QUANTIFYING LOSSES OF PLANT NUTRIENTS AND ELEMENTS DURING WINDROW COMPOSTING OF VARIOUS FEEDSTOCKS

By

David A. Schellinger
LAES, Agronomy Department
Louisiana State University
Baton Rouge, Louisiana

Dr. Gary Breitenbeck
LAES, Agronomy Department
Louisiana State University
Baton Rouge, Louisiana

INTRODUCTION

The viability of composting as a practical alternative for disposal of the large quantities of organic wastes generated by municipalities, industry and agricultural processing depends, to a large degree, on adequate local markets for finished compost. In many areas, the use of composts as soil amendments in nearby agricultural fields offers a large potential market. The benefits of adding stabilized organic matter on water dynamics and other physical and chemical soil properties is well established. Often, however, these benefits do not result in sufficient improvement in crop performance to offset the costs of producing, shipping and applying composts. When composts also supply a portion or all of the soil nutrients required by crops, their value as a soil amendment is greatly enhanced by reducing need for industrially produced fertilizers to produce high-yielding crops.

During composting, microorganisms utilize N, P and other essential nutrients contained in the organic wastes to mineralize readily available carbon substrates. As these substrates are depleted, the ratios of organic C to the various crop nutrients tends to decrease. The C:N ratio has been used extensively to indicate compost maturation. As a general rule, when the C:N ratio is less than 30:1, the supply of N is considered sufficient to meet microbial demand and the compost can be added to soils without possibility of inducing immobilation of plant nutrients. While application of mature composts minimizes the risks of immobilization of plant nutrients present in soils, it does not ensure that the nutrients contained in composts will be released to meet the demands of a growing crop. The capacity of finished composts to recycle essential plant nutrients in organic wastes and to supply them to crops varies greatly among composts derived from various feedstocks. Composts derived from carbonaceous wastes, such as municipal solid waste and wood wastes, appear to have a limited capacity to supply N, P and other nutrients. In contrast, composts derived from nutrient-rich materials such as municipal biosolids and animal wastes, can supply substantial amounts of nutrients when used as soil amendments.

The capacity of composting to recycle plant nutrients in organic wastes is reduced when substantial quantities of nutrients are lost during the composting process. Gaseous emissions of ammonia and dimethyldisulfide during the alkaline phase of composting commonly exceed odor thresholds (Dunson, 1993). These emissions also represent potentially significant losses of N and S. Most studies of nutrient losses during composting have focused on losses via leachate and runoff. For example, Stilwell and Sawhney (1993) reported that leachate from MSW compost contained 2.5 mg Cu/L, 32 mg Zn/L, 1 mg Pb/L and 0.11 mg Cd/L. While total losses are difficult to calculate from such data, evidence for elevated concentrations of nutrients and regulated metals in leachate serves to underscore a potential concern for compost facility managers. Cumulative leachate losses over a large number of composting cycles may result in potentially hazardous levels in pads and the sediments and discharge from collection basins. Nienaber and Ferguson (1992) reported that the soil underlying a feedlot manure composting facility contained nitrate levels exceeding the drinking water standard of 10 mg/kg to a depth of 6 m and in excess of 75 mg/kg. In addition, they reported P levels in excess of 400 mg/kg and K near 3000 mg/kg in the surface 0.15 m.

The potential for nutrient loss during composting may be disguised by the apparent increases in concentration of N and other nutrients that frequently occur as organic C is oxidized and released as CO2. These increases in nutrient

concentrations, however, may not be sufficient to fully account for the loss of mass that occurs during the process. When the loss of total mass during decomposition is known, the expected final concentration of a nutrient can be calculated. For example, if half of the mass of an initial feedstock was lost during composting, a doubling in nutrient concentration would indicate no nutrient loss. Similarly, if the nutrient concentration in the finished compost was similar to that of the initial feedstock, we can assume that half the amount of nutrient initially present was lost. Unfortunately, obtaining reliable estimates of nutrient losses during windrow or other large-scale composting is hindered by the difficulty in obtaining reliable direct measurement of total mass lost. Fluctuations in pile geometry and bulk density, especially during the initial stages of composting, contribute to large errors in such measurements. Comparing changes in nutrient concentrations to that of an element that is conserved during the composting process offers an alternative approach for estimating the extent of nutrient loss. Haug (1993) proposed the use of ash as an internal standard for monitoring changes in organic C to determine compost biodegradability.

