Compost Science & Utilization

ISSN: 1065-657X (Print) 2326-2397 (Online) Journal homepage: http://www.tandfonline.com/loi/ucsu20

Compost Sampling for Nutrient and Quality Parameters: Variability of Sampler, Timing and Pile Depth

William F Brinton, Jean Bonhotal & Tom Fiesinger

To cite this article: William F Brinton, Jean Bonhotal & Tom Fiesinger (2012) Compost Sampling for Nutrient and Quality Parameters: Variability of Sampler, Timing and Pile Depth, Compost Science & Utilization, 20:3, 141-149, DOI: 10.1080/1065657X.2012.10737039

To link to this article: http://dx.doi.org/10.1080/1065657X.2012.10737039

Compost Science & Utilization, (2012), Vol. 20, No. 3, 141-149

Compost Sampling for Nutrient and Quality Parameters: Variability of Sampler, Timing and Pile Depth

William F Brinton*[1], Jean Bonhotal[2] and Tom Fiesinger[3]

1. Woods End Laboratories, Inc., Mount Vernon, Maine

2. Cornell Waste Management Institute, Ithaca, New York

3. New York State Energy Research and Development Authority, Albany, New York

**Email contact: will.brinton@woodsend.org*

In order to establish analysis-based quality guidelines for composts, it is necessary to have information about the variability of these traits as dependent on sampling methods. Composts exhibit significant spatial, site and time-related variability. In a preliminary survey of commercial and home users of compost in New York State, respondents indicated strong interest in test quality of purchased composts. However, little work has been done examining the consistency of reported values in composts sampled and shipped to laboratories. We evaluated within-farm and between-sampler variability of test traits at 7 farm compost sites. In one study we compared farmer and extension agents as separate samplers of the same compost piles. In the next study we examined repeated sampling by same sampler visiting the site a second time. Finally, we compared depth-based sampling variability at 3 selected farm compost sites. Analysis of variance was employed to distinguish effects of samplers, sampling timing and farms. The data showed very small differences in test values due to samplers for all parameters except weed seed and fecal coliforms. Geometric mean transformation eliminated fecal counts as a source of significant variability. Repeated sampling after two weeks of matured compost indicated no appreciable differences between points of time except for weed seeds. The sampling-depth study revealed significant variation of several selected test parameters attributed to pile stratification, and the variables most affected were moisture, potassium and weed seeds. Weed seed testing may not be useful for a quality parameter unless methodological variance is better understood. Overall, biological parameters varied less than chemical traits. The study underscores that prior to establishing numerical quality guidelines the preferred compost pile sampling protocol should be very carefully described.

Introduction

There is increased interest in compost products by commercial growers and the general public and with this the need to adopt controlled labeling standards (Fiesinger *et al.* 2001). Establishing test standards requires sources of variability to be understood at two primary levels; on-site sampling and processing in the laboratory. Both manure (MAP) and compost (CAP) testing proficiency programs are available in the USA (Peters 2003; Miller and Kotuby-Amacher (2001). However, these programs eliminate variability at the source in order to test inter-laboratory variability. There are few if any studies we know of examining sources of variation from on-farm compost sampling prior to laboratory testing.

Farm compost piles are of irregular size and shape and composition and manifest several forms of variability in dependence on management specific parameters (NRCS 2000). Therefore sampling procedures to obtain representative samples need to be able to adequately control intrinsic nonhomogeneity. Even from farms of fixed animal populations, this variability has been observed. Changing ingredients to composts reflected by seasonal drift related to feeding and pasturing patterns, influence composition over time of manures in regard to moisture and nutrient content. Management of compost by piling, turning, and aerating are subsequent factors that may impose structural alterations that improve or decrease homogeneity. These circumstances impose uncertainties for sampling farm composts for laboratory testing, and translate into variability and potential unreliability of information reported from test traits. Before official state-based guidelines are constructed governing parameters to report for composts, these aspects of variability and reliability of data should be better quantified.

