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ARTICLE

Estimation of potential methane production through the mass balance equations from agricultural biomass in Korea

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Abstract Biomass is a renewable energy resource derived from all organic materials produced by both human and natural activities. Total biomass is amounted to be 58,010 Gg yr^{-1} from agricultural sector during 2013 in Korea: livestock manure, crop residues, and agro-industrial wastes. Potential methane production from agricultural biomass was calculated based on IPCC guidelines using manipulated equations. The main parameters were emission factor, total waste amount, and physico-chemical properties of each waste to estimate methane production. Calculated total potential methane production from the different categories for livestock, crop residues, and agro-industrial wastes was 502 Gg yr^{-1} in Korea. Poultry waste generated the highest methane potential with 227 Gg yr^{-1} followed by 80 Gg yr^{-1} from cattle waste. For crop residues and agro-industrial wastes, estimated methane production was 1 and 126 Gg yr^{-1}, respectively. Results of this study show that livestock manure gave the highest methane emission in the agricultural sector. With this, more effective management of livestock wastes is necessary to develop and maximize technology on harnessing methane as alternative energy.

Keywords Agricultural biomass · Global warming · Greenhouse gas (GHG) · Inventory · Potential methane

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Introduction

Global warming is becoming a critical issue around the world. Numerous researchers and organizations have been involved in reducing the greenhouse gases from various sources (Monni et al. 2004; Laifeld and Fuhrer 2005; Wang et al. 2011). Since many countries recognized the effects of greenhouse gases (GHG), including methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O), the estimation of GHG emission was conducted for a comprehensive understanding of these effects in each country in terms of global warming and the significant mitigation potential (Janssen et al. 1999; Olivier et al. 1999; Yang et al. 2003; Wang et al. 2011).

Biomass is composed of carbon-rich materials including all plants, animals, nutrients, excrements, and bio-waste from households and industries (Deublin and Steinhauser 2011). Unused or discarded biomass residues from agricultural areas are potential energy resource, but at same time can be a source of GHG emissions, causing a significant environmental problem. Potential energy production from crop and animal residue is globally estimated to be about 34 EJ (exajoule = 10^{18} joules) out of a total 70 EJ (Bauen et al. 2004). In Korea, it is estimated that over

5×10^4 Gg of organic wastes are produced every year in agricultural sector out of over 8×10^4 Gg (MIFAFF 2010). The interest in biomass in resource-poor countries such as Korea is therefore increasing.

Anaerobic digestion (AD) is a biological process that converts the solid or liquid biomass into gas in the absence of oxygen (Khanal 2008). Many studies on anaerobic digestion in Korea have focused on pig manure and food wastes as substrates (Youn and Shin 2005; Shin et al. 2008; Yoon et al. 2011). Methane, the main product from this process, is a clean green fuel as well as a greenhouse gas.

Anaerobic digestion for methane production using organic waste in the agricultural sector is becoming economically feasible for intermediate to large-scale animal production operations. Methane produced by the digester can be used as an energy source for electricity and heat generation. This can reduce the treatment cost and methane emission into the atmosphere. However, some of the organic wastes are recycled as compost after an aerobic treatment, which end in landfills or dumped in the ocean. These practices are either consuming a lot of energy, i.e., aerobic digestion or a waste of resources.

Several studies on the agricultural biomass estimation were also conducted in Korea based on the crop-cultivated area (Hong et al. 1989), using an elemental analysis and heating value (Hong 2004). Using dry weight of crops and harvest index is being followed by Food and Agriculture Organization and the U.S. Department of Agriculture (NREL 2005). Estimating the methane production potential from the amounted biomass is a necessary process to make both greenhouse gases (GHGs) and bio-energy conversion inventoried in South Korea. However, an estimated potential methane production from biomass in Korea has not been studied.

The main objective of this study was to estimate the amount of potential methane production based on the total amount of production and characteristics of agricultural biomass in Korea.