The principal objectives of the work reported here was to (1) assess the suitability of using ash content or concentrations of other elements as an internal standard for estimating nutrient losses during composting and (2) to use the most promising internal standard to calculate the losses of organic C, N, P and K during composting of nine windrows comprised of different feedstocks.

MATERIALS AND METHODS

Windrow Composition and Maintenance

Windrow composting of selected feedstock materials was performed at the LSU Organic Recycling Center located in Baton Rouge, LA. Eight windrows were constructed using each of the following feedstocks: hardwood bark (Bark), ground rice hulls (Hulls), cotton gin trash (CGT), horse barn bedding (HBed), bull barn bedding (BBed), spoiled silage (Silage), bagasse, and filterpress mud (FPM). Bagasse and filterpress mud are wastes generated during sugarcane milling. Bagasse is comprised of crushed stalks remaining after sugar extraction and filterpress mud is comprised of finely ground cane residues and mineral soil. An additional windrow was constructed using a 1:1 ratio by volume of filterpress mud and bagasse (FP&Bag). The bagasse used in this windrow showed signs of substantially greater decomposition than that used in the windrow containing only bagasse. Bagasse and hardwood bark were ground prior to windrow construction using a TORO Progrind® 1000 Tub Grinder (Bloomington, MN) to a 5.5-cm maximum size.

Windrows were constructed of approximately 20 m in length, 2 m in height, and 2 m in basal width. Internal windrow temperatures were monitored but not used to determine when to turn the piles. The windrows were turned weekly (7 d intervals) using a tractor drawn Wildcat® Turning Machine (Wildcat Manufacturing Co., Freeman, SD). Although little self-heating was evident in windrows after 90 d, turning of windrows at 7 d intervals was continued to ensure thorough mixing prior to sample collection. To control odors and pests, the windrow consisting of spoiled silage was turned two additional times during the initial 21 d of composting. Moisture levels of windrows were initially adjusted to approximately 60% (total weight basis) and maintained at that level by addition of water prior to turning of windrows.

Sampling of Windrows

Windrows were sampled upon construction and after each turning thereafter over a 141 day period. Each windrow was divided into three 1-m sections (one located at half the length of the windrow and the other two located 2-3 m from each end) to serve as replicate sampling sites. At each sampling, composite samples of approximately 5 L were collected from three horizontal levels at each of the sample sites at an approximate depth of 1/4 the width of the pile. The subsamples were well mixed by tumbling and ~1 kg representative sample was obtained for laboratory analysis.

Sample Preparation

Moisture content and pH were determined on fresh samples immediately after collection. The remaining samples were dried at 35°C for 48 h in a forced-air drying oven. Dried samples were then ground in a Thomas-Wiley® Model 4 Cutting Mill to pass a 1-mm screen. Samples were thoroughly mixed and a 5 g subsample collected for

elemental analysis was then ground in a Tecator Cyclotech® Model 1093 Sample Mill (Fisher Scientific, Pittsburgh, PA) to pass a 100-mesh sieve. Ground samples were re-dried (65°C; 12 h) and stored in air-tight containers until use.

Compost Analyses

Moisture was determined gravimetrically on fresh samples using a Cenco Model 26680 moisture balance (CSC Scientific Company, Inc., Fairfax VA). The pH values were obtained on fresh samples with a flat surface electrode and an Corning® model 250 Ion Analyzer. Total organic C and N concentrations were determined using a Heraeus CHN-O-Rapid® Analyzer (UIC, Joliet, IL) which employs modifications of the Pregl-Dumas dry combustion technique. Ammonium and nitrate concentrations (mg kg^{-1}) were determined in 1:10 dilutions of a 1 N KCl extract of each ground sample using an automated NH_3 diffusion technique initially described by Carlson (1978).

Total elemental analysis was preformed using a modified method as described by Bernas (1968). A 0.10 g sample of ground, oven-dry material was treated with 2-mL nitric acid and 3-mL hydrofluoric acid in 50 mL Teflon® inserts for stainless steel bombs. The assembled bombs were heated to 140°C for 8 h. After cooling, the bombs were opened and 1.4 g of crystalline boric acid were added and mixed well with the insert contents to complex any remaining hydrofluoric acid . The contents were then quantitatively transferred to 50 mL volumetric flasks and brought to volume with deionized water. After capping and shaking by inverting the flasks 4 times, a 11 mL sample was decanted into a 12 mL plastic culture tube. The samples were then analyzed for elemental content on a Perkin Elmer Optima® model 3000 Inductively Coupled Plasma Ion Spectrometer (Norwalk, CT).

