Appendix G

Nutrient Balance: Fate of Nitrogen and Phosphorus

A summary of preliminary findings funded by the
Farm Manure-to-Energy Initiative

January 2016

Contents

1. Introduction

A critical design objective for the thermal technologies demonstrated by the Farm Manure-to-Energy Initiative was to reduce nitrogen and phosphorus transported to surface waters relative to local land application of poultry litter for use as a fertilizer.

Poultry litter contains nitrogen, phosphorus, potassium, organic matter, and trace minerals and is a valued form of fertilizer. The project focused on high-density animal production areas of the Chesapeake Bay region because these are areas where long-term use of poultry litter as a fertilizer has resulted in especially high rates of phosphorus loading (on a per acre basis) (Figure 1).

The addition of phytase to poultry feed (which reduces phosphorus concentrations in poultry litter) and improved feed conversion efficiency has increased the nitrogen-to-phosphorus ratio in poultry litter so that it more closely matches crop nutrient requirements. However, in general, application of poultry litter to meet crop nitrogen requirements results in over-application of phosphorus. Use of poultry litter as the crop's primary nitrogen source results in soils saturated with phosphorus and increased risk of phosphorus transport to surface waters, either via surface runoff or subsurface drainage. Subsurface transport of phosphorus can occur in fields with high water tables and drainage systems (e.g., tile drains or field ditches). However, nitrogen-based poultry litter applications are largely no longer allowed in the Chesapeake Bay watershed as states have moved to a phosphorus-based nutrient management plan, thus limiting use of poultry litter as a fertilizer in high-density production areas. To support compliance with regulations, stakeholders in the Chesapeake Bay region are working with poultry growers to identify opportunities for recycling this valuable fertilizer.

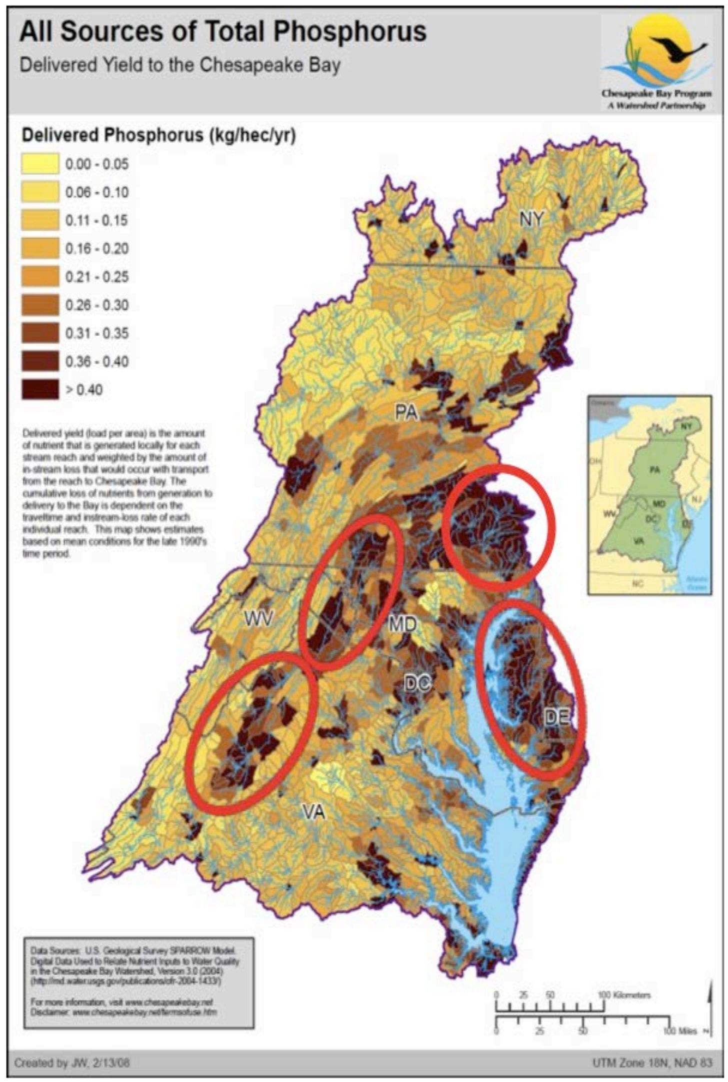

Figure 1. U.S. Geological Survey SPARROW map of the Chesapeake Bay regions contributing the most phosphorus to the Chesapeake Bay. Red circles indicate areas of high density animal production.