Materials and methods

Data collection and sampling

In order to make a comprehensive inventory for estimating the potential methane production from livestock wastes, crop residues, and agro-industrial wastes, a field visit was conducted to characterize the waste management systems used and to verify the information collected through other sources by sampling the agricultural biomass. In addition, interviews with local experts from pertinent ministries (e.g., ministries of agriculture, environment, and energy), local Non-Governmental Organizations and engineering consulting companies working on agriculture and rural development, current users of AD technologies, and other stakeholders including the Ministry of Food, Agriculture, Forest, and Fisheries (MIFAFF), the Ministry of Environment, the Rural Development Administration (RDA), and the National Veterinary Research and Quarantine Service in Korea were done. Secondary data, including national statistical data, were used for estimating the methane yield from Korean statistics.

Calculation of agricultural biomass inventories

The produced amount of animal manure can be varied depending on the species and body weight of livestock, feed sources, and management systems. The agricultural and forestry biomass were calculated as total and volatile dry weights of livestock manure per year based on statistics (NIAS 2009). Fresh manure production from cattle, dairy, swine, and poultry were calculated using the average fresh manure production per Mg to livestock and average weights of corresponding animals in Korea. The average fresh manure productions for cattle, dairy, swine, and layer and broiler chickens were 8.0, 24.6, 1.6, 0.15, and 0.13 kg head^{-1} day^{-1}, respectively (MIFAFF 2009). The average weights of these animals adopted were 350, 473, 111, 1.6, and 1.3 kg, respectively (MIFAFF 2009). The annual total dry weight and volatile dry weight for each type of fresh manure were calculated by multiplying the total annual mass of fresh manure by the average percent solid contents (3.8 % for cattle, 3.9 % for dairy, 4.1 % for swine, and 20.3 % for poultry) and by the average volatile solids fraction (2.7 % for cattle, 2.8 % for dairy, 2.6 % for swine, and 19.8 % for poultry) according to the National Academy of Agricultural Science (MIFAFF 2009). The total volatile dry weight for all agricultural manure was used for the calculation of potential methane production for this category of biomass residues.

As most of cattle are housed within the feedlots in Korea, a 97 % collectible factor was assumed, and the final calculations are shown in Eqs. 1, 2, 3, and 4 (NRC 1983).

$$\text{Total amount of cattle waste} = (\text{population of cattle}) \times 365 \times 13.7 \times 0.97, \quad (1)$$

where 13.7 = unit factors (kg head^{-1} day^{-1}) and 0.97 = collectable factor.

There is no investigated population of dairy cows and calves in Korea; combined population of dairy was used for the calculation. An 85 % collection availability factor was used for the province in confined animal operation (JAYCOR 1990).

$$\text{Total waste amount from dairy} = \text{total population} \times 45.6 \times 365 \times 0.85, \quad (2)$$

where 45.6 = unit factors (kg head^{-1} day^{-1}) and 0.85 = collectable factor.

The calculation of total waste amount generated from swine was based on "Biomass Inventory and Bio-energy Assessment" in Washington, USA (Frear et al. 2005). Also, because most of the swine are raised in farm, the collectable factor was assumed to be 100 %.

$$\text{Total waste amount from swine} = (\text{total population} \times 8.6\,\text{kg head}^{-1}\,\text{day}^{-1} \times 365), \quad (3)$$

where 8.6 = unit factors (kg head^{-1} day^{-1}).

To calculate the total waste amount from poultry, its total population was multiplied by the combined average manure production factor for egg layer and broiler in Korea. Also, an 80 % collectable factor was considered for the final calculation.

$$\text{Total waste amount from poultry} = (\text{total population} \times 0.14 \times 365 \times 0.8), \quad (4)$$

where 0.14 = unit factors (kg head^{-1} day^{-1}) and 0.80 = collectable factor.

The annual total dry weight of crop residues was derived from the report of Lee and Kim (2008).

Estimation of potential methane production related with manure

The 2006 IPCC Guidelines (GLs) for National Greenhouse Gas Inventories Tier 2 method (IPCC 2006) was used for estimating the methane production from each commodity group in the livestock production sector. Using the Tier 2 method, methane potential production for each livestock commodity group (M) and existing manure management system (S) and climate (k) combination were estimated (see below) using Eq. 5;

$$CH_{4(M)} = \left(VS \times H_{(M)} \times 365\ \text{days/year}\right) \times \left[B_{o(M)} \times 0.67\ \text{kg}\ CH_4/m^3 CH_4 \times MCF_{S,k}\right], \quad (5)$$

where $CH_{4\ (M)}$ = estimated methane potential production from manure for livestock category M, kg CH_4 per year, $VS_{(M)}$ = average daily volatile solids excretion rate for livestock category M, kg volatile solids per animal-day, $H_{(M)}$ = average number of animals in livestock category M, $B_{o(M)}$ = maximum methane production capacity for manure produced by livestock category M, m^3 CH_4 per kg volatile solids excreted, and $MCF_{(S,k)}$ = methane conversion factor for manure management system S for climate k, decimal.