Ashing of samples was accomplished by first determining the weight of 25-mL ashing thimbles dried 105°C and cooled in a desiccator. Ground samples were then placed in the thimbles which were then dried and cooled as above, then weighed for dry-weight determination. The thimbles and samples were then ashed in a muffle furnace at 550°C for 2 h, allowed to cool to near 100 °C, then cooled to room temperature in a desiccator. The ash weight was calculated and expressed as g ash/g dry weight of sample.

Internal Standard Evaluation and Selection

Correlations between various elemental concentrations and those of organic C and the standard deviations and coefficients of variation were calculated using Statistica (StatSoft, Inc., Tulsa OK). Only the averages of the sums of nutrient and elemental concentrations for feedstocks and finished composts are presented here due to the extensive amount of data.

Calculating Losses of Plant Nutrients and Elements

Nutrient and metal losses were calculated based on an internal standard were calculated using the following equation:

$$\%\ L = \{1 - [(Nf/Ni)/(Si/Sf)]\} \times 100$$

,where

%L = Percentage of nutrient or element lost from compost
Nf = elemental concentration in finished compost
Ni = Nutrient or element concentration in initial feedstock
Si = Concentration of internal standard in initial feedstock
Sf = Concentration of internal standard in finished compost

RESULTS AND DISCUSSION

To initially identify possible chemical properties suitable for use as an internal standard, the elemental compositions of samples collected from the nine windrows at weekly intervals were correlated with organic C concentrations. Because much of the mass loss during composting is known to result from the mineralization of organic C to CO_2, an element that was conserved during composting would be expected to display a strong inverse correlation with organic

C. Conversely, a weak correlation with organic C would be expected of elements that were readily lost. Ash displayed the strongest inverse relationship (r^2=-0.93). Si and Al, constituents of soil minerals, were also strongly correlated as were several trace metals. The precision by which a soil property can be measured is an important consideration in selecting a suitable internal standard because the error associated with this measurement compounds with that of measuring individual nutrients when calculating nutrient loss. Table 1 shows the average standard deviations and coefficients of variations (CV) within replicate samples collect from the nine windrows at various times. Because of the wide range in mean values for the properties tested, the CV is a more useful in indicating the contribution of the error associated with an internal standard. Ash displayed a significantly lower CV (2.6%) than the other elements tested. Because of its ability to reflect change in organic C concentration and the low error associated with its measure, ash content appears to be the most suitable property for use as an internal standard for monitoring losses of nutrients during composting.

Table 1. Average mean, and average standard deviation and coefficient of variation within three replicate samples of chemical properties displaying the strongest inverse correlations to organic C concentrations during composting.

Property	Mean	Std Dev	CV	Correlation to Org. C
	------- mg/Kg -------		%	r^2
Al	11212	1420	16.3	-0.83
Ash	39490	0.91	2.6	-0.93
Be	1.8	0.23	20.1	-0.74
Fe	8532	974	15.2	-0.77
Na	2568	177	12.7	-0.83
Si	115740	7646	8.1	-0.89
Ti	1064	80.8	11.4	-0.85
V	24.8	2.6	23.6	-0.81
Zn	113	15.5	17.6	-0.58

To determine losses of various plant nutrients and metals during windrow composting, the elemental composition of finished composts were compared to the corresponding initial concentrations in samples obtained immediately after construction and initial turning of windrows. Using ash content as an internal standard, the expected concentration of nutrients and trace metals in finished compost was calculated. The average values obtained from the nine windrows are shown in Table 2. On average, finished compost contained 51.3% less organic C than the feedstock from which it was derived. Concentrations of N, P and K, the principal nutrients supplied in fertilizers, were greater in final compost than in initial feedstocks, but these increases were less than expected when ash content was used to adjust for total loss of mass. Losses of N, P and K averaged 26.6%, 30.7% and 30.1%, respectively. Appreciable losses of the cations Ca (34.2%) and Mg (40.2%) were observed. Losses of Na, however, averaged only 11.4%. Sulfur losses averaged only 11.9%. With the exception of silage, windrows remained aerobic during the composting cycle, and the distinctive odor of reduced organosulfur compounds was not detected. No losses of Fe were detected.

