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# Gypsum Additions Reduce Ammonia Nitrogen Losses During Composting of Dairy Manure and Biosolids

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Composting of N rich organic materials often leads to N loss via ammonia volatilization. Literature references from as early as 1922 have suggested gypsum can prevent N loss from manure. Millions of tons of high quality by-product gypsum are produced each year in the United States as a result of flue gas desulfurization (FGD) scrubbing of sulfur dioxide during combustion of coal. Our objective was to determine the impact of this gypsum on N release when mixed with dairy manure and biosolids during composting. A preliminary experiment was conducted involving 4-liter vessels containing 1.1 kg of dairy manure mixed with by-product gypsum at dry weight rates (w/w) of 0, 6%, 13% and 23% and composted for 18 days. The ammonia-N released in the off gas was trapped in 0.67 M boric acid solution. Loss of ammonia-N was essentially complete after seven days. When expressed as percent of initial N in the mixes, the amount of N lost ranged from 6.4% for the zero rate control to 2.6–2.8% for the gypsum treatments. Composting studies were also conducted in insulated 210-liter stainless steel vessels over a 28-day period using dairy manure and biosolids treated with or without 17% gypsum (dry weight, w/w). Results revealed the amount of N lost, as a percentage of that originally present in the compost mix, was 7.27% and 15.6% without gypsum for dairy manure and biosolids, respectively, and 3.62% and 13.6% with gypsum. The difference between the dairy manure and biosolids results is attributed primarily to a lower C:N ratio of the biosolids compared to the dairy manure. The final composts were found to contain significant amounts of plant nutrients while heavy metals were well below values considered to be harmful to surface water quality or for crop production. We conclude that combining organic waste streams, especially N-rich streams, with by-product gypsum produces a quality product while also decreasing the loss of N and reducing odors associated with the volatilization of ammonia during the composting process.

## *Introduction*

In the United States, farms generate approximately 2.9 billion pounds of manure a year, which is more than 100 times the amount of human biosolids generated annually (USDA 2007). Nitrogen is a primary nutrient in manure that has value for crop production. A conservative estimate is that 20-30% of the N contained in manure is volatilized during collection, treatment and application (Midwest Plant Service 2004). This represents 715,000 tons of N released into the atmosphere annually with an agronomic value of nearly $300 million. Tremendous amounts of energy are used to replace this lost N by fixing atmospheric N in fertilizers, thereby reducing agricultural efficiency.

Composting of manures may reduce total N lost compared to liquid storage of manure and/or applying manure to fields directly. Even with composting, however, about 10 to 30% of the N present in dairy manure is lost (Michel *et al.* 2004, Fukumori *et al.* 2003). Obviously, there is need to improve the composting and other manure management processes so as to conserve more of the N.

Composting is one of the preferred methods for treating and stabilizing biosolids and manures to create marketable end products that are easy to handle, store, and use. Such products are usually humus-like materials without detectable levels of pathogens that can be safely applied as soil conditioners and fertilizers to gardens, food and feed crops, and rangelands. Biosolids and dairy manure compost uses, for example, generally have high degrees of acceptability by the public.

In pioneering work by Heiden (see Crocker 1922), gypsum was reported to have a great ability to prevent losses of volatile N from manure, conserving it for future application to soil. More recently, gypsum was found to reduce ammonia losses from dairy manure storage by 14 percent (Iowa State University Extension Service 2004). Koenig *et al.* (2005) reported that addition of gypsum at rates of 4% and 12%, when composting poultry manure with wood chips, significantly decreased evolution of ammonia. Similarly, incorporation of gypsum into soil before application of N fertilizers significantly reduced losses of N via ammonia volatilization and "may substantially improve N use efficiency for crop production by reducing N loss" (Zia *et al.* 1999). Gypsum does this, in large part, by converting the ammonium carbonate to ammonium sulfate along with the formation of calcium carbonate. The N in ammonium carbonate is much more apt to be lost as ammonia than when it is in the ammonium sulfate form. In addition, the formation of the relatively insoluble calcium carbonate pulls the reaction to an equilibrium that favors formation of ammonium sulfate.

Gypsum has been used as a soil amendment for hundreds of years and was studied early on in the history of the United States (Crocker 1922). Gypsum is a quality source of both Ca and S for plant nutrition and the use of gypsum for yield enhancement of root crops, such as peanuts, are well known (Chen *et al.* 2005; Sumner *et al.* 1998). Other soil chemical and physical benefits brought about by gypsum have been documented (Dick *et al.* 2006). It is commonly used for reclamation of sodic soils. Amending the soil surface with gypsum prevents dispersion of soil clays and improves surface air and water infiltration rates by inhibiting or delaying surface seal formation (Shainberg *et al.* 1989). Because of its greater solubility than agricultural lime, Ritchey *et al*. (1995) and Farina and Channon (1988) reported that application of gypsum to the plow layer reduces the effects of subsurface acidity and improves deep rooting so that water and nutrient uptake by corn, wheat, soybean and sorghum are dramatically improved.

