environments

MDPI

Article

Fertilizer Efficacy of Poultry Litter Ash Blended with Lime or Gypsum as Fillers

Philip J. Bauer, Ariel A. Szogi * and Paul D. Shumaker

United States Department of Agriculture-Agricultural Research Service, Coastal Plains, Soil, Water and Plant Research Center, 2611 W. Lucas St., Florence, SC 29501, USA; lbauer@sc.rr.com (P.J.B.); paul.shumaker@ars.usda.gov (P.D.S.)

* Correspondence: ariel.szogi@ars.usda.gov; Tel.: +1-843-669-5203

Received: 2 April 2019; Accepted: 29 April 2019; Published: 1 May 2019

Abstract: Ash from power plants that incinerate poultry litter has fertilizer value, but research is lacking on optimal land application methodologies. Experiments were conducted to evaluate calcitic lime and flue gas desulfurization gypsum (FGDG) as potential fillers for poultry litter ash land applications. The ash had phosphorus (P) and potassium (K) contents of 68 and 59 g kg^{-1}, respectively. Soil extractable P and K were measured in an incubation pot study, comparing calcitic lime to FGDG at filler/ash ratios of 1:3, 1:2, 1:1, 2:1, and 3:1. After one month, soils were sampled and annual ryegrass (*Lolium multiflorum* Lam.) seeds were planted to investigate how plant growth and uptake of P and K were influenced by the fillers. Application of ash alone or with fillers increased soil extractable P and K levels above unamended controls by 100% and 70%, respectively. Filler materials did not affect biomass or P and K concentration of the ryegrass. A field study with a commercial spinner disc fertilizer applicator was conducted to compare application uniformity of ash alone and filler/ash blends. Overall, test data suggested that uniform distribution of ash alone or with fillers is feasible in field applications using a commercial fertilizer spreader.

Keywords: poultry litter ash; fertilizer filler; phosphorus; potassium; flue gas desulfurization gypsum; calcitic lime

---

1. Introduction

The intensive production of poultry generates large amounts of spent litter, most of which is applied to agricultural land as a nutrient source in forage and crop production [1]. Repeated land applications of spent poultry litter have resulted in many fields containing nutrient levels above the assimilative capacity of soils [2]. In turn, these high soil nutrient levels cause great concern because of the environmental consequences associated with air and water quality [3,4]. As an alternative to land application, poultry litter incineration is being adopted in Europe and the United States to produce energy and reduce the volume of disposed poultry litter [1,2,5]. The ash from incinerated poultry litter has fertilizer value with high concentrations of plant nutrients, such as phosphorus (P) and potassium (K). Recycling these nutrients is essential to close the nutrient loop in food systems, given that both P and K are limited mined resources being depleted by global demand in production agriculture [6,7]. By concentrating nutrients such as P and K in the ash, it is more economically feasible to transport them to distant croplands with nutrient deficient soils. However, research is needed for environmentally safe and uniform field applications of poultry litter ash products.

Nutrient content of ash generated from poultry litter can be widely variable, due to the type of poultry production (i.e., broilers, layers, bird species), nutrient content of the rations fed to the birds, type of bedding material, number of birds in a flock, number of flocks, and incineration process conditions [2,5,8]. Nevertheless, poultry litter ash usually contains substantial amounts of P and K.

For example, poultry litter ash from a commercial farm in South Carolina contained minimal contents of nitrogen (N) but had 9.1% P_2O_5 and 7.9% K_2O [9]. Thus, poultry litter ash has generally been reported as a satisfactory source of nutrients for crops [10–12]. While as much as 20% of the P in raw poultry litter is readily water-soluble [13], P in poultry litter ash is relatively insoluble in water [8,14]. In a P fractionation study of poultry litter ash, Codling [15] found water-extractable P to be about 1.5% of the total P. Potassium, on the other hand, is highly water-soluble in raw poultry litter and it remains water-soluble even after poultry litter is converted into ash [14,16].

Fertilizers usually contain two types of ingredients: Active and inactive. The active ingredients are the plant macro- and micro-nutrients. The inactive ingredients, also called fillers, may include sand, granular limestone, or sawdust. Filler materials are commonly added to commercial fertilizer blends, so nutrients are evenly applied in amounts based on soil test results. Two readily available potential fillers for the Southeast USA are calcitic limestone and flue gas desulfurization gypsum (FGDG). Calcitic limestone is used to neutralize acid soils, especially in fields not requiring magnesium [17]. In 2016, about 670 thousand tons of FGDG were used in agriculture as a source of calcium and sulfur and to improve the soil's physical properties [18,19]. In addition, fillers may improve the distribution uniformity of the spreading of ash on agricultural fields, as concerns have been raised about the need to uniformly apply poultry litter ash [9].

Codling et al. [20] evaluated how broiler litter ash with and without FGDG affected peanut yield and nutrient uptake, but in their experiment, the ash was mixed in the soil and incubated for three weeks before planting peanuts and surface applying FGDG. Apart from the Codling et al. [20] study, we are unaware of other published research evaluating the availability of P and K in poultry litter ash when applied with either calcitic lime or FGDG. Use of poultry litter ash directly from the incinerator with minimal processing can make it cost effective and attractive as a substitute for commercial fertilizers. Except for blending with lime or FGDG, our study did not include additional processing, common in commercial fertilizer production (crushing, extrusion, granulation, etc.). Meanwhile, farmers use both conventional and conservation tillage. Placement of the ash and fillers (mixed with soil or left on the surface) needs to be evaluated for both management systems for the efficacy of ash–filler blends to supply nutrients. The goal of this research was to evaluate fertilizer effectiveness of poultry litter ash when applied in blends with calcitic lime and FGDG. We conducted a controlled environment study with the objective of determining whether placement, filler material, and filler/ash ratios influence soil-extractable P and K, plant growth, and plant uptake of those nutrients. In addition, we conducted a field study to determine if blends of ash with calcitic lime or FGDG improved uniformity of application over ash by itself with commercial fertilizer application equipment.