One potential benefit of the technologies selected for demonstration in the Farm Manure-to-Energy Initiative is that these technologies concentrate poultry litter phosphorus in an ash or biochar co-product. Field trials on row crops as well as laboratory analysis indicated that the concentrated ash has value as a fertilizer (Appendix F) and that this material could be cost-effectively transported out of high-density animal production areas for use in regions that are phosphorus-deficient. The ash co-product could also be used locally on crops where untreated poultry litter is typically not used, like fresh market vegetables, for which untreated poultry litter increases risks for pathogen transport. Thermal treatment of poultry litter eliminates pathogens that pose a risk to public health.

2. Nutrient Balance Performance Objectives

For nutrient balance, the project team set the following criteria for appropriate technologies:

- The technology must facilitate the transport and re-use of excess phosphorus from areas of high-density animal production regions to areas with phosphorus deficiency and/or facilitate local use on crops that cannot currently use untreated poultry litter as a fertilizer.
- Reactive nitrogen emissions to the atmosphere should be reduced and, at the minimum, should not exceed reactive nitrogen emissions from local land application as a fertilizer.

3. Methods

A nutrient mass balance was developed for three poultry litter-fueled technologies: the Ecoremedy ® gasifier, Blue Flame boiler, and Bio-Burner 500.

Nitrogen and phosphorus concentrations in untreated poultry litter were compared to nitrogen and phosphorus in the ash (including the bottom ash from the thermal conversion chamber and the fly ash collected by the emissions control systems). Methods for determination of fertilizer value of the poultry litter and ash are detailed in Appendix F. Fresh poultry litter and ash samples (0.5 g) were digested in nitric acid and hydrogen peroxide using method 3050B (U.S. EPA, 1996) and then analyzed using ICP-OES (Spectro Analytical Instruments, Kleve, Germany) at the Virginia Tech Soil Testing Laboratory (Maguire and Henkendorn, 2011).

- Nitrogen (NOx and ammonia) and phosphorus concentrations in air emissions were measured using methods detailed in Appendix E.
- Poultry litter feed rate and ash production rates were also measured. Methods for poultry litter feed rate are detailed in Appendix E.
- Ash production rates were measured by the volume of ash produced over time intervals concurrent with air emissions testing. The bulk density of the ash was used to convert the volume rate to a mass rate for the Blue Flame boiler (Reiter and Daniel, 2013). For the Bio-Burner 500, ash production was measured by

weighing all ash produced over selected time intervals during the emissions testing period.

Analysis of fuel feed rate, ash production, poultry litter, and ash nutrient concentrations, as well as nitrogen and phosphorus in air emissions, were conducted simultaneously. On the same day that data on air emissions was being collected by the certified air emissions testing company, data on poultry litter and ash nutrients, fuel feed rates, and ash production rates were also collected.

Annual poultry litter use, ash production rate, and nitrogen and phosphorus in air emissions assume the unit is operating 24 hours a day for 365 days a year. In reality, the thermal manure-to-energy systems do not operate during periods of high ambient air temperature. One vendor (Bhsl), however, does recommends that their clients use dry heat from the thermal poultry litter-fueled technology to reduce moisture in the poultry houses during all times of the year except when the house is ventilated with tunnel fans (e.g., the hottest periods of the year).