The source of gypsum has, in the past, been from geologic deposits that are mined. More recently, gypsum has been obtained as a high quality product derived from the scrubbing process to remove sulfur dioxide from flue gases when coal is burned as an energy source. This flue gas desulfurization (FGD) gypsum has been compared to natural gypsum in terms of its metals content (Dontsova *et al.* 2005). It is a clean source of gypsum with excellent crystalline properties and besides its use in agriculture, it is also widely used for manufacture of wallboard (ACAA 2007). Solubility rates of FDG-gypsum in an unsaturated solution are an order of magnitude faster than that of mined gypsum because of its higher external surface area (Wendell and Ritchey 1996).

We hypothesized that mixing FGD gypsum with organic materials prior to composting would result in less ammonia release that would, in turn, translate into less odors and reduced overall loss of N during the composting process. The final product would contain humic matter, gypsum and gypsum-derived minerals that could benefit many soils. However, little quantitative information is available on the proper mixing ratio of gypsum with organic materials and the amount of N saved as a result of gypsum addition to composting mixes. Therefore, our primary objective was to conduct studies that evaluated N release during composting of dairy manure and biosolids with or without addition of by-product gypsum.

## *Materials and Methods*

### *Composted Materials*

Studies were conducted at the Ohio State University Composting Research Center in Wooster, OH, USA. Straw-based dairy manure (80% $H_2O$) was obtained from the dairy farm at the Ohio Agricultural Research and Development Center/ Ohio State University at Wooster, Ohio. Kiln dried hardwood sawdust was obtained from a commercial supplier (Dalton Wood Products, Orrville, OH). Biosolids were obtained from the Akron, OH wastewater treatment plant. Flue gas desulfurization (FGD) by-product gypsum (> 96% $CaSO_4{\bullet}H_2O$) was obtained from Cinergy Corporation (Cincinnati, OH). Selected characteristics of the by-product gypsum are shown in **Table** 1.

TABLE 1.
Selected characteristics of the
flue gas desulfurization (FGD) gypsum

| Characteristic | Value |
|---|---|
| Particle size (% less than 105 µm) | 96.7 |
| pH | 8.0 |
| Macronutrients (g $kg^{-1}$) | |
| N | 0.97 |
| P | <0.01 |
| K | <0.07 |
| Ca | 243 |
| Mg | 0.20 |
| S | 185 |
| Micronutrients (mg $kg^{-1}$) | |
| B | 12.7 |
| Cu | <0.38 |
| Fe | 150 |
| Mn | 0.63 |
| Mo | 3.20 |
| Zn | 1.20 |

### *Experiment 1.*

An initial laboratory scale composting experiment was conducted to evaluate the effect of various gypsum additions on ammonia evolution. A total of four treatments were tested (**Table** 2) with three replications of each treatment.

Composting was performed using a bench scale compost reactor system (Grewal *et al.* 2006). The system consisted of 4-liter-capacity vessels (length 30 cm and diameter 15 cm), made of PVC pipe, placed in an incubator set at 55°C. Compost mixes in the vessels were placed on two metal screens of 1-cm and 1-mm mesh sizes, respectively, supported by a perforated Plexiglas disk. To maintain aerobic conditions, air was introduced to each vessel at a constant rate of 100 ± 2 ml/min. This air was bubbled through bottles containing water at the incubator temperature to humidify the air and thus avoid drying during composting. The moist air from the bottles entered at the bottom of the vessels and was exhausted at the top of the vessels before being bubbled through flasks containing 100 ml of a 0.67 M boric acid solution with a methyl red/bromocresol green indicator to trap ammonia. These ammonia trap flasks were placed in a water bath at 9°C to condense moisture from the off-gas and to regulate the temperature of the boric acid solution. Carbon dioxide concentration of the off gas from each vessel was measured every 12 minutes. Each vessel was also equipped with a K-type thermocouple to measure temperature in the mix near the middle of the compost, and data was recorded automatically every 12 min. Relative humidity and temperature were also recorded in the room where the bench scale composting vessels were being used.

Sawdust was first mixed with dairy manure at a 1:2 ratio. Moisture content of the initial raw manure and sawdust mix before addition of gypsum was 62.8% and volatile solids averaged 77.8%. The manure-sawdust mix was combined with gypsum to give a target final rate of gypsum of 2%, 5% and 10% on a wet weight basis and a zero rate control. The actual amount of gypsum added, calculated on a dry weight basis, was approximately 6%, 13% and 23%. A total of 1.10 kg of each mix was added to individual composting vessels.

