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Characterization of Man-made Foreign Matter And its Presence in Multiple Size Fractions From Mixed Waste Composting

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Municipal solid waste (MSW) has for decades been processed into compost. Community collection of residential trash of various degrees of separation followed by some form of presorting, tumbling or batch processing along with aerated static or mechanical-turned windrowing are typical in the industry. A significant portion of MSW is plastic or synthetic material including woven polyester and polyethylene materials that may easily reduce into fine fragments. European studies in the 1980's indicated significant contamination as a result of mixing and grinding which caused metals and glass to become reduced and enter the fine compost fraction. The results of these early studies provided impetus towards source separation, nongrinding of initial MSW and later introduction of novel biodegradable plastics and natural polymers to replace plastic content for collection of household organics. The present study was conducted using several mixed waste compost streams from archived lab samples taken recently from across North America. The objective is to determine the extent that laboratory sieving and microscopy techniques may fully characterize compost with regard to foreign, man-made content. Results indicated that foreign matter comprised principally of glass and plastic fibers occupied all size fractions from 25 mm down to 420-micron sieving. Owing to the very small dimensions of certain foreign material, fragments are not easily measured by classical sorting procedures. We employ various separation techniques including dry and wet ultrasonic sieving, optical microscopy and FTIR to separate and classify foreign matter fines. The origin of fine nondegradable materials as observed in the compost was likely building materials, carpets, textiles and diapers. Fragments of PET, polyester, polystyrene and foam were identified by simple and polarized-light microscopy and estimated to occupy up to 5% for all fractions. The study suggests that refined and improved characterization techniques for MSW compost may be important for better understanding of the fate and content of inerts. The study did not evaluate the potential risks of accumulation of nonbiodegradable fragments within sustainable soil systems nor ecological toxicity of components of these fractions. These data support the concept that in order to attain a high degree of cleanliness of finished MSW compost, early sorting and separation steps must be implemented prior to composting.

Introduction

A renewed emphasis on compost quality is evident in the composting world (Hogg *et al.* 2001). Early evidence for heavy metal contamination of mixed waste composts, resulting from failure to observe adequate source separation combined with the practice of pregrinding MSW prior to composting, were presented more than a decade ago. Between 1982 to 1990, scientific surveys of heavy metals in household wastes strengthened this direction (Bidlingmeier 1982, 1990). In other studies, source separated green waste composts were found to contain on average one-tenth to one-quarter the heavy metal content of mixed waste composts (Wiemer & Kern 1989; Kraus & Grammel 1992). The issue of the relevancy of contaminated composts of any kind for sustainable agriculture has been recently raised (Candinas *et al.* 1999).

The practice of mixed waste composting has been seen to possess potentially large economic benefits from reduced waste disposal costs. However, in Northern Europe, MSW composting has been largely phased out over the past decade, while it has grown slowly in the United States (Block & Goldstein 2000). It is noteworthy that several large plants in America have been shut down in this same time with a net loss of one-million metric tons/year composting capacity (SWANA 1995). Mixed economic performance and persistent issues with regard to marketability of MSW composts are perceived to be the primary risk factors (Hickman 1999).

A limited number of states have statutory guidelines for compost quality pertinent to MSW that pertain to inerts and foreign matter. Washington and New York specify that compost shall not contain sharps; however, neither a threshold nor a laboratory procedure is specified to determine the parameter (NYSDEC 2001; WDOE 1994). Texas states that compost shall not contain foreign matter of a quantity greater than 1.5% "over a 4 mm screen" (TNRCC 1995). New York's 2002 Draft regulation proposes a 2% threshold for "gross contamination under a sieve size of 10 mm". Washington DOE specifies that Grade A compost shall not contain more than "1% manufactured inerts".

