ELSEVIER

Comparison of arsenic content in pelletized poultry house waste and biosolids fertilizer

Keeve E. Nachman [a,*], Jana N. Mihalic [b], Thomas A. Burke [c], Alison S. Geyh [b]

[a] *National Center for Environmental Economics, Office of Policy, Economics and Innovation, United States Environmental Protection Agency, 1200 Pennsylvania Avenue, N.W., EPA West 4339-M, MC 1809T, Washington, DC 20460, United States*
[b] *Department of Environmental Health Sciences, Johns Hopkins Bloomberg School of Public Health, 615 N, Wolfe Street, Baltimore, MD 21205, United States*
[c] *Department of Health Policy and Management, Johns Hopkins Bloomberg School of Public Health, 615 N, Wolfe Street, Baltimore, MD 21205, United States*

Abstract

Managers of human biosolids have been incorporating the practice of waste pelletization for use as fertilizer since the mid 1920s, and waste pelletization has recently been embraced by some poultry producers as a way to move nutrients away from saturated agricultural land. However, the presence of arsenic in pelletized poultry house waste (PPHW) resulting from the use of organoarsenical antimicrobial drugs in poultry production raises concerns regarding additional incremental population exposures. Arsenic concentrations were determined in PPHW and pelletized biosolids fertilizer (PBF) samples. Pellets were processed using strong acid microwave digestion and analyzed by graphite furnace atomic absorption spectroscopy. The mean arsenic concentration in PPHW (20.1 ppm) fell within the lower part of the range of previously report arsenic concentrations in unpelletized poultry house waste. Arsenic concentrations in PBF, the source of which is less clear than for PPHW, were approximately a factor of 5 times lower than those in PPHW, with a mean concentration of 4.1 ppm. The pelletization and sale of these biological waste fertilizers present new pathways of exposure to arsenic in consumer populations who would otherwise not come into contact with these wastes. Arsenic exposures in humans resulting from use of these fertilizer pellets should be quantified to avoid potential unintended negative consequences of managing wastes through pelletization.
© 2007 Elsevier Ltd. All rights reserved.

Keywords: Roxarsone; Biosolids; Animal waste; Poultry; Arsenic

1. Introduction

Arsenic has been characterized as a known human carcinogen by the International Agency for Research on Cancer (IARC) and the US Environmental Protection Agency (USEPA) (International Agency for Research on Cancer, 1987; United States Environmental Protection Agency, 2002), and exposures to high levels of arsenic in drinking water have been linked to cancers of the bladder, lung and skin, as well as non-cancer health effects including cardiovascular disease, diabetes, keratosis and other skin disorders (Agency for Toxic Substances and Disease Registry, 2005). Recent reviews of the arsenic epidemiologic literature by the National Research Council (National Research Council, 1999, 2001) and concerns over lower level exposures have resulted in the USEPA lowering the maximum contaminant level in drinking water from $50 \, \mu g \, l^{-1}$ to $10 \, \mu g \, l^{-1}$ and convening a committee of the USEPA Scientific Advisory Board to examine the latest research on arsenic toxicity (United States Environmental Protection Agency, 2001, 2005). These new developments

and the continued interest in chronic low level arsenic exposures highlight the need for the understanding of the contribution of a range of exposure sources.

The arsenic-containing compound roxarsone (3-nitro-4-hydroxyphenylarsonic acid) was introduced into poultry feed in the late 1940s for the purpose of growth promotion, improved feed conversion (ratio of feed ingested to broiler weight at slaughter) and pigmentation, and combating intestinal parasites (Kowalski and Reid, 1972). It has been estimated that approximately 70% of domestically raised broiler chickens receive roxarsone (Chapman and Johnson, 2002), totaling between 1.7 and 2.2 million pounds of the drug added to poultry feed per each year (Wallinga, 2006). It is not certain how much of the ingested roxarsone is retained in the edible tissue of the broilers, but a recent market basket study of uncooked and prepared chicken tissue by the Institute for Agriculture and Trade Policy found detectable levels of arsenic in a variety of poultry products (Wallinga, 2006). While some roxarsone remains in chicken tissue, much of the drug has been shown to be excreted in the waste (Rutherford et al., 2003).