The mixes were incubated for 18 days at 55°C. Composting mixes were mixed in a plastic bucket every week and the contents weighed to allow for calculation of wet-weight loss during composting. Samples from each composting reactor were evaluated for moisture at day 0 and 18 (beginning and end of experiment) and submitted to the Soil Testing And Research Laboratory (http://www.oardc.ohio-state.edu/starlab/) at the Ohio Agriculture Research and Development Center in Wooster, Ohio, to determine initial and final pH, moisture, volatile solids, total N, NH$_3$-N, NO$_3$-N, and C content.

Boric acid solutions containing trapped ammonia from the off-gas were titrated with hydrochloric acid (0.703 N HCl) to an end point defined as that at which the color of the solution changed from blue-green to light pink. Boric acid flasks with trapped ammonia and condensate were replaced with flasks containing 100 ml boric acid as needed over the course of the experiment. The percent loss of N, as ammonia, during composting was calculated by dividing the total cumulative amount of N in the trap solutions by the total initial N in each treatment using the formula below (Hong *et al.* 1998; Elwell *et al.* 2002).

TABLE 2.
Initial (Day 0) and final (Day 14) results for the dairy manure laboratory composting experiment.

| | Gypsum Treatment (% dry weight, w/w) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0 | | 6 | | 13 | | 23 | |
| Parameter | Day 0 | Day 14 | Day 0 | Day 14 | Day 0 | Day 14 | Day 0 | Day 14 |
| Initial moisture content (%)[a] | 61.7 | - | 61.4 | - | 59.3 | - | 56.9 | |
| Volatile Solids (%) | 96.6 | 94.5 | 91.7 | 88.5 | 86.5 | 80.2 | 77.1 | 70.4 |
| Solids (%)a | 38.3 | 27.4 | 38.6 | 32.8 | 40.7 | 36.1 | 43.1 | 40.8 |
| Ash (%) | 3.36 | 5.47 | 8.30 | 11.5 | 13.5 | 19.8 | 22.9 | 29.6 |
| pH | 7.87 | 7.76 | 7.94 | 7.31 | 7.96 | 7.24 | 7.83 | 7.30 |
| Total Nitrogen (%) | 0.984 | 1.63 | 1.120 | 1.48 | 0.985 | 1.29 | 0.905 | 1.09 |
| Total Carbon (%) | 50.6 | 45.3 | 49.9 | 44.1 | 44.9 | 40.0 | 37.1 | 34.2 |
| C:N ratio | 51.5 | 27.9 | 44.6 | 29.9 | 45.6 | 31.3 | 41.0 | 31.4 |
| NH3-N (mg kg-1) | 1070 | 69.1 | 1220 | 17.9 | 1190 | 40.0 | 1150 | 25.9 |
| NO3-N (mg kg-1) | 31.2 | 22.4 | 0.0 | 5.16 | 0.0 | 16.1 | 0.0 | 10.4 |
| Salt (dS m-1) | 6.00 | 4.77 | 7.20 | 7.00 | 8.10 | 9.04 | 8.85 | 10.3 |
| Sulfur (%) | 0.149 | 0.22 | 1.11 | 1.88 | 2.48 | 4.15 | 4.22 | 6.92 |

[a] Wet weight basis.

$$NH_3\text{-N lost (\% of initial)} = [(\text{HCl (ml)} \times 9.29 \text{ mg } NH_3\text{-N ml}^{-1}) / \text{mg initial N}] \times 100$$

where 9.29 mg $NH_3$-N/ml is an empirically determined titration factor.

### *Experiment 2*

Composting was conducted indoors using insulated 210-liter stainless steel composting vessels (i.e. 55 gallon barrels). Sawdust was mixed with dairy manure to achieve a 3:1 (w/w) manure to sawdust ratio. By-product gypsum was then added to this dairy manure/sawdust mix at an approximate 5% wet weight basis. However, the actual amount added on a dry weight basis was 17%. The C:N ratio in the final mix was approximately 36. A control treatment without gypsum was included in the experiment. Each treatment (with or without gypsum) was replicated four times. The total volume of material added to each vessel was approximately 80 liters. Compost in each vessel was completely mixed weekly, its weight and volume measured and samples for determination of moisture content and chemical analysis were collected.

The composting process used feedback temperature control of aeration at a setpoint temperature of 60ºC. A small fan provided air continuously and a larger fan provided aeration when the setpoint temperature was exceeded. During composting, temperature and evolved $CO_2$ in the off-gas were automatically measured and recorded. Volatilized ammonia ($NH_3$) was continuously trapped in boric acid as described above for Experiment 1. However, only a fraction (100 ml/min) of the total offgas passed through the trapping solution. The total volume of air entering the reactor was calculated based on the recorded fan on and off periods, and the pressure drop across an orifice plate at the reactor inlet. The ratio of the total volume entering the reactor to the volume entering the trapping solution was integrated over time and used to calculate the total amount of ammonia-N in the off-gas. This value was divided by the total initial N in the composting mix to determine the %N loss during the experiment.

