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MORPHOLOGICAL AND CHEMICAL PROPERTIES OF PLASTIC RESIDUES IN COMPOSTS

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Abstract

The relative quantity of plastic film residues and other man-made materials in composts prepared from municipal solid wastes (MSW), biosolids, yard wastes, and pine bark was evaluated utilizing light and scanning electron microscopy equipped with energy dispersive X-ray analyzer. MSW composts screened through a 4 mm screen contained significant but highly variable quantities of plastic film residues and other man-made materials that escaped detection with the unaided eye. The other composts were free of such particles. We conclude that the database for evaluation of man-made materials in MSW composts is inadequate and must be developed further.

Key Words: Municipal solid wastes, scanning electron microscopy, energy dispersive X-ray analysis, compost safety.

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Introduction

During the early part of the twentieth century, organic fractions in municipal solid wastes (MSW) were readily diverted from landfills through composting (Bidlingmaier, 1993). After man-made non-biodegradable materials appeared in this waste stream in increasing quantities and society became more aware of the potential impacts of heavy metals and other potentially toxic substances in composts prepared from MSW, the quality of these composts became a concern (Bidlingmaier *et al.*, 1987; de Haan and Lubbers, 1984; Richard and Woodbury, 1994; Richard *et al.*, 1993; Terman and Mays, 1973). Production of acceptable quality composts from MSW has indeed become a challenge.

The most common response in the Western World has been to separate yard wastes, food and restaurant wastes, paper, cardboard, and other organic fractions from MSW. High quality composts, low in concentrations of heavy metals and other potentially toxic substances, can be produced from these separated materials (Fricke and Vogtmann, 1989; Richard and Woodbury, 1994; Spencer, 1994; Stegmann and Krogmann, 1989). Separation by itself has not solved all MSW problems, however. Total separation of organic biodegradable fractions from other materials in MSW may not be achieved in all communities in the United States. Thus, MSW composting probably will remain an alternative to landfilling in the United States for years to come.

The impact of inerts such as "sharps" (glass, metal objects, etc.) and plastic film residues in MSW composts has received little attention. Plastic film residues are defined in this paper as particulate remnants of plastic sheets, wrappers and bags. The effect of these materials on compost quality typically is determined by an analysis of particles that collect on a screen (Bidlingmaier, 1993; Bidlingmaier *et al.*, 1987). Particles passing through a small screen (4-6 mm) have generally been assumed to not affect quality (Volk, 1976). It has been suggested, however, that small pieces of glass and other sharp materials in MSW compost may cause "hardware disease" in cattle grazing on treated soils (Terman and Mays, 1973). Technology in use today makes this less likely because glass in MSW can be ground to a particle size small enough to pose less of a threat (Gould and Meckert, 1994). Furthermore, metallic pieces are removed electromagnetically and better screening systems are in use (Bidlingmaier *et al.*, 1987). One of the factors that remains a concern, however, is the fate of plastics in composts, which is the focus of this paper.

The objectives of this research were: (1) to examine the physical and chemical nature of plastic contaminants in MSW composts produced at recently constructed facilities; and (2) determine the degree to which MSW composts are contaminated with plastics relative to composts produced from separated wastes. A preliminary report on this work was published earlier (Hoitink *et al.*, 1993).

Materials and Methods

Description of composts

Composts used in this work were prepared from MSW, yard wastes, biosolids, and pine bark. MSW composts were collected from two sources where large, non-biodegradable materials were removed before processing. The composition of unsorted MSW has been described earlier (Franklin and Associates, Ltd., 1989). Both MSW plants utilized a rotating drum homogenizer (three-day residence time) that reduced particle size and destroyed part of the most readily biodegradable fraction (Stentiford, 1993). At one of the MSW plants, the material was then screened and composted in an in-vessel system, as described by Iannotti *et al.* (1994). This compost will be referred to as MSW-1. The second location utilized a forced-aeration static pile process with turning to produce the compost product referred to hereafter as MSW-2. Composts from both locations were screened and cured for periods long enough to produce mature products (Iannotti *et al.*, 1994).

Composted yard waste was collected from two sources, both receiving grass clippings, brush and leaves. Materials were shredded and then screened to remove plastic bags at one site. The second plant did not accept yard waste in plastic bags and screening at this stage in the process was not necessary. At both sites, compost was prepared in wind-rows over a six month period utilizing turning machines. Thereafter, composts were passed through a 1-inch (2.54 cm) screen and cured in piles, as described by Grebus *et al.* (1994).

Composted biosolids were collected from a site at which an in-vessel system and additional outdoor curing were utilized (Kuter *et al.*, 1985). Bark, sawdust and recycled compost were used as bulking agents at this plant. Composted pine bark prepared in wind-rows as described by Hoitink *et al.* (1991) was obtained from Paygro Company, Inc., S. Charleston, OH.

Compost sampling

Compost samples were collected at four locations from curing piles at each plant. Each sample was a composite of three subsamples collected from the surface, midway into, and from the center of the curing pile. Samples (35-45% moisture, w/w) were screened through a 4 mm sieve. This screen size was chosen because: (1) it is the minimum size that can be operated successfully under most conditions at composting sites; and (2) it provides an opportunity for removal of large pieces of plastics. The screened sample was collected in a polyethylene bag and blended two minutes by vigorous shaking and tumbling to minimize separation of particles into size fractions.