As shown in Eq. 5, estimated methane production requires an average daily volatile solids excretion rate for the livestock category. Therefore, the measured values of volatile solids for dairy cows, cattle, swine, and poultry were used for this calculation.

For the livestock wastes, contents of total solid (TS) and volatile solid (VS) were similar for cattle, dairy, and swine, and their ratios of VS/TS averaged at 70.8, 71.8, and 63.4 %, respectively. However, TS and VS values for poultry were much higher than the other livestock species. Moisture content of poultry manure was averaged at 74 % for broilers and layers. Total suspended solid and VS were measured on a dry basis, and BOD_5 and COD were also measured for estimating the methane potential (Table 1).

Realistic estimates of methane production also require identification of the appropriate MCF, which is a function of the current manure management system and climate. MCFs for various types of manure management systems for average annual ambient temperatures were referred to the 2006 IPCC GLs for National Greenhouse Gas Inventories. Specification of the potential methane production (Bo) for the type of manure was considered according to the 2006 IPCC GLs for National Greenhouse Gas Inventories.

Estimation of potential methane production from crop residues and agro-industry wastes

To calculate the potential methane production from crop residues and agro-industrial wastes, two different calculation methods were used based on data availability.

For crop residues, the method of calculation from IPCC GLs was adapted because of the lack of available information for element analysis of crop residues. For emission factor of anaerobic digestion, a dry weight basis emission factor of 1 g CH_4 kg^{-1} waste treated was used (Table 2).

$$CH_4\,\text{emission} = \sum_i (M_i \cdot EF_i) \cdot 10^{-3} - R, \quad (6)$$

where CH_4 emission = total CH_4 emissions in inventory year, Gg CH_4, M_i = mass of organic waste treated by

Table 1 Sources of livestock wastes in Korea

Sources	TS	VS	VS/TS	SCOD	TCOD	NH_3–N	TN
	%			mg L^{-1}			
Cattle	3.8	2.7	70.82	16,818	83,133	1792	4498
Dairy	3.9	2.8	71.79	–	48,026	–	–
Swine	4.1	2.6	63.41	3354	42,402	2403	4004
Poultry	20.3	19.8	97.43	–	196,839	3252	16,900

TS total solid, *VS* volatile solid, *SCOD* soluble chemical oxygen demand, *TCOD* total chemical oxygen demand, *TN* total nitrogen

Table 2 Default emission factor for methane emission from biological treatment of waste

Type of biological treatment	CH_4 emission factors (g CH_4 kg^{-1} waste treated)	
	On a dry weight basis	On a wet weight basis
Composting	10 (0.08–20)	4 (0.03–8)
Anaerobic digestion at biogas facilities	2 (0–20)	1 (0–8)

Source IPCC guideline (2006)

biological treatment type i, Gg, EF = emission factor for treatment i, g CH_4 kg^{-1} waste treated, i = composting or anaerobic digestion, R = total amount of CH_4 recovered in inventory year, Gg CH_4.

Since no distinctive statistical information was available for agro-industrial wastes, the average value of elemental analysis was used for calculation. When information on elemental analysis was available, theoretical methane production, as shown in Eq. 7, was applied.

$$C_aH_bO_cN_d + \left(\frac{4a-b-2c+3d}{4}\right) H_2O \rightarrow \left(\frac{4a+b-2c-3d}{8}\right) CH_4 + \left(\frac{4a-b+2c+3d}{8}\right) CO_2 + dNH_3 \quad (7)$$

Results

Estimation of livestock waste

Populations of different livestock (cattle, dairy, and swine) and poultry species were calculated and examined. The amount of manure mainly depends on the rate of waste production per animal and the number of animals. The main parameters for calculating the total waste amount from livestock are total population of livestock, unit factor, and collectable factors. For determining collectable factors, the management practice of each livestock was considered. Similarly, dairy, swine, and poultry are raised in confined animal feeding operations in Korea. Therefore, the collectable factors were assumed to be 85, 100, and 80 %, respectively, based on the previous study (JAYCOR 1990).