In a Pennsylvania study, Dou *et al.* (2001) examine variability among animal farms with regard to manure composition. Sample variability within farms, expressed as the coefficient of variation (CV), was mostly 6 to 8% for farms that used agitation in

manure storage but much higher (20-30%) on farms where no agitation was applied during the sampling period. This may be analogous to farm composting as in the practice of turning contrasted to static pile methods which involve no turning. Lindley et al (1988) discuss the significant effects handling and storage systems impose on tested manure values. A range of site-specific and temporal aspects determine the need for more or less samples to obtain reliable data. Peters (2000) discussed sampling technique for manures to reduce variability. In a national survey in Germany, Kreft (1998) drew attention to variability of compost samples imposed by on-site conditions. Butler *et al.* (2001) examined variability of test traits of biosolids compost as a function of age and storage in the lab, and found that most but not all test traits continue to change slowly over time and also during lab storage prior to testing. In a study of manure and compost composition for the state of North-Rhine Westfalen in Germany, variability of analytical traits was categorized and was attributed to regional differences in industry and farming practices (NRW 1999). These findings suggest that imposing uniform quality standards across states (or countries) would have to account for intrinsic sources of variation that affect chosen test parameters. In North America, localized forces in determining soil makeup play a principal role in dictating selection of soil test methods by region (Havlin and Jacobsen 1994).

Composts are generally perceived to be of the same entity, and, like manure, are mostly distinguished, if at all, in classes according to source ingredient (biosolids, leaf and yard waste, manure). In European composting, where source-separated green waste is the primary form of composting, 9 technology categories are used to distinguish how individual composts are evaluated for pathogen related hygiene (Kehres and Hackenberg 2001).

While compost may be similar to manure in some respects, fluctuations of input source materials and variable technology employed during on-farm composting very likely differentiate composts over that of classes of stockpiled manures. Woodbury and Breslin (1992) concluded from studying MSW compost variability that a large number of random samples would need to be collected from a batch of compost in order to accurately assess metal content. Seekins *et al.* (1995) examined paired compost samples from 39 farms using widely varying methods and ingredients for composting. They reported significant analytical differences attributable to age of sample and compost technology. We are not aware of any study that examines specifically on-farm compost sampling within the same class of farms and manure types, nor are we aware of any study that compares types of samplers in that setting.

The objectives in this study were threefold: 1) to distinguish if when provided suitable information farmer composters would sample compost at the same efficiency as trained State Extension samplers; 2) to determine if repeating sampling of the same material after a short interval of time caused significant differences, and 3) considering the spatial configuration of piles, to determine if sampling at differing depths appreciably influenced test traits.

Materials and Methods

A compost-sampling plan was drawn up to which all samplers would adhere based on the publication on sampling from Woods End Laboratories (2000), incorporated in a national guideline (TMECC 2002). The basic sampling model was that for each replicate a minimum of 3 grab samples are taken each at three depths cut laterally into the compost pile at each of 3 to 4 locations repeated down the length of the compost pile. Cuts into the pile by means of a bucket loader were used with large piles not easily accessed with a spading shovel. The entire sampling process was composited into single samples for each replicate (Woods End 2000). To assure that composts were reasonably completed and mature for all comparisons, farmer-composters were instructed to provide access only to composts that were ready to sell.

Farm Study and Repeated-Sample Study

To compare samplers and time of sampling, we selected 7 dairy farms which have similar animal populations (dairy/beef) and established composting operations. The composting technology would be classed windrow or bucket-turned. In the first event, two groups of paired samples were each separately taken by the farmer and by trained NY State Extension personnel. Farmers were provided 1-page written instructions on how to make representative samples. To minimize time-related effects, the two groups of samplers coordinated access to piles within a few days of each other for each site. To conduct a repeated sampling study, one each of these sample events was considered the first visit, and the same Extension sampler returned after a lapse of 2 weeks and re-sampled the same pile. The same 7 farms and same compost batches were used for this study. The time interval of 2-3 weeks was selected for the repeated sampling to minimize biological confounding such as due to the natural progression of compost aging (Butler 2001) but long enough to minimize sampler bias when returning to the site and possibly sampling at the same specific locations.

Sampling-Depth Study

We selected 3 farms that employed bucket-turned pile methods of similar manure composition and which were not a sub-group of the previous 7 farms. For each of these farms, three sample locations were established independent of overall pile size as follows: "Core" (30 cm above the pile center bottom); "Edge" (30 cm from outside); and "Middle" (half-way between the outer and the core locations) and 5 grabs taken from each and the process repeated for each zone. The core, edge, and middle were variables used in later ANOVA tests. The same sampler took all samples for all three sites within a period of several days.

Packing, Shipping and Analysis

All compost samples were randomly coded (single-blind study) and packed in cooler containers with prefrozen ice-packs and shipped to the lab within 24 hour. The samples were prepared by sieving at 10mm and discarding the overs, and subsequently analyzed in duplicate, and decoded as to sample type after test results were available. Analyses were conducted according to published procedures as follows: TS, pH, EC, TN, NH_4, NO_3, P, K, Ca, Cu, Mg taken from MAP guidelines (Peters 2003); *Lepidium sativa* (cress) biomass test and weed seed content from the Compost Test Methods Manual (Kehres and Pohle 1998). Analyses for fecal coliforms and volatile organic acids (modified with HPLC for detection) were derived from Standard Methods (APHA 1995). Solvita® volumetric gas emission testing was conducted according to prevailing manufacturer instructions (Solvita 2008). For on-site compost sampling procedures we modified instructions based on TMECC (2002). All data was reported on a total solids (TS) dry weight unless otherwise noted as fresh basis (FW).