Laboratory screening techniques for physical analysis and inert matter classification are undergoing changes. Some recent European modifications of compost testing methods specify that compost foreign matter must be described down to a 2 mm-size fraction with separate classification of stones and man-made inerts (Kehres & Pohle 1998). A newer procedure requires separation of MSW composts into sequential sizes of 9.5, 4 and 2 mm with classification of inerts within each group (TMECC 2002). Since this type of analysis is inherently variable, studies are underway in some countries to improve accuracy and reduce variability observed in testing of foreign matter. In a recent comparison of 145 European laboratories, the coefficient of variation for foreign matter tests was 43% and had declined significantly since an earlier round of lab comparisons (Kreft 1998).

Mixed waste composts have been known for some time to contain significant inert matter. In a set of comparisons, compost of differing sources including backyard compost, separated biowaste or mixed municipal waste (MSW) gave a range of 0.1, 0.33 and 11.0%, respectively, for foreign matter (Vogtman *et al.* 1989). The current view is that the amount of foreign matter in any compost determines the cleanliness, and cleanliness relates directly to safety, usefulness and marketability (Barth 1999). In Germany, compost is considered free of foreign matter at <0.1% dry weight, relatively free at <0.5%, moderately contaminated at >0.5% and very significantly contaminated at >2%. Overall in Europe, the amount of foreign matter tolerated in marketed composts currently ranges from 0.2% up to a maximum of 0.5% of dry matter with some states separating glass from plastics (Hogg *et al.* 2001; EC 2001). In the United States, we are not aware of a case where a foreign matter standard has been enforced for composts.

An additional dimension for inert matter testing arises as a result of the fact that polymers assumed to be biodegradable have recently entered the market and may be a part of the MSW and source separated biowaste stream. These materials are likely to have differing decomposition and disintegration traits and are distinguished from plastic by their behavior in composts. Current approaches to evaluating biodegradability vary somewhat but are generally based on confirming mineralization into CO_2 over a specified period of time and the degree of disintegration under controlled conditions (ASTM 1996; DIN 1997; ISO 2002). While representing an enormous potential to replace some forms of plastic contamination of compost, bioplastics may still pose a risk of visual contamination if present at the completion of composting, and when present in reduced form can not be readily distinguished from regular nondegradable plastics and would therefore fall into a general inert category according to current unsophisticated test methods. Under updated test guidelines for foreign matter within Germany, in addition to the standard foreign matter test cited above, the presence of man-made surfaces within compost must be determined. This test is performed by measuring the surface area of plastic-like fragments per volume of compost, where 800 mm^2 per liter total surface contamination (approx. 1-$inch^2$) is the threshold for acceptability (Kehres & Pohle 1998).

Compositional analysis and the representation of cleanliness is obviously dependent on the size of sorting limits. At any size limit, there is theoretically an overs and unders fraction. It is generally assumed that screening may remove all or most the plastic inert materials from a compost. In this study, however there is no limit assumed other than that imposed by the technical complexity of diminishing smaller size separations. Normally, in the trade, all material under a 3/8-inch (~10 mm) screen size is considered to be compost but in some cases this limit may be somewhat larger at 1/2-inch (12.5 mm). In special horticultural markets, a 1/4-inch (6 mm) limit is often used. The level of precision and accuracy of foreign matter determination at all size ranges is naturally a matter of concern: in these studies, the principle cause of variability between labs is the problem of compost adhering to plastics, causing a negative error. The use of microscopic separation and more refined techniques including FTIR and SEM for fiber classification suggests that ultimately a compost can be classified very precisely regarding foreign matter content over a virtually infinite size range. We present data herein from a survey across America on composition and screening quality for compost products resulting from either MSW composting or semi-source separate collection of community food wastes and green (leaf and yard) wastes from 25 mm down to 420-micron size ranges.