The number of cattle, swine, and poultry has increased by 60.5, 10.6, and 38.0 %, respectively, from 2005 to 2013, while dairy has gradually decreased during this period countrywide (Table 3).

Based on Eqs. 1, 2, 3, and 4, the calculated total waste amount related to livestock manure was 57,456 Gg yr^{-1} in 2013. Among the livestock species, swine had the highest amount of waste with 31,114 Gg yr^{-1}, which accounts for 54.2 % of the total wastes (Fig. 1).

The waste produced from cattle was 24.6 % (14,153 Gg yr^{-1}) of the total waste followed by dairy with 10.4 % (6001 Gg yr^{-1}) (Table 4). The least amount of waste came from poultry because of its lower unit factor compared to other livestock species.

Estimation of crop residues and agro-industrial wastes

Crop residues are also one of the main organic biomasses produced from agricultural practices. Biomass from 13 kinds of crop residues was investigated (Table 5). The total amount of crop residues was estimated at 7820 Gg yr^{-1} in 2013. For rice and barley, the estimated total biomass was 6741 and 38 Gg yr^{-1}, respectively. In the pulse category, the biomass related to soybeans and peanuts was determined for each province in Korea and summed together to calculate the total amount. Estimated total biomass for soybeans was 218 and 22 Gg yr^{-1} for peanuts.

In the vegetable category, four vegetables, namely, watermelon, carrot, garlic, and green onion were investigated. Estimated total biomass were 9.4 Gg yr^{-1} for watermelon, 1.2 Gg yr^{-1} for carrot, 72.2 Gg yr^{-1} for garlic, and 29.5 Gg yr^{-1} for green onion. Among the four

Table 3 Population of the different livestock species in Korea (MIFAFF, 2006–2014)

Livestock	Year					Increase rate (%)
	Populations (heads)					
	2005	2007	2009	2011	2013	
Cattle	1818,549	2200,573	2634,705	2949,664	2917,929	60.5
Dairy	478,865	453,403	444,648	403,689	424,202	−11.4
Swine	8961,505	9605,831	9584,903	8170,979	9912,204	10.6
Poultry	109,627,646	119,365,107	138,767,543	149,511,309	151,337,054	38.0

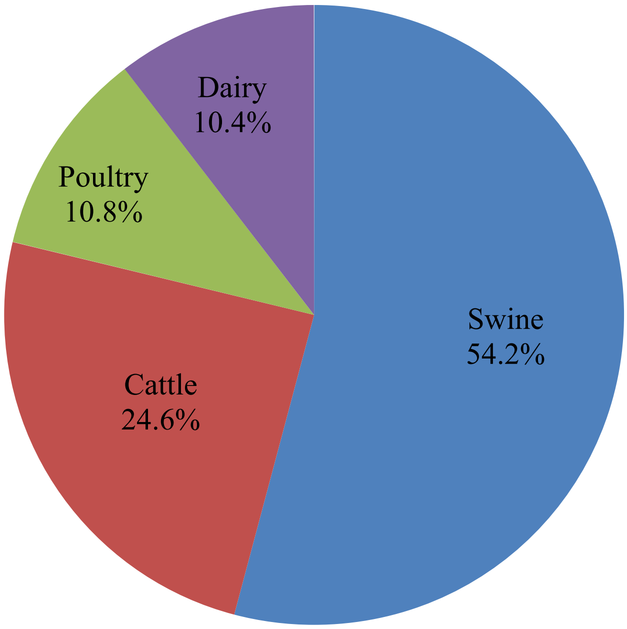

Fig. 1 Percentage of waste generation from different livestock species (Grand total amount of waste was 57,456 Gg yr^{-1})

Table 4 Annual waste amount estimated from different livestock species in Korea

Livestock	Wastes (Gg yr^{-1})				
	2005	2007	2009	2011	2013
Cattle	8820.8	10,673.8	12,779.6	14,307.3	14,153.4
Dairy	6774.7	6414.5	6290.6	5711.1	6001.4
Swine	28,130.2	30,152.7	30,087.0	25,648.7	31,114.4
Poultry	4481.6	4879.6	5672.8	6112.0	6186.7

vegetables, biomass of garlic was the highest. Estimated total biomass for sweet potatoes was 280.1, and it was 131 Gg yr^{-1} for potatoes. For the oil-seed crops, sesame and perilla seeds were investigated. The total biomass was estimated at 71.9, 204 and 751 Gg yr^{-1}, respectively (Table 5).