A growing body of evidence for the environmental conversion of roxarsone to the more toxic inorganic arsenic has emerged. Research by the US Geological Survey (USGS) has shown that the majority of arsenic in post-excretion waste is rapidly converted once in the environment through both biotic and abiotic processes into more leachable inorganic forms (Garbarino et al., 2003). In the absence of oxygen, roxarsone is rapidly converted to 4-hydroxy-3-aminophenylarsonic acid and 4-aminopheynlarsonic acid, which further degrade via biological processes almost completely over time in the presence of methane and sulfate-reducing conditions to arsenite and arsenate (Cortinas et al., 2006). It has also been determined that clostridia, the dominant microbial species of the chicken cecum, is responsible for transformation of roxarsone into inorganic arsenic at much faster rates than previously reported (Stolz et al., 2007).

The United States produced 8.87 billion broiler chickens in 2005 (United States Department of Agriculture, 2006), and broiler production is projected to increase by 1% in 2007 (United States Department of Agriculture, 2007). A single broiler excretes approximately 4.9 kg of waste in a typical 48-day lifetime (American Society of Agricultural Engineers, 2005), 150 mg of which is assumed to be roxarsone or its metabolites (Rutherford et al., 2003). As domestic broiler production increases and broiler operations continue to concentrate regionally, the management of poultry house waste (PHW) remains a critical public health issue, and concerns about the potential health effects of arsenic increase these management concerns. Published estimates of arsenic concentrations in PHW range from 14 to 76 ppm (Jackson and Bertsch, 2001; Arai et al., 2003; Garbarino et al., 2003; Jackson et al., 2003).

Application of PHW to farmland has been traditionally viewed as the preferred management strategy, though concerns of nutrient overloading and the resultant eutrophication from loss of nutrients to surface waters (Horrigan et al., 2002) have forced managers of PHW to search out and implement other disposal strategies. A recently developed management option is the pelletization and sale of PHW as fertilizer (Nachman et al., 2005). The pelletization process involves dehydration, heating and crushing, and finally the cooling and formation of the litter into pellets. In the pelletized form, PHW can be more easily transported away from poultry producing regions, and used as fertilizer in residential and commercial settings. Despite the potential for different, non-agricultural populations to be exposed to the waste through use of pellets, arsenic concentrations in pelletized PHW fertilizer (PPHW) have not been addressed in the literature.

Another potential source of arsenic-containing biological waste is pelletized fertilizer produced from Class A biosolids, or treated human sewage sludge. It is estimated that of the 5.6 million dry tons of biosolids produced annually, approximately 3.4 million dry tons are land-applied as fertilizer or soil amendments (National Research Council, 2002). Of the biosolids that are land-applied, approximately one million dry tons are considered acceptable for use at public contact sites or distribution in bags (National Research Council, 2002). Little information is available to suggest the degree of arsenic contamination of processed human biosolids or pelletized biosolids fertilizer (PBF), as waste streams at sewage sludge treatment facilities vary depending on the nature of waste inputs. Indirect arsenic inputs into biosolids would include any arsenic-contaminated media entering into the wastewater stream, including excreted arsenic originating from human exposures (from environmental and dietary sources) and household or commercial wastewater.

Determination of arsenic content in PPHW and PBF will fill a critical information gap regarding poultry and human waste management practices and the subsequent potential for human exposures. The purpose of this paper is to characterize arsenic concentrations in PPHW and PBF. In addition, these arsenic concentrations will be compared with those in raw PHW and background soils.

2. Experimental section

2.1. Pelletized poultry house waste sample collection

PPHW is produced by a variety of companies and is sold under multiple brand names which are distributed throughout the country. For this study, PPHW was purchased from commercial vendors. To obtain as representative a sample as possible, bags of PPHW under four different brand names were purchased from five commercial vendors in the Baltimore metropolitan area in Maryland and one commercial vendor in Asheville, North Carolina. Bags were placed into sealed plastic tubs where they were stored until needed for sample preparation and analysis.

2.2. Pelletized biosolids fertilizer sample collection

While PBF is sold commercially, its availability and distribution differs from PPHW. In addition to sales by retail vendors, some local wastewater treatment systems offer free onsite pickup of pellets. For this study, two sources of PBF were identified. Two samples were acquired from the Synagro biosolids pelletization facility in the backriver wastewater treatment plant (BWTP) in Baltimore, Maryland. Two samples were purchased from a commercial vendor in Baltimore County, Maryland. The PBF purchased commercially was processed in Milwaukee, Wisconsin. Upon purchase, PBF bags were placed into sealed plastic tubs where they were stored until needed for sample preparation and analysis.

2.3. Sample preparation

Bags containing PPHW or PBF were opened in a vented hood. The PPHW was both granular and cylindrical in form. The granular form of the fertilizer was approximately 4 mm by 3 mm in size, and weighed approximately 30 mg per pellet. The cylindrical form was approximately 8 mm in length, with a 1.5 mm radius, and weighed approximately 90 mg. PBF came in granular and spherical or bead-shaped form. The granular form of the fertilizer was approximately 4 mm by 3 mm in size and 30 mg in weight per pellet. The spherical/bead form was approximately 2 mm in diameter and 6 mg in weight. Pellets in each bag were thoroughly mixed before a sample was removed.