2. Materials and Methods

2.1. Characterization of Ash, Calcitic Lime, and FGDG

The poultry litter ash used in the soil and plant response study was turkey litter ash from a power plant. It was provided by Carolina Eastern, Inc. (Charleston, SC, USA). The FGDG was also provided by Carolina Eastern, Inc. and was from a coal-fueled power plant. Calcitic lime was from a mine near Loris, SC, USA and was provided by Wake Stone Corporation, Knightdale, NC, USA. Elemental analysis of the ash, lime, and FGDG was determined by digesting the materials in nitric acid with peroxide (EPA 3050B), using a block digester [21], followed by quantifying elements in the digest using inductively coupled plasma optical emission spectroscopy (ICP-OES).

2.2. Plant-Available P of Ash and Ash–Filler Blends

Duplicate samples of ash and ash blended with fillers (calcitic lime and FGDG) at different ratios (3:1, 2:1, 1:1, 1:2, and 1:3) on a mass basis were analyzed for water-soluble P, citrate-insoluble P, and citrate-soluble P as $\%P_2O_5$, according to AOAC Official Methods 958.01, 977.01, 963.03 B(a) [22]. The "plant-available P" was determined using the AOAC "available P" test for fertilizing materials and it is the citrate-soluble P (which includes the water-soluble P fraction) [22]. Total N in the ash was determined by combustion with a Leco TruSpec CN analyzer (Leco Corp., St. Joseph, MI, USA).

2.3. Soil and Plant Resposnse

Soil was collected from the surface, 15 cm of a Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Kandiudults) at Clemson University's Pee Dee Research and Education Center (Florence, SC, USA). The collected soil was spread out on greenhouse benches to dry, prior to conducting the experiment. After drying, the soil was passed through a 6.35-mm screen to remove roots and large soil particles.

A controlled environment study was conducted with the following treatments: Unamended control, 100% ash, and ash supplied as 75, 66, 50, 33, and 25% of mixtures with either calcitic lime or FGDG. The selected ash levels matched the filler/ash ratios of 3:1, 2:1, 1:1, 1:2, and 1:3. In all treatment combinations (except the unfertilized control), the rates of P and K applied to the soil were the same. The 100% ash treatment was added to the soil at a ratio of 0.9 g ash to 1.0 kg soil. Prior to soil application, calcitic lime and FGDG were first blended with ash for each filler/ash treatment that resulted in application rates of 0.3, 0.6, 0.9, 1.8, and 2.7 g filler per kg of soil. The study was conducted using 20-cm diameter pots in which the soil depth was 12 cm. The ash, FGDG, and calcitic lime were all applied on an air-dry mass basis, either incorporated or left on the soil surface. There were three replicates in the experiment and the experiment was conducted twice. Pots were watered to 100 g kg^{-1} soil water content, covered with newsprint, and stored in a room with no environmental control for 30 days during the summer. During storage, pots were monitored and a small amount of water was added if the soil surface appeared dry.

After 30 days, a 1-cm diameter cork borer was used to sample the soil in the pots to a depth of 10 cm. Six cores were collected from each pot, homogonized, and dried at 60 °C for three days. Following drying, soil pH (1:1, soil to water) was measured and plant-available P and K in soil samples were quantified by ICP-OES in Mehlich-1 extracts [23]. The plant-available P and K in soil extracts hereafter are called "available soil P and K", respectively.

After soil sampling, the pots were moved to a greenhouse and the holes made by sampling were filled with unamended soil. Ryegrass seed (1.11 g per pot) was placed on the soil surface of each pot and covered with dry unamended soil. The pots were watered as needed with tap water for the duration of the experiment. Three harvests of plant shoot tissues were made by cutting plants 2.5 cm above the soil surface three, five, and seven weeks after planting. A small amount of N (1.0 g of NH_4NO_3) was added to each pot following the first two harvests. Plant tissue samples were dried at 60 °C for three days and then weighed and ground. Total P and K concentrations in digested plant tissues were quantified using the same method used for ash characterization [21].

2.4. Spreading Uniformity Test

The spreading uniformity of ash, ash with calcitic lime, and ash with FGDG was evaluated using a commercial spinner disc fertilizer/lime spreading truck. The source of the ash supplied by Carolina Eastern Inc. was from a power plant in the region that co-incinerates wood and poultry litter. This test consisted of three treatments: Ash alone, ash mixed with calcitic lime, and ash mixed with FGDG. It was conducted under low wind speeds (<1.8 m s^{-1}) on a crop field under conservation tillage with less than 2% slope.