Agro-industrial wastes include the generated wastes from food manufacturing and processing, slaughterhouses, and tobacco manufacturing and processing. The total amount of agro-industrial wastes was estimated at 845 Gg yr^{-1} in 2007.

The average carbon contents of the crops' different portions, namely the leaf, grain or fruit, and root were presented in Table 6. In the leaf part, rapeseed showed the highest carbon content followed by perilla seed and sesame. For grain or fruit and root parts, rapeseed and peanut showed the highest carbon contents with 57.6 and 59.6 %, respectively. Since the biomass of rice was the highest among other crops, the estimated total carbon content of rice was 87 % of the total carbon content among the 13 crops (Table 6).

Agro-industrial wastes have no category distinction in Korea. For the different sources of agro-industrial wastes (Table 7), the value of pH ranged from 3.9 to 7.3. Moisture content also varied and was observed to be highest in food manufacturing with 95.3 % followed by 82.3 % in slaughterhouse waste. In case of elemental analysis, the average carbon content was 47.0 % for all examined agro-industrial wastes, and the highest carbon content was observed in food manufacturing residues.

Estimation of potential methane production from manure

In order to estimate the methane (CH_4) production during storage and treatment of manure, two main factors including the amount of manure produced and the portion of manure that decomposes anaerobically, were considered. Using Eq. 5, estimated total methane production potential was 375.5 Gg yr^{-1} in Korea (Table 8). The highest methane production is estimated to be 227.3 Gg yr^{-1} for poultry waste, and the lowest was 12.1 Gg yr^{-1} for swine waste.

Potential methane production from crop residues and agro-industrial wastes

To calculate the methane production from crop residues and agro-industrial wastes, two different calculation methods were used based on data availability.

For the crop residues, the calculation method from IPCC GLs was adapted because of the lack of available information for element analysis of crop residues. For emission factor of anaerobic digestion, a wet weight basis emission factor of 1 g CH_4 kg^{-1} waste treated was used. In addition, two assumptions were made to calculate the methane production from crop residues. If this is used for alternative energy production, it can be assumed as following: first, 30 % of the total production of each crop residues is collectable from the field, and second, the utilization rate of crop residues for anaerobic digestion ranges from 10 to 30 % of collectable crop residues.

Based on those two assumptions, methane potential production from crop residues was estimated using Eq. 6 (Table 9).

When information on elemental analysis was available, theoretical methane production was applied (Eq. 7). Based on the calculation, the potential methane production from

Table 5 Estimated total organic wastes of crop residues and agro-industrial wastes in Korea

Sources			Organic waste amount (Gg yr^{-1})	References
Crop residuals	Rice	Rice	6742	MIFAFF (2014)
	Barley	Common barley	38	MIFAFF (2014)
	Pulse	Soybean	218	MIFAFF (2014)
		Peanut	22	MIFAFF (2014)
	Vegetables	Watermelon	9	MIFAFF (2014)
		Carrot	1	MIFAFF (2014)
		Garlic	72	MIFAFF (2014)
		Green onions	30	MIFAFF (2014)
	Potato	Sweet potato	280	MIFAFF (2014)
		Potato	131	MIFAFF (2014)
	Oil-seed	Sesame	72	MIFAFF (2014)
		Perilla seed	205	MIFAFF (2014)
		Rapeseed	0	MIFAFF (2014)
	Sub-total		7820	
Agro-industrial wastes			845	MOE (2008)
Total			5560	

Table 6 Average carbon content of each crop (Lee and Kim 2008)

Crops	Carbon content (%)		
	Leaf	Grain or fruit	Root
Rice	37.6	42.5	42.5
Common barley	37.7	36.8	36.8
Soybean	40.5	49.2	49.2
Peanut	40.0	59.6	59.6
Watermelon	33.7	41.9	41.9
Carrot	33.5	–	36.8
Garlic	36.7	39.2	39.2
Green onions	38.1	–	38.1
Sweet potato	38.3	–	39.5
Potato	37.5	40.7	40.7
Sesame	40.7	56.2	56.2
Perilla seed	41.7	54.0	54.0
Rape	44.5	57.6	57.6

agro-industrial wastes was estimated at 125.7 Gg yr^{-1} (Table 10).