Samples to be prepared by microwave digestion were stored in autoclaved 950 ml glass mason jars. Before digestion, pellets were ground and size separated using a 75 μm stainless steel sieve to ensure that the particle size was less than or equal to that of the Standard Reference Material used in the study (NIST material 2709 San Joaquin soil, National Institute of Standards, Rockville, MD). Prior to digestion, sieved samples were weighed in digestion vessels (CEM, Matthews NC) to 0.20 g ± 0.03 g using a balance (Model AG204, Mettler Toledo, Columbus OH). Sample digestion was conducted in a microwave digestion oven (Model MARS5 XPress, CEM Corp., Matthews NC) using concentrated reagent grade nitric acid (HNO_3) (Fisher Scientific, Columbia MD) and ultra high purity water (Millipore, Billerica MA). Ten (10) ml of HNO_3 were added to each sample. The vessels were allowed to sit uncapped to vent for 15 min. For quality control purposes, one to two SRM 2709 samples were digested for every ten samples prepared. Samples were irradiated in a one step ramp-to-temperature method reaching a maximum temperature of 210 °C. Samples were filtered and diluted with ultra pure water to a volume of 50 ml. From that, an aliquot was taken and diluted to a final HNO_3 concentration of 5%. Precision was estimated from replicate measurements of each sample.

A limited number of samples were also processed using both HNO_3 and hydrofluoric acid (HF) to determine if any undigested silicate material in the pellets was introducing a negative bias in the detected arsenic concentrations (National Institute for Standards and Technology, 2003). These samples were digested with 9 ml of reagent grade HNO_3 and 3 ml of optima grade HF (Fisher Scientific, Columbia MD). Samples were filtered and diluted with ultra pure water to a volume of 50 ml. From that, an aliquot was taken and diluted to a final HF concentration of 0.5%. Other than these modifications, the aforementioned protocol was followed.

2.4. Arsenic analysis

Arsenic analysis was conducted using a Perkin Elmer AA600 Graphite Furnace Atomic Absorption Spectrometer (AA600) (Perkin Elmer, Wellesley MA) equipped with an electrode-less discharge lamp. Samples were analyzed at 193.7 nm at a slit width of 0.7 nm. Samples were introduced into the AA600 by an autosampler, which injects a 20 μl aliquot of sample into the graphite furnace. Each aliquot was automatically combined with 5 μl of a matrix modifier (High Purity Standards, Charleston SC), a solution of Pd and $Mg(NO_3)_2$ used to ensure that the arsenic remained in solution during the pyrolysis stage. The matrix modifier was also added to the calibration standards.

A 6 point calibration curve was calculated at the beginning of each sample analysis session. A standard solution of $H_3As_2O_4$-$0.5H_2O$ in 2% HNO_3 with an arsenic standard concentration of 1000 μg ml^{-1} in aqueous solution was used to create the set of calibration standards; 10 μg l^{-1}, 20 μg l^{-1}, 30 μg l^{-1}, 40 μg l^{-1} and 50 μg l^{-1}. The method detection limit (MDL), 5 μg l^{-1}, was determined using three times the standard deviation of 13 replicate measures of the lowest calibration standard. Standards were prepared using 2% optima nitric acid in ultra pure water and were stored for 6 months or until the correlation coefficient fell outside the acceptable range. A correlation coefficient of 0.99 ± 0.02 was required in order to accept the calibration before sample analysis was started. To check for calibration and instrumentation drift throughout the duration of the run, validation checks of the calibration were performed using a 25 μg l^{-1} standard and a blank every tenth sample resulting in a coefficient of variation of 0.08. At the completion of the analytical run, the validation checks were repeated along with the samples that were run immediately after the validation checks throughout the analytical run. A mean concentration resulting from two injections of the same sample was reported as the concentration value for the sample. For results below the MDL, a value equivalent to the MDL divided by the square root of 2 was imputed for statistical purposes (Hornung and Reed, 1990).