A front-end loader and a belt elevator conveyor were used to load all materials into the spreading truck. Lime and FGDG were mixed with ash to make 1:4 (filler/ash) blends. This blend ratio was requested by the supplier to further reduce the filler/ash ratio, according to our laboratory tests. To make the blends, four front-end loads of ash followed by a load of filler material were loaded into the truck with a belt elevator conveyor. This was repeated until the truck contained 16 loads of ash and four loads of lime or FGDG. The filler/ash mix in the truck was then emptied onto the ground, into a pile, repeatedly scooped and dumped with the front-end loader, and then reloaded into the truck using the belt elevator conveyor. Bulk densities of the ash and the mixtures were estimated using a hand-held Fertilizer Density Scale (Berckes Mfg., Canby, MN, USA). The bulk density of the ash was approximately 481 kg m^{-3} while the bulk density of both the lime/ash and FGDG/ash mixtures were approximately 641 kg m^{-3}. These density values were used to adjust settings in the truck so all application rates were about 2242 kg ha^{-1}. Duplicate samples of the three treatments were collected for gravimetric water content determinations. Water content of the ash without filler was 112 g kg^{-1}, the FGDG/ash blend was 111 g kg^{-1}, and the lime/ash blend was 88 g kg^{-1}. Particle densities were determined by pouring a known mass of product into a known volume of distilled water and immediately recording the new total volume. The particle density was calculated as the dry mass of the product divided by the displaced volume. Particle densities for ash alone and mixtures of lime/ash and FGDG/ash were 1.93, 2.02, and 1.96 g mL^{-1}, respectively. Particle size distribution of ash, calcitic lime, and FGDG alone and mixtures of lime/ash and FGDG/ash were determined using a sieve shaker to pass a known mass through American Society for Testing and Materials (ASTM) sieve Nos. 1/2, 5/16, 5, 10, 18, and 35. (Table 1).

Table 1. Particle size distribution of ash alone, lime, and flue gas desulfurization gypsum (FGDG), and mixtures of 1:4 lime/ash and 1:4 FGDG/ash used in the field spreading uniformity experiment. Data are the mean of four replicate samples.

Particle Size	Ash	Lime	FGDG	Lime/Ash	FGDG/Ash
mm	Percent finer by weight				
>12.5	3.1	0.0	0.0	4.2	2.2
8.0–12.7	3.9	0.0	1.0	3.5	2.9
4.0–8.0	12.9	0.6	4.7	12.3	12.8
2.0–4.0	17.3	0.7	3.7	13.9	14.7
1.0–2.0	18.3	1.7	1.6	12.8	13.1
0.5–1.0	16.6	14.3	0.5	15.5	11.9
<0.5	27.9	82.7	88.5	37.7	42.4

The spreading uniformity of the three treatments was evaluated using a catch-pan method, typically used to calibrate spreader applicators [24]. Catch pans were placed 1.5 m apart along a line perpendicular to the direction of travel of the spreader truck. The spreader application test method was done such that the spreader truck was driven next to the pan at the end of the line when performing the test. The distribution of the spread of the ash and filler/ash blends was evaluated on each side (right on right and left on left swaths) of the spreader application [24]. Evaluation of material spread on both sides of the spreader was considered one replication. The total mass of the materials caught in each individual evaluation (right and left) was determined and the mass of material in each catch pan was converted to a percentage of the total. Treatments were replicated twice.

2.5. Data Analysis

Data were analyzed using SAS version 9.4. All data from the controlled environment study were analyzed in two ways. First, to determine if interactions occurred among placement (placement was not a part of the analysis for plant available P), filler material, and filler ratio, an analysis of variance (ANOVA) was conducted, excluding the data for the unamended control and ash alone. Means of significant interactions were separated using pairwise comparisons. Second, main effect means were compared using all the data by conducting an ANOVA and computing single degree of freedom contrasts. The contrasts compared means of ash alone to the control, calcitic lime to the control, FGDG to the control, calcitic lime to ash alone, FGDG to ash alone, and calcitic lime to FGDG. Sources of variation and contrasts were considered significant when probability of >F values were ≤ 0.05. An ANOVA was conducted to determine the effect of ash alone and the different filler/ash ratio combinations on ryegrass biomass and P and K content in plant tissue. For the spreader uniformity study, standard deviation and percent coefficient of variation were calculated for each treatment at each swath spacing from the spreader truck [24].

3. Results and Discussion

3.1. Poultry Litter Ash, Calcitic Lime, and FGDG Characterization

The turkey litter ash used to evaluate soil and plant response had high amounts of Ca, P, and K (Table 2), which is typical of poultry litter ashes [16]. It had P and K contents equivalent to 15.5% P_2O_5 and 7.0% K_2O, but almost no N (0.6%) because incineration causes almost all the N in feedstocks to be converted to N_2 and nitric oxide gases [9,25]. Both calcitic lime and FGDG had, as expected, high amounts of Ca and FGDG had a high amount of S, while the P and K content of the filler materials was very low (Table 2). The concentration of Cu and Zn in poultry litter ash is of agronomic concern because of the risk of accumulation in soils at toxic levels for plants. In our study, a soil application rate of 0.9 g ash kg^{-1} was equivalent to applying 1.0 mg Cu kg^{-1} and 0.9 mg Zn kg^{-1}. These Cu and Zn rates are well below the total Cu and Zn concentrations of 8.5 mg Cu kg^{-1} and 20.1 mg Zn kg^{-1} found in sandy soils of the U.S. Coastal Plain region, impacted by long-term application of swine manure [26]. Concentrations of other plant nutrients in the ash and the two filler materials are shown in Table 2.

Table 2. Plant nutrient composition of the poultry litter ash, calcitic lime, flue gas desulfurization gypsum (FGDG) used in the greenhouse experiment.

Plant Nutrient	Ash	Lime	FGDG
P (g kg^{-1})	68	0.1	0.04
K (g kg^{-1})	59	0.3	0.4
Ca (g kg^{-1})	134	396	250
Mg (g kg^{-1})	13	3	0.6
S (g kg^{-1})	8	7	192
Cu (mg kg^{-1})	1151	BD [1]	BD
Fe (mg kg^{-1})	4827	2847	541
Mn (mg kg^{-1})	1084	40	BD
Mo (mg kg^{-1})	12	BD	BD
Zn (mg kg^{-1})	797	BD	BD

[1] BD indicates that nutrient was below detection level.

