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Evaluation of Fiber Content Relative to Other Measures of Compost Stability

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Improved methods for assessing compost stability are needed. We collected thirteen separate compost samples from a single windrow over a 91 d period. Initial assessment of compost stability used standard analyses, including total C and N concentration, C:N ratio, and inorganic N concentration. Compost C and N lability were assessed by measuring CO_2 evolution during a 24 hr period, and also using a commercially available compost evaluation kit which includes both CO_2 and NH_3 release to establish a Maturity Index. We also estimated slowly degradable C fractions in the composts using neutral detergent fiber (NDF) and lignin methods developed for ruminant feed analysis. The relationship between stability and each compost constituent was evaluated using simple linear regression. Some widely-used parameters, like compost C:N ratio, changed very little during compost aging. Compost CO_2 evolution showed a strong linear relationship with the compost age, with a coefficient of determination (r^2) of 0.82. Likewise, fiber and lignin concentration increased during compost maturation as more easily available C was used by microbes (r^2 = 0.70 to 0.80). The Solvita Maturity Index was related to the compost age (r^2=0.59), but fluctuated due to temporary changes in windrow conditions. These results indicate that microbial respiration and fiber analysis can be used to establish relative differences in compost stability.

Introduction

Maintaining or increasing soil organic matter (SOM) in intensive agricultural production systems is a challenge increasingly met by the application of compost or other amendments. Compost quality and nutrient content influences plant growth and can vary widely depending on the compost feedstocks and on the stability and maturity of the product at the time of use. Reliable estimates of compost stability, maturity, and nutrient availability are needed to plan and implement the best use of these materials in crop and soil management strategies. Compost stability is an attribute that relates to nutrient bioavailability, whereas compost maturity relates more specifically to plant growth (Cooperband *et al.* 2003; Ozores-Hampton *et al.* 1999).

Predicting compost stability and maturity will help growers make appropriate decisions about compost use. Avoiding adverse consequences is especially important, including decreased soil oxygen concentrations resulting from high microbial mineralization rates (Zmora-Nahum *et al.* 2005), accumulation of excessive nitrogen (N), phosphorus (P) or other nutrients, or release of phytotoxins (Ozores-Hampton *et al.* 1999; Wang *et al.* 2004; Zmora-Nahum *et al.* 2005) from immature composts.

The assessment of compost stability often involves measurement of the rate of microbial respiration (CO_2 production) under standardized conditions (Brewer and Sullivan 2003; Wang *et al.* 2004), and may also include measurement of ammonia (NH_3) production. Some commercially available compost stability tests (Changa *et al.* 2003) provide a means of indexing CO_2 and NH_3 production. Others approaches to assessing stability include measuring water soluble C (García-Gomez *et al.*, (2005) and dissolved organic C (Zmora-Nahum *et al.* 2005) in compost. Alternatively, quantifying of the slowly- or nondegradable constituents including humic and fulvic acids (Adani *et al.* 1999; Bernal *et al.* 1998; Francou *et al.* 2005; García-Gómez *et al.* 2005), humification (Adani *et al.* 1999), and fiber or lignin (Griffin *et al.* 2005; Griffin and Hutchinson 2007) provide information about compost constituents that contribute directly to stabile SOM.

The research reported here evaluates the predictive relationship between compost age and individual compost stability parameters. These parameters included several common compost quality measures (C, N, microbial respiration), as well as two other measures: neutral detergent fiber (NDF) and lignin content. The latter two were included because Griffin *et al.* (2005) and Griffin and Hutchinson (2007) demonstrated that both NDF and lignin were predictors of N mineralization or im-

mobilization from raw and composted dairy manures. The relationships among these compost stability measures were also evaluated to determine which analyses were most closely associated with widely accepted measures of stability like microbial respiration

Materials and Methods

A single compost windrow at a commercial composting site in Thorndike, Maine, was sampled 13 times over a 91 d period. The sampling of a single windrow over time minimized the heterogeneity that can occur because of variation in feedstock inputs and proportions, and pile management. Sampling began 18 d after windrow formation. Prior to sampling, the temperature in the windrow fluctuated between 54 and 77°C for 15 consecutive days, during which the windrow was turned five times. Feedstocks included fish processing residuals, heifer manure, waste silage, wood shavings and sea urchin processing residual, at volume ratios of approximately 1:3:1:2: 0.5. The material was mixed with a tractor-mounted front-end loader, and formed into a single windrow measuring 2.5 m high x 7 m wide x 39 m long.