We conducted a similar composting experiment, as described above, except that biosolids instead of dairy manure was used. The biosolids were obtained from the Akron, OH municipal waste water treatment plant one day prior to the initiation of the experiment.

### *Analytical Methods*

Samples were analyzed for pH, soluble salts, ash content, total Kjeldahl N, total N, extractable macronutrients and micronutrients, and heavy metals at the beginning and end of the composting process. Samples were sent in their moist condition to The Ohio State University's Service Testing and Analytical Laboratory for analyses using standard procedures. For the N analyses, samples were immediately analyzed by weighing an aliquot into a combustion vessel and analyzed using a C and N combustion analyzer. Unless otherwise noted, all data are reported on a dry weight basis, with dry weight determined on an aliquot after oven drying at 70ºC for a minimum of 24 hours.

### *Data Analyses*

Data were subjected to analysis of variance (ANOVA) using the PROC GLM statement of the SAS statistics program (SAS Inst. 2004). When ANOVA generated a significant F value for treatment ($P \leq 0.05$), means were compared by the LSD test.

## Results and Discussion

### *Experiment 1*

The overall purpose of this research was to determine the effect of gypsum on the evolution of $NH_3$-N during composting. In the initial laboratory scale experiment, the specific goal was to obtain preliminary data under carefully controlled conditions that would allow design of a second, larger scale experiment. In the first experiment, dairy manure was composted with sawdust and treated with gypsum at dry weight rates of 0, 6%, 13% and 23% (w/w).

Gypsum addition affected the initial compost moisture content, volatile solids content, nitrate content and C:N ratio. The moisture content (wet weight) at the time the composting process started was 61.7% for the zero rate control and became dryer as increasing amounts of gypsum were added (Table 2). Nitrate that was 31.4 mg $kg^{-1}$ in the unamended compost, was below detection limits in all of the gypsum amended composts. The initial C:N ratio of the dairy manure-sawdust mix before any addition of gypsum was very high (51.5; Table 2). This was a higher value than the optimal value of 30:1 for composting due to the dairy manure having more C than expected. The C:N ratios for the mixes containing gypsum were also fairly high and ranged between 44.6 for the 6% gypsum treatment to 41.0

for the 23% gypsum treatment. The reason for the differences in C:N ratio due to gypsum addition is not known since the FGD gypsum used was very pure and contained almost no C and N. Thus the ratios of C to N should not have changed by simply adding gypsum to the mix prior to composting. Inspection of the data suggested that the gypsum may have interfered with the analyses of C as these concentrations decreased faster than can be explained by simple dilution caused by gypsum addition to the mixes.

Various parameters were measured at the beginning of the experiment and then again after 18 days (Table 2). The data were statistically analyzed and, with only a few exceptions, all the parameters were significantly affected ($P < 0.001$) by an interaction between gypsum application rate and the composting process (i.e. comparison of the initial and final conditions). For example, the initial volatile solids concentrations were less affected by gypsum application rate in the initial mixes than in the final composted material. There was a decrease in volatile solids concentrations from 96.6% (zero gypsum rate) to 77.1% (23% gypsum rate) in the initial mix. However, in the final compost product the decrease was from 94.5% (zero gypsum rate) to 70.4% (23% gypsum rate) (Table 2). In contrast, solids concentrations increased as gypsum was added and this increase was greater in the final compost product that in the initial mixes.

Ash content was especially affected by addition of gypsum as gypsum does not combust and remains in the ash. Thus the ash content was greatly increased from 5.47% in the final compost product without gypsum to 29.6% when 23% gypsum was added. Visual observation of the final compost product indicated that it had the look and feel of a synthetic soil because of the large amount of inorganic material contained in it.

Although pH in the initial mixes was unaffected by gypsum addition, the pH in the final composts decreased as gypsum rate increased (Table 2). This may partly explain some of its ability to reduce ammonia volatilization during the composting process since the pKa of ammonia is near pH 8.3. The concentrations of mineral N (i.e. $NH_3$-N and $NO_3$-N) in the finished compost were highly variable and, in all cases where gypsum was added, were less than in the zero control compost. Salt concentration also increased as a result of gypsum addition and this may have been due to increases in S concentrations from 0.22% in the final zero rate compost to 6.92% in the final compost containing 23% gypsum. The S was, presumably, primarily in the form of sulfate and thus contributed to the salt measurements.

The amount of ammonia volatilization was high at the beginning of the composting process, but tapered off fairly quickly and was almost nil by the end of the second week (**Figure** 1). The high initial C:N ratios may have reduced the total amount of ammonia volatilized. However, even for this set of mixes, ammonia volatilization occurred and the effect of gypsum was very significant as 2.0 to 2.4 times less ammonia was volatilized from the gypsum treatments versus the zero rate control. The difference between the 6% gypsum application rate and the zero rate was much greater than between the 6% and the 23% application rates. We decided to use approximately 13% gypsum in a second, larger scale experiment because even though the 23% gypsum treatment rate lowered the evolution of ammonia slightly more than the 13% gypsum treatment, it was not a large difference. A 23% application rate would also have involved the use of larger amounts of gypsum in the experimental setup, which may be prohibitively expensive when doing large scale composting where this resource may not be readily available.