3. Results and discussion

Summary results including mean, minimum and maximum values for PPHW are displayed in Table 1, and as

Table 1
Summary of arsenic concentrations in PPHW fertilizer

Bag ID	Replicates	As concentration (ppm)		
		Mean (SD)	Min	Max
PPHW1	8	24.7 (1.3)	23.2	27.0
PPHW2	10	16.3 (1.3)	14.2	18.1
PPHW3	11	20.6 (1.9)	16.2	23.2
PPHW4	11	25.2 (0.9)	23.9	26.9
PPHW5	11	18.1 (1.2)	16.0	19.5
PPHW6	11	15.4 (2.3)	12.2	18.9
USGS Soil (1984)[a]	–	5.2 (2.2)[b]	–	–

[a] As reported by United States Geological Survey (USGS) in "Element concentrations in soils and other surficial materials of the conterminous United States", 1984.
[b] USGS reports geometric means and standard deviations.

box plots in Fig. 1. Recovery for the analyte was within 10% based on reported values of the NIST SRM 2709 analysis (17.7 ± 0.6 ppm), with a mean concentration of 15.6 ppm and a standard deviation of 1.8 ppm. The overall mean concentration of arsenic in PHW fertilizer pellet bags was 20.1 ppm. Mean arsenic concentrations for individual bags ranged from 15.4 to 25.2 ppm. All reported values were well above the detection limit (3.5 ppm). The relative standard deviation (RSD) from within and between bags was 0.21 ppm. The mean arsenic concentration for all HF/ HNO_3 digested samples was 21.0 ppm, slightly higher than the mean of the PPHW samples digested only with HNO_3. The distribution of sample arsenic concentrations in the HF/ HNO_3 digested samples was similar to the HNO_3-only digest, with a RSD of 0.22 ppm from within and between bags. The range of concentrations of arsenic in HF/ HNO_3 digested samples, 15.6–29.1 ppm, was also
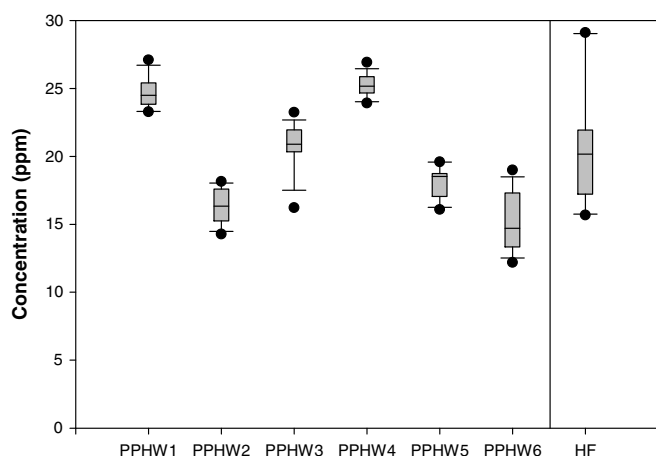

Fig. 1. Boxplots of replicate sample distributions for pelletized PHW fertilizer bags. PPHW1–PPHW6 corresponds to replicate sample results for bags of pelletized biosolids fertilizer digested with HNO_3. HF corresponds to replicate sample results from each of the six PPHW bags digested with HF and HNO_3. In boxplots, central line corresponds to mean, upper box line corresponds to 75th percentile, lower box line corresponds to 25th percentile, whiskers represent 95% confidence interval and dots represent outliers.

slightly wider than that for the weaker digest. In order to determine whether the HF and HNO_3 digest method produced different results than the HNO_3-only digest, it was necessary to evaluate whether the mean values for each digest type were statistically different. A Wilcoxon Rank-Sum test was performed to test the difference in mean concentrations resulting from the two types of digests. The test statistic and resulting *p*-value corresponding to the hypothesis that the means were equivalent were 0.434 and 0.66, respectively, indicating that the null hypothesis cannot be rejected and that the two digestion methods did not produce statistically different results.

Biosolids fertilizer bag summary results (including mean, minimum and maximum values and the number of samples below the limit of detection (LOD)) are displayed in Table 2 and Fig. 2. The overall mean arsenic concentration in PBF bags was 4.1 ppm, and mean arsenic concentrations for individual bags were less variable than PPHW, with a standard deviation of 1 ppm and ranging from 3.1 ppm to 5.1 ppm. The RSD for all PBF samples was 0.41 ppm from within and between bags. Six out of fifteen replicate samples from PBF 3 and eight out of fifteen replicate samples from PBF 4 were below the LOD.

Concentrations of arsenic in PPHW fell within previously reported ranges for raw PHW, and also were within the range of previously reported preliminary data (18.0 to 21.8 ppm) from a single source (Nachman et al., 2005). From these data, it does not appear that the pelletization process concentrates arsenic in PPHW. The mean arsenic concentration in PPHW falls within the lower part of the range of arsenic concentrations in PHW reported in multiple studies (Arai et al., 2003; Garbarino et al., 2003; Rutherford et al., 2003), suggesting the possibility that the PPHW in the bags sampled in this study were pelletized from PHW having arsenic concentrations on the lower end of the previously reported range.

