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Distribution of Plant Nutrient Elements and Carbon in Particle Size Fractions of Broiler Litter Ash

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Abstract: An estimated 10.8 million tons of broiler litter and 3.0 million tons of turkey litter were produced in the United States in 2009. Poultry litter is a mixture of manure, bedding material (e.g. wood chips, sawdust, or straw), feathers, and spilled feed. Poultry litter contains high levels of Ca, N, P, and K, and is often applied as a fertilizer on fields in close proximity to poultry houses. Repeated poultry litter application to these fields can increase soil P to levels in excess of plant requirements, resulting in potential environmental risk. An alternative to land application of poultry litter is its use as a fuel in electricity generation. Ash from this process has been used as a fertilizer after sieving to < 1.27 cm, with the larger fraction being discarded in landfills. The objective of this study was to determine the elemental composition of size fractions of broiler litter ash samples produced using a variety of burn durations and temperatures. Ten 2-kg broiler litter ash samples were collected from a biomass gasification test plant and sieved into five size fractions. Nutrients in the ash were extracted using Mehlich-1 solution. In most cases, nutrient concentrations were higher in the finer two fractions while C concentration was higher in the coarser (> 0.5 mm) fractions. Nevertheless, the amount of P in the coarsest fraction ranged from 15 to 25 percent of the total extractable phosphorus in the ash. With such high P content in the coarse fraction, there is a potential of P leaching when this fraction is disposed of in landfills. We recommend that the coarse fraction should be crushed and mixed with the fine fractions before the ash is used as a fertilizer and soil amendment.

Keywords: Broiler litter ash, fractions.

INTRODUCTION

An estimated 10.8 million tons of broiler litter and 3.0 million tons of turkey litter were produced in the United States in 2009 [1]. Poultry litter (PL) is a mixture of manure, bedding material (e.g., wood chips, sawdust, or straw), feathers, and spilled feed [2]. PL may also contain some soil and rock from the poultry house floor. PL has a high content of nutrients such as Ca, N, P, and K, and is therefore often applied as fertilizer on fields near poultry houses [3]. Generally, more PL is produced than is needed to supply crop nutrients in the vicinity of poultry houses. PL application to fields with excess nutrients may result in potential environmental risk [4]. This can be through runoff and/or leaching, especially of P and N, into surface and ground waters, resulting in compromised water quality through eutrophication [3-5]. In Pennsylvania, the application of PL to agricultural fields has been restricted in order to protect bodies of water. Proposed alternatives to the application of PL to fields with excess P include composting, pelletizing, or burning the PL, or transporting it to fields low in P that are further away. Transporting PL for very long distances would not be economically profitable due to transport costs.

Because PL contains high-cellulose bedding material, it has been used as a fuel in electricity generation, both in pilot studies and in fully operational power plants [6]. In the UK, a PL-fueled power station has been in operation since 1992 [7], while in the U.S., a PL-fueled power plant was installed in Benson, Minnesota, in 2007 [8]. A small broiler litter combustion facility (Enginuity LLC) in Mechanicsburg, PA, is conducting pilot studies to determine the effects of temperature and duration of burning on energy production and on the ratio of ash to char in the combustion residue. It has been found that in energy production and the ash: char ratio also depend on whether the PL used was pre-dried before combustion, the speed at which PL moves through the furnace, and the CO_2/O_2 ratio in the combustion chamber. The poultry litter ash (PLA) that remains after combustion of PL is rich in the plant nutrients Ca, P, Mg, and K and also contains Zn, Cu, and Mn, making it potentially useful as a fertilizer [9, 10]. Recycling of these plant nutrients is important, especially in the case of P, of which resources are limited [11]. However, water soluble P in PLA is much lower than in commercial fertilizers or PL, as a result of the burning process [19]. The nutrient content and availability of PLA also depend on the type of bedding material and the ratio of bedding material to manure [12]. Because of the higher nutrient density of PLA relative to PL, the cost of transporting PLA is lower; thus PLA can be applied to fields further away from where it is produced [13]. PLA also has a high pH and

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Table 1. Combustion Parameters, pH, and Electrical Conductivity of the Broiler Litter Ash Samples

Sample	Date	Time	Duration of Burning [min]	Average Burning Temperature [°C]	pH	EC mS /cm
1	8/22/2011	4:33 pm - 8:30 pm	237	778	11.7 d†	55.1 ab
2	8/22/2011	11:50 am - 4:33 pm	283	760	11.8 cde	61.8 a
3	8/23/2011	7:25 am - 10:45 am	200	732	11.6 e	59.5 ab
4	8/23/2011	12:50 pm - 4:10 pm	200	704	13.3 a	47.1ab
5	8/23/2011	4:10 pm - 8:30 pm	260	759	13.2 a	48.3 ab
6	8/21/2011	3:10 pm - 5:45 pm	155	804	11.9 cde	55.8 ab
7	8/23/2011	3:10 am - 7:25 am	255	771	12.1 bc	57.8 ab
8	8/22/2011	4:00 am - 9:56 am	356	746	12.0 bcd	47.5 ab
9	8/23/2011	10:45 am - 12:50 pm	125	670	12.4 b	53.2 ab
10	5/5/2011	6:30 am - 9:00 am	150	601	12.0 bcd	44.3 b

† Means within columns having a letter in common are not significantly different at P<0.05 using Duncan multiple range test.

may be useful as a soil liming agent. The liming effects of PLA may be affected by the bedding material. It has been shown that wood ash can increase soil pH and benefit plant growth [14], so bedding material containing sawdust or wood chips may have a similar effect. An additional advantage of using PLA on soil is the potential of carbon sequestration when PLA that is rich in char (charcoal) is applied to soil. Application of char to soil provides a long-term sink for atmospheric carbon dioxide in the terrestrial ecosystem [15]; [16]. Char can also improve soil physical and biological properties and enhance plant growth [17, 18]. A potential concern in using PLA as a fertilizer is the arsenic (As) content of the ash, because As is added to poultry feed to control intestinal parasites and to increase weight gain, and it is found in the manure [20, 21]. However, this may be a problem of the past, as some poultry producers have already stopped using As. Recently; Maryland became the first state in the U.S. to ban the feeding of As to poultry [22].

The broiler litter ash used in this experiment was from a small pilot broiler litter combustion facility (Enginuity LLC) in Mechanicsburg, PA. At this facility, broiler litter ash (BLA) is sieved using a 1.27-cm sieve to produce an ash fraction that can be applied with farm machinery, while the BLA fraction > 1.27 cm is discarded in a landfill. The objective of this study was to determine the concentration of plant nutrients and carbon in five size fractions of ten broiler litter ash samples produced with a range of burn durations and temperatures.

MATERIALS AND METHODS

Broiler Litter Ash Collection, Processes and Analysis

Ten 2-kg BLA samples were collected from a biomass gasification test plant (Enginuity LLC) in Mechanicsburg, PA. The ten BLA samples represent four different burning days. The BLA samples were stored in Ziploc plastic bags until use. Information on the temperature and duration of combustion for each sample is presented in Table **1**.

Each BLA sample was sieved into five fractions with a range of particle sizes (Table **2**). For analysis, a sub-sample of 10 g was taken from each size fraction of each sample.

Table 2. Particle Sizes of the Broiler Litter ash Fractions Separated by Screening

Fraction	Size in mm
1	>2.38
2	<2.38 to 2.00
3	<2.00 to 0.50
4	<0.50 to 0.25
5	<0.25

Sub-samples were ground using a mortar and pestle to a size of < 0.25 mm and analyzed with three replicates. The pH was determined 1:2 (BLA to de-ionized water, by volume) slurry after 1 hr using a glass electrode [23]. Electrical conductivity was also determined by using an Orion model 160 conductivity meter in a 1: 2 (BLA to de-ionized water, by volume) slurry after 1 hr. Total carbon (C) concentration was measured using a rapid CS analyzer (Elementar, Hanau, Germany). Thirty mg of ground BLA sample and 30 mg of conditioner (Tungsten VI and Wolfram VI oxides) were wrapped in tin foil prior to measurement. The detection limit of the instrument was 0.01 mg C, corresponding to a C concentration of 0.03 % in a 30-mg sample. Near-total P concentration was measured in Mehlich-1 extracts. The Mehlich-1 extracting method [24] was used to determine the near-total P concentration in the BLA fractions. A 0.1-g sample of ground (<25mm) BLA was placed in a 250-ml Erlenmeyer flask and 100 ml of Mehlich-1 solution (0.025 N H_2SO_4 + 0.05 N HCl) was added. Samples were shaken for 5 min on a horizontal shaker at 200 rpm. Extracts were filtered through Whatman No. 42 filter paper and stored until analysis. Phosphorus (P) concentration was analyzed with two methods: colorimetrically and by inductively coupled plasma optical emission spectrometry (ICP-OES; PerkinElmer, Wellesley, MA) with scandium as the internal standard. Colorimetric P determination was done by the ascorbic acid method [24]. Absorption was measured at 880 nm with an UV/VIS Lambda 25 spectrometer (PerkinElmer, Wellesley, MA). Potassium (K), calcium (Ca), and magnesium (Mg) were also measured in Mehlich-1 extract using ICP-OES.

Statistical Analysis

Statistical analysis of the data was performed using PC-SAS [25]. Data were analyzed by one-way ANOVA to test the significance of differences in mean elemental concentrations between size fractions of each ash sample. Separation of means was done using Duncan's multiple-range test [26].

RESULTS AND DISCUSSION

pH and Electrical Conductivity

There were no significant differences in pH or electrical conductivity (EC) of BLA between size fractions within samples. Therefore, pH and EC results for each sample were averaged over size fractions. With the exception of samples 4 and 5, which had higher pH values, there was little difference in BLA pH between samples (Table **1**). However, samples 4 and 5 did not have higher burn durations or temperatures, which contrasted with the results of a previous study that observed increased pH of BLA with increasing burning temperature [27]. Burning temperature and burning duration did not influence EC of BLA (Table **1**). Although samples 1, 2, 3, 6, and 7 had the highest EC values, the differences were not significant.

Total Carbon

Within ash samples, there was some relationship between the C concentration of BLA and its particle size. In samples 1, 3, 7, and 9, for example, C concentration decreased with decreasing particle size, whereas for samples 2, 6, 8, and 10 the highest C concentration was found in the fraction < 2-0.5 mm, which is in the middle of the range (Table **3**). Among the ten samples, sample 9 had the highest C concentration in each size fraction. The high C concentration in sample 9 may have resulted from its shorter burning time (125 minutes) and from its having the second lowest average burning temperature (670 °C), which resulted in less ash and more char for this sample (Table **1**). Samples 2, 5, and 7 had low C concentrations, probably as a result of their relatively high burning times and temperatures. Sample 8, with a similar burning temperature as samples 2, 5, and 7 but a longer burning duration, had a higher C concentration, with values of 47.6, 34.5, 53.7, and 95.2 mg g^{-1} for samples 2, 5, 7, and 8, respectively. The high level of C in sample 8 could have been influenced by the type of bedding material and the ratio of bedding material to manure, which generally differ in their flammability and/or C content. Mante and Agblevor [28] reported that the C concentration of wood based bedding material is generally higher than that of manure. Finally, the composition of poultry manure often varies between farms due to different management practices [29, 12]. The application of carbon-rich BLA to soil could contribute to the sequestration of carbon. Lehmann *et al*. [15] reported that application of char to soil is a long-term sink for atmospheric carbon dioxide in the terrestrial ecosystem. Char can also improve soil physical and biological properties and enhance plant growth when applied to soil [17, 18].

Extractable Nutrients

Because there was very little difference between P concentration determined colorimetrically and that determined by ICP-OES, P determined by ICP-OES was used for this manuscript. Averaged over fractions, sample 8 had the highest P concentration (392 mg g^{-1}) while sample 9 had the lowest (302 mg g^{-1}). The lower level of P observed in sample 9 may have been a consequence of its higher C concentration (Table **3**). Faridullah *et al*. [27] reported increased P concentration but decreased C concentration of PLA with increasing burning temperature. Adams [30], however, observed no change in P with increasing temperature. Although there were significant differences in P concentration between some size fractions within each ash sample, all fractions had at least 60 mg P g^{-1}, with the exception of the coarsest fraction of sample 9 (Table **3**). The coarser fractions (> 2.0 mm; fractions 1 and 2) generally had lower P concentrations compared to the finer fractions (< 0.5 mm; fractions 4 and 5). Nevertheless, when the content of P in the size fractions was examined (data not shown), the differences were slight. For example, P content of the coarsest fraction, expressed as percent of the total P in the sample, ranged from 14.8 to 25.0 across the ten samples, compared to a range of 20.6 to 25.0 percent for the finest fraction. The P content of the coarsest fraction could potentially contribute to environmental problems such as eutrophication if it is discarded in landfills. For most samples, Ca concentration was higher in the fractions < 0.50 mm, although for samples 1, 4, and 5, the highest Ca level was in the coarsest fraction (Table **3**). The higher Ca levels generally found in the fine fractions may have resulted from the large quantity of soluble Ca that is fed to broilers and then secreted in the manure [31, 32]. Averaged over the five fractions, samples 4 and 5 had significantly higher Ca concentrations compared to the other samples (Table **3**). In all cases, K concentration was generally higher in the finer fractions (< 2.0 mm) than in the coarse fraction (> 2.38 mm). With the exception of sample 4, Mg concentration was generally higher in the finer fractions than in the coarser fractions (Table **3**). When averaged over fractions, nutrients concentrations were in the order Ca > K > P > Mg for all samples. The high Ca to P ratio observed in BLA resulted from the higher level of Ca, compared to that of P, in the broilers' diet. Ansar *et al*. [33] state that a dietary Ca:P ratio of 1:0.5 is essential for the performance of various functions in the birds, and that a deficiency or excess of one can interfere with the proper utilization of the other. Although concentrations of P, Ca, K, and Mg were lower in the coarsest fraction, its content of these elements was still substantial. Instead of being sieved out and discarded, as it is currently, it should be crushed and mixed with the finer fractions for use as a fertilizer. Dumping or land filling the coarse fraction of BLA would result in a loss of valuable plant nutrients and potentially contribute to the eutrophication of surface water.

CONCLUSIONS

Analysis of 10 broiler litter ash (BLA) samples revealed large variations in their concentrations of plant nutrients and carbon, possibly resulting from variations in broiler litter source and combustion parameters. For most BLA samples, carbon concentration was highest in the larger size fractions (> 0.5 mm), while concentrations of the plant nutrients P, Ca, K, and Mg were highest in the finer size fractions (< 0.5 mm). Nevertheless, the amount of P, Ca, K, and Mg in the coarsest (>2.38 mm) fraction of all BLA samples was high enough that disposal of these materials in landfills could result in the leaching of valuable plant nutrients and the eutrophication of water bodies. Crushing the coarse fraction

Table 3. Results of One-Way ANOVA between Particle Size Fractions of each Broiler Litter ash Sample for the Elements C, P, Ca, K, and Mg

fraction [mm]	Sample 1 [mg/g]	Sample 2 [mg/g]	Sample 3 [mg/g]	Sample 4 [mg/g]	Sample 5 [mg/g]	Sample 6 [mg/g]	Sample 7 [mg/g]	Sample 8 [mg/g]	Sample 9 [mg/g]	Sample 10 [mg/g]
Carbon										
>2.38	34.2a†	7.4 d	45.4 a	23.6 d	7.5 a	20.2 d	12.2 a	14.6 d	189.7 a	46.9 c
<2.38-2.0	23.0 b	9.5 c	31.7 b	24.1 d	7.4 a	30.9 b	11.9 ab	19.0 c	152.5 b	76.0 b
<2.0-0.5	20.6 c	11.2 a	32.8 b	30.8 c	5.4 b	37.0 a	11.2 b	27.1 a	153.5 b	84.4 a
<0.5-0.25	18.3 d	10.0 b	22.4 c	50.5 b	6.1 b	28.6 c	10.8 b	21.0 b	130.1 c	63.5 b
<0.25	14.0 e	9.5 bc	18.9 d	58.1 a	8.1 a	19.5 d	7.6 c	13.5 e	79.6 d	27.7 d
Phosphorus										
>2.38	77.7 ab	75.0 b	68.6 c	61.6 c	68.7 cd	75.5 ab	73.3 b	62.8 c	45.0c	71.0 b
<2.38-2.0	no sample	75.7 b	72.3 b	58.2 d	63.9 d	74.9 b	75.4 ab	75.3 b	56.1 b	60.3 d
<2.0-0.5	76.3 b	78.8 a	78.9 a	66.6 b	73.4 bc	78.9 a	80.7 ab	79.9 ab	62.9 bc	66.9 c
<0.5-0.25	77.0 ab	78.6 a	79.3 a	72.7 a	77.7 a	78.7 a	79.3 a	86.1 a	67.9 a	71.6 b
<0.25	79.7 a	80.4 ab	79.3 a	71.4 a	75.6 ab	79.7 a	80.7 a	87.8 a	70.6 a	78.0 a
Calcium										
>2.38	140.8 a	128.2b	122.4 c	168.5 a	163.8 a	125.8 bc	131.8 bc	113.2 c	105.6 c	125.0 b
<2.38-2.0	no sample	127.5 b	130.0 b	167.6 a	145.5 b	128.1 c	130.8c	131.5 b	124.9 b	109.0 d
<2.0-0.5	132.7 b	135.4 ab	137.3 a	157.9 b	145.4 b	133.1 ab	137.4 abc	137.5 b	123.7 b	118.7 c
<0.5-0.25	133.2 b	137.1 a	139.0 a	150.3 c	144.6 b	133.5 a	135.9 ab	147.9 a	128.3 b	125.2 b
<0.25	135.5 b	138.0 a	142.0 a	149.2 c	149.1 ab	133.9 ab	135.5 a	146.9 a	146.2 a	134.0 a
Potassium										
>2.38	84.7 c	101.5 c	98.8 c	78.4 c	77.3 c	93.9 c	91.0 d	65.0 c	71.7 d	86.2 b
<2.38-2.0	no sample	104.5 bc	104.8 c	78.4 c	91.4 b	107.7 bc	97.4 bcd	89.6 b	81.6 c	91.6 d
<2.0-0.5	109.6 a	111.6 b	112.0 b	92.0 b	91.1 b	109.8 b	107.9 c	100.1 b	92.0 b	94.4 c
<0.5-0.25	114.8 a	122.4 ab	120.1 ab	106.6 a	102.4 ab	115.8 ab	112.4 b	119.7 a	102.5 ab	108.7 b
<0.25	118.7 a	124.5 a	119.5 a	108.2 ab	108.2 a	123.2 a	117.4 a	122.3 a	105.4 a	117.2 a
Magnesium										
>2.38	28.5 d	29.6c	28.2 d	48.2 a	35.0 ab	27.8 d	31.2 c	27.4 c	34.8 c	25.0 d
<2.38-2.0	no sample	29.3 c	30.3 c	47.5 a	37.2 b	31.5 c	31.3 c	30.2 bc	37.3 b	26.5 c
<2.0-0.5	29.2 c	30.2 c	31.6 bc	38.9 b	33.4 a	32.9 b	33.6 b	30.4 bc	32.9 d	25.7 d
<0.5-0.25	31.7 b	32.8 b	33.1 bc	36.3 c	33.4 a	35.4 b	33.8 b	37.0 a	35.0 c	28.5 b
<0.25	36.0 a	38.4 a	37.3 a	38.7 b	39.5 a	39.9 a	38.2 a	40.7 a	44.2 a	35.7 a

† Means within columns and elements having a letter in common are not significantly different at $P<0.05$ using Duncan multiple range test.

and mixing it with the finer fractions before their utilization as a fertilizer would reduce the potential for nutrient loss to the environment.

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