Average losses of regulated metals, presumably in leachate and runoff, varied greatly among metals and within windrows (Table 3). Losses of As were negligible in most windrows, whereas an average of more than 50% of the Co, Cu and Ni initially detected in feedstocks were not recovered in finished compost. Windrows comprised of bagasse and hardwood bark displayed the greatest losses of metals. Although the initial and final concentrations of all metals were within the ceiling limits established for land application of biosolids under EPA Part 503 Rule, the magnitude of these losses suggests vigilance on the part of managers of uncovered facilities where repeated compost cycles may significantly enrich the regulated metals concentrations in porous pads and the underlying soil. It is noteworthy that the errors associated with replicate analyses of most regulated metals were large, especially in the initial samples collected from newly constructed windrows where it is difficult to obtain an adequately representative

sample from the heterogeneous compost matrix. Directly measuring the concentrations of regulated metals in soils, basin sediments and discharge waters would likely prove a more reliable technique for monitoring accumulation of potentially hazardous regulated metals.

Table 2. Average initial, final, and expected final concentrations (ash basis), and percent losses of principal plant nutrients in nine windrows composted for 141d.

Element	Initial conc.	Final conc.	Expected conc.	Loss
		mg/kg		%
C	320200	242600	498490	51.3
N	9526	11376	15444	26.3
P	3681	3970	5730	30.7
K	8945	9736	13925	30.1
Ca	15434	15808	24028	34.2
Mg	3523	3279	5485	40.2
Na	1949	2690	3034	11.4
Mn	467	533	726	26.6

Table 3. Average initial, final, and expected final concentrations (ash basis), and percent losses of regulated metals in nine windrows composted for 141d.

Element	Initial conc.	Final conc.	Expected conc.	Loss (ash basis
		mg/kg		%
As	64.2	88.4	87.1	-1.5
Cd	6.0	6.4	9.4	31.1
Co	15.2	10.4	23.2	55.0
Cr	84.7	72.9	121.4	39.9
Cu	38.3	28.3	59.7	52.5
Ni	104.5	53.9	162.7	66.9
Pb	71.5	90.7	111.3	18.6
Zn	106.4	120.5	165.6	27.2

The total mass lost during windrow composting ranged from 5.4% in the windrow comprised of a mixture of filterpress mud and aged bagasse to 76.5% in the windrow comprised of spoiled silage (data not shown). The average mass lost in the nine windrows was 37.3%. Losses of total mass were inversely correlated with initial ash content (r^2 = 0.60) and strongly correlated to losses of organic C (r^2 = 0.83), as expected. Composting the mixture of filterpress mud and aged bagasse resulted in a loss of 22.5% of the organic C initially present (Fig. 1). The corresponding reduction in organic C in compost derived from spoiled silage was 88.2%. Spoiled horse barn bedding lost substantially less organic C (35.1%) than did spoiled bedding from a bull barn (75.7%). The bedding from the horse barn contained approximately 2 ½ times the amount of soil as the bedding from the bull barn, and was more

decomposed prior to use for windrow construction. These findings illustrate the fact that mineral contamination and the state of decomposition are important considerations when estimating biodegradability of organic wastes.

N losses during composting ranged from negligible to more than 63% of the total N initially present in feedstocks. (Fig. 2). Although N losses from Silage and CGT exceeded 56%, finished composts of these feedstocks contained appreciable amounts of mineral N after 141 d. Losses of N were much less in windrows constructed of partially decomposed organic material. This finding is consistent with the observation that a substantial portion of the N lost during composting occurred within the initial 28 d, though N losses were detected throughout the composting process. Stepwise regression to identify compost properties correlated with N loss indicated that initial ash content was the most reliable indicator. Rice hulls were an exception, possibly because they contain significant amounts of silica but offer little cation exchange capacity to retain ammonium. An additional experiment (not reported) to compare N losses from windrows comprised of rotted cotton gin to those comprised of 2:1 mixture of rotted gin trash and silt loam soil showed confirmed that the presence soil was highly effective in reducing N losses. In that study, N losses from rotted gin trash averaged approximately 7% whereas no losses of N were detected in the windrow constructed of a mixture of gin trash and soil.

