Renewable and Sustainable Energy Reviews 15 (2011) 4910–4916

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Utilization of waste nitrogen for biofuel production in China

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ARTICLE INFO

Article history:
Received 19 January 2011
Received in revised form 18 April 2011
Accepted 7 July 2011
Available online 22 September 2011

Keywords:
Energy consumption
Land resource
N pollution
Water
Sustainable development
Tibet

ABSTRACT

Nitrogen (N) is the limiting factor for current biofuel production. Enormous quantities of waste N from agricultural, industrial and domestic use have been lost to the environment resulting in serious negative consequences. In this study, we discuss biofuel production using waste N (BPWN) on untilled or marginal land. Taking China as an example, the total waste N lost to surface water was estimated at 11.3 Tg N (1 Tg = 10^{12} g) in 2008, accounting for 40% of total fertilizer N applied to China's cropland. The total potential biofuel produced by waste N was estimated at 16,436.3 PJ year^{-1} (1 PJ = 10^{15} J), accounting for ~20% of China's total energy consumption, or five times China's total gasoline demand in 2008.

The net energy balance (Output–Input) of BPWN is 570 GJ ha^{-1} year^{-1} (1 GJ = 10^9 J) in China, about 15–30 times that of current major biofuel production systems (e.g. corn, switchgrass, low-input high-diversity grassland). The feasibility analysis shows that, although the land resources for BPWN are not sufficient in one-fifth of China's provinces if considering all of the potential waste N supply, the total maximum land requirement is only 17.5% of China's total untilled land resource. Further research on the imbalance between land requirement and waste N supply on the regional and local scales will help to refine the estimate of biofuel production potential.

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1. Introduction

The energy crisis has given rise to concern over future energy supplies and global climate change, thus, sustainable alternative biofuels have attracted much attention [1]. The two current major biofuel production systems, monoculture crop and cellulosic ethanol biomass, are nitrogen (N) fertilizer dependent if a high-energy yield is expected [2,3]. However, the high N input of current biofuel production has led to a large amount of waste reactive N lost

Abbreviations: BPWN, biofuel production using waste nitrogen; CW, constructed wetland; DW, dry weight; GHG, greenhouse gas; LIHD, low-input high-diversity grassland; N, nitrogen; NEB, net energy balance; NER, net energy balance ratio; NUE, nitrogen use efficiency; WTP, wastewater treatment plant.

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1364-0321/$ – see front matter
doi:10.1016/j.rser.2011.07.062

Table 1
Productivity potential of aboveground biomass, N and land requirement and energy yield of current and potential biofuel plants.

Plant	Productivity ($MT\,ha^{-1}\,year^{-1}$)	Nitrogen requirement ($kg\,ha^{-1}\,year^{-1}$)	Net energy yield/N ($GJ\,kg^{-1}$ N)	Land requirement/N ($ha\,Gg^{-1}$ N)	Reference
Miscanthus[a]	25	200	2.1	5000	[21]
Giant reed[b]	45	600	1.2	1670	[20]
Napiergrass[c]	88	–	–	–	[24]
Alemangrass[d]	100	–	–	–	[24]
Corn	10	120	0.2	8333	[24]
Switchgrass[e]	11	75	1.0	13,333	[3]
LIHD[f]	6	–	–	–	[28]

1 MT = 10^6 g; 1 GJ = 10^9 J; 1 Gg = 10^9 g.
[a] Latin name of the plant is *Miscanthus* x *giganteus*.
[b] Latin name of the plant is *Arundo donax*.
[c] Latin name of the plant is *Pennisetum purpureum*.
[d] Latin name of the plant is *Echinochloa polystachya*.
[e] Latin name of the plant is *Panicum virgatum*.
[f] Latin name of the plant is including 18 perennial prairie species, e.g. *Lupinis perennis*, *Andropogon gerardi*, and *Poa pratensis*.

to the environment [3]. This, together with the waste N derived from agricultural, industrial and domestic use, has contributed to the massive waste N lost to the environment [4] and resulted in serious environmental problems, e.g. the 'dead zone' from the Gulf of Mexico [2]. Enormous investments have been spent to produce N fertilizers and solve the environmental pollution and human health problems driven by excessive waste N [5]. In this context, ideas for using the waste nutrients and biomass have been suggested which could supply biofuels without N fertilizer requirement [6].