Results

Sampler Study

Table 1 presents results comparing test results where the variable was compost samplers.

These data show small numerical differences in test traits of samples taken of the same piles across all farms when comparing 2 different samplers (a) vs. (b) sampling at about the same time. This result alone indicated the same person taking a second set of sam-

TABLE 1.
Sample means, differences and standard deviation of extension vs. farmer sampling of 7 farm composts

	(a) Extension Sampler (ES)	(b) Farmer Sampler (FS)	(c) Difference (FS – ES)	(d) Difference As % Of Mean	(e) Standard Deviation Extension Sampler	(f) Standard Deviation Farmer Sampler
Moisture	37.4	38.1	0.7	1.9%	8.8	8.7
pH	7.70	7.58	-0.12	1.6%	0.6	0.6
Organic content	45.8	45.9	-0.10	0.2%	17.2	16.9
Conductivity	3.2	3.3	0.07	2.2%	1.8	2.1
C:N ratio	15.2	14.6	-0.61	4.1%	4.7	3.3
Seed germination	96.6	95.6	-0.97	1.0%	10.0	7.7
Growth rate	93.0	91.3	-1.73	1.9%	9.7	9.1
Maturity index	6.6	6.4	-0.17	2.6%	0.8	0.8
CO_2 Solvita	6.6	6.5	-0.10	1.6%	0.8	0.8
NH_3 Solvita	4.9	4.8	-0.13	2.6%	0.3	0.6
Fecal coliform	425	103	-321	121.8%	925	187
Weed seeds	10	16	6	45.2%	24	38
Total-N	1.74	1.78	0.04	2.0%	0.8	0.8
Phosphorus	0.34	0.35	0.01	2.8%	0.2	0.2
Potassium	0.77	0.69	-0.08	10.3%	0.5	0.5
Copper	317	285	-33	10.9%	287	272
Zinc	193	196	4	1.9%	80	88
Iron	6154	6858	704	10.8%	4547	4419
Manganese	471	509	38	7.8%	238	231

‡ Notes to table: FW is Fresh Weight (as-is), TS is total-solids (dry) basis reporting; Units are as follows: Moisture % FW; pH sat. paste; Organic content % TS; Conductivity as dS cm-1 FW; Seed Germination is % of total; Growth Rate *Lepidium sativa* biomass as % of commercial Fafard Germination mix; Maturity Index is intercept value of CO_2 respiration and NH_3 emissions by volumetric 100cc Solvita test; F. coliform MPN g^{-1}; Weed Seeds count per liter; total-N, Phosphorus, Potassium as % of TS; Copper, Zinc, Iron, Manganese as mg kg^{-1} TS.

ples imposed as much variability as a second sampler visiting the same pile. Only two test traits show differences of more than 11% between the samplers. The coefficient of variation (CV), which is the standard deviation divided into the mean, was for most traits within an acceptable range.

The standard deviations of duplicate test results for each sampler group (e) vs. (f) which represents the variability across the farms for that test trait and sampler were much larger than the differences between samplers for same-pile sampling. The magnitude of the deviations (e) vs. (f) (Table 1) was very consistent between samplers (e) vs. (f). These findings indicate that compost variability between the farms for the same traits is about 5-times greater than same-pile sampler variability ($y = 4.9x + 0.18^{***}$ where y = between farm variability and x = same compost pile variability) . This observation is most likely realistic as it would be very unusual to see very low variability of test traits in composts from different farms even though comprised of similar manure types.

Of the two test traits that stood out, farmer-sampled composts gave appreciably higher weed seed counts in the lab tests than did extension-sampled composts. Extension sampled composts gave appreciably higher fecal coliform results than farmer-sampler. The fecal coliform differences were not statistically significant at all comparisons while the interaction effect *farms x sampler* were highly significant for weed count ($p \leq 0.009$). Following review with all personnel it was felt that the most likely explanation for these differences was that extension samplers were taking samples more diligently from deeper layers (less weeds, more fecal coliform). Overall, the standard deviation for test results from extension versus farmer samplers were highly correlated ($r=0.987$, $p< 0.001$) indicating the two groups of data from different samplers represents the same population.