Summary of potential methane production from agricultural biomass

Potential methane production for bio-energy from agricultural biomass in Korea was estimated based on animal manure, crop residues, and agro-industrial wastes (Table 11).

Total methane potential production from agricultural biomass was estimated to be 502 Gg yr^{-1}. Among the three categories, estimated methane production from animal manure was the highest at 74 % of the total methane production. It is considered that methane production from crop residues was the smallest because of high recycled efficiency for animal feeding stock. With fossil energy sources eventually dwindling and becoming increasingly more expensive, bio-energy systems are likely to have

Table 7 Different sources of agro-industrial wastes in Korea

Sources	pH	MC %	TS	VS	C	H	O	N	S
Food manufacturing	4.4	95.3	4.7	3.9	57.2	6.4	33.7	2.6	0.1
Tobacco manufacturing	5.5	15.4	84.6	60.3	40.1	3.8	53.1	2.5	0.4
Slaughter house	6.4	82.3	17.7	12.1	46.9	5.5	35.7	10.1	1.7
Livestock processed products	7.3	46.7	54.3	20.1	44.1	5.8	44.1	5.3	0.7
Agricultural processed products	3.9	81.1	18.9	16.9	47.4	5.6	40.2	6.5	0.2
Meat processed products	6.9	78.8	21.2	20.4	46.1	6.9	37.2	2.8	7.0
Average	5.7	66.6	33.6	22.3	47.0	5.7	40.7	5.0	1.7

MC moisture contents, *TS* total solids, *VS* volatile solids

Table 8 Estimated methane production from manure-related waste

Characteristics	Cattle	Dairy	Swine	Poultry
VS (kg head^{-1} day^{-1})	1.51	5.45	0.023	0.021
H (population)	2917,929	424,202	9912,204	151,337,054
B_0 (m^3 CH_4 kg^{-1} VS)	0.10	0.13	0.29	0.39
MCF	0.75	0.75	0.75	0.75
CH_4 (Mg yr^{-1})	80,920	55,094	12,126	227,331
Total CH_4 (Mg yr^{-1})	375,471			

VS volatile solids, *MCF* methane conversion factor

Table 9 Estimated methane production from crop residues

Crops	Organic waste amount (Gg yr^{-1})	CH_4 production (Mg yr^{-1})		
		10 %	20 %	30 %
Rice	6742	337.1	674.2	1011.3
Common barley	38	1.9	3.8	5.7
Soybean	218	10.9	21.8	32.7
Peanut	22	1.1	2.2	3.3
Watermelon	9	0.45	0.9	1.35
Carrot	1	0.05	0.1	0.15
Garlic	72	3.6	7.2	10.8
Green onions	30	1.5	3.0	4.5
Sweet potato	280	14.0	28.0	42.0
Potato	131	6.55	13.1	19.65
Sesame	72	3.6	7.2	10.8
Perilla seed	205	10.25	20.5	30.75
Rapeseed	0	0	0	0
Total	7820	391.0	782.0	1173.0

Calculation was conducted by assuming that 10–30 % of crop residues were used for anaerobic digestion method, respectively

Table 10 Estimated methane production potential from agro-industrial wastes

Agricultural Industrial wastes	C %	H	O	N	Total biomass (Mg yr^{-1})	Methane production (Mg yr^{-1})
	47.0	5.7	40.7	5.0	844,866	125,650

Average value of elemental analysis was used

Table 11 Estimated total potential methane production from agricultural wastes in Korea

Sources	Methane production (Gg yr^{-1})
Animal manure	375.5
Crop residues	1.2
Agro-industrial wastes	125.7
Total	502.3

future attraction. The improvements in digestion system obtained from better preprocessing and recovery techniques would also help improve their viability in general.