Windrow temperatures were monitored approximately weekly for 109 d at depths of 30 cm and 90 cm. Each temperature measurement is an average of six temperature readings taken at three equally spaced locations along both sides of pile. Temperatures were taken using probe thermometers. The windrow was actively composting (thermophilic stage; temperature at 30 cm depth > 40°C) during the entire 109 d monitoring and collection period (Figure 1). The windrow was turned using a tractor-mounted front-end loader when internal and external pile temperatures differences where less than 20°C

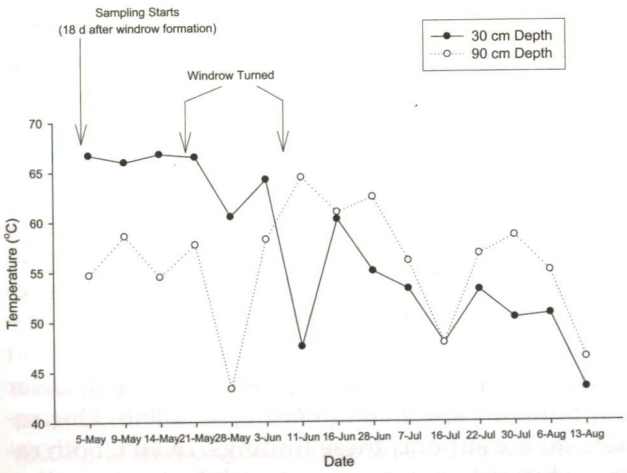

FIGURE 1. Compost windrow temperatures at depths of 30 cm and 90 cm.

Composite samples of compost were collected approximately weekly between 18 and 109 d after the pile was established. Subsamples were collected at three locations on each side of the windrow, from the 30–90 cm layer. These six subsamples were composited, mixed well and a 4 L sample was retained. All compost samples were stored frozen (-20°C) for subsequent analysis. There were a total of thirteen samples.

Characterization of compost samples included both chemical and biological parameters. All analyses were done in triplicate, and included sample blanks where appropriate. Total solids (TS) were estimated by drying 200 g at 70°C for 48 hr. This sample was ground (2 mm) and total volatile solids (TVS) was estimated by combustion of a 1 g subsample at 550°C for 6 hr. Organic N concentration was estimated as the difference between total Kjeldahl N (Kane 1998) and NH_4 concentration determined by distillation of NH_4 with MgO (AOAC Method 973.49). Neutral detergent fiber (Mertens 2002) concentration of a dried and ground subsamples was estimated by agitating a 1.0 g sample in an individual pre-weighed Dacron bag, using an automated Ankom 200 Fiber Analyzer (ANKOM Technology, Fairport, New York), rinsing three times, and drying to constant weight. Lignin concentration was estimated by digesting the NDF residue in 12 *M* H_2SO_4, following Robertson and Van Soest (1981). Total C concentration in the compost was determined by thermal conductivity detection following combustion at 1650°C, on a CE Instruments NA2500 Elemental Analyzer (ThermaQuest Italia S.p.A., Rodano, Italy). Compost stability was assessed using the Solvita Maturity Index (Woods End Lab, Mt. Vernon, Maine), which qualitatively assesses CO_2 and NH_3 evolution from compost by color changes in paddles, which are enclosed with a 25 g sample for a 4 hr period. Compost stability was also assessed by measuring CO_2 evolution from the same 25 g sample during 24 hr incubation in a sealed 1 L glass jar (immediately after ending Solvita test). A 1 *M* NaOH trap was used to capture CO_2. The trap was terminated with 5 mL of 1.5 *M* $BaCl_2$, was and then titrated with standardized 1 *M* HCl (Zibilske 1994). Compost samples were left at room temperature for 5 d prior to conducting these biological assessments.