The coefficient of variation (CV) for these 19 analytes averaged by farm for all farms ranged from 2 to 115%. Within this same set, the CV of mineral and metal traits ranged from 3 to 22%. Test data results in dependence on samplers did not differ by more than 10.9% for all 7 farms, excluding the fecal data. Thus, while most sources of variability fell within an expected range of < 20%, fecal and weed seeds test variability, both very important traits, fell outside normally accepted ranges.

The weed seed test employed for this study was under development at the time of the sampling (Kehres and Pohle 1998). This test protocol has been subjected to round-robin lab trials recently in Europe. A study in Germany with 33 participating labs showed a standard deviation for green waste composts of between 20 and 30.2% for the weed seed protocol, or slightly less than our results (Lanuv 2008). In such round-robin tests, however, weed seeds are placed in pre-homogenized samples, whereas we are comparing raw field samples of unknown composition. A deficiency in these statistics from the point of view of field samplers is that compost test validation studies performed in the USA and Europe (Peters 2003, Miller and Kutuby-Amacher 2001, Lanuv 2008) use pre-homogenized materials, and thus effectively factor-out field variability, which may be as large if not larger than inter-laboratory variance.

Fecal coliform testing is performed by serial dilution techniques to accommodate the potentially very large range expected for bacteria counts. Such data are typically subject of order-of-magnitude variation and a single aberrant high or low value may throw off the arithmetic mean considerably. Thus, averaging is not necessarily the best approach to characterize or perform statistics for bacteria count. An alternative is to employ geometric mean transformation such as EPA recommends for daily sampling of wastewater facilities (minimum 5 samples). For example, the geometric mean transformation of our fecal data shows the two groups at 19 and 13 MPN g^{-1}, respectively, for extension and farmer samplers. These are relatively low counts and the difference is of very small magnitude and is also not significant. Brinton *et al.* (2009) in a survey of west coast green waste compost facilities found fecal coliform counts in finished composts varied from log MPN 0.5 to 7.5 (< 10 MPN g^{-1} to > 3 x 10^7 MPN g^{-1}) with a mean of log 5.7 (5.1 x 10^5 MPN g^{-1}). Thus, comparatively, the fecal bacteria count in these NY State farm manure composts is very low and also of low variance. We know of no efforts in the USA to determine if geometric mean handling of compost bacteria data would be appropriate, but single grab results are essentially unreliable. Recent European Community analytic standards for *Enterobacteriaceae* in composts require 5 sub-samples tested and 2 out of 5 results may exceed the allowed norm unless any single value exceeds the ceiling value (EC 2002).

Our data showed consistently high copper averages in the sampled manure composts, but actual copper concentrations varied significantly across farm compost sites. The relatively high copper concentration in these composts was found to be dependent on the practice of hoof-copper dips, not used on all farms. Variance of copper test result between samplers and between time of sampling was relatively low indicating both groups and times accurately reflected the same large range in copper values.

Repeat-Sampling Study

Table 2 presents results of comparing same-batches of compost where the variable is sampling date (a 2-3 week interval), using the same sampler (Extension). Taking the difference between the two sampling times and comparing to the difference between the two sampler types (Table 1) shows the two highly correlated ($r = 0.87$ $p < 0.001$). This means that we cannot statistically distinguish differences between sampler groups and differing times of sampling. The similarity of trends is also seen in comparing standard deviations (SD) by trait. For the first project (Table 1) the SD's of extension sampler and farmer sampler correlate highly ($r = 0.99$ $p < 0.001$). Similarly, if we take the SD from the first sampling (extension sampler) and compare to the SD's from the next study (Table 2, week 3 interval), they are highly correlated ($r = 0.961$ $p < 0.001$). Variability of test parameters as rSD increased from lowest to the highest in the following order:seed germination (rSD =0.08) < pH (0.10) < Maturity (0.12) < Growth Rate (0.15) < CN (0.19) < Moisture (0.24) < Organic Matter (0.32) < total-N (0.35) < Minerals [Mn, P, Zn, K, Fe] (0.64) < Conductivity (0.69) < Cu (0.86) < fecal count (1.7) and lastly weed-seed count (2.0). These data suggest that should a set of such farm manure composts be selected for quality standards, the numerical reporting limits accepted for any category of quality should take into account normal variation, if confirmed by inter-laboratory trials. For these data, biological parameters including plant tests and maturity were all very reliably reported at less than 15% variance. A mid-group of variability of 20-25% was observed for primary physical parameters OM and moisture content and also for chemical parameters C:N, and Total-N. A moderate to highly variable group (50-80% variability) comprised minerals and electrical conductivity, and a very highly variable single item was copper (86%- due to variable use on farms of copper biocides, as noted). An extremely variable group was observed to be fecal count and weed seed content. If, however, fecal counts are transposed as log10 values, then this group declines to a status of low variability and therefore only weed seed counts appear to have a relative mean variance greater than 1.0 (100% variance).