Materials and Methods

For physical characterization of the compost fractions, sequential physical separation of compost size groups was undertaken. Facilities normally produce a "product" that has been prescreened at some larger size limit, such as 12.5 mm (1/2 inch). For all composts, we determine overs vs. unders at the 10 mm-size separation, and then at the 4-10 mm range. For all this work, the procedure employed was a modification of German procedure of pincer-picking, drying and weighing of foreign matter by individual material groups comprising the following: glass, metal, hard-plastic, soft-plastic and textiles (Kehres & Pohle 1998). Stones and bones are separately measured. In addition to this, selected composts were subjected to further compositional analysis from 4 mm to 1 mm by wet and dry sieving and picking under dissecting scope of the foreign matter components. Subsequently, selected samples were observed with smaller size partitioning down to the range of 400µm with a wet-sieving technique followed by drying and visual recognition by polarized light microscopy. Because of difficulties in classifying certain microscopic size fragments, we employed scanning electron microscope (SEM) equipped with a Gresham energy dispersive spectroscopy (EDS) detector and Fourier Transform Infrared spectroscopy (FTIR) in an attempt to determine the nature of these fractions as compared to standard controls (napkin-cellulose, diaper-polyethylene/polyesters, textile-mixed fibers, styrofoam). In FTIR, ultrasonic detergent cleaning of conglomerates in the 0.1-0.5 mm range was used in order to obtain sufficient material to image.

Compost foreign matter characterization is further dependent on the relative state of decomposition of the product. This ultimately determines the extent of dilution of inert material in the organic, digestible fraction. Compost facilities which achieve low dry matter decomposition as a result of either short-term processing or conditions inimical to biological degradation may therefore appear to have lesser foreign matter than facilities of high performance. There are no known guidelines to characterize acceptable limits for degradation among various methods and facilities. Partly as a result of this, European procedures call for normalization of test data to a 30% organic content basis. One method to characterize degradation efficiency is by gross mass balance computations on the incoming waste minus overs or the discarded material versus outgoing fractions. Determinations made by such a procedure have a large margin of error. In our studies, we employ chemical properties of the compost before and after composting to determine total solids loss. Simultaneously, since it cannot be known from facility testing what potential degradation is achievable, we conduct bench-scale composting of selected mixed-waste streams. Test methods for the characterization of compost samples were modified after test procedures developed by the Bundesgütegemeinschaft Kompost (Kehres and Polde 1998), TMECC (2002) and ISO (ISO 2002).

Results

Performance of MSW Composting

An objective in composting is an amount of degradation to attain a C: N ratio of 17:1 or less, at which point compost is not likely to immobilize nitrogen and may be stable such that it is beneficial to plants. Degradation involves loss of solids and therefore an increase in apparent inerts. In this study, composting was tracked in the first 21 days to determine the extent of this degradation. However, short-term composting does not necessarily result in a finished compost by some standards (Block & Goldstein 2000).

In Figure 1, we plot four typical parameters (C: N, Moisture, VOA and relative OM) from the five facilities studied, plotted against compost age. These data indicated somewhat variable results. C:N effects were not consistent as expected and at one facility increased over time, most likely a result of N-loss. Moisture was low to moderate and declined to a variable extent. Volatile organic acids (VOA), which may retard decomposition, increased in three and declined in two facilities. Organic matter recovery varied between the facilities ranging from 51 to 80% over 21 days. This variable extent of solids loss obviously significantly affected the apparent concentration of foreign matter determined in the study, and could easily be different at another sampling time.

The trendline for relative organic matter as seen in Figure 1 shows a clear relationship to time and there were statistically significant differences observed in the rate of decline between facilities. Some facilities did not appear to have optimized the composting which may have been the effect of moisture or VOA content previously discussed. The concentration factor for inerts was from 1.2 to 1.5 with a mean of 1.3 for all facilities. However, under laboratory bench scale conditions with the same source composts the mean concentrating factor was slightly greater at 1.4 with one as high as 1.6. Foreign matter limits set for composts must be managed for all purposes at the facility level by accounting for actual (and potential) decomposition goals. If compost analyses of contaminant content are corrected for organic content as is practiced in Europe, this becomes of less concern.

For all facilities, we examined screened compost prior to release, at sieve sizes ranging from 12.5 mm (1/2”) to 25.4 mm (1”). In Table 1, we show composition of foreign matter for bulk 1” screened compost from these facilities.