Reactive nitrogen in air emissions (including NOx and ammonia species) were compared with published estimates of ammonia emissions associated with the use of poultry litter as a fertilizer in conservation tillage systems (Pote and Meisinger, 2014). Because the method used to apply fertilizer impacts the potential ammonia emissions, estimates are provided for poultry litter that is immediately incorporated (tilled in with shallow disking) as well as poultry litter that is left on the surface of the field. Pote and Meisinger (2014) documented total ammonia (as ammonium-nitrogen [NH_4-N] from poultry litter applied over a two-year period and found that injected poultry litter had the lowest total ammonia loss (Mean = 12.1 and 7.9% for 2008 and 2009, respectively), followed by shallow disc injection (Mean 21.5 and 32.4% for 2008 and 2009). Surface application had the highest rate of ammonia loss ranging from a mean of 73.9% of poultry litter ammonia in 2008 to a mean of 95.2% in 2009.

4. Results

Calculation of fuel feed rate and ash production rates are presented in Table 1. Fly ash from the Ecoremedy gasifier was not feasible to collect according to proposed methods. Two cyclones for ash collection were on this unit and ash varied from being dry to wet during collection periods. Also, ash volume was not consistent over the runs as the material was sticking within the cyclone collection system. For instance, some collection periods had a few inches of ash in a 5-gallon bucket and sometimes hardly enough to cover the bottom of the bucket.

Table 1. Calculation of fuel feed rate and ash production

	Bio-Burner 500	Ecoremedy Gasifier	Blue Flame Boiler
	lbs/hr		
Poultry Litter	73	260	333
Bottom Ash	14	42	20
Fly Ash	2.5	n/a	3.9
Total Ash	16.8	42.5	24.35
PL:Ash Production Ratio	4.35	6.12	13.68

Results from system input and output analysis are presented in Tables 2 and 3. System outputs for poultry litter are based on poultry litter feed rates; system outputs for ash are based on ash production rates; and system outputs for air emissions are based on reported values (lbs/hr). For the Ecoremedy gasifier, nutrients in fly ash were not taken into consideration in the nutrient balance since we could not quantify the mass being produced on an hourly rate.

Table 2. Nutrient balance comparing nitrogren (N) and phosphorus (P) in poultry litter with N and P in ash and air emissions

	Bio-Burner 500	Ecoremedy Gasifier	Blue Flame Boiler
	Input / Output rate		
System Inputs	lbs/hr		
Poultry Litter Fuel			
NH4-N	0.55	1.85	1.53
NO3-N	7.91E-03	9.98E-02	1.57E-02
TOTAL N	2.08	7.25	7.97
TOTAL P	0.82	2.05	2.60
System Outputs			
Air Emissions			
NO x (lbs/hr)	0.16	0.13	1.36
NO x derived - Elemental N (lbs/hr)	4.87E-02	3.96E-02	0.41
NH3 (lbs/hr)	1.00E-04	3.90E-03	1.00E-04
NH3 derived - Elemental N (lbs/hr)	8.22E-05	3.21E-03	1.20E-03
TOTAL N (sum of NH4-N and NO3-N)	4.88E-02	4.28E-02	0.42
Total P	4.33E-03	1.65E-03	1.99E-02
Ash			
Bottom Ash (Total Elemental N)	0.16	0.25	0.80
Fly Ash (Total Elemental N)	4.93E-04	n/a	1.80
TOTAL N (Bottom + Fly Ash)	0.16	0.25	2.60
Bottom Ash (Total Elemental P)	0.72	3.38	1.94
Fly Ash (Total Elemental P)	0.27	0.00	0.26
TOTAL P (Bottom + Fly Ash)	0.99	3.38	2.20

Table 3 summarizes unaccounted-for nitrogen and phosphorus based on analysis of inputs and outputs. The percent of unaccounted-for nitrogen ranges from 90.1 to 95.9% of the total poultry litter nitrogen content. Unaccounted-for phosphorus is more variable, ranging from -64.9 to 14.5% of the total poultry litter phosphorus. A negative number means that calculations suggest there is more phosphorus in the outputs than in the inputs. Concentrations of nitrogen and phosphorus in untreated poultry litter, ash, and air emissions for each of the technologies are presented graphically in Figures 1-3.