Certain study limitations increase the uncertainty of the estimation of variability of arsenic content in PPHW. Without lot numbers or other identifying information, it was not possible to ascertain the facility where, or on the date which pellets were processed. Without this information,

Table 2
Summary of arsenic concentrations in PBF fertilizer

Bag ID	Replicates	As concentration (ppm)			
		Mean (SD)	#<LOD	Min	Max
PBF1	11	5.1 (0.6)	0 (0%)	4.6	6.5
PBF2	11	5.0 (0.6)	0 (0%)	4.1	5.9
PBF3	15	3.4 (0.8)	6 (40%)	2.5[c]	4.4
PBF4	15	3.1 (0.7)	8 (53%)	2.5[c]	4.3
USGS Soil (1984)[a]	–	5.2 (2.2)[b]	–	–	–

[a] As reported by United States Geological Survey (USGS) in "Element concentrations in soils and other surficial materials of the conterminous United States", 1984.
[b] USGS reports geometric means and standard deviations.
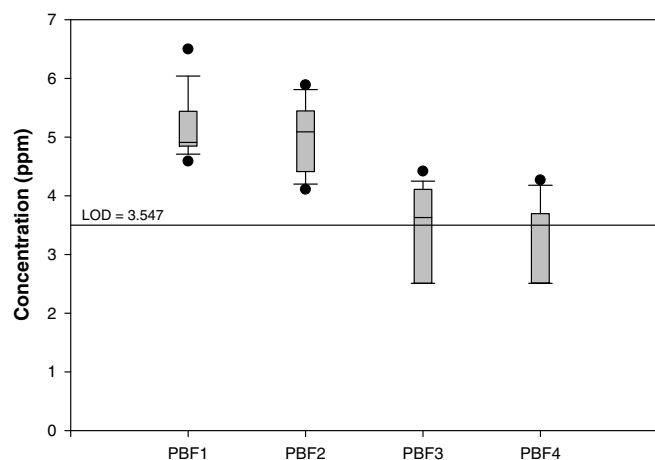[c] Minimum value was less than limit of detection.

Fig. 2. Boxplots of replicate sample distributions for pelletized biosolids fertilizer bags. PBF1–PBF4 corresponds to replicate sample results for bags of pelletized biosolids fertilizer digested with HNO_3. In boxplots, central line corresponds to mean, upper box line corresponds to 75th percentile, lower box line corresponds to 25th percentile, whiskers represent 95% confidence interval and dots represent outliers.

it is possible that pellets from multiple bags were from the same lot of processed PHW. The relative novelty of the pelletization management strategy may facilitate assumptions about where pellets are processed. For all of the bags except for the one from North Carolina, it is assumed that the samples came from a pelletization facility in Seaford, Delaware, since it is the only known pelletization facility in the Delmarva region. It is uncertain where the North Carolina pellets were manufactured, as information regarding the existence of pelletization facilities in the region was not available. Further, without knowing where pellets were processed, it is also impossible to determine where the PHW used to make the pellets was acquired. However, it is reasonable to assume that in the case of the pellets produced at the Delaware plant, the PHW came from Delmarva Peninsula poultry houses, since the pelletization facility has advertised free broiler litter cleanout and removal service (Perdue Agrirecycle, 2007).

Uncertainty in the geographic location of the pelletization of PHW is not expected to have a significant influence on the representative nature of the results of the presented results, assuming the use of domestic PHW from poultry fed roxarsone. Roxarsone is approved for addition to broiler feed at a specified rate of 45 g ton^{-1}, and the formulation of feed is carried out in a uniform fashion by poultry integrators, or the owners of the birds. Poultry growers, who house the birds, are not responsible for providing or mixing feed. Given the uniform rate of addition of roxarsone to feed, it is unlikely that arsenic concentrations will vary widely. For this reason, the results of the arsenic analysis are expected to be representative of domestically-pelletized PPHW.

Arsenic concentrations in PPHW were approximately a factor of 5 higher than those in PBF. The mean arsenic concentration found in PBF was 4.1 ppm, which is lower than the estimated geometric mean arsenic concentration of 5.2 ppm in soils and other surface materials of the conterminous United States (United States Geological Survey, 1984). A study of arsenic concentrations in Baltimore, Maryland sediments reported a geometric mean range from 1.25 to 7.29 ppm (Miles and Tome, 1997), a range that includes the results from this study.