The foreign matter content ranged from 4.1% to 17.1% on a dry weight basis. Some differences between various paired facilities were statistically sig-

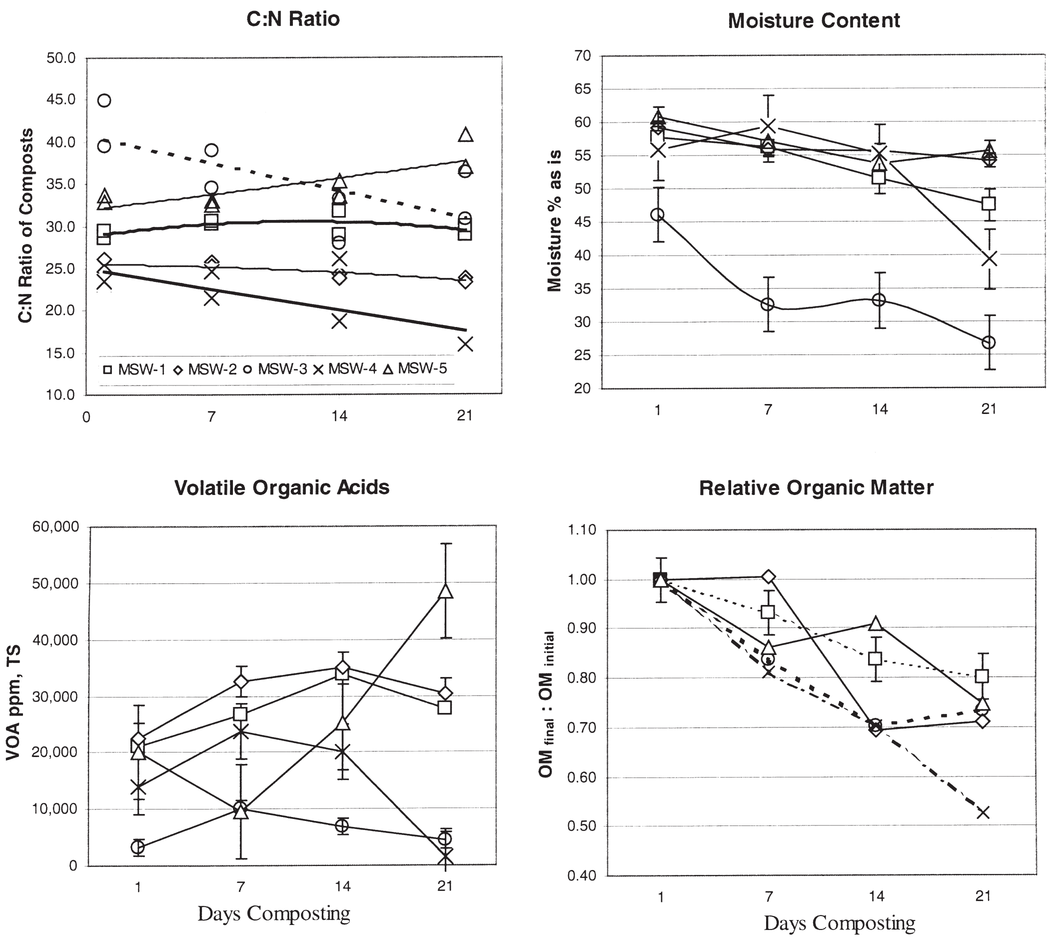

FIGURE 1. Performance of MSW composts as measured at five-facilities for parameters CN, moisture, VOA and OM recovery.