Discussion

This research was conducted to suggest an alternative calculation for constructing the typical Korean-specific GHG inventory as well as the bio-energy conversion potential in agricultural sector. Significant amounts of agriculture-based biomass are produced from animal wastes as cattle, dairy, swine and poultry; crop residues as mainly rice and barely straws; and agro-industrial wastes, in agricultural sector across Korea. Large sources of biomass are often located at a distance from potential energy production sites. Since most of the cattle are housed within feedlots in Korea, a 97 % collectable factor was assumed (NRC 1983). However, a significant amount of livestock manure, as much as 25–35 % of the total residues, may remain un-recoverable in the field (Woods and Layzell 2003). The collection, transport, and processing of biomass also pose a significant challenge to their use in energy production (Abu-Ashour et al., 2010). With regard to the utilization of agricultural biomass, the costs of these feedstocks are directly proportional to the costs of collection and transportation to energy production sites (Overend 2002). Agricultural biomass in Korea totally generated could be 68,011 Gg year^{-1}. It has been widely reported that the maturity stage of the plant is of major importance for specific methane yield since it determines biomass composition (Amon et al. 2007; Kaparaju et al. 2002; Gunaseelan 2004). The biggest contributor was animal manure which was estimated to be 375.5 Gg year^{-1} for a potential methane production. On the other hand, crop residues and agro-industrial wastes were calculated to be 1.2 and 125.7 Gg year^{-1}, respectively. Agricultural biomass each year in Korea can currently offer the greatest potential for alternative bio-energy production with various points. Our assessments indicated that this potential methane yield is supposed to be about 2 % of annual amount of total energy consumption (23,650 Gg yr^{-1}) in Korea (RDA 2009). However, the potential methane yield was the greatest in animal manure, which is equivalent with 5 % of 6.8 Tg yr^{-1} in the EU (Moss et al. 2000). Results of this study indicated that animal manure was the main source of methane production in agricultural sector. However, it is acknowledged that assessment of potential methane production has some limitations due to non-application of various bio-energy production technologies with different feeding stocks. In spite of having some limitations, this assessment provides useful data that can be used in prioritizing agricultural biomass for further analysis, research exploitation as well as identifying the biomass sources which may have higher significance. Good management practices for livestock wastes are necessary to develop and maximize the technology on harnessing methane using agricultural wastes as alternative energy.

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References

Abu-Ashour J, Abu Qdais H, Al-Widyan M (2010) Estimation of animal and olive solid wastes in Jordan and their potential as a supplementary energy source: an overview. Renew Sustain Energy Rev. doi:10.1016/j.rser.2010.03.001

Amon T, Amon B, Kryvoruchko V, Machmüller A, Hopfner-Sixt K, Bodiroza V, Hrbek R, Friedel J, Pötsch E, Wagentristl H, Schreniner M, Zollitsch W (2007) Methane production through anaerobic digestion of various energy crops grown in sustainable crop rotations. Bioresour Technol. doi:10.1016/j.biortech.2006.07.007

Bauen A, Woods J, Hailes R (2004) Biopowerswitch!—a biomass blueprint to meet 15% of OECD electricity demand by 2020. WWF Climate change program

Deublin D, Steinhauser A (2011) Biogas from waste and renewable resources, 2nd edn. Wiley, Weinheim

Frear C, Zhao B, Fu G, Richardson M, Chen S (2005) Biomass inventory and bioenergy assessment. Washington State Department of Ecology. 05-07-047

Gunaseelan VN (2004) Biochemical methane potential of fruits and vegetable solid waste feedstocks. Biomass Bioenergy. doi:10.1016/j.biombioe.2003.08.006

Hong S (2004) Evaluation of agricultural biomass resources for renewable energy—biomass from orchards and non-paddy fields. J Korean Soc Agric Eng. doi:10.5389/KSAE.2004.46.3.085

Hong J, Moon G, Lee J, Cho J (1989) Biomass resources survey and energy evaluation. Korean Institute of Energy Research, Daejeon

IPCC (2006) IPCC guidelines for national greenhouse gas inventories. Intergovernmental Panels on Climate Change, London

Janssen LHJM, Olivier JGJ, van Amstel AR (1999) Comparison of CH_4 emission inventory data and emission estimates from atmospheric transport models and concentration measurements. Environ Sci Policy. doi:10.1016/S1462-9011(99)00020-9