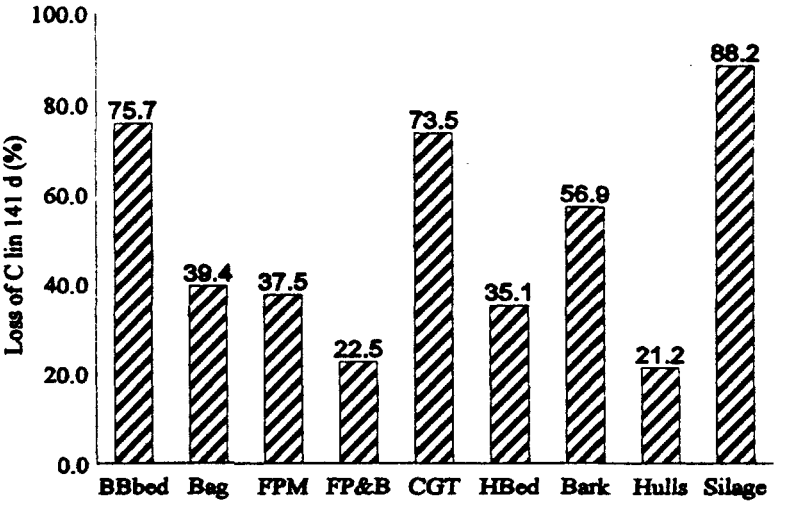

Figure 1. Percentage of C lost after windrow composting various feedstocks for 141

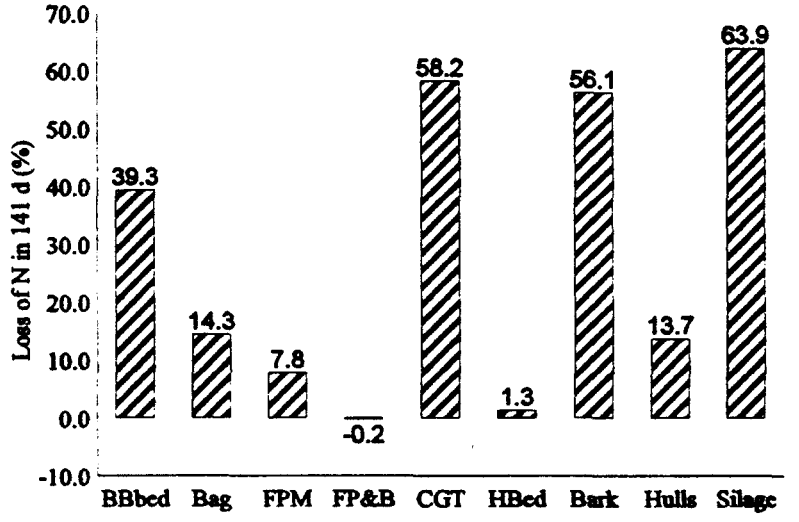

Figure 2. Percentage of N lost after windrow composting various feedstocks

Losses of P ranged from 9% to more than 70% of the P initially contained in feedstocks (Fig. 3). Such losses represent a substantial loss of this nonrenewable essential plant nutrient. As with N, the greatest losses of P occurred in windrows that contained low amounts of mineral matter. While the mechanism of loss was not studied, leaching of organically bound P or of orthophosphate may have been responsible for the losses observed. Regression analyses indicated no relationship between the magnitude of P losses and the amount initially present in feedstocks.

Losses of K during composting also varied greatly among windrows constructed of different feedstocks (Fig. 4). As with N and P, the greatest losses occurred in windrows of Silage, Bark and CGT, feedstocks that contained large amounts of readily degraded organic substrate and low amounts of mineral matter. The smallest losses occurred in windrows where organic matter contained appreciable amounts of clay and other soil contaminants.

These findings indicate that windrow composting of some feedstocks does not provide efficient recycling of plant nutrients contained in these feedstocks and nutrient losses reduce the fertilizer value of finished composts. Composting of partially decomposed organic matter generally resulted in a smaller proportion of nutrients lost than did composting of fresh material. It is possible, however, that partially decomposed feedstocks lost significant amounts of their essential nutrients prior to windrow construction. The presence of soil contaminants appears to reduce losses of the nutrients in feedstocks. Additional research is needed to determine if addition of mature composts or soil during windrow construction can effectively reduce losses of nutrients and regulated metals during windrow processing.