The N loss from global cropland has been estimated at ~65 Tg N year^{-1} (1 Tg = 10^{12} g) [7], and ~35 Tg N year^{-1} from livestock production [8]. Meanwhile, human excretion has added ~20 Tg N year^{-1} to the global environment [9]. These waste N levels lost to the environment supply an enormous potential for the nutrient requirement of biofuel production. Coupling the waste N and biofuel production can not only mitigate the global N pollution and reduce the investment in N pollution control [6], but can also provide N for biofuel production [10,11]. At the same time, there is a reduced health risk from using waste N for biofuel production compared to using it for agricultural food production [12]. This might be a win–win strategy for mitigating both the environmental N pollution and the energy crisis.

China, as the world's largest agricultural economy, consumes one-third of global fertilizer N production [13]. The over-fertilization on cropland [14] and the decoupling of livestock and cropland [15] in China have resulted in a large amount of waste N lost to the environment. The population of China ranks first globally, and the low domestic wastewater treatment ratio [16] has also contributed to the waste N discharge. The development of waste N patterns in China during the past few decades can be regarded as the epitome of the development history of developed countries, and can also offer a case study for the sustainable development of other developing countries. In this study, taking China as an example, we: (1) determined the potential for biofuel production using waste N (BPWN); (2) examined the spatial pattern of total and per capita BPWN potential; and (3) analyzed the feasibility of BPWN on the basis of water supply and land resources. The outcomes not only concern China, but might also provide a potential alternative route for solving environmental and energy problems in other countries.

2. Advantages of BPWN

Biofuel production using waste N by planting energy crops on untilled or marginal land is emphasized in this paper. Such an idea can be extended to biomass production using wastewater via constructed wetlands (CW) [17], cropland runoff via riparian buffer strip and marginal land [18], etc. Compared to current biofuel production, BPWN has the following advantages:

(1) There is no need for N fertilizer application and so it can reduce the cost of energy input and increase the net energy balance ratio (NER, Output/Input).
(2) BPWN can reduce environmental N pollution, the cost of pollution control and greenhouse gas (GHG) emissions since there is no need for the waste N to be treated via treatment facilities, e.g. wastewater treatment plant (WTP).
(3) Waste N is coupled to water supply, such as domestic wastewater, and the effluent water can be reused for irrigation; therefore, there is less water deficiency stress on BPWN.
(4) BPWN can use untilled or marginal land and so can avoid competing with food production on fertile soils.
(5) BPWN can also provide other ecosystem services, including renewal of soil fertility, and avoiding health risks since if the waste N is not being used for biofuel production, it might be used for agricultural food production instead.

3. Biomass and energy yield of BPWN

In this paper, BPWN was performed by planting two typical energy crops, *Arundo donax* and *Miscanthus* x *giganteus* [19–21]. *A. donax* is a native species in subtropical and tropical regions of China and has been used for biomass production in CWs [22]. *A. donax* has also been recommended as an energy crop in Australia and North America using wastewater irrigation [19,20]. The potential biomass production of *A. donax* can reach ~45 MT (1 MT = 10^6 g) dry weight (DW) ha^{-1} year^{-1} with an N supply around 600 kg N ha^{-1} year^{-1} [20]. *M.* x *giganteus* has been introduced to China as energy crop that is suitable for planting in the temperate zone and Qinghai–Tibet plateau [23]. As a novel energy crop in Europe, *M.* x *giganteus* can still achieve a high-energy yield in high latitude regions [19,21]. The biomass production potential of *M.* x *giganteus* can reach ~25 MT dry DW ha^{-1} year^{-1} with a N supply around 200 kg N ha^{-1} year^{-1} (Table 1). The average biomass production of BPWN with the above two species is much higher than that of switchgrass and low-input high-diversity (LIHD) grassland, as well as corn with considering the whole aboveground biomass (Table 1); however, it is still lower than that of the biofuel feedstock found in tropical regions, ~100 MT DW ha^{-1} year^{-1} [24].

Compared to corn, switchgrass and LIHD grassland, the net energy balance (NEB, Output–Input) of BPWN is the largest, reaching 570 GJ ha^{-1} year^{-1}, followed by switchgrass, which is about one-tenth of that of BPWN, while the LIHD and monoculture crop biofuels are the smallest, at around 3% of that of BPWN (Fig. 1). The NER of BPWN is about 2–20 times that of corn, switchgrass and LIHD grassland (Fig. 1), since the no N fertilizer application (replaced by waste N) can largely reduce the energy input.