Preparation of samples for light and scanning electron microscopy (SEM)

Aluminum stubs or mounts coated with colloidal graphite (Ted Pella, Inc., Redding, CA) and a carbon conductive tab (Ted Pella) were pressed onto the surface of a compost sample. Four such mounts prepared for each sample were first examined under low magnification (x20) with a light stereomicroscope (model SV-8, Zeiss, Batavia, IL). The ratio of plastic residue to the total number of particles in a marked quadrant of the surface area of each mount was then determined with a hand-held counter. Each area was also photographed to verify counts. Particle identity was verified further with electron beam analysis (EBA) after Krause (1985) using a Hitachi S-500 SEM (Nissei Sangyo America, Ltd., Mountain View, CA) equipped with a TN-5500 energy dispersive X-ray analyzer (Noran, Middleton, WI). The X-ray detector was equipped with a "Pioneer" thin window (Noran), permitting detection of low energy emissions including the detection of the light elements boron, carbon, nitrogen, and oxygen. Operational parameters were an acquisition time of 100 seconds at an accelerating voltage of 20 kV with a working distance of 15 mm.

Statistical analysis

The total number of particles adhering to the surface of the mounts varied widely among subsamples of the same compost source. It was assumed that the plastic films were randomly scattered throughout the samples, so that each mount was representative of the total sample from which it was collected. A basis for comparisons among samples was the population proportion/percent. This was derived for each sample by dividing the number of plastic residue particles by the total number of particles per quadrant counted. Mean percentages, along with their corresponding confidence intervals (CI), were calculated for each compost sample.

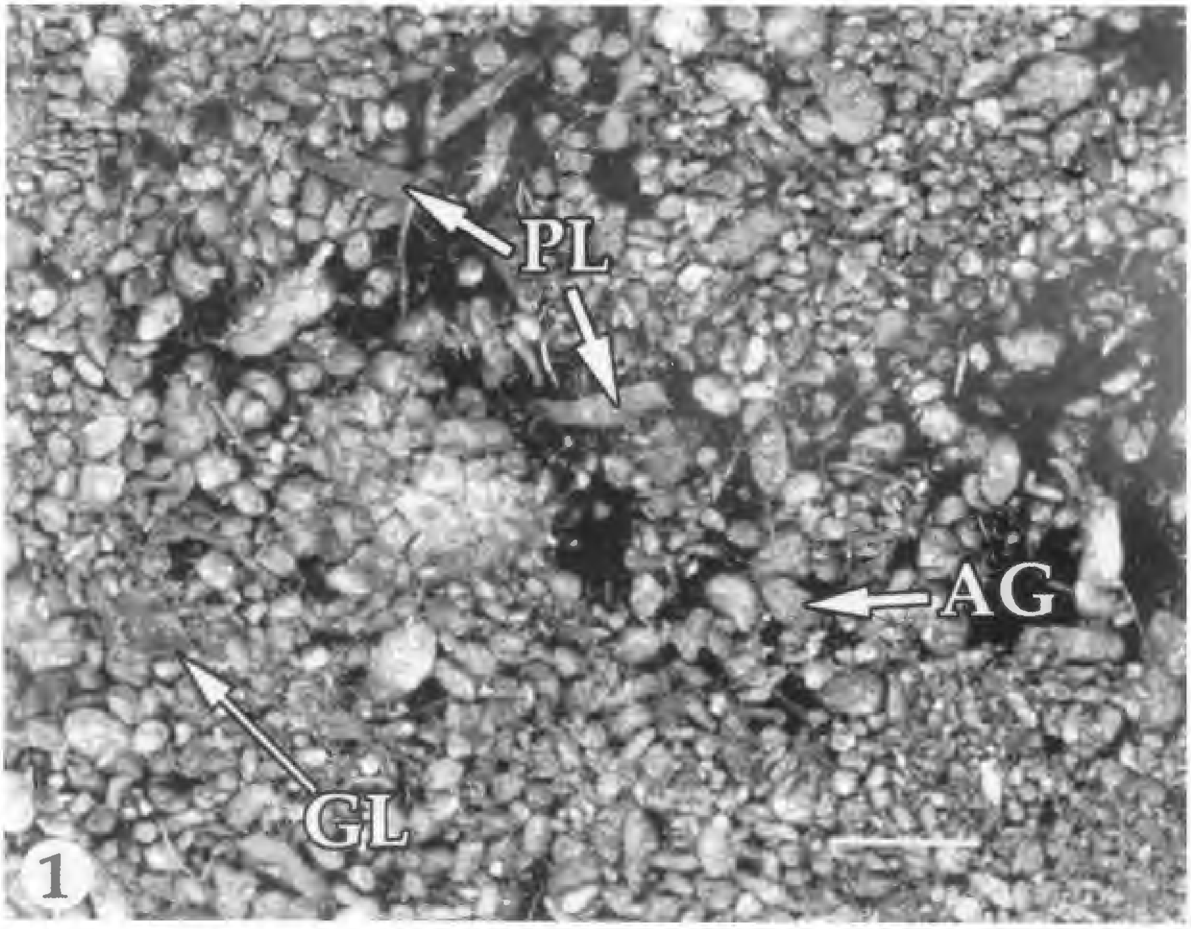

Figure 1. Composted municipal solid waste viewed through a light microscope. Note "soil" aggregates (AG), glass particles (GL), and plastic-like particles or fibers (PL). Bar = 5 mm.