Nitrogen mass balances for Experiment 1 do not agree with the ammonia volatilization data (**Table** 3). At the zero rate of gypsum amendment, the calculated N balance did not show any loss. The 13% gypsum amendment rate showed as much as 12.3% of the initial N was lost. However, it must be noted that there are many potential sources of sampling and measurement errors when calculating mass balances and such balances do not negate the results obtained from actual trapping of evolved ammonia-N that occurred during composting of the various mixes.

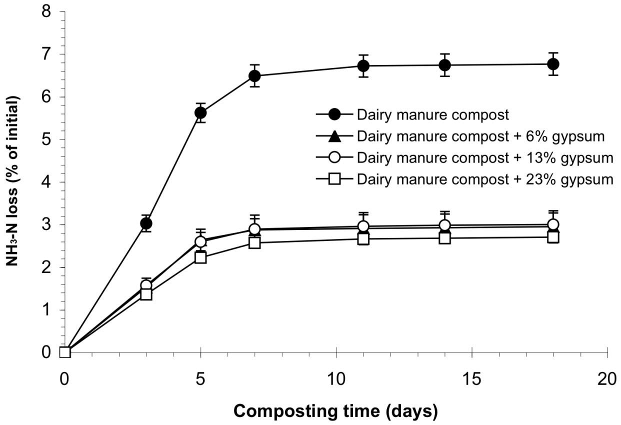

FIGURE 1. Cumulative ammonia-N loss, as percent of initial N in dairy manure, during the small scale composting experiment, (Experiment 1) after treatment with various rates of gypsum (dry weight, w/w).

TABLE 3.
Nitrogen mass balances for Experiments 1 and 2

| Treatment[a] | Sampling Time (day) | Dry Weight[b] (g) | N Concentration (%) | Total N Content (g) | N Loss (%) |
|---|---|---|---|---|---|
| | | Experiment 1 | | | |
| 0 | 0 | 100 | 0.984 | 9.84 | |
| | 14 | 61 | 1.63 | 9.94 | -1.0 |
| 6 | 0 | 100 | 1.12 | 11.2 | |
| | 14 | 72 | 1.48 | 10.7 | 4.5 |
| 13 | 0 | 100 | 0.985 | 9.85 | |
| | 14 | 68 | 1.29 | 8.77 | 12.3 |
| 23 | 0 | 100 | 0.905 | 9.05 | |
| | 14 | 77 | 1.09 | 8.39 | 7.3 |
| | | Experiment 2 | | | |
| DM | 0 | 100 | 1.31 | 13.1 | |
| | 28 | 71 | 1.55 | 11.0 | 16.0 |
| DM + G | 0 | 100 | 1.14 | 11.4 | |
| | 28 | 79 | 1.35 | 10.7 | 6.1 |
| Bio | 0 | 100 | 2.85 | 28.5 | |
| | 28 | 61 | 3.03 | 18.5 | 35.1 |
| Bio + G | 0 | 100 | 1.85 | 18.5 | |
| | 28 | 65 | 2.53 | 16.4 | 11.4 |

[a] Treatments for Experiment 1 were FGD gypsum added at 0%, 6%, 13% or 23% (dry weight, w/w) to dairy manure prior to the initiation of composting. For Experiment 2, treatments were DM, dairy manure compost; DM+G, dairy manure compost with 17% gypsum (dry weight, w/w); BioS, biosolids; and BioS+G, biosolids with 17% gypsum (dry weight, w/w). [b] Nitrogen mass balances were calculated by normalizing the dry weight of the initial compost mix to 100 g.

### *Experiment 2*

The initial C:N ratio of the dairy manure mix was 36 and decreased gradually during the compost time to about 30 for both treatments. For the biosolids/sawdust/gypsum mix, the initial C:N ratio was 19 and decreased to 12 in the final compost product. It is clear that the C:N ratios for the biosolids composts are much lower when compared with those of cow manure composts. This greatly affected N dynamics as described below.

The amount of ammonia released, as a percentage of the original N content, during composting of dairy manure from both gypsum treated and untreated vessels was highest at the beginning of the composting process. Evolution of ammonia decreased gradually and stopped almost completely after two weeks for the dairy manure compost (**Figure** 2). However, for biosolids, evolution of ammonia continued throughout the entire 28 day composting time, although the losses were small after the 14th day compared to the previous days. Overall, the loss of ammonia-N during composting of biosolids was 2.1 times greater than from dairy manure when gypsum was not present but 3.8 times greater when gypsum was present.