This study has examined the arsenic content of PBF from two geographic regions, Baltimore, Maryland and Milwaukee, Wisconsin. However, unlike in the case of PHW, pelletization of biosolids has been a faster growing practice, with pelletization facilities in operation in Texas (Synagro, 2005; BCF, 2006), Kentucky (Green, 2005), New York (Bulkflow Technologies, 2006) and California (E-Wire, 2003). It should be noted that differences in arsenic concentrations between PBF regions were not statistically significant, suggesting that the characterizations presented in this study may also be representative of PBF produced in other domestic facilities. Further analysis of pellets from other facilities would reduce uncertainty about representativeness and provide a more complete understanding of the variability of arsenic contamination in PBF.

Regulations regarding arsenic content in land-applied fertilizer derived from biological waste differ by origin of the waste. Currently, no federal regulations exist addressing the presence of arsenic in PHW, though the Part 503 Rule of the USEPA's clean water act (CWA) sets concentration limits for arsenic in land-applied biosolids. Biosolids-based arsenic is restricted to a ceiling concentration limit of 75 mg kg^{-1} dry weight for any single application, and a pollutant concentration limit of 41 mg kg^{-1} dry weight averaged over monthly applications. Land disposal of PHW is not regulated in terms of its arsenic content, but guidance is in place regarding nitrogen and phosphorous via nutrient management plans. Based on the findings of this study and existing arsenic regulation of land-applied biosolids, it may also be sensible to consider arsenic-based application and monitoring standards for PPHW.

Some states have different types of regulations or guidance in place to address soil arsenic concentrations in residential sites, typically in the form of notification, action or cleanup levels (Association for the Environmental Health of Soils, 1998). One of the largest domestic poultry producing regions, the Delmarva Peninsula, is composed of the eastern shores of Delaware, Maryland, and Virginia. A comparison of state-level soil arsenic guidance for these states is presented in Table 3. Delaware has established an allowable soil arsenic concentration of 2 ppm for nonrestricted sites, above which the state must be notified. The state of Maryland, which does not have a notification level, defaults to the USEPA Region 3 recommended risk based screening concentration (RBC) of 0.43 ppm for its action level, above which some type of remedial or control activities must be undertaken. Maryland also has separate guidance regarding cleanup levels, requiring an attainment of a soil concentration of 2.0 ppm or less for residential site

Table 3
Delmarva Peninsula state-specific soil arsenic guidance and screening levels

| State | Type of level (mg As/kg soil) | | | | | |
| | Residential soil | | | Non-residential/industrial soil | | |
	Notification	Action	Cleanup	Notification	Action	Cleanup
Delaware	2.00	None	23.00	61.00	None	23.00
Maryland	None	0.43	2.00	None	3.80	3.80
Virginia	None	0.43	None	None	1.90	None

use (Maryland Department of the Environment, 2001). The state of Virginia does not have soil arsenic notification or action levels in place, but defaults to the USEPA Region 3 screening level RBC of 0.43 ppm. It also notes that site background arsenic concentrations are frequently higher than the USEPA RBC screening level, and that site-specific background concentrations are often more appropriate screening levels (Virginia Department of Environmental Quality, 2006).

For all three Delmarva Peninsula states, arsenic concentrations reported for all PPHW samples exceed state notification and action levels. In addition, prior research has shown increased concentrations of water-extractable arsenic in agricultural fields tilled with PHW as opposed to those that had not been amended. Arsenic concentrations on these amended fields followed a negative gradient according to depth and increased over subsequent applications of PHW (Rutherford et al., 2003), possibly suggesting that arsenic accumulates in the surface soils, and that less of the arsenic introduced by land application is transported into deeper soils. If this is the case, it seems likely that residential use of PPHW would increase surficial soil arsenic concentrations, pushing the resulting soil levels further beyond existing notification and action levels.

Pelletized waste fertilizers introduce exposure scenarios that are different than those from land-applied PHW and biosolids (United States Environmental Protection Agency, 1995). The commercial sale of PPHW adds the general population as a receptor to a set of potential exposures that previously only concerned poultry and agricultural workers and nearby residents of farms. The use of PPHW and PBF in home gardens and commercial landscaping may result in increased incremental exposures to waste-based contaminants in residential scenarios.