The mean relative deviation for both studies correlated highly ($r^2 = 0.898$, $p < 0.001$) (Figure 1). This indicates that variability of test traits is very consistent within the category of test trait examined. This observation strongly suggests that compost test traits could be arranged from least to most variable which would assist interpretation where standards may be proposed.

TABLE 2.
Sample means, differences and standard deviation for sampling similar compost at differing time spans for 7 farms

Trait†	Week 1 (n=14)	Week 3 (n=14)	Difference Week 1-Week 3	Difference as % of Mean	Std Dev Week 1	Std Dev Week 3
Moisture	36.7	36.4	-0.4	1.0%	8.5	9.2
pH 1:2	7.7	7.72	0.02	0.3%	0.7	1.1
Organic content	56.93	51.23	-5.7	10.5%	12.1	16.9
Conductivity	3	3.8	0.8	22.0%	2.6	2.6
C:N ratio	12.9	11.9	-1	8.0%	1.3	1.4
Germination	96.5	94	-2.5	2.6%	8.1	5.8
Growth rate	80.5	80	-0.5	0.6%	15.3	15.1
Maturity	6.3	6.5	0.3	3.9%	1	0.6
CO_2 Solvita	6.3	6.5	0.3	3.9%	1	0.6
NH_3 Solvita	5	5	0	0.0%	0	0
Fecal coliform	176	9	-167	181%	349	9
Weed seeds	5	61	57	171%	10	111
Total-N	2.38	2.29	-0.09	3.8%	0.5	0.6
Phosphorus	0.43	0.42	-0.01	1.9%	0.2	0.2
Potassium	0.76	0.8	0.05	5.9%	0.6	0.7
Copper	525	506	-19	3.7%	430	394
Zinc	229	745	515	106%	91	977
Iron	5285	5687	402	7.0%	4377	4981
Manganese	494	584	90	17.0%	221	287

† for key to units of traits, see Table1.

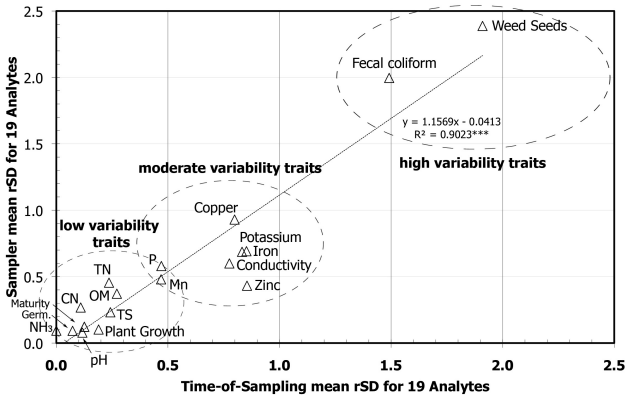

FIGURE 1. Correlation of mean relative standard deviations by test traits for Samplers versus Time-of-Sampling (1 = 100% SD)

Depth-of-Sampling

In an attempt to better understand the sources of within farm variability, we examined 3 farm compost piles individually by varying depth of sampling within the pile. A replicated trial of 3 types of samplings (edge, middle and core) was undertaken and the results are shown in Table 3 with the statistical significance for difference of traits shown for each.

TABLE 3.
Test traits in dependence
of sampling location within the compost pile

Trait	Edge (n=9)	Mid (n=9)	Core (n=9)	Sign. (‡)
Moisture	52.03	67.1	67.27	***Δ
pH	7.32	8.0	8.37	**Δ
Organic matter	44.3	47.8	46.45	nsΔ
Total-N	1.86	1.53	1.63	*
C:N ratio	13.4	17.67	16.5	**
Nitrate-N	190	390	118	ns
Nitrite-N	1	2	11	*
VOA	323	655	602	ns
Density	0.77	0.84	0.93	nsΔ
Conductivity	1.93	4.13	5.23	**Δ
Germination	96	99	102	ns
Plant weight	99	82	78	*Δ
Solvita CO_2	6	6	7	ns
Solvita NH_3	5	5	4	nsΔ
Weed count	4	1	1	*
Fecal coliform	131	28	1	ns
Copper	350	264	215	nsΔ
Zinc	392	363	373	ns
Iron	6,614	5,899	5,412	ns
Manganese	252	538	591	*Δ
Phosphorus	0.37	0.3	0.29	**Δ
Potassium	0.54	0.89	1.04	**