Our first objective was to evaluate the predictive relationship between the compost age and each compost stability parameter. Simple linear regression was used in most cases, with a linear relationship being preferable to either curvilinear or nonlinear relationships. Using compost total N concentration as an example, these relationships were of the form

$$\text{Compost N concentration (\%)} = A + b^{*}\text{days} \quad (1)$$

where A is the intercept and b is the slope. Equations were fit using mean values of triplicate analyses, and parameters were estimated using the linear regression module of SYSTAT, Version 10.0 (SPSS Corp., Chicago Illinois). The strength of the relationship was evaluated using the coefficient of determination (r^2) for the regression equation. The relationship *between* compost characteristics was evaluated using simple linear correlation.

Results and Discussion

Relationship Between Compost Age And Compost Stability Characteristics

Organic constituents in compost are degraded during the composting process, resulting in a relative increase in the size of the mineral pool. The compost characteristics examined here have, in the past, been reported on a both a TS and TVS basis (Brewer and Sullivan 2003; Changa *et al.* 2003; Dell'Abate *et al.* 1998; García-Gómez *et al.* 2005). We estimated each compost stability parameter on both TS and TVS bases, and correlated each to compost age. The correlations between compost age and stability characteristics were consistently stronger when estimated on a TVS basis (Table 1). For example, the correlation between NDF and compost age increased from 0.62 to 0.89 (significant at 0.05 and 0.001, respectively). For this reason, all subsequent results are based on a TVS basis.

TABLE 1.
Relationship between compost ageing period and compost stability parameters on total solids (TS) basis and total volatile solids (TVS) basis, using Pearson correlation coefficient.

Maturity Parameter	TS Basis	TVS Basis
	r	
Total volatile solids (TVS)	-0.727**	—
TVS/Total solids	-0.917***	—
C:N ratio	-0.347	0.707**
C:Organic N ratio	0.058	0.648**
Neutral detergent fiber (NDF)	0.623*	0.892***
Lignin	0.696**	0.850***
Compost CO_2 evolution	-0.911***	-0.891***
Solvita maturity index	0.768**	0.768**

*, **, *** are significant at 0.05, 0.01, and 0.001 level of probability, respectively. n = 13.

Loss of organic matter and transformation of constituents into their mineral forms is expected during the composting process and accounts for most of the cited changes in nutrient content. This OM loss in our samples is shown in Figure 2; as the compost ages, TVS decreased linearly, with $r^2 = 0.53$, similar to the

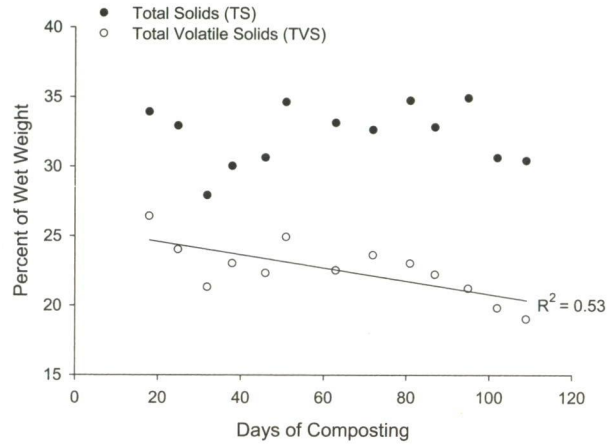

FIGURE 2. Relationship between compost age and total solids and total volatile solids.

findings of Changa *et al.* (2003) for composted dairy manure, Dell-Abate *et al.* (1998) for a range of compost types, and Tomati *et al.* (2000). The TS content (e.g., the dry matter content) was relatively constant as the compost aged.

Total nutrient concentration is reported on most standard compost analyses, including N, P, K, and also C. However, C and N subpools which are differentially degradable are not reported. The concentration of C and N in the remaining organic matter of our samples changed very little during the 91 day sampling period (Figure 3a, 3b). Neither constituent was significantly related to the compost age (*i.e.* the slope of the relationship was not significantly different from zero, thus no best-fit line is included). Previous reports of declining compost C concentration (Brewer and Sullivan 2003; Changa *et al.* 2003; Eggen and Vethe 2001) were typically estimated as a proportion of TS or dry matter, rather than concentration within compost organic matter.