TABLE 1.
Content of inerts for whole <25 mm fraction of selected mixed waste composts (n=20)

	Glass	Hard Plastic	Film Plastic	Metal	Textile, Fibers	Total Inerts
	% of total, dry weight					
Mean	5.20	1.84	2.05	0.18	1.70	10.96
Min	0.53	0.51	0.45	0.00	0.10	4.13
Max	12.87	3.45	4.38	0.79	5.53	17.07

TABLE 2.
Foreign matter content of 4-10 mm fraction as a percent of under 10 mm screening for MSW Composts (n=7)

	Glass	Hard Plastic	Film Plastic	Metals	Textile, Fibers	Total
	% of total, dry weight					
Mean	2.70	0.93	1.16	0.03	1.42	6.22
Min	0.38	0.59	0.30	0.00	0.07	2.59
Max	6.95	1.30	2.11	0.15	4.33	9.43

nificant at $p \leq 0.05$, but it was difficult to explain the differences without comprehensive information on the collection methods and existence, if any, of community source separation. Plastics alone (hard and soft) ranged from 0.99% to 7.8% and comprised on average 35% of the total foreign content. The fiber-textile fraction was mostly synthetic. If summed along with the plastic total, then 54% of foreign matter is essentially plastic. Disposal of this nonbiodegradable compost sieve result is a significant cost factor to all facilities.

Compost from the facilities was subsequently rescreened and "unders" or fine fraction in the 4-10 mm sieve range was evaluated (Table 2). This size range including the 4 mm unders would normally be considered the marketable compost fraction. The lower size limit (4 mm) down to which the physical fractionation scheme was conducted was selected simply based on convenience as it represented a practical lower limit for separation by unaided eye or with minimal support of a dissecting scope and pincers. The foreign matter content for this fine fraction ranged from 2.6 to 9.4% with an average of 6.2% or slightly less than the gross whole compost fraction observed in Table 1. Thus physical screening removed only a small portion of inerts and had only a slight effect on its composition. In this fine fraction, of the total foreign matter, 63% was plastics + textiles, or slightly more on a percent basis than in the whole bulk compost fraction.

Subsequent to the determination of foreign matter in the compost 4-10 mm fractions, we employed a wet sieving method to obtain similar compositional separations for the very fine fraction of 1-4 mm. Table 3 presents data obtained from dissecting scope screening for two of the MSW streams.

TABLE 3.
Foreign matter content of 1-4 mm fraction for MSW composts (n=4)

	Glass	Hard Plastic	Film Plastic	Metal	Textile, Fibers	Total
	% of total, dry weight					
Mean	2.05	1.03	0.315	0.105	0.625	3.775
Min	1.05	0.84	0.31	0	0.41	3.26
Max	3.05	1.22	0.32	0.21	0.84	4.29

Analysis of variance (ANOVA) of triplicate sort data indicated highly significant (p=0.001) differences for plastic content of composts derived from differing MSW compost streams. Only slightly significant (p=0.041) differences are observed in plastic content between whole (25 mm) versus very fine (4-10 mm) fractions and we found no significant differences of textile content (p=0.128) or glass content (p=0.058) in whole vs. the same fine fractions, suggesting that screening below 25 mm had little effect on non degradable content. There were highly significant interaction effects of facility x size- fraction, which indicates that facility-specific factors such as separation, sorting and sieving technology apparently exert a significant effect on cleanliness.

These data clearly show evidence that foreign nondegradable matter of similar make-up may be reduced to smaller size fractions during the composting process. Some of the composts we examined contained appreciable extreme fines (under 1 mm). For example, we obtained in three paired comparison results of 33, 51 and 47% of particles passing a 420 µm screen size. Therefore, we examined these fine fractions microscopically to qualitatively identify fragments of or less than 420 µm screen dimension. A combination of polarized light microscopy and environmental scanning electron microscopy (ESEM) completed the observation and identification. We estimated the percentage of the fraction that comprised the foreign matter (Table 4).