Despite the recognized benefit of nutrient mobility given to waste by the pelletization process, the potential adverse health impacts that may result from moving beyond the use of waste as a large-scale agricultural amendment should be a public health consideration, as the presence of arsenic in PPHW and PBF could lead to additional incremental population exposures. In addition to the pathways of exposure considered for land application of biosolids, exposure pathways related to the handling and application of pelletized waste fertilizers need to be acknowledged. Also, given the uncertainty associated with the adverse health endpoint of "hyperpigmentation, keratosis and possible vascular complications" (United States Environmental Protection

Agency, 2002) used in derivation of arsenic standards in the case of land-applied biosolids, the use of pelletized waste fertilizer may be premature until a better understanding of the risks is attained through reductions of exposure-related uncertainty. Further, the fraction of arsenic that is bioavailable via these exposure pathways is not known and also complicates the characterization of exposure-related risks.

The enormous volume of waste generated both by municipal sources and from the industrial production of animals has created a need for management strategies other than landfilling or agricultural land application. Waste pelletization has been seen by many as a potential solution to this management crisis. The use of PPHW and PBF is of particular interest because of its potential for widespread use in residential gardening and commercial landscaping. The arsenic content in these wastes, whether originating as an intentional additive or as a result of environmental sources, is of concern, because chronic arsenic exposures increase health risks. Arsenic exposures in humans resulting from use of these fertilizer pellets should be quantified to avoid potential unintended negative consequences of managing wastes through pelletization. The results of this study provide arsenic concentrations in PPHW and PBF, which are key to determining the magnitudes of human exposures to arsenic and corresponding potential risks to persons using these fertilizers.

Building upon this research, efforts are underway to assess incremental cancer risks and non-cancer hazards resulting from human exposures to arsenic resulting from the use of PPHW and PBF in the residential setting. In addition, the potential for adverse health effects resulting from acute exposures to children, particularly through the pica pathway (intentional ingestion of non-food items), will be assessed.

References

Agency for Toxic Substances and Disease Registry, 2005. Draft Toxicological Profile for Arsenic. United States Department of Health and Human Services.

American Society of Agricultural Engineers, 2005. Manure Production and Characteristics. American Society of Agricultural Engineers, St. Joseph. ASAE D384.2.

Arai, Y., Lanzirotti, A., Sutton, S., Davis, J.A., Sparks, D.L., 2003. Arsenic speciation and reactivity in poultry litter. Environ. Sci. Technol. 37, 4083–4090.

Association for the Environmental Health of Soils, 1998. Study of State Soil Arsenic Regulations. Amherst, MA. Association for the Environmental Health of Soils.

BCF, 2006. Hou-Act Brochure [online]. Available from http://www.bcfproducts.com/Hou-Act-Brochure.pdf [Accessed May 3, 2007].

Bulkflow Technologies, I., 2006. Cool Biosolids [online]. Available from http://www.bulkflow.com/applications_products_biosolids.htm [Accessed January 24, 2006].

Chapman, H.D., Johnson, Z.B., 2002. Use of antibiotics and roxarsone in broiler chickens in the USA: analysis for the years 1995 to 2000. Poultry Sci. 81, 356–364.

Cortinas, I., Field, J.A., Kopplin, M., Garbarino, J.R., Gandolfi, A.J., Sierra-Alvarez, R., 2006. Anaerobic biotransformation of roxarsone and related N-substituted phenylarsonic acids. Environ. Sci. Technol. 40, 2951–2957.

E-Wire, 2003. Construction to Begin on New California Biosolids Recycling Plant Environmental Focus, New Technology, Good Neighbor Design a "First for State" [online]. Available from http://www.ewire.com/display.cfm/Wire_ID/1698 [Accessed January 24, 2006].

Garbarino, J.R., Bednar, A.J., Rutherford, D.W., Beyer, R.S., Wershaw, R.L., 2003. Environmental fate of roxarsone in poultry litter. I. Degradation of roxarsone during composting. Environ. Sci. Technol. 37, 1509–1514.

Green, L., 2005. Louisville Green [online]. Available from http://www.louisvillegreen.com/index.htm [Accessed January 24, 2006].

Hornung, R.W., Reed, L.D., 1990. Estimation of average concentration in the presence of nondetectable values. Appl. Occup. Environ. Hyg. 5, 46–51.

Horrigan, L., Lawrence, R.S., Walker, P., 2002. How sustainable agriculture can address the environmental and human health harms of industrial agriculture. Environ. Health Perspect. 110, 445–456.

International Agency for Research on Cancer, 1987. Arsenic and Arsenic Compounds (IARC Summary & Evaluation, Supplement 7, 1987) [online]. Available from http://www.inchem.org/documents/iarc/suppl7/arsenic.html [Accessed December 18, 2006].

Jackson, B.P., Bertsch, P.M., 2001. Determination of arsenic speciation in poultry wastes by IC-ICP-MS. Environ. Sci. Technol. 35, 4868–4873.