We estimated both total C: total N ratio and total C: organic N ratio, the latter included because some composts early in the collection period had significant NH_4 concentration. Although widely discussed as indicators of compost stability, neither ratio was strongly related to compost age. Brewer and Sullivan (2003) also reported that the relationship between C:N and various compost stability characteristics was weak. As in our paper, they presented their results on a TVS basis. Previous reports have indicated that compost C:N ratio decreased during active composting and subsequent curing, stabilizing in the range of 10-15:1 (Brewer and Sullivan 2003; Ouatmane *et al.* 2000). Our results do not support these findings. In fact, both ratios exhibited an increasing trend during sampling and both were relatively high during the entire

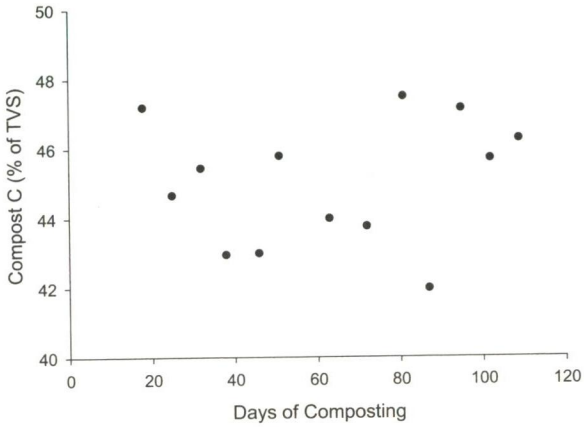

FIGURE 3A. Relationship between compost age and compost carbon (C) concentration as a proportion of total volatile solids.

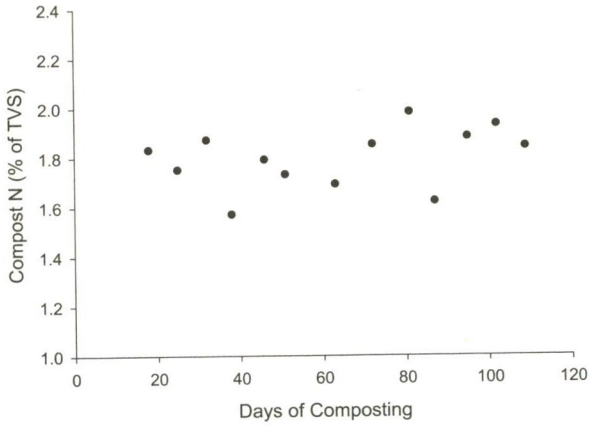

FIGURE 3B. Relationship between compost age and compost nitrogen (N) concentration as a proportion of total volatile solids.

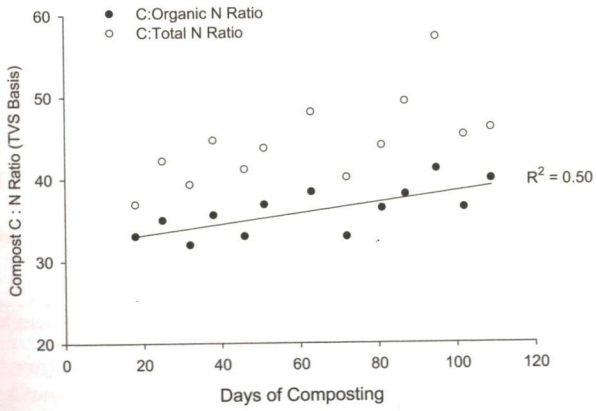

FIGURE 3C. Relationship between compost age and compost C:N ratio based on total volatile solids.

sampling period (Figure 3c). A key difference between our results and those of Brewer and Sullivan (2003), is that our sampling was initiated after the initial thermophilic stage, a period when rapid changes would be expected.