Table 3. Unaccounted-for nitrogen (N) and phosphorus (P) presented in lb/hr and percent of total

	Bio-Burner 500	Ecoremedy Gasifier	Blue Flame Boiler
N (lb/hr)	1.87	6.96	7.53
P (lb/hr)	-0.18	-1.33	0.38
N (% total)	90.1	95.9	94.5
P (% total)	-21.6	-64.9	14.5

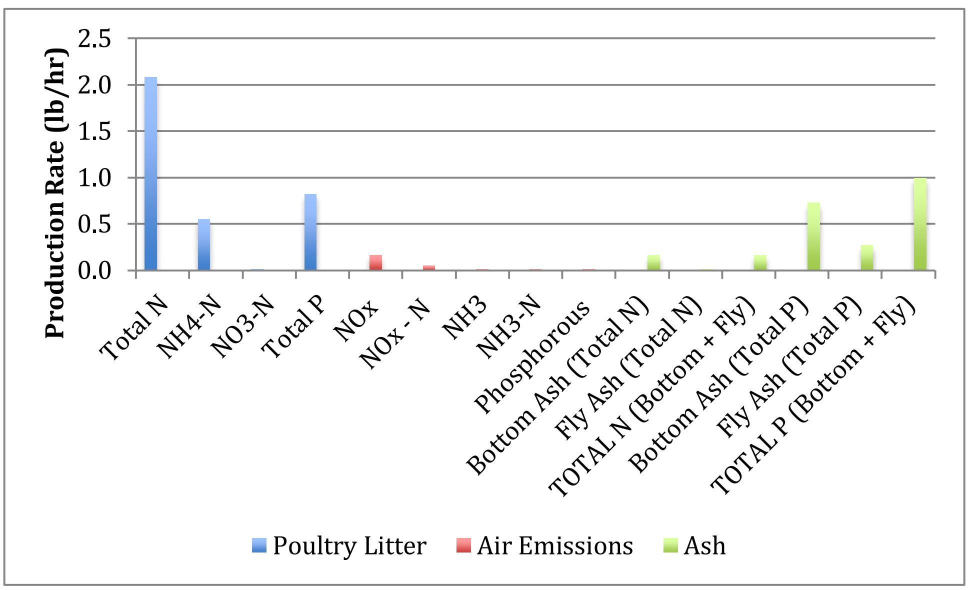

Figure 1. Nutrient balance (poultry litter inputs and ash and air emissions outputs) for the Bio-Burner 500

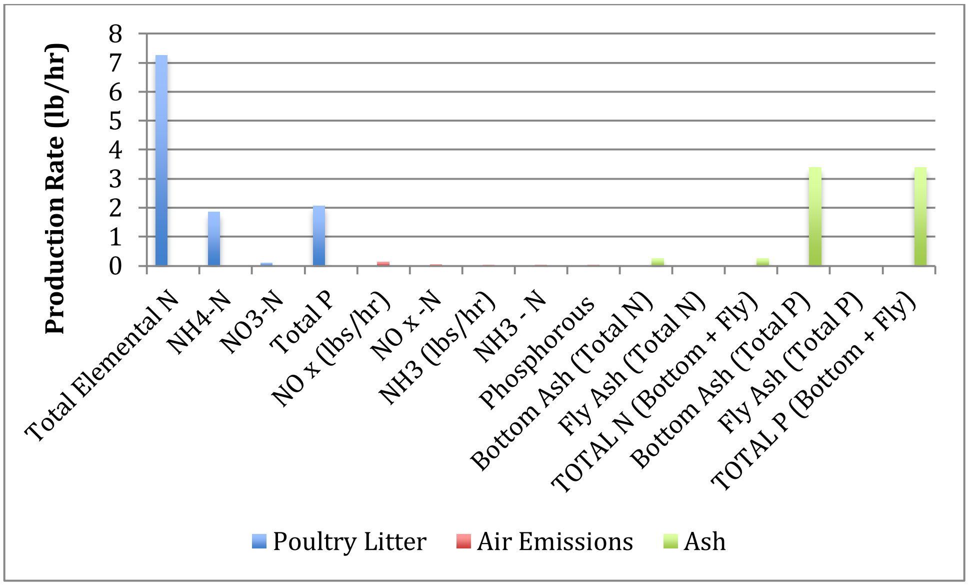

Figure 2. Nutrient balance (poultry litter inputs and ash and air emissions outputs) for the Ecoremedy gasifier