TABLE 4.
Foreign matter fragment identification of very fine 420µm fraction for MSW composts

MSW Sample 1	MSW Sample 2.	MSW Sample 3
Approximately Percentage, 0.3-2.0%	Approximate percentage 0.6-2.5%	Approximate percentage 0.5-5.0%
Glass, maroon fibers tangled with cellulose, polyester fibers, foam	Foil, red-acrylic fibers, polyester fibers, carpet synthetic fibers	Purple synthetic fibers, red and clear polyester fibers, blue and yellow carpet fibers, foam, blue-dyed plastics, birefringent vinyon/acetate fibers

One of the explanations that plastic fibers are found in the fine fraction has to do with the nature of plastic composites in the waste stream. In Figure 2, we show a 30x image of a plastic outer laminate material typical of diaper covers found in MSW. This material comprises a layered polyethylene and polypropylene fiber strand network that has been heat annealed to create the impression of a woven fabric. This innovation came about partly to make a plastic sheet that felt soft to the touch and did not have the "noise" typical of solid polyethylene sheets, used in trash bags. We observed that the heat seal points rupture easily in composting whereby the fibers unravel and disperse into the compost. This is different behavior to that of polyethylene bags, such as those used in leaf collection. Such plastics rupture and tear into sheets which are more easily partially removed by screen-

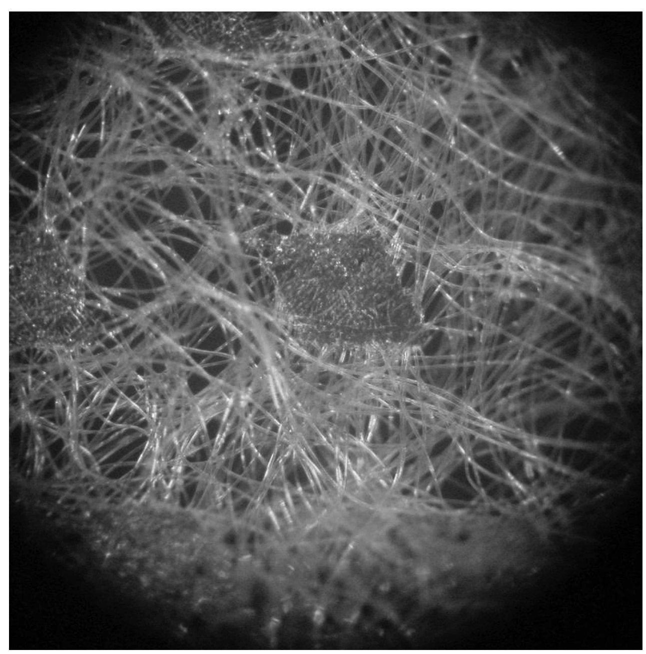

FIGURE 2. Polyethylene composited fiber foil layer comprised of heat annealed plastic strands, from raw MSW compost input material

FIGURE 3. Expanded, delaminated plastic fibers interlaced with <2 mm fraction of MSW compost.

ing. Figure 3 shows unraveled polyethylene fibers aggregated with the under 2 mm humus fraction. Other similar results may be expected with synthetic textiles and fiber-filled products; these also rupture or break to release plasticizing phthalates (McDonough and Braungart 2002). We estimated textiles and non-degradable fines to be about 4.4 to 6.2% of the collected MSW. We are also assuming PVC products may enter the compost stream. The fate of recycled textile and plastic strands in the environment has not been fully appraised (McDonough & Braungart 2002). One study estimated disposable diapers are composed of 11-22% synthetic fibers, and that they alone comprise 2.8-3.8% of household waste (Franke 1991). This would by calculation mean on the low side 0.3-0.4% plastic in the waste stream, which multiplied by our estimate of a concentration factor of 1.5 for 30-day MSW compost (Figure 1) would translate into 0.5-0.6% of MSW compost as plastic fines from a single source.

Plastic Bag and Yard Waste Compost Programs.

The question arises how much plastic and other inert contamination is seen in yard debris composting programs that use either plastic leaf-bag or food waste collection. A variety of regional composts were selected and the compost evaluated at the ≥10 mm and 4-10 mm fractions. This data is seen in Tables 5 and 6.