Compost fiber analysis has not been widely used to characterize compost stability. Neutral detergent fiber and lignin concentration characterize the compost by quantifying the degradation of C in the feedstocks during the composting process. Microbes preferentially utilize readily degradable C during composting, and NDF and lignin would likely represent slowly-and nondegradable C pools, respectively. Both NDF and lignin concentration increased with the compost age (Figure 4), indicating that as the compost matured, a greater portion of the remaining OM was recalcitrant C. As pointed out by Adani *et al.* (1999), recalcitrant or humified compounds are not being formed during the compost process. Rather, they represent a greater portion of what remains as microbes utilize more degradable substrates for growth; both Dell'Abate *et al.* (1998) and Tomati *et al.* (2000) demonstrated that humic and fulvic acid concentration in compost OM increased as the composting process progressed. This suggests that NDF and lignin (or other recalcitrant constituents) would not be influenced by relatively transient changes in the windrow or compost pile conditions.

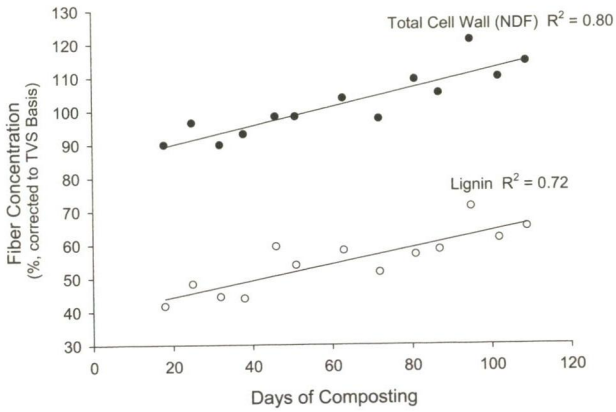

FIGURE 4. Relationship between compost age and fiber concentrations (total cell wall, NDF, and lignin). Corrected to a total volatile solids basis.

The continued microbial degradation in the compost windrow would be expected to slow as the concentration of recalcitrant C increases. In our samples, a strong (negative) linear relationship between CO_2 evolution and compost age ($r^2 = 0.85$; Figure 5) indicates that C mineralization slowed substantially during the sampling period. In evaluating a variety of compost material, Brewer and Sullivan (2003) proposed that respiration rates of less than approximately 2 g CO_2-C kg^{-1} compost C d^{-1}, would be considered stable compost. This is in close agreement with the evaluation of composted manures by Wang et.al (2004); they found that compost with respiration rates

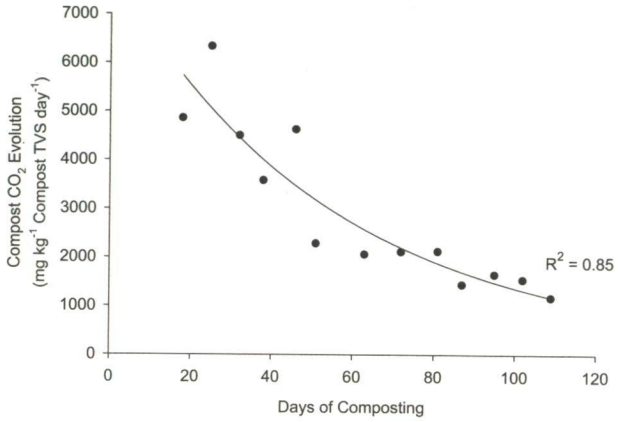

FIGURE 5. Relationship between compost age and CO_2 evolution.

less than 1 g CO_2-C kg^{-1} compost dry weight d^{-1}, (equivalent to approximately 2.2 g CO_2-C kg^{-1} compost C d^{-1}) were not phytotoxic to seedlings and would be considered stable. As shown in Figure 5, respiration rates from our samples were 10-12 mg g CO_2-C kg^{-1} compost C d^{-1}, early in our collection period, but stabilized at the threshold value of 2 g CO_2-C kg^{-1} compost C d^{-1} by the end of the collection period.