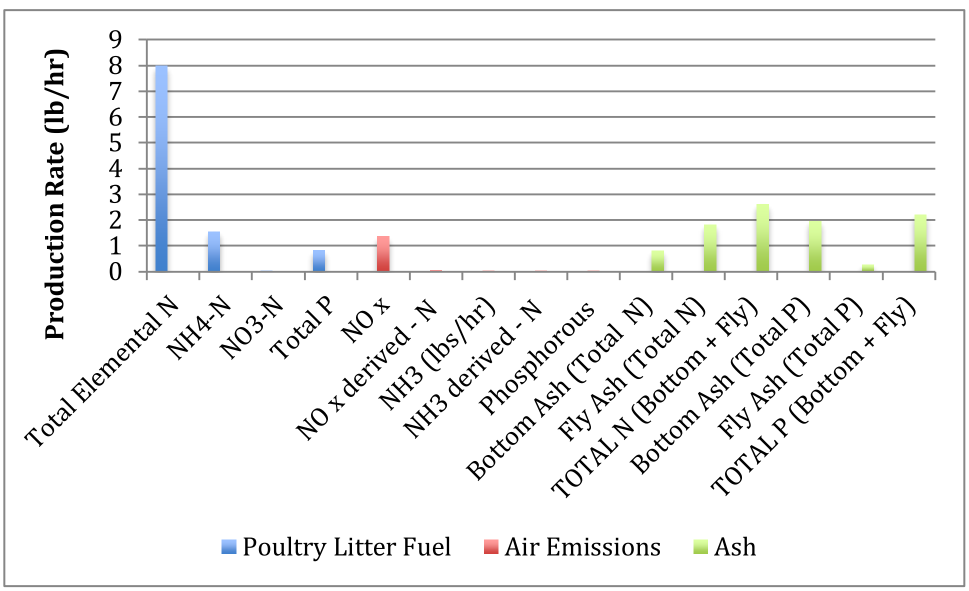

Figure 3. Nutrient balance (poultry litter inputs and ash and air emissions outputs) for the Blue Flame boiler

Reactive nitrogen emissions in feedstock poultry litter compared to estimated reactive nitrogen emissions from land application are presented in Table 4 and Figure 4.

Table 4. Reactive nitrogen (N) loss from three thermal manure-to-energy systems using poultry litter as a fuel over 1 hour compared to Pote and Meisinger (2014) reactive nitrogen (as ammonium-nitrogen) loss from the same amount of poultry litter land applied to conservation tillage systems

	Poultry Litter Used as Fuel in Manure-to-Energy Scenario			Poultry Litter Land Application Scenario (lbs NH-4-N Emissions Associated with Poultry Litter Used to Fuel 1-hr of Operation)		
	Total Reactive N in Air Emissions (lb/hr)	Feed rate for Manure-to-Energy Systems	NH4-N Content in Untreated Poultry Litter	NH4-N in Air Emissions (Injected - 9.6% NH4-N Loss)	NH4-N in Air Emissions (Disked-in, Assume 27% NH4-N Loss)	NH4-N in Air Emissions (Surface Applied, Assume 85% NH4-N Loss)
	lb/hr		lb NH4-N Associated with Poultry Litter Required to Fuel 1-Hr of manure-to-energy operation			
Bio-Burner 500	0.05	73	0.55	0.05	0.15	0.47
Ecoremedy Gasifier	0.04	260	1.85	0.18	0.50	1.57
Blue Flame Boiler	0.42	333	1.53	0.15	0.41	1.30