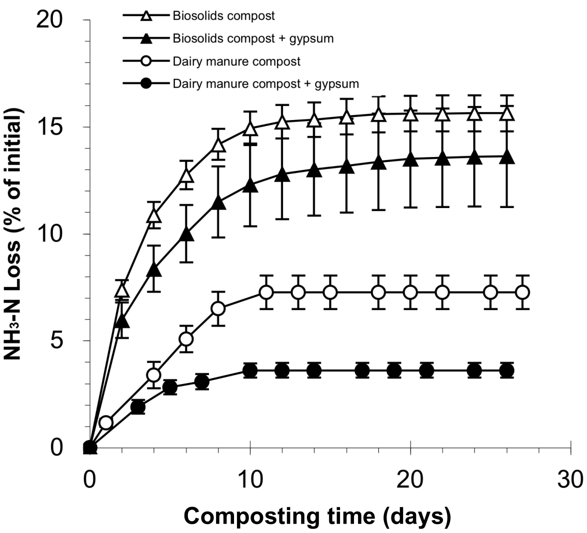

FIGURE 2. Cumulative ammonia-N loss, as percent of initial N in dairy manure and biosolids, during composting with or without gypsum (Experiment 2). The application rates of gypsum were 0% and 17% (dry weight, w/w).

The amount of ammonia released during composting of both dairy manure and biosolids was decreased by the 13% gypsum treatment. For dairy manure, the amount of N lost as a percentage of that originally present in the compost mix was from 7.27% without gypsum to only 3.62% with gypsum (Figure 2). For biosolids, the decrease in the initial N lost as ammonia was not as dramatic but still highly significant. The values were 15.6% N loss without gypsum to 13.6% with gypsum. The difference in response is due to the lower C:N ratio and the type of material in the biosolids compared to the dairy manure. Increasing the initial C:N ratio, or increasing the gypsum rate above 13% as was done in the first laboratory scale experiment, would likely further reduce ammonia loss. However, this would also add cost and mineral content to the finished compost product.

In contrast to Experiment 1, N mass balances calculated for Experiment 2 (Table 3) were consistent with the ammonia-N trap data. The unamended dairy manure mixes were calculated to have lost 16% of their original N while the treatment containing 17% FGD gypsum lost only 6.1% of its original N. Similarly, the biosolids alone lost 25.1% of its original N, and this was reduced more than three-fold to only 11.4% of the original N lost when 17% FGD gypsum was included in the compost mix.

Dry weight of the compost mix decreased throughout the composting process. In the case of dairy manure mixes, 79% and 71% of the initial dry weight remained after 28 days of composting with

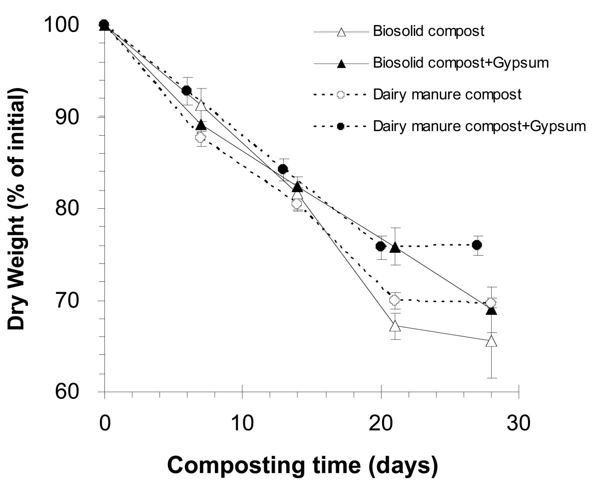

FIGURE 3. Relative dry weight remaining after composting of dairy manure and biosolids with and without gypsum (Experiment 2). The application rates of gypsum were 0% and 17% (dry weight, w/w).

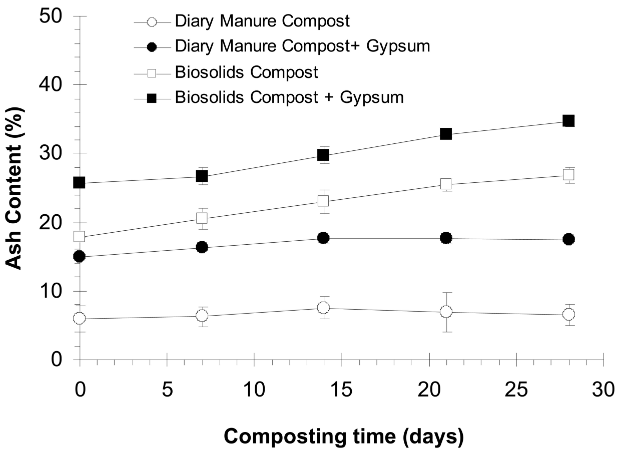

FIGURE 4. Ash content change during composting of dairy manure and biosolids with and without gypsum (Experiment 2). The application rates of gypsum were 0% and 17% (dry weight, w/w).

and without 17% gypsum, respectively (**Figure** 3). Biosolid mixes resulted in 65% and 61% of the dry weight remaining with and without 17% gypsum. We also observed that addition of 17% gypsum significantly reduced the moisture content in both dairy manure and biosolids composts. Gypsum is already hydrated, but it may take up additional water that is not part of the mineral structure, thereby creating finished compost that contains less moisture. Ash content of the different compost mixes also gradually increased with composting time and the mixes treated with gypsum had significantly higher ash contents than the untreated composts (**Figure** 4).