This data indicates significantly less foreign matter in all size groups for green waste composts than encountered for MSW; never the less, glass and plastic are found in both the whole and 4-10 mm fraction, but the total content in the fine fraction is only 0.35%.

The results of separately determining the components of inerts as influenced by sieve sizing down to 1-4 mm for MSW compost are seen in Figure 4. In Figure

TABLE 5.
Content of inert materials for unscreened yard debris/food waste compost

	Glass	Hard Plastic	Film Plastic	Metal	Textile, Fibers	Total
	% of total, dry weight					
Mean	0.45	0.40	0.38	1.20	0.00	2.38
Min	0.00	0.10	0.00	0.00	0.00	0.10
Max	1.80	0.70	0.70	4.80	0.00	7.40

TABLE 6.
Content of 4-10 mm foreign matter as a percent of under 10 mm fraction for municipal collection green waste compost

	Glass	Hard Plastic	Film Plastic	Metal	Textile, Fibers	Total
	% of total, dry weight					
Mean	0.23	0.13	0.03	0.00	0.00	0.35
Min	0.00	0.10	0.00	0.00	0.00	0.10
Max	0.40	0.20	0.10	0.00	0.00	0.60

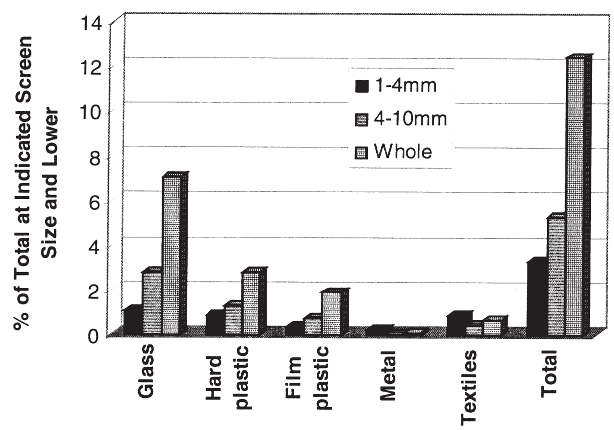

FIGURE 4. Foreign matter speciation in three screen ranges from MSW composting

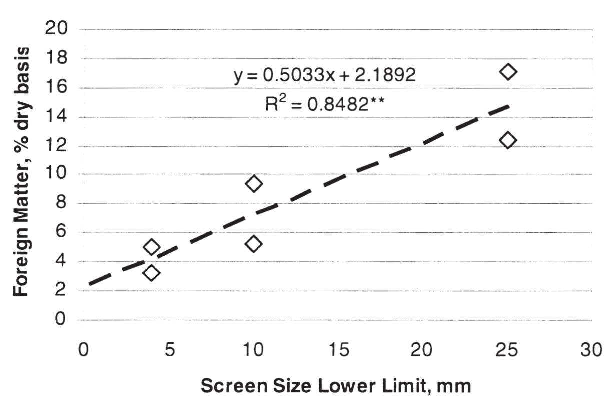

FIGURE 5. Relation of foreign matter content of MSW compost vs. upper screen size limits

5, the overall correlation of total inerts to the upper sieve limit is shown. These findings indicate a significant but by no means complete reduction of inerts at lower size fractions with the exception that textile-fabric inerts appeared unaffected by screen size if not slightly more in the fine fraction.

In the regression of screen size upper limits and recovered inert content, the Y-intercept of 2.1% foreign matter occurs at a screen size of approximately zero (0) mm. This indicates the nearly impossible challenge to obtain clean material (<2% inerts) by compost screening alone.

This data supports the conclusion that to achieve a high degree of cleanliness of MSW compost, sorting and separation steps must apparently be implemented early in recycling and prior to composting, to avoid inert reduction into finer fractions. Reduction and concentration factors appeared to be highly variable between compost facilities, partly reflecting source ingredients and optimization. The study indicates that nondegradable textiles and plastic comprised of strands of synthetic material may be a principle inert component of fine fractions of compost.

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