† for key to units of traits, see Table 1. Additional traits are: Nitrate and Nitrite as mg kg^{-1} TS; VOA is volatile organic acids mg kg^{-1} TS; density is g cc^{-1} FW; ‡ Significance based on ANOVA for depth effects: asterisks indicate probability where * is $p \leq 0.05$; ** is $p \leq 0.01$ and *** $p \leq 0.001$; Δ denotes significant interaction effect. ns= not significant $p > 0.05$

Several traits were significantly affected by location within the pile. In the data set, 11 out of 22 analytical variables examined showed statistically significant dependence on the variable of depth of sampling. Piles were significantly drier on the surface than mid and core samples. pH was significantly higher in the core. Nitrite (NO_2), a reduced form of N indicative of oxygen depletion, was significantly higher in the core than mid and edge, and organic acids increased with depth but not statistically significantly. Dairy manure composts are typically low in organic acids and high levels would be viewed as >5,000 ppm (Brinton 1998). Of most interest is the higher conductivity and potassium content in the core, indicative of diffusion downwards in the piles. Many of these differences are expected. For some, such as potassium, a farmer labeling a product for nutrients should be concerned about position in pile of samples.

It is apparent in this dataset that without controlling depth of sampling or accounting for stratification of piles obscured in the samples, basic traits like moisture, total-N, salts, density, weed count, and metals could not be established at CV's much under 30%. This potentially would translate into large variability of a bagging line, introducing nonhomogeneity across similar batches of bagged, distributed product.

Table 4 examines the coefficients of variance (standard deviation as percent of means) for each farm site for all samples per site for all projects (n=47). Highlighted data indicates a farm with one test parameter at the maximum variability for that test trait. These extreme samples are mostly randomly strewn across all farm sets with the possible exception of one farm (sample F) which had 7 out of 19 tests at maximum variability. This observation might be pursued in terms of what types of management does this particular farm have that impose greater variability when samples are taken for labs? The farm with the greatest variability for copper was also a farm using copper dips, which has apparently been expressed unevenly across the batches of compost sampled.

While these variance data overall are not of great concern (mean variance for all samples for all farms after removal of outliers is 37%) the range suggests that attention to sampling and testing method details when analyzing particular traits needs to be exercised. We have explained that if geometric means (averaging log10 transformation) of bacteria data were employed, our fecal coliform results would be eliminated from the list of extremely variable data. Weed seed data is highly variable but not enough is known about weed seed counts to fully evaluate the range in which we observe differences. To be considered weed-free unofficially, green waste compost in Germany must be less

TABLE 4.
Coefficient of variance (CV %) for test data by farm for 10 farm sites where 3 sites (b) also have bagged compost

Sites	F	F(b)	FF	FF(b)	FG	FG(b)	F-H	F-P	F-W	F-Wi
# Samples	6	4	6	4	4	4	4	4	5	6
Moisture	**25**	6	6	10	3	6	19	2	4	11
pH 1:2	2	2	2	2	1	0	3	2	**4**	3
Organic content	4	11	2	**14**	5	8	8	0	9	13
Conductivity	41	30	6	17	36	22	12	10	**47**	17
C:N ratio	10	15	5	4	11	**17**	**17**	8	6	**17**
Germination	**20**	7	2	1	5	3	19	3	6	3
Plant growth	13	9	15	3	7	**48**	14	5	11	13
CO_2 Solvita	**14**	0	13	9	0	9	10	0	0	7
NH_3 Solvita	0	0	**19**	0	11	0	0	0	0	0
F. coliform	**205**	40	159	130	122	158	69	122	203	35
Weed seeds	110	82	-	-	55	45	-	-	**224**	-
Total-N	10	9	5	14	11	11	**22**	8	3	17
P	5	5	6	11	6	19	**20**	7	6	10
K	**41**	15	11	16	19	15	10	4	18	9
Cu	8	9	6	29	20	11	**72**	7	4	26
Zn	7	2	11	4	3	3	20	3	4	**150**
Fe	**48**	14	6	15	15	5	16	8	9	5
Mn	**33.0**	16.0	5.0	2.0	7.0	7.0	15.0	4.0	9.0	12.0