In general, the total Kjeldahl nitrogen concentrations in the final compost products were significantly ($P < 0.005$) increased for all treatments compared to the concentrations in the initial mixes (**Table** 4). Similarly, concentrations of extractable macronutrients, but not micronutrients, were increased during composting. Even though less N was lost from the materials during composting when 17% gypsum was added, the concentrations in the final compost were lower because of the dilution effect caused by the gypsum. However, the concentrations of N were still considered sufficient to support good plant growth.

The final pH values were also significantly ($P < 0.001$) decreased when 17% gypsum was added to the dairy manure compost mix and, as previously mentioned, this may explain some of its effect on re-

TABLE 4.
Concentration of pH, soluble salts and macronutrients in initial (Day 0) and final (Day 28) compost.

| | | | | | Extractable Concentrations (g kg) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Compost[a] | Sampling Time (day) | pH | SS[b] (dS m$^{-1}$) | Total N (g/kg$^{-1}$) | S | P | K | Ca | Mg |
| DM | 0 | 7.52 | 10.9 | 13.1 | 1.86 | 1.62 | 5.66 | 6.81 | 2.20 |
| | 28 | 8.19 | 4.54 | 15.5 | 2.21 | 1.67 | 11.3 | 7.81 | 2.33 |
| DM+G | 0 | 7.58 | 12.1 | 11.4 | 22.3 | 1.34 | 4.94 | 41.1 | 1.92 |
| | 28 | 7.37 | 7.78 | 13.5 | 29.9 | 1.27 | 9.92 | 34.2 | 2.05 |
| BioS | 0 | 7.70 | 8.75 | 28.5 | 4.42 | 6.78 | 2.66 | 13.4 | 2.71 |
| | 28 | 6.42 | 2.98 | 30.3 | 10.9 | 10.8 | 3.53 | 19.6 | 3.94 |
| BioS+G | 0 | 7.40 | 11.5 | 18.5 | 28.8 | 5.26 | 1.91 | 43.4 | 2.14 |
| | 28 | 6.43 | 5.93 | 25.3 | 44.5 | 10.3 | 2.85 | 55.0 | 4.09 |
| | | | | | Statistics[c] | | | | |
| Gypsum | | *** | *** | *** | *** | *** | *** | *** | * |
| Organic Source | | *** | *** | *** | *** | ** | *** | *** | *** |
| Time | | *** | *** | *** | * | *** | *** | *** | *** |
| Gypsum x Org. Source | | *** | *** | *** | *** | NS | NS | * | NS |
| Gypsum x Time | | *** | *** | *** | NS | NS | NS | NS | * |

[a] DM, dairy manure compost; DM+G, dairy manure compost with 17% gypsum (dry weight, w/w); BioS, biosolids; and BioS+G, biosolids with 17% gypsum (dry weight, w/w). [b] SS, soluble salts. [c] Levels of significance of the direct or interactive effects of the variables gypsum (with or without), organic sources (dairy manure or biosolids) and time (0 or 28 days) are indicated by * = $P < 0.05$, ** = $P < 0.01$ and *** = $P < 0.001$. NS = not significant.

ducing ammonia-N loss during composting (Table 4). Soluble salts decreased with composting time throughout the composting process for both dairy manure and biosolids composts in all treatment (Table 4). However, addition of gypsum, noticeably increase salt content compared to the no gypsum treatment. If attempts are used to grow plants using only these finished composts, the levels of salts may prove inhibitory. Soils are rated as having extreme salinity if their soluble salts values exceed 4 dS m$^{-1}$ (Lal *et al.* 2004). All of the values except the biosolids without gypsum exceeded this value. These materials could be used if applied to a soil at rates that would dilute the salt concentration. Alternatively, they could be leached before use, although any N in the form of nitrate would also be lost.