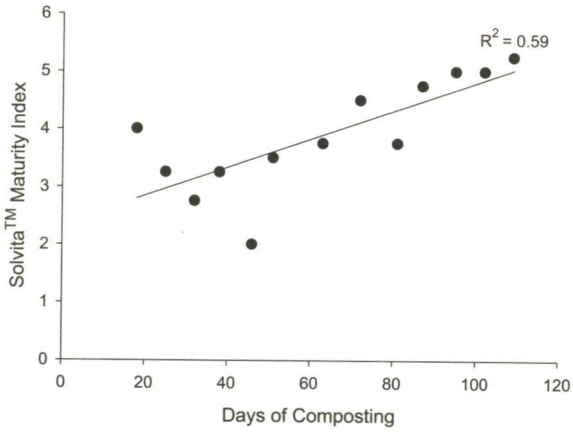

FIGURE 6. Relationship between compost age and Solvita™ Maturity Index.

The commercially available Solvita Maturity Index includes an evaluation of respiration and ammonia production. The overall Solvita Maturity Index showed a positive linear relationship with compost age (r^2 =0.59; Figure 6); this relationship is much stronger than either Solvita CO_2 or Solvita NH_3 alone (data not shown). The relationship indicates that CO_2 evolution and NH_3 production decreased over the sampling period. Changa et al (2003) conducted an extensive evaluation of the Solvita Maturity Index on three different composts as they matured, and found that it was strongly correlated with compost CO_2 evolution and compost age, within and across compost types.

Relationships Between Compost Characteristics

In addition to the relationships between compost age and compost stability characteristics, inter-relationships *between* compost characteristics should be consistent with the biological respiration of composting. Certain characteristics that do not change substantially during composting, like compost C and N concentrations, also have little relationship with other compost parameters (Table 2), or with mineralization in soil (Griffin and Hutchinson 2007). The two constituent ratios that we calculated (C:N and C:organic N) are weakly related to compost age but exhibit surprisingly strong (P = 0.01) correlations with recalcitrant fiber (NDF and lignin). Likewise, compost CO_2 evolution or Solvita Maturity Index showed moderate to nonsignificant relationships with C:N or C: organic N. The fiber constituents are strongly related to each other (Table 2, and Figure 4), and to compost CO_2 evolution. The relationship of NDF to the Solvita Maturity Index was very strong (p<0.01), but the relationship with lignin was not. This may be due to the conceptual difference between these two approaches; the Solvita assesses soluble, readily-available C and N pools, which are influenced by both compost age and compost pile conditions. The

TABLE 2.
Pairwise correlation matrix between compost stability parameters, using Pearson correlation coefficients (r).

	Days	Total C	Total N	C:N	C:Organic N	NDF	Lignin	CO_2 Evolution	Solvita MI
					r				
Days	1.000								
Total C	0.138	1.000							
Total N	0.325	0.747**	1.000						
C:N	0.707**	0.194	-0.082	1.000					
C:Organic N	0.649*	0.028	-0.111	0.898***	1.000				
NDF	0.892***	0.325	0.353	0.853***	0.817***	1.000			
Lignin	0.850***	0.152	0.282	0.768**	0.777**	0.939***	1.000		
CO2 Evolution	-0.906***	-0.111	-0.176	-0.690**	-0.617*	-0.758**	-0.740**	1.000	
Solvita MI	0.768**	0.289	0.229	0.648*	0.517	0.681**	0.521	-0.712**	1.000

*, **, *** are significant at 0.05, 0.01, and 0.001 level of probability, respectively. n=13.

fiber fractions estimate the recalcitrant, very slowly-degradable C pools and are less sensitive to transient changes in compost pile conditions.

Conclusion

Our results support numerous earlier reports indicating that elemental C and N concentration and C:N ratios are not robustly related to compost stability, or to other compost characteristics. Few research projects have used fiber concentration (NDF or lignin) as a compost characteristic. Both of these parameters were successful at characterizing compost stability. These parameters measure the availability of the remaining C substrate for microbes in the compost windrow, and are thus strongly related to parameters that quantify the by-products of the composting process, like CO_2 evolution. Additionally, because these fiber pools are not directly influenced by environmental conditions, they are appropriate tools to assess compost stability.

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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.

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