Results and Discussion

The vast majority of particles in MSW compost samples were aggregates resembling soil organic matter. They ranged from 1 to 4 mm in diameter. No attempt was made to crush such "soil" aggregates and thus examine internal components for plastic residues or other man-made materials. Glass particles with sharp edges were visible in MSW and less frequently in yard waste composts, but not in pine bark or biosolids composts. The glass nature of these particles was verified with electron beam analysis.

Both sources of MSW compost samples contained a great assortment of sizes and shapes of films and other plastic residues readily visible under the light microscope (Fig. 1). The sizes of most film particles ranged from 0.05 to 0.8 mm in width and 0.9 to $\geq$ 4.0 mm in length. With the unaided eye, they could easily be mistaken for lignocellulosic fiber. The appearance of these film particles was confirmed with the SEM (Fig. 2). Larger plastic film pieces were readily distinguishable as strips of man-made materials with the unaided eye, even though they were discolored as a result of a coating consisting of microbial biomass and mineral particles. A small number of plastic and sponge-like particles representing a variety of materials comminuted during processing of MSW were also observed. An example of a sponge-like material, possibly representing a small portion of a filter system, is illustrated in Figure 3.

The surface of the soil aggregates in MSW compost in this study (Fig. 4) typical of that encountered in soils or on composted pine bark particles as described by Foster *et al.* (1983). On the other hand, the density of microorganisms on surfaces of plastic film residues (Fig. 5) was very low compared to that in biofilms in aggregates of MSW compost or organic fractions in soils (Foster *et al.*, 1983). Evidence for decomposition such as "pitting" observed on biodegradable films (Narayan, 1993) was not present.

Mean percentages of total particles identified as plastic film residues in MSW-1 and MSW-2 were 0.2 (95% CI -0.1, 0.5) and 4.0 (95% CI -1.5, 9.6), respectively. Based on light and scanning electron microscopic observations, a considerable proportion of all particles in one of the MSW composts (MSW-2) were plastic film residues even though many would not be recognized as such by the unaided eye. Analysis of variance showed that the source of the compost had a highly significant effect ($p \leq 0.004$) on the quantity of plastic film. However, differences among the MSW-1 and MSW-2 composts could be due to batch effects. Materials delivered to MSW plants may differ greatly from day to day.

Light and scanning electron microscopy did not reveal plastic film particles in the yard waste compost samples. Apparently, procedures used for shredding and processing of yard wastes, followed by screening of the cured compost, prevented the formation of small pieces of plastic film residues. It is widely recognized, however, that films can also be present in such composts unless great care is taken to separate these materials before processing. No plastic film residues were detected in compost prepared from either composted biosolids or pine bark samples. The foregoing reveals that man-made materials such as residues of various plastics in MSW composts cannot be characterized with the unaided eye but must be examined, at a minimum, with a light microscope. A question that remains to be answered is how the total quantity of such materials in composts is to be assessed. A great diversity of non-biodegradable plastic materials are present in MSW (Franklin and Associates Ltd, 1989). Quantitative procedures for estimation of their concentrations in soils or composts have not been developed. In addition, the fates and impacts of such materials in soils must be examined further.

Knowledge of the fate of plastic film residues and other man-made materials largely has been derived from studies on aquatic animals interacting with such wastes deposited in the marine environment (reviewed in EPA, 1990). The general public recognizes impacts of discarded fish nets on mammals in oceans. Such materials do not pose a problem in MSW composts because they are readily removed through screening. Less widely recognized is the impact of ingestion of small pieces of plastics on marine life (reviewed in EPA, 1990). The consequence of debris ingestion can be quite significant in many types of animals. For example, drifting plastic debris, particularly small plastic pellets that resemble sargassum floats, can be ingested by young turtles and other animals (Carr, 1987; Mummert and Drenner, 1986; Thompson *et al.*, 1994). Such ingestion results in inadequate nutrition, internal injury, blockage, and suffocation. Because these plastic materials have become ubiquitous in distribution in oceans, ingestion of debris has become a concern throughout the marine environment (O'Hara and Iudicello, 1987). A more obvious aspect of pollution with plastics is its effects on tourism

(Figures 2 and 3 on facing page)

Figure 2. Scanning electron micrograph of composted municipal solid waste. Note "soil" aggregates (AG), a glass particle (GL), plastic-like particles or fibers (PL) and sponge-like (SP) material. Bar = 400 μm.

Figure 3. Scanning electron micrograph enlargement of Figure 1 showing the sponge-like material (SP) and "soil" aggregate (AG). Bar = 100 μm.

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