Jackson, B.P., Bertsch, P.M., Cabrera, M.L., Camberato, J.J., Seaman, J.C., Wood, C.W., 2003. Trace element speciation in poultry litter. J. Environ. Qual. 32, 535–540.

Kowalski, L.M., Reid, W.M., 1972. Roxarsone: efficacy against eimeria brunetti infections in chickens. Poultry Sci. 51, 1586–1589.

Maryland Department of the Environment, 2001. Cleanup Standards for Soil and Groundwater, Interim Final Guidance [online]. Available from http://www.mde.state.md.us/assets/document/hazcleanup_Aug2001.pdf [Accessed April 4, 2007].

Miles, A.K., Tome, M.W., 1997. Spatial and temporal heterogeneity in metallic elements in industrialized aquatic bird habitats. Environ. Pollut. 95, 75–84.

Nachman, K.E., Graham, J.P., Price, L.B., Silbergeld, E.K., 2005. Arsenic: a roadblock to potential animal waste management solutions. Environ. Health Perspect. 113, 1123–1124.

National Institute for Standards and Technology, 2003. Certificate of Analysis – Standard Reference Material 2709 San Joaquin Soil. 13.

National Research Council, 1999. Arsenic in Drinking Water. National Academy Press, Washington, DC.

National Research Council, 2001. Arsenic in Drinking Water: 2001 Update. National Academy Press, Washington, DC.

National Research Council, 2002. Biosolids Applied to Land – Advancing Standards and Practices. National Academy Press, Washington, DC.

Perdue Agrirecycle, 2007. Perdue AgriRecycle – For Delmarva Poultry Producers online. Available from http://www.perdueagrirecycle.com/delmarva.html, Accessed May 4, 2007.

Rutherford, D.W., Bednar, A.J., Garbarino, J.R., Needham, R., Staver, K.W., Wershaw, R.L., 2003. Environmental fate of roxarsone in poultry litter. Part II. Mobility of arsenic in soils amended with poultry litter. Environ. Sci. Technol. 37, 1515–1520.

Stolz, J.F., Perera, E., Kilonzo, B., Kail, B., Crable, B., Fisher, E., Ranganathan, M., Wormer, L., Basu, P., 2007. Biotransformation of 3-nitro-4-hydroxybenzene arsonic acid (roxarsone) and release of inorganic arsenic by Clostridium species. Environ. Sci. Technol. 41, 818–823.

Synagro, 2005. South online. Available from http://synagro.com/locations/south.htm [Accessed January 24, 2006].

United States Department of Agriculture, 2006. Poultry – Production and Value – 2005 Summary [online]. Available from http://usda.mannlib.cornell.edu/usda/current/PoulProdVa/PoulProdVa-05-18-2006_revision.pdf [Accessed April 3, 2007].

United States Department of Agriculture, 2007. ERS/USDA Briefing Room – Farm Income and Costs: 2007 Farm Sector Income Forecast [online]. Available from http://www.ers.usda.gov/Briefing/FarmIncome/nationalestimates.htm [Accessed April 3, 2007].

United States Environmental Protection Agency, 1995. A Guide to the Biosolids Risk Assessments for the EPA Part 503 Rule. United States Environmental Protection Agency.

United States Environmental Protection Agency, 2001. EPA: Federal Register: National Primary Drinking Water Regulations; Arsenic and Clarifications to Compliance and New Source Contaminants Monitoring [online]. Available from http://www.epa.gov/fedrgstr/EPA-WATER/2001/January/Day-22/w1668.htm [Accessed 18 December 2006].

United States Environmental Protection Agency, 2002. Arsenic, inorganic (CASRN 7440-38-2), IRIS, Environmental Protection Agency [online]. Available from http://www.epa.gov/iris/subst/0278.htm [Accessed May 12, 2006].

United States Environmental Protection Agency, 2005. Charge to EPA Science Advisory Board Arsenic Review Panel [online]. Available from http://epa.gov/sab/pdf/arsenic_review_panel_final_charge_7-25-05.pdf [Accessed February 16, 2006].

United States Geological Survey, 1984. Element Concentrations in Soils and other Surficial Materials of the Conterminous United States. US Department of the Interior. Professional Paper 1270.

Virginia Department of Environmental Quality, 2006. Table 2.5 Soil: Unrestricted [online]. Available from http://www.deq.state.va.us/vrprisk/files/screen/vrp25.xls [Accessed April 4, 2007].

Wallinga, D., 2006. Playing Chicken: Avoiding Arsenic in Your Meat. Institute for Agriculture and Trade Policy, Minneapolis, Minnesota.