of bioenergy and by-product based fertilizer production are expected to ensure sufficient nutrients inputs for crop production and for promotion of energy. However, there are certain region specific research issues to be addressed in the area of by-product utilization to adequately upgrade these to a general acceptable level or to make it competent with the chemical fertilizer.

Keeping in view of the above discussion, this work is undertaken to generate required knowhow to promote BEBPs into value added commodity. A comprehensive characterization of the BEBP with all possible options of its application would help to evaluate

Table 1
Energy, power and fertilizer scenario in India.

Energy requirement and availability scenario in August, 2015[a] India	
Requirement (in MU)	99,281
Availability (in MU)	96,739
Deficiency, %	2.6
Energy requirement and availability scenario in August, 2015[a] North East India	
Requirement (in MU)	1297
Availability (in MU)	1221
Deficiency, %	5.9
Per capita consumption of electricity, 2011–12 (kW h year^{-1})[b]	
India average	884
North East India	403
Assam	250
Per ha fertilizer consumption during 2012–13 (kg/ha)[b]	
India average	128
North East India	52
Assam	66

MU: Million Unit.
[a] Annual report (2013-14), Power and Energy Division, Planning commission, Govt. of India.
[b] Executive summary, Power sector, 2016, Govt. of India, Ministry of Power.