Note: Bold data denote test trait of highest variability for that farm in that category

than 0.5 germinable weeds per liter (0.5 liter^{-1}). Less than 2 per liter (2 liter^{-1}) is considered "relatively weed-free" while > 2 liter^{-1} is viewed as "containing appreciable weeds" (Kehres and Polde 1998). Consensus on weed seed protocols has still not emerged in Europe despite recent lab round-robin trials, reportedly due to insufficient inter-laboratory data (Siebert and Amlinger 2011). In our first and second data set, the standard deviation of weed counts for all samples ranged from 24 to 111 liter^{-1} which suggests that the test method and or the compost, is inherently extremely variable, and therefore a lab test would not be able to distinguish weed seeds accurately at the standard level proposed in Europe. In the USA, among horticulturalists, any presence of a viable weed seed in compost used in container media is considered unacceptable (Mark Yelanich , *personal communication*, February 3, 2011). It is very likely that the primary source of weed seeds in the composts tested is surface contamination, since a significant correlation is observed to depth of sampling (Table 3). Compost piles when cut open with a shovel or bucket loader do not necessarily maintain the shape but tend to collapse inwards which may contaminate inner with outer material. It just happens that weed testing is particularly sensitive since contamination could be entirely exogenous.

In Table 5 a summary is given of the results of all the observations in terms of categories of most likely sources of test variance and is based on ranking of ANOVA results. FARM is the factor assigned to differences that were principally expressed statistically going from farm to farm (where manures and compost technology vary). DEPTH expresses the traits that are significantly impacted by depth of sampling. Interaction effects where farm and depth-of-sampling influenced the data are also indicated.

TABLE 5.
Relationship of test trait variability to compost samples

Analytical Trait Affected Mostly By FARM	Analytical Trait Affected Mostly By DEPTH	Analytical Trait With Interaction Effects Of Farm x Depth	Analytical Trait With No Apparent Relationship
Organic matter	Moisture content	Total-nitrogen	Fecal coliform
Total Nitrogen	pH	Nitrate	Manganese
C:N ratio	Weed content	Salt content	Cress germination
VOA	Potassium	Cress test	
Solvita CO_2	Phosphorus	Ammonia	
Copper		Zinc	
Iron		Density	

Conclusion

The data from this study provide strong evidence that any informed sampler should be able to make efficient, representative samples of compost for laboratory testing. Both the averages and the variances of analytical test traits were essentially the same for two groups of samples taken by either farmers or by extension agents over 7 farm compost operations. The study also reinforces a conclusion that repeated sampling of the same compost pile within a few weeks around the time of maturity is not likely to produce test results that differ significantly from each other. This most likely would not be the case if composts were in an early, hot stage and changes such as in total solids and volatile nitrogen were taking place more rapidly. We examined moderately matured samples by choosing only composts that the farmers considered ready for market and therefore we did not address fully the variable of compost age.

In a depth-of-sampling study, the findings revealed that the variable of depth alone exerted a very significant effect on resulting lab test data. Traits most affected by lateral position of sampling in the pile were: moisture, pH, weed seeds, phosphorus and potassium. This finding suggests that pile configuration may be the primary force in nonuniformity in submitted samples. For example, if a pile has been turned thoroughly just before sampling, the depth effect is likely to be absent for a period of time thereafter. We were not able to independently evaluate the factor of composting technology in this study, but a cited study (Seekins *et al.* 1995) found technology exerted a significant influence on measured compost traits.

Great variability of fecal coliform counts was observed in this study but was largely eliminated by using log10 transformation before performing statistics. This protocol should be routine when repeat testing is performed. Weed seed counts also varied enormously and ranged well beyond levels suggested in Europe to be acceptable for marketable composts (Kehres and Polde 1998). Weeds seeds may pose a unique challenge in lab test data since some or potentially all the measured content may be due to outside infestation.

These findings underscore that sampling of finished composts may be practiced by differing persons on differing dates and still achieve acceptable uniformity. However, failure to account for nonhomogeneity imposed by depth-in-pile sampling could be a source of significant variability. More effort to control pile structural variability when sampling for lab testing and setting compost standards would result in more reliable reporting to consumers.

References

American Public Health Association. 1995. Standard methods for the examination of water and wastewater (SM). 1995. American Public Health Association, Washington, DC.

Brinton, W. 1998. Volatile Organic Acids in Composts: Production and Odorant Aspects. *Compost Sci. Util.,* Vol. 3:75-82.

Brinton, W.F., Storms, P. and Blewett, C. 2009. Occurrence and levels of fecal indicators and pathogenic bacteria in market-ready recycled organic matter composts. *J. Food Protection,* 72:332-339.

Butler, T.A., Sikora, L., Steinhilber, P.M. and Douglass, L.W. 2001. Compost Age and Sample Storage Effects on Maturity Indicators of Biosolids Compost. *J. Environ. Qual.,* 30:2141–2148.