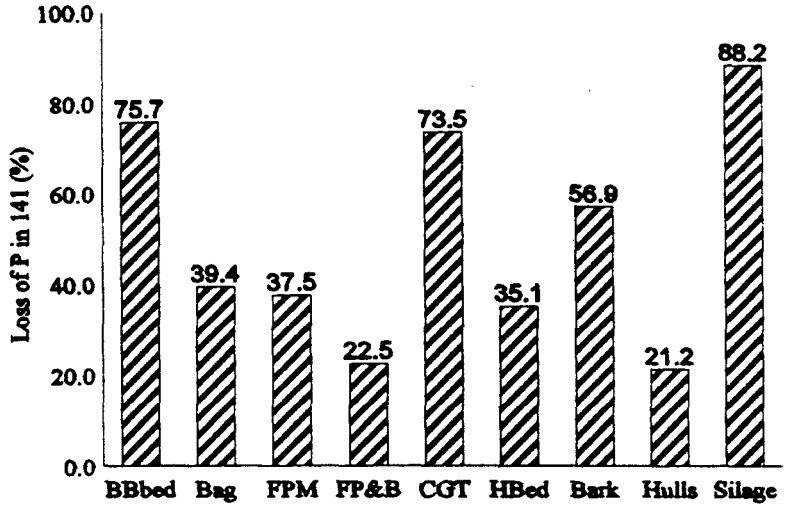

Figure 3. Percentage of P lost after windrow composting various feedstocks

CONCLUSIONS

The use of an internal standard to calculate nutrient losses during composting of various feedstocks provided satisfactory results. The principal limitation of this approach lies in difficulty in obtaining representative initial samples, especially from compost piles constructed of different feedstocks that tend to naturally segregate. High variability was a more severe limitation when estimating losses of metals that occur in low concentrations than when estimating losses of macronutrients. Ash content was found to be the most suitable internal standard because of its strong relationship with organic C loss and low sampling and analytical errors. Losses of N and other important crop nutrients varied greatly during composting of different feedstocks. Regression analyses suggested that greater losses of plant nutrients occurred when composting readily degradable feedstocks that contained low amounts of mineral matter than when composting partially decomposed feedstocks containing appreciable amounts of soil. Some feedstocks lost substantial proportions of their regulated metals in addition to nutrients, suggesting the possibility that enrichment by potentially hazardous contaminants may develop with time at uncovered compost facilities in the humid south.

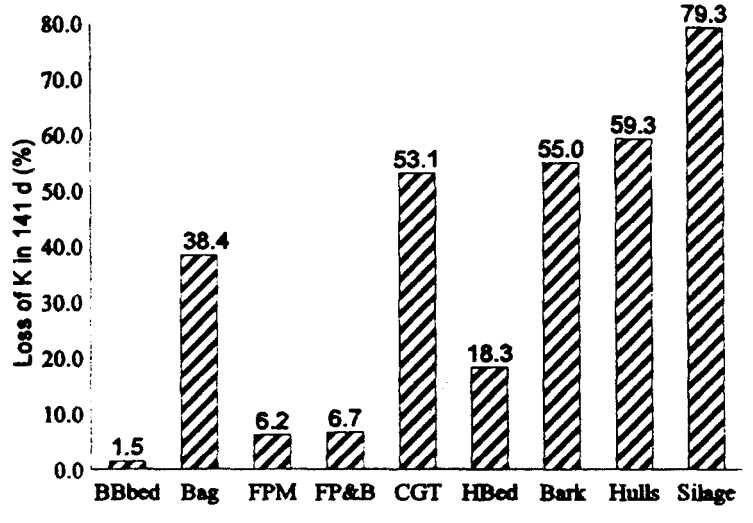

Figure 4. Percentage of K loss after windrow composting for 141 d.

REFERENCES

Bernas, B., 1968. A New Method For Decomposition and Comprehensive Analysis of Silicates by Atomic Absorption Spectrometry. Analytical Chemistry, 40:11:1682-1686.

Carlson, R. M., 1978. Automated Separation and Conductimetric Determination of Ammonia and Dissolved Carbon Dioxide. Analytical Chemistry, 50:1528.

Dunson, J. B. Jr., 1993. Control of Odors by Physical-Chemical Approaches. In: Hoitink, H. A. J. and Keener, H. M. (Editors), Science and Engineering of Composting: Design, Environmental, Microbiological and Utilization Aspects. Renaissance Publications, Worthington, OH, pp. 243-261.

Haug, R. T., 1993. Substrate Biodegradability. The Practical Handbook of Compost Engineering. Lewis Publishers, Boca Raton, FL, pp. 307-334.

Nienaber, J. A. and Ferguson, R. B., 1992. Nitrate Movement Beneath a Beef Cattle Manure Composting Site. Proceeding of the December, 1992 meeting of the American Society of Agricultural Engineers.

Stilwell, D. E. and Shawney, B. L., 1993. Elemental Analysis of Municipal Solid Waste Compost II. Refuse Derived Fuels Unders. Compost Science & Utilization, 1:4:49-53.