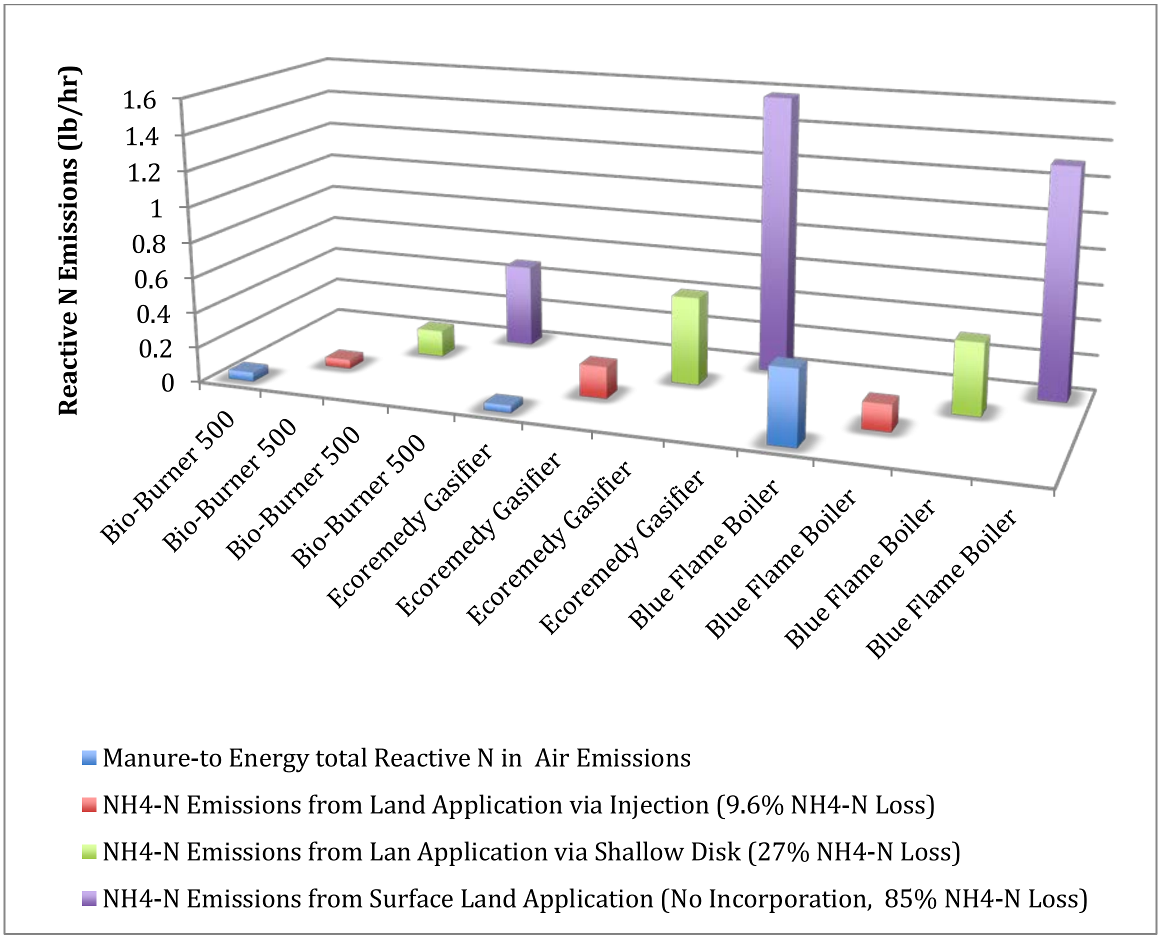

Figure 4. Reactive nitrogen emission from poultry litter used to fuel manure-to-energy technologies for 1 hour compared to land application of the same amount of poultry litter using three different methods: injection, light disking following application, and surface application only (no incorporation). Emissions of NH4-N are from Pote and Meisinger (2014).

5. Discussion

Calculating nutrient balance in poultry litter using a poultry litter "in" and ash and air emissions "out" approach was not as straightforward as anticipated. Initial analysis of elemental nitrogen and phosphorus in the poultry litter fuel did not correlate directly with the sum of elemental nitrogen and phosphorus measured in the ash and nitrogen (as NH3-N and NOx) and phosphorus measured in air emissions. For example, results from mass balance for the Bio-Burner 500 and Ecoremedy gasifier indicated that there is more phosphorus in the system outputs (ash and air emissions) than was present in the poultry litter fuel; this is likely due to the mass balance methodology, among similar discrepancies.