JAYCOR (1990) Regional assessment of non-forestry-related biomass resources, summary volume Report No. 684-0035a/90. Southeastern Regional Biomass Energy Program, Muscle Shoals

Kaparaju P, Luostarinen S, Kalmari E, Kalmari J, Rintala J (2002) Co-digestion of energy crops and industrial confectionery by-products with cow manure: batch-scale and farm-scale evaluation. Water Sci Technol 45(10):275–280

Khanal SK (2008) Anaerobic biotechnology for bioenergy production: principles and applications. Wiley-Blackwell, Ames

Laifeld J, Fuhrer J (2005) Greenhouse gas emissions from Swiss agriculture since 1990: implications for environmental policies to mitigate global warming. Environ Sci. doi:10.1016/j.envsci.2005.04.001

Lee J, Kim G (2008) The potential of soil carbon sequestration by land use. In: Study on carbon sink agricultural sector regarding UNFCCC, RDA Final Report

MIFAFF (2009) Annual statistics in food, agriculture, fisheries and forestry in 2008. Korean Ministry for Food, Agriculture, Fisheries and Forestry

MIFAFF (2010) Annual statistics in food, agriculture, fisheries and forestry in 2009. Korean Ministry for Food, Agriculture, Fisheries and Forestry, Gwacheon

MIFAFF (2014) Annual statistics in food, agriculture, fisheries and forestry in 2013. Korean Ministry for Food, Agriculture, Fisheries and Forestry, Gwacheon

MOE (2008) Annual report of Korean environment in 2007. Korean Ministry of Environment, Sejong

Monni S, Syri S, Savolainen I (2004) Uncertainties in the Finnish greenhouse gas emission inventory. Environ Sci Policy. doi:10.1016/j.envsci.2004.01.002

Moss AR, Jounay JP, Newbold J (2000) Methane production by ruminants: its contribution to global warming. Ann Zootech 49:231–253

NIAS (2009) The Study to re-establish the amount and major compositions of manure from livestock. National Institute of Animal Science, Rural Development Administration, Jeonju

NRC (1983) National Research Council Committee on animal nutrition, underutilized resources as animal feedstuffs. The National Academy of Science, Washington

NREL (2005) A geographic perspective on the current biomass resource availability in the United States, A. Milbrandt
Olivier JGJ, Bouwman AF, Berdowski JJM, Veldt C, Bloos JPJ, Visschedijk AJH, van der Maas CWM, Zandveld PYJ (1999) Sectoral emission inventories of greenhouse gases for 1990 on a per country basis as well as on 1x1. Environ Sci Policy. doi:10.1016/S1462-9011(99)00027-1
Overend RP (2002) Biomass-fired power generation in North America. In: Kyoto University international symposium on post-petrofuels in the 21st century: prospects in the future of biomass energy, Montreal, 3–4 Sept
RDA (2009) International workshop of development bioenergy and conserving the natural ecosystem in APEC member economies. Rural Administration Development, Jeonju
Shin J, Han S, Eom K, Sung S, Park S, Kim H (2008) Predicting methane production potential of anaerobic co-digestion of swine manure and food waste. Environ Eng Res. doi:10.4491/eer.2008.13.2.093
Wang J, Cardenas LM, Misselbrook TH, Gilhespy S (2011) Development and application of a detailed inventory framework for estimating nitrous oxide and methane emission from agriculture. Atmos Environ. doi:10.1016/j.atmosenv.2010.12.014
Woods SM, Layzell DB (2003) A Canadian biomass inventory: feedstock for a bio-based economy. BIOCAP-Industry Canada Contract # 5006125. Final Report
Yang SS, Liu CM, Lai CM, Liu YL (2003) Estimation of methane and nitrous oxide from paddy fields and uplands during 1990-2000 in Taiwan. Chemosphere. doi:10.1016/S0045-6535(03)00029-8
Yoon Y, Kim H, Yoo J, Kim S, Hong S, Kim C (2011) The performance of anaerobic co-digester of wine slurry and food waste. Korean J Soil Sci Fert 44:104–111
Youn J, Shin H (2005) Comparative performance between temperature-phased and conventional mesophilic two-phased processes in terms of anaerobically produced bioenergy from food waste. Waste Manag Res 23:32–38