Concentrations of other essential macronutrients (Table 4) and micronutrients (**Table** 5) were generally affected by gypsum addition, organic source and time. In almost all cases, the concentrations in the material that had been composted for 28 days were greater than the initial or time zero concentrations. This is because the total compost mass decreased during composting and concentrated the nutrients. With the exception of Ca and S, which increased, the concentrations of all nutrients decreased when 17% gypsum was added because of a dilution effect. Concentrations of heavy metals were only measured when biosolids were composted (**Table** 6). The trends for these elements were similar to those of the nutrients measured, i.e. the composting process increased concentrations while the addition of gypsum tended to decrease concentrations. However, none of the concentrations in the biosolids compost were considered high enough to cause concern if used to grow plants after land application or if the composts were used as a mix for nursery/greenhouse production (USEPA 1993).

TABLE 5.
Concentrations of various micronutrients in initial (Day 0) and finished (Day 28) compost with and without gypsum.

| Compost Treatment[a] | SamplingTime (day) | B | Cu | Fe | Mn | Mo | Zn |
|---|---|---|---|---|---|---|---|
| | | (mg kg$^{-1}$) | | | | | |
| DM | 0 | 11.4 | 9.72 | 0.476 | 0.089 | 1.01 | 0.091 |
| | 28 | 14.5 | 19.6 | 0.435 | 0.091 | 1.09 | 0.126 |
| DM+G | 0 | 10.9 | 6.89 | 0.444 | 0.078 | 0.96 | 0.080 |
| | 28 | 13.3 | 17.6 | 0.384 | 0.075 | 0.56 | 0.098 |
| BioS | 0 | 19.1 | 174 | 11.5 | 1.38 | 3.28 | 0.91 |
| | 28 | 34.4 | 294 | 18.7 | 2.29 | 5.72 | 0.84 |
| BioS+G | 0 | 16.5 | 137 | 8.61 | 1.03 | 2.39 | 0.69 |
| | 28 | 30.6 | 243 | 15.5 | 1.96 | 5.25 | 0.75 |
| | | Statistics[b] | | | | | |
| Gypsum | | *** | *** | NS | *** | * | *** |
| Organic Source | | *** | *** | *** | *** | *** | *** |
| Time | | *** | *** | *** | *** | *** | NS |
| Gypsum x Org. Source | | * | *** | NS | *** | NS | *** |
| Gypsum x Time | | NS | NS | NS | NS | NS | * |

[a] DM, dairy manure compost; DM+G, dairy manure compost with 17% gypsum (dry weight, w/w); BioS, biosolids; and BioS+G, biosolids with 17% gypsum (dry weight, w/w). [b] Levels of significance of the direct or interactive effects of the variables gypsum (with or without), organic sources (dairy manure or biosolids) and time (0 or 28 days) are indicated by * = $P < 0.05$, ** = $P < 0.01$ and *** = $P < 0.001$. NS = not significant.

TABLE 6.
Concentrations of heavy metals in initial (day 0) and finished (day 28) biosolids compost with and without gypsum.

| Compost Treatment[a] | Sampling Time (days) | Al | As | Ba | Cd | Co | Cr | Ni | Pb | Sr | V |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | (mg kg$^{-1}$) | | | | | | | | | |
| BioS | 0 | 5.53 | 5.92 | 239 | 1.73 | 4.45 | 23.1 | 14.5 | 31.1 | 59.1 | 17.9 |
| | 28 | 8.48 | 7.61 | 326 | 5.65 | 6.53 | 50.2 | 30.7 | 47.6 | 83.1 | 17.2 |
| BioS+G | 0 | 3.50 | 4.44 | 189 | 1.48 | 3.51 | 16.7 | 10.4 | 23.8 | 72.8 | 13.4 |
| | 28 | 7.58 | 5.93 | 297 | 4.46 | 5.67 | 36.2 | 23.7 | 43.5 | 103 | 14.7 |
| | | Statistics[b] | | | | | | | | | |
| Gypsum | | *** | ** | *** | * | *** | *** | ** | * | *** | *** |
| Time | | *** | ** | *** | *** | *** | *** | *** | *** | *** | NS |
| Gypsum x Time | | * | NS | * | NS | NS | NS | NS | NS | NS | * |

[a] BioS, biosolids; and BioS+G, biosolids with 17% gypsum (dry weight, w/w). [b] Levels of significance of the direct or interactive effects of the variables gypsum (with or without) and time (0 or 28 days) are indicated by * = $P < 0.05$, ** = $P < 0.01$ and *** = $P < 0.001$. NS = not significant.

## Conclusions

Combining organic waste streams, especially N-rich streams, with by-product gypsum can help control odors and air pollution associated with release of ammonia and conserve more total N in the final compost product. This effect may be enhanced if the C:N of the initial composting mix is adjusted to values between 30 and 45 when using N-rich feedstocks such as biosolids. The gypsum in the final product may also provide benefits to certain soils that are lacking in calcium and sulfur, that are high in sodium or that suffer from subsurface acidity problems. The final product created can thus be viewed as a material that has application both at the front end, during the composting process itself, and the back end as a valuable resource for use as a soil amendment or as a component of a greenhouse/nursery mix (Bardhan 2005).

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