Table 4 also indicated a significant amount of unaccounted-for nitrogen, ranging from 90 to 96%. Loss of reactive nitrogen (NH_4 and NOx) as non-reactive nitrogen (N_2) is anticipated in the thermal conversion process. However, nitrogen in air can contribute to nitrogen emissions. At temperatures above 950°C, thermal NOx formation from nitrogen contained in combustion air can occur (Quaak, P. et. al. 1999). Stubenberger (2008) discussed nitrogen species release from different solid biomass fuels and suggested that thermal NOx production occurs at temperatures above 1300°C, which are not likely to occur in most biomass combustion systems. Rather, they observed that the fuel's nitrogen content was the dominant source of NOx.

Koger et. al, 2005 and Koger et. al. 2004 also observed discrepancies in nutrient balance determination for a batch-fed gasifier fueled with pig manure. Their mass balance (using fuel feed rate, ash production rate, and air emissions) accounted for 85 to 100% of the fuel's nitrogen, phosphorus, potassium, and calcium. Magnesium measured in the system outputs accounted for 75% of magnesium in the fuel. Output for several minerals (copper and zinc) suggested outputs contained more than inputs. For this reason, Kroger et. al. 2005 concluded that "further analytical work is needed to clarify this issue."

The discrepancy between nitrogen and phosphorus in fuel versus nitrogen and phosphorus in system outputs (air emissions and ash) could be the result of a number of issues. For example, the use of composite samples to estimate mean nitrogen and phosphorus values in poultry litter and ash could have introduced error. Poultry litter is not a homogenous material. Characteristics vary from farm-to-farm (see Table 5 in Appendix E, as well as within a house or houses on the same farm. Poultry litter contains large wood particles and rocks. Nutrient concentration, moisture, and air emissions from poultry litter vary spatially throughout the poultry house (Miles et. al., 2008). While poultry litter sampling protocols were selected to generate composite samples for analysis reflective of all poultry litter and were replicated, increasing the number of poultry litter and ash samples over time along with more runs of air emissions data (i.e., different times of year, ambient air temperature, etc.) will improve accuracy of mass balance calculations.

The method by which bulk density was calculated (e.g., field measurements versus laboratory measurements) also demonstrated variability that impacts the nutrient balance. Increased sample size could help to refine bulk density calculations and improve the accuracy of ash nutrient production estimates. While field bulk density measurements were used for this nutrient balance, it warrants further investigation to determine which approach is the most appropriate for use future analysis.

Also, for one technology (the Ecoremedy gasifier), the fly ash generation rate was difficult to quantify and therefore not reported. Thus, Table 4 likely underestimates unaccounted for nitrogen and phosphorus.

Given limitations of this data, it appears that a considerable amount of reactive nitrogen is reduced when poultry litter is used as a fuel in thermal manure-to-energy systems. Compared to land application, all the technologies have reactive nitrogen emissions similar to or lower than best practices for land application of poultry litter (shallow disk incorporation). Even the system with the highest reactive nitrogen emissions demonstrates reduced nitrogen loss to the atmosphere when compared with surface application of poultry litter, a common practice in the region.

The Blue Flame boiler and Bio-Burner 500 had the highest rates of reactive nitrogen emissions, but this may have been due to a lack of tuning. Stubenberger (2008) found that in addition to the fuel nitrogen content, the stoichiometric air ratio has a major influence on NOx emissions in biomass systems. Stoichiometric air ratio can be adjusted by tuning the system to optimize performance and reduce NOx emissions.

It also appears that a small amount of phosphorus is released in air emissions. This phosphorus is likely associated with particulate matter, and thus efforts to further reduce particulate matter should also reduce phosphorus loss to the atmosphere. However, phosphorus loss via emissions was minor and most of the phosphorus was concentrated in the ash. This conclusion is consistent with findings presented in Appendix F.

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