Dou, Z., Galligan, D.T., Allshouse, R.D., Toth, J.D., Ramberg Jr., C.F. and Ferguson, J.D. 2001. Manure Sampling for Nutrient Analysis: Variability and Sampling Efficacy. *J. Environ. Qual.*, 30:1432 1437.

EC. 2002. Regulation No. 1774/2002 of the European Parliament and of the Council laying down health rules concerning animal byproducts not intended for human consumption. Off. J. Eur. Commun. L 273. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32002R1774:EN:HTML (verified 10/19/11).

Fiesinger, T., Harrison, E. and Brinton, W.F. 2001. Compost Marketing and Labeling Project. New York State Energy Research and Development Authority. Albany NY. http://compost.css.cornell.edu/FinalReport.pdf (verified Oct 28 2011)

Havlin, J.L. and Jacobsen, J.S. (eds). 1994. Soil Testing: Prospects for Improving Nutrient Recommendations. *Soil Sci Soc Amer Publication*, 40, Madison, WI.

Kehres, B. and Pohle, J. 1998. [Methods Manual for Analysis of Composts] Methodenbuch zur Analyse von Kompost. Bundesgütegemeinschaft Kompost e.V. Köln www.kompost.de.

Kehres, B.S. and Hackenberg, S. 2001. Hygiene-Baumusterprüfsystem. Bundesgütegemeinschaft Kompost e. V., Köln. www.kompost.de.

Kreft, G.H. 1998. [Accuracy of Compost Quality Tests] Genauigkeit der Kompost-Qualitäts Prüfung- Zentrales Element eines umfassenden Kompost-Qualitatsmanagements. Forum Siedlungswasserwirtschaft und Abfallwirtschaft University of Essen.

Lanuv. 2008. [Roundrobin Biowaste Compost 2008] Ringversuch Bioabfall 2008. NRW, Recklinghausen. www.lanuv.nrw.de/analytik/ringversuche/pdf/bioabfall_rv2008.pdf (verified Oct 15 2011)

Lindley, J.A., Johnson, D.W. and Clanton, C.J. 1988. Effects of handling and storage systems on manure value. *Appl. Eng. Agric.*, 4: 246 252.

Miller, R.O. and Kotuby-Amacher, K. 2001. The Proficiency of Laboratory Compost Analysis. Circular, Utah State University.

NRCS. 2001. Compost. Part 637 Environmental Engineering, National Engineering Handbook. USDA. Washington, DC.

NRW. 1999. [Bio-waste Collection and Compost Recycling] Bioabfallsammlung und Kompostverwertung. Nordrhein-Westfalen. Germany Ministry for Environment.

NYS-DEC. 2001. NYCRR Subpart 360-5 Draft Standards for

Composting and Other Organic Waste Processing Facilities. New York State Department Of Environmental Conservation, Albany, NY.

Peters, J.B. 2000. Manure sampling and testing. p. 369-379. In Managing nutrients and pathogens from animal agriculture. Proc. Managing Nutrients and Pathogens from Animal Agric., Camp Hill, PA. 28 30 Mar. 2000. Natural Resour. Agric., and Eng. Serv. (NRAES), Ithaca, NY.

Peters, J. (ed.) 2003. Recommended methods of manure analysis. Publ. A3769. University of Wisconsin. Available at: http:// learningstore.uwex.edu/pdf/A3769.pdf. Accessed 19 March 2009.

Seekins, M.D., Brinton, W. and King, M. 1995. Compost Maturity Traits As Influenced by Age and Management Systems. Maine Dept Ag. Manuscript.

Siebert, S.F. and Amlinger, F. 2011. [Status of European Compost Standards] Stand der Entwicklung Europäischer Normen. Humuswirtschaft and Kompost Vol. 1/2 -11 Köln-Gremberghoven.

Solvita. 2008. Solvita Instructional Manual. Vers 7.0, Woods End Laboratories, Inc Mt Vernon Maine.

TMECC. 2002. Field Sampling of Compost Materials. Method 02.01-A.Compost Sampling Principles. U.S. Composting Council. http://compostingcouncil.org/admin/wp-content/plugins/wp-pdfupload/pdf/34/TMECC%20Field%20Sampling%20Protocol.pdf (verfified Oct 25 2011).

Woodbury, P.B. and Breslin, V.T. 1992. Assuring Compost Quality: Suggestions for Facility Managers, Regulators, and Researchers. *Biomass and Bioenergy*, Vol. 3, No 3-4, pp. 213-225.

Woods End. 2000. Compost Sampling for Lab Analysis: Principles and Practice. Journal of the Woods End Research Laboratory. http://www.woodsend.org/pdf-files/sampli~1.pdf (verified Oct 25 2011).