3.2. Plant-Available P in Ash Material

Averaged over all treatment combinations, 44% of the total P in the ash was plant-available, according to the AOAC citrate-soluble test [22]. Previously, Clarholm [27] found that only 20% of the total P in granulated wood ash was extractable with ammonium acetate, while Codling [15] found that hydrochloric acid extractable P in poultry litter ash was 82% of total P. Table 3 shows that, averaged over all filler/ash ratios, the two filler materials did not significantly change plant-available P from ash alone (100% ash). For ash blended with lime, none of the treatment combinations differed from the lime 1:2 filler/ash ratio, which was numerically similar to the plant-available P of ash alone. The lime 1:3 filler/ash ratio had the lowest percentage of plant-available P (34.8%), while the FGDG 1:3 filler/ash ratio had the highest (48.5%). Averaged across ratios, the ash blended with lime had approximately 8% more plant-available P than ash blended with FGDG. A significant filler × ratio interaction supported the observations that increasing amounts of lime enhanced percentage of P availability, while increasing amounts of FGDG diminished percentage of P availability (Table 3).

Table 3. Percentage of the P in ash that was plant-available as affected by calcitic lime and flue gas desulfurization gypsum (FGDG).

Filler	**Ratio**	**Ash**	**Plant Available P**
	Filler/Ash	Percentage	Percentage
Lime	1:3	75	34.8de [1]
	1:2	66	46.9abcde
	1:1	50	55.7a
	2:1	33	52.0ab
	3:1	25	51.3abc
FGDG	1:3	75	48.5abcd
	1:2	66	37.0cde
	1:1	50	33.7e
	2:1	33	41.3bcde
	3:1	25	39.3bcde
$p > \text{F}$ [2]			0.03
Means Over Ratio			
Lime			48.2
FGDG			40.0
Ash			46.5
Contrast Comparisons of Means			$p > \text{F}$
Lime vs. Ash			0.74
FGDG vs. Ash			0.20
Lime vs. FGDG			0.01

[1] Means followed by the same letter are not significantly different according to least square difference (LSD 0.05).
[2] Probability of a greater F value of the filler × ratio interaction.

In previous work, Codling et al. [15] reported that poultry litter ash contains very little to no water-soluble P. Similarly, the ash materials in our study had extremely low water-soluble P (0.37% P_2O_5). Gypsum mixed with animal manure has been found to reduce water-soluble P [28–30], which may result from Ca in the gypsum binding with the water-soluble P to form water-insoluble calcium phosphate [31]. Watts and Torbert [32] found that gypsum applied to grass buffer strips downslope from a poultry litter application reduced soluble P in runoff. Furthermore, Endale et al. [33] found that FGDG applied with poultry litter reduced soluble P in runoff in one of two years. However, the low amount of water-soluble P in poultry litter ash suggests that such binding effects of gypsum with soluble water P with this P fertilizer source would be negligible.

3.3. Plant Available P and K in Soil

Lime and FGDG as fillers did not affect how available soil P and K levels responded to ash placement. No interactions occurred involving placement and filler material or placement and filler ratio. Similarly, the filler material × filler/ash ratio interaction was not significant for either available soil P or K ($p > \text{F} = 0.52$ for P and 0.09 for K; Table 4). As expected, application of ash alone increased available soil P and K in soil above levels in the controls (Table 4). Ash left on the surface resulted in an available soil P level of 112 mg kg^{-1}, while ash mixed into the soil had 99 mg kg^{-1} available soil P ($p = 0.036$). Similarly, available soil K was 150 mg kg^{-1} when ash was surface-applied and 129 mg kg^{-1} when the ash was incorporated into the soil ($p < 0.001$). Higher available soil P and K levels for soil where ash was left on the surface is not surprising. Mixing the ash with soil would have distributed the nutrients throughout the pots. Since only the top 10 cm of the pots were sampled, more of the nutrients were in the sampling area for the pots with ash spread on the surface.

For available soil P, the ash alone was similar to both filler/ash blends. For available soil K, ash alone was similar to the FGDG/ash blends, but the lime/ash blends were somewhat higher than both ash alone and the FGDG/ash blends (Table 4). It is not clear why using calcitic lime as filler increased available soil K above levels in the soil amended with ash alone or the FGDG/ash blends, since both filler materials had low K concentrations (Table 2).

Table 4. Soil Available P and K (Mehlich-1) as affected by poultry litter ash amendment and filler/ash ratio. Soil was collected from pots after a 30-day incubation period.

Filler	Ratio	P	K
	Filler/Ash	mg kg^{-1}	mg kg^{-1}
Lime	1:3	97	131
	1:2	102	143
	1:1	99	139
	2:1	103	142
	3:1	136	171
FGDG	1:3	115	138
	1:2	103	141
	1:1	109	131
	2:1	90	131
	3:1	123	140
$p > \mathrm{F}$ [1]		0.52 ns	0.09 ns
Means Over Ratios			
Lime		108	145
FGDG		108	136
Ash		86	128
Control		48	80
Contrast Comparisons of Means		$p > \mathrm{F}$	
Ash vs. Control		0.036	<0.001
Lime vs. Control		<0.001	<0.001
FGDG vs. Control		<0.001	<0.001
Lime vs. Ash		0.06	0.02
FGDG vs. Ash		0.06	0.26
Lime vs. FGDG		0.95	0.03

[1] Probability of a greater F value of the filler × ratio interaction; $p > 0.05$; ns = non-significant difference.

3.4. Soil pH

Wood ash can be used as a liming material to neutralize acid soils. Adotey et al. [34] recently compared wood ash to two commercial liming products and found similar soil pH changes when wood ash rates were normalized for $CaCO_3$. The application rate of ash in our study corresponded to 168 kg ha^{-1} of total P_2O_5 (based on area of the top of the pots). Since plant-available P was 46.5% of total P, the application rate corresponded to 78 kg ha^{-1} of plant-available P_2O_5, which is a typical P application rate. This rate slightly raised the soil pH from 5.1 for the unamended control to 5.3 for the soil amended with ash alone and the FGDG/ash blends. As expected, FGDG did not impact soil pH, whereas ash blended with calcitic lime significantly increased soil pH. For lime/ash blend treatments, soil pH ranged from 5.8 for the 1:3 filler/ash ratio to 6.3 for the 3:1 filler/ash ratio. Applying poultry litter ash at high rates for liming purposes would result in excess P application, as discussed by Chastain et al [9]. However, blending poultry litter ash with calcitic limestone could simultaneously add P to the soil system and adjust soil pH to between 6.0 and 6.5 to favor P dissolution and availability to plants [35], thus providing a fertilizer application with recommended amounts of nutrients.

3.5. Ryegrass Biomass and P and K Uptake

Filler material and filler/ash ratio did not affect biomass or P and K concentration of the ryegrass (Figure 1). Analysis of variance results indicate that none of the filler/ratio treatment combinations differ from ash alone. These results suggest that the addition of either calcitic lime or FGDG as filler materials will not adversely affect plant uptake of P and K from soil. Others have found poultry litter ash to be effective in providing P to plants [10,36–38], while the high level of water-soluble K in ash [16] suggests it is readily plant available. Lack of response to ash application for P and K in the biomass of the ryegrass in this study was likely due to the adequate amounts of soil P and K concentrations in the soil used (48 P mg kg^{-1} and 80 mg K kg^{-1} in the unamended soil control; Table 4) [23], and the relatively short duration (seven weeks) of the plant biomass experiments.

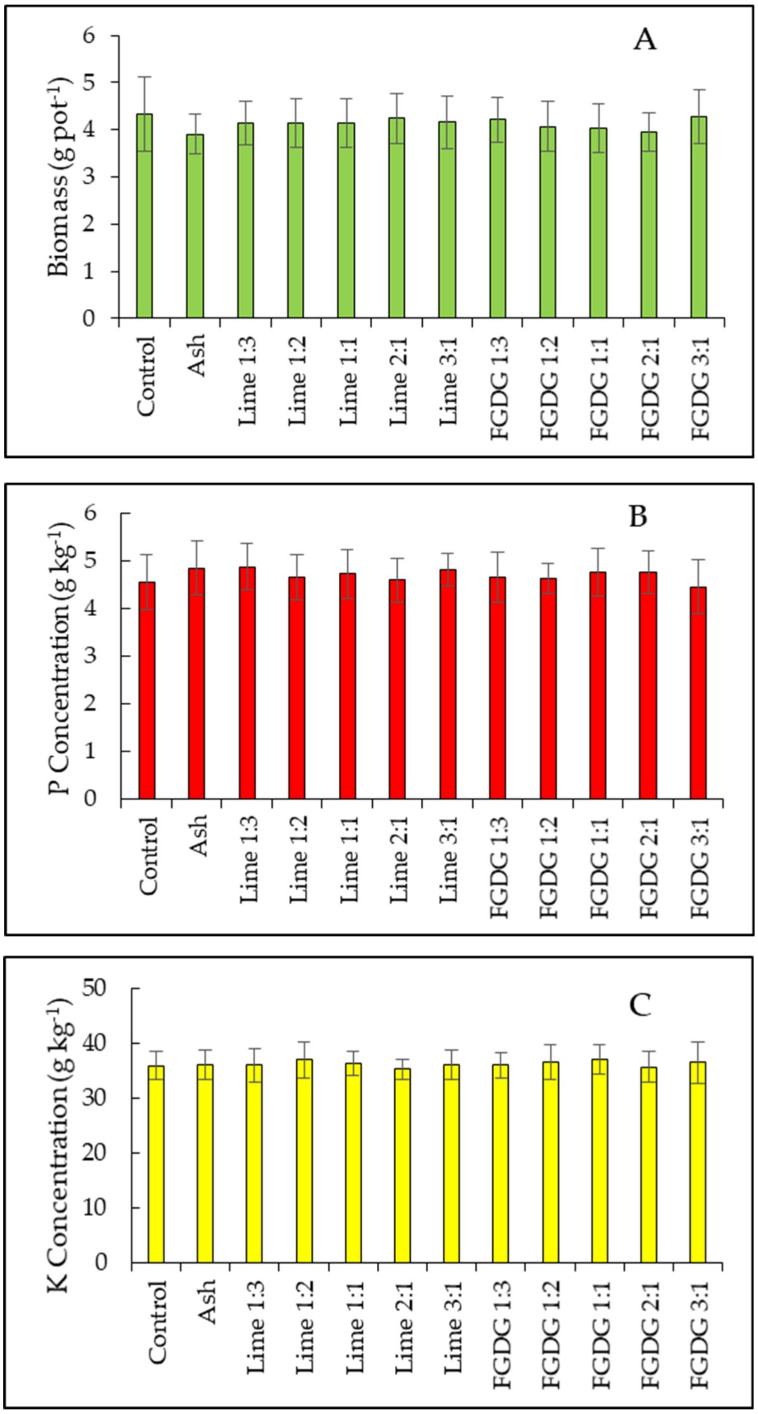

Figure 1. Effect of calcitic lime and flue gas desulfurization gypsum (FGDG) as fertilizer fillers for poultry litter ash on ryegrass biomass (**A**), P concentration in ryegrass (**B**), and K concentration in ryegrass (**C**). Error bars indicate ± one standard error of means.

3.6. Spreading Uniformity

The distribution pattern of poultry litter ash spread with and without the two filler materials is shown in Figure 2. Because of its low density, we expected application of ash alone to be irregular [39]. Surprisingly, spread of ash alone was quite uniform in the percentage of total weight within a 6.1-m swath distance from the truck (Figure 2A). Only a small amount of ash was caught in the catch pans beyond this swath width. Consistent with this distribution pattern, coefficients of vatiation (CV) values of spread uniformity for ash alone were in the range of 10 to 38% within the 6.1-m swath (Figure 2B). Even though ash alone particles have irregular shapes and a wide particle size distribution (Table 1), the CV values in our study were somewhat similar to average CV uniformity values of granular fertilizer applications (12 to 31%) [40]. Adding either filler did not substantially improve the distribution pattern of ash application but increased the swath distance by 1.5 m. At 7.6 m distance, the catch pans recovered a substantial portion of the ash material with fillers (8–10% of total weight captured in the pans). Lime/ash and FGDG/ash blends had coefficients of variation for the 6.1-m swath distance in the range of 28 to 44% and 20 to 61%, respectively (Figure 2B).

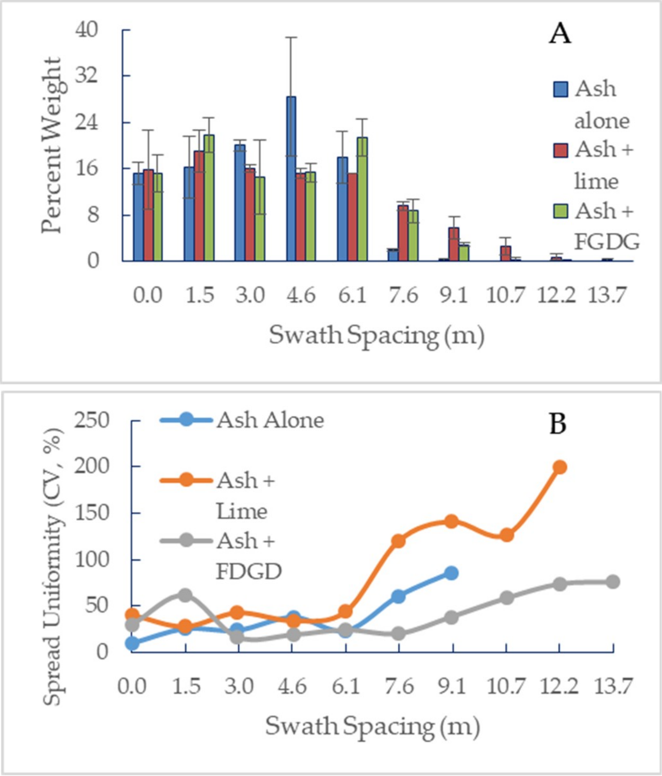

Figure 2. Spread pattern of the fertilizer applicator truck for poultry litter ash and ash mixed with calcitic lime or flue gas desulfurization gypsum (FGDG): (**A**) Average weight percent of the products at each swath spacing with respect to total weight caught in the pans; (**B**) Coefficient of variation (CV%) of spread uniformity. Swath spacing in the *x*-axis represents the catch pans placed 1.5 m apart along a line perpendicular to direction of travel. Error bars indicate ± one standard deviation.

In our study, the ash, calcitic lime, and FGDG were transported to the field and stored in open piles before the tests were conducted. Wetting the ash before being transported is a common practice necessary for dust control [41]. In addition, it rained between the times when the materials were delivered and when the spreading uniformity field test was performed. The wetted ash (which had a water content of about 100 g kg^{-1}) resulted in a better distribution when it was applied alone than could be expected from the spread of dry ash alone, directly from an incinerator. The addition of both fillers to wetted ash lumped some of the ash and filler blended materials into larger particle sizes than those reported in Table 1. Given that larger particles are thrown further by spinner spreaders than smaller particles [40], it explains the spreading of some particles of the lime/ash and FGDG/ash blends beyond the 7.6-swath distance. The moisture content of the products was a variable not controlled in our spreading test. Therefore, research on determining acceptable moisture contents that ensure economic transportation and optimal spreading is needed. Overall, our data suggest that spreading of the ash with commercial spinner disc applicators alone or blended with calcitic lime or FGDG as fillers is feasible using commercial fertilizer spreaders. Further evaluations of the spreading distribution of poultry litter ash both with and without fillers should be conducted at various moisture contents with varying wind speed and direction, along with fugitive dust collection studies.

4. Conclusions

Incineration of poultry litter is being used both to produce energy in power plants and as a method of waste handling and treatment in areas with high concentrations of poultry production. With its relatively high concentration of plant nutrients, poultry litter ash is a power plant byproduct with potential use as fertilizer. However, environmental concerns exist about the need to uniformly land-apply poultry litter ash. In this research, we evaluated if blending ash with two potential filler materials affected soil and plant parameters and their possible impact on field application patterns with a spinner disc applicator. The two potential fillers evaluated, calcitic lime and FGDG, appear to be appropriate filler materials for land-applying the ash. Neither of these materials negatively affected plant available concentrations of P and K in the soil, nor ryegrass biomass and plant P and K concentrations. The uniform distribution of poultry litter ash in field application using a commercial fertilizer spreader is feasible for ash alone, ash blended with calcitic lime, and ash blended with FGDG. More field testing on the potential of these fillers to enhance poultry litter ash application appears warranted, especially field studies with varying moisture contents of the products, wind speed, and wind direction that evaluate how these fillers may affect fugitive dust during application.

Author Contributions: Conceptualization, P.J.B.; Data curation, P.D.S.; Formal analysis, P.J.B. and A.A.S.; Investigation, P.J.B.; Methodology, P.J.B., A.A.S., and P.D.S.; Writing—original draft, P.J.B. and A.A.S.; Writing—review & editing, A.A.S. and P.D.S.

Funding: This research received no external funding.

Acknowledgments: This research was part of USDA-ARS National Programs 211 Water Availability and Watershed Management, Project 6082-13000-010-00D; and 212 Soil and Air ARS Project 6082-12630-001-00D. The authors thank Mr. Thomas Kemp and Carolina Eastern, Inc. for the ash, lime, and FGDG used in this research, the field equipment, and labor provided to conduct the spreader study. Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Bolan, N.S.; Szogi, A.A.; Chuasavathi, T.; Seshadri, B.; Rothrock, M.J.; Panneerselvam, P. Uses and management of poultry litter. *World Poultry Sci. J.* **2010**, *66*, 673–698. [CrossRef]
2. Szogi, A.A.; Vanotti, M.B.; Ro, K.S. Methods for treatment of animal manures to reduce nutrient pollution prior to soil application. *Curr. Pollut. Rep.* **2015**, *1*, 47–56. [CrossRef]
3. Kaise, D.E.; Mallarino, A.P.; Haq, M.U. Runoff phosphorus loss immediately after poultry manure application as influenced by application rate and tillage. *J. Environ. Qual.* **2009**, *38*, 299–308. [CrossRef]
4. Cassity-Duffey, K.; Cabrera, M.; Rema, J. Ammonia volatilization from broiler litter: Effect of soil water content and humidity. *Soil Sci. Soc. Am. J.* **2015**, *79*, 543–550. [CrossRef]
5. Lynch, D.; Henihan, A.M.; Bowen, B.; Lynch, D.; McDonnell, K.; Kwapinski, W.; Leahy, J.J. Utilisation of poultry litter as an energy feedstock. *Biomass Bioenerg.* **2013**, *49*, 197–204. [CrossRef]
6. Karunanithi, R.; Szogi, A.A.; Bolan, N.; Naidu, R.; Loganathan, P.; Hunt, P.G.; Vanotti, M.B.; Saint, C.P.; Ok, Y.S.; Krishnamoorthy, S. Phosphorus recovery and reuse from waste streams. *Adv. Agron.* **2015**, *131*, 173–250.

7. Jurgilevich, A.; Birge, T.; Kentala-Lehtonen, J.; Korhonen-Kurki, K.; Pietikäinen, J.; Saikku, L.; Schösler, H. Transition towards circular economy in the food system. *Sustainability* **2016**, *8*, 69. [CrossRef]
8. Tan, Z.; Lagerkvist, A. Phosphorus recovery from the biomass ash: a review. *Renew. Sust. Energ. Rev.* **2011**, *15*, 3588–3602. [CrossRef]
9. Chastain, J.P.; Coloma-del Valle, A.; Moore, K.P. Using broiler litter as an energy source: Energy content and ash composition. *Appl. Eng. Agric.* **2012**, *28*, 513–522. [CrossRef]
10. Codling, E.E.; Chaney, R.L.; Sherwell, J. Poultry litter ash as a potential phosphorus source for agricultural crops. *J. Environ. Qual.* **2002**, *31*, 954–961. [CrossRef] [PubMed]
11. Pagliari, P.H.; Rosen, C.J.; Strock, J.S. Turkey manure ash effects on alfalfa yield, tissue elemental composition, and chemical soil properties. *Comm. Soil Sci. Plant Anal.* **2009**, *40*, 2874–2897. [CrossRef]
12. Pagliari, P.H.; Rosen, C.J.; Strock, J.S. Characterization of turkey manure ash and its nutrient value for corn and soybean production. *Crop Manag.* **2009**. [CrossRef]
13. Szogi, A.A.; Vanotti, M.B. Prospects of phosphorus recovery from poultry litter. *Bioresour. Technol.* **2008**, *100*, 5461–5465. [CrossRef]
14. Demeyer, A.; Voundi Nkana, J.C.; Verloo, M.G. Characteristics of wood ash and influence on soil properties and nutrient uptake: An overview. *Bioresour. Technol.* **2001**, *77*, 287–295. [CrossRef]
15. Codling, E.E. Laboratory characterization of extractable phosphorus in poultry litter and poultry litter ash. *Soil Sci.* **2006**, *171*, 858–864. [CrossRef]
16. Bogush, A.A.; Stegemann, J.A.; Williams, R.; Wood, I.G. Element speciation in UK biomass power plant residues based on composition, mineralogy, microstructure and leaching. *Fuel* **2018**, *211*, 712–725. [CrossRef]
17. Pagani, A.; Mallarino, A.P. Soil pH Change over Time as Affected by Sources and Application Rates of Liming Materials. Iowa State Research Farm Progress Reports 259. 2011. Available online: https://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=1269&context=farms_reports (accessed on 16 March 2019).
18. Chen, L.; Dick, W.A. *Gypsum as an Agricultural Amendment: General Use Guidelines*; The Ohio State University Extension: Columbus, OH, USA, 2011.
19. American Coal Ash Association. 2016 Coal Combustion Product (CCP) Production and Use Survey Report. Available online: https://www.acaa-usa.org/Portals/9/Files/PDFs/2016-Survey-Results.pdf (accessed on 16 March 2019).
20. Codling, E.E.; Lewis, J.; Watts, D.B. Broiler litter ash and flue gas desulfurization gypsum effects on peanut yield and uptake of nutrients. *Comm. Soil Sci. Plant Anal.* **2015**, *46*, 2553–2575. [CrossRef]
21. Unit III 5.5: Digestion and dissolution methods for P, K, Ca, Mg, and trace elements. In *Recommended Methods of Manure Analysis (A3769)*; Peters, J. (Ed.) University of Wisconsin-Extension Publication: Madison, WI, USA, 2003.
22. AOAC International. *Official Methods of Analysis*, 17th ed.; AOAC: Gaithersburg, MD, USA, 2000.
23. Sikora, F.J.; Moore, K.P. *Soil Test Methods of from the Southeastern United States, Southern Cooperative Series Bulletin No. 419*; Southern Extension and Research Activity-Information Exchange Group 6: Clemson, SC, USA, 2014.
24. ASABE Standards S341.5. *Procedure for Measuring Distribution Uniformity and Calibrating Granular Broadcast Spreaders*; American Society of Agricultural and Biological Engineers: St. Joseph, MI, USA, 2018.
25. Obernberger, I.; Brunner, T.; Barnthaler, G. Chemical properties of solid biofuels-significance and impact. *Biomass Bioenerg.* **2006**, *30*, 973–982. [CrossRef]
26. Novak, J.M.; Szogi, A.A.; Watts, D.W. Copper and zinc accumulation in sandy soils and constructed wetlands receiving pig manure effluent application. In *Trace Elements in Animal Production Systems*; Schlegel, P., Durosoy, S., Jongbloed, A.W., Eds.; Wageningen Academic Publishers: Wageningen, The Netherlands, 2008; pp. 45–54.
27. Clarholm, M. Granulated wood ash and a 'N-free' fertilizer to a forest soil-effects on P availability. *Forest Ecol. Manag.* **1994**, *66*, 127–136. [CrossRef]
28. Moore, P.A., Jr.; Miller, D.M. Decreasing phosphorus solubility in poultry litter with aluminum, calcium and iron amendments. *J. Environ. Qual.* **1994**, *23*, 325–330. [CrossRef]
29. Anderson, D.L.; Tuovinen, O.H.; Faber, A.; Ostrokowski, I. Use of soil amendments to reduce soluble phosphorus in dairy soils. *Ecol. Eng.* **1995**, *5*, 229–246. [CrossRef]
30. Dou, Z.; Zhang, G.Y.; Stout, W.L.; Toth, J.D.; Ferguson, J.D. Efficacy of alum and coal combustion by-products in stabilizing manure phosphorus. *J. Environ. Qual.* **2003**, *32*, 1490–1497. [CrossRef] [PubMed]

31. Brauer, D.; Aiken, G.E.; Pote, D.H.; Livingston, S.J.; Norton, L.D.; Way, T.R.; Edwards, J.H. Amendments effects on soil test phosphorus. *J. Environ. Qual.* **2005**, *34*, 1682–1686. [CrossRef] [PubMed]
32. Watts, D.B.; Torbert, H.A. Impact of gypsum applied to grass buffer strips on reducing soluble P in surface water runoff. *J. Environ. Qual.* **2009**, *38*, 1511–1517. [CrossRef] [PubMed]
33. Endale, D.M.; Schomberg, H.H.; Fisher, D.S.; Franklin, D.H.; Jenkins, M.B. Flue gas desulfurization gypsum: implication for runoff and nutrient losses associated with broiler litter use on pastures on Ultisols. *J. Environ. Qual.* **2014**, *43*, 281–289. [CrossRef]
34. Adotey, N.; Harrell, K.L.; Weatherford, W.P. Characterization and liming effect of wood ash generated from a biomass-fueled commercial power plant. *Comm. Soil Sci. Plant Anal.* **2018**, *49*, 38–49. [CrossRef]
35. Havlin, J.L.; Tisdale, S.L.; Nelson, W.L.; Beaton, J.D. *Soil Fertility and Fertilizers: An Introduction to Nutrient Management*, 6th ed.; Prentice Hall: Upper Saddle River, NJ, USA, 1999.
36. Pagliari, P.; Rosen, C.; Strock, J.; Russelle, M. Phosphorus availability and early corn growth response in soil amended with turkey manure ash. *Comm. Soil Sci. Plant Anal.* **2010**, *41*, 1369–1382. [CrossRef]
37. Wells, D.E.; Beasley, J.S.; Bush, E.W.; Gaston, L.A. Poultry litter ash rate and placement affect phosphorus dissolution in a horticultural substrate. *J. Environ. Hort.* **2017**, *35*, 117–127.
38. Wells, D.E.; Beasley, J.S.; Gaston, L.A.; Bush, E.W.; Thiessen, M.E. Poultry litter ash reduces phosphorus losses during greenhouse production of *Lantana camara* L. 'New Gold'. *HortScience* **2017**, *52*, 592–597. [CrossRef]
39. Sumner, P.E. *Calibration of Bulk Dry Fertilizer Applicators, The University of Georgia Cooperative Extension Circular 798*; University of Georgia College of Agricultural Environmental Sciences: Athens, GA, USA, 2012.
40. Smith, D.B.; Willcutt, M.H.; Doler, J.C.; Diallo, Y. Uniformity of granular fertilizer applications with a spinner truck. *App. Eng. Agric.* **2004**, *20*, 289–295. [CrossRef]
41. Kemp, T.; Carolina Eastern Inc., Charleston, SC, USA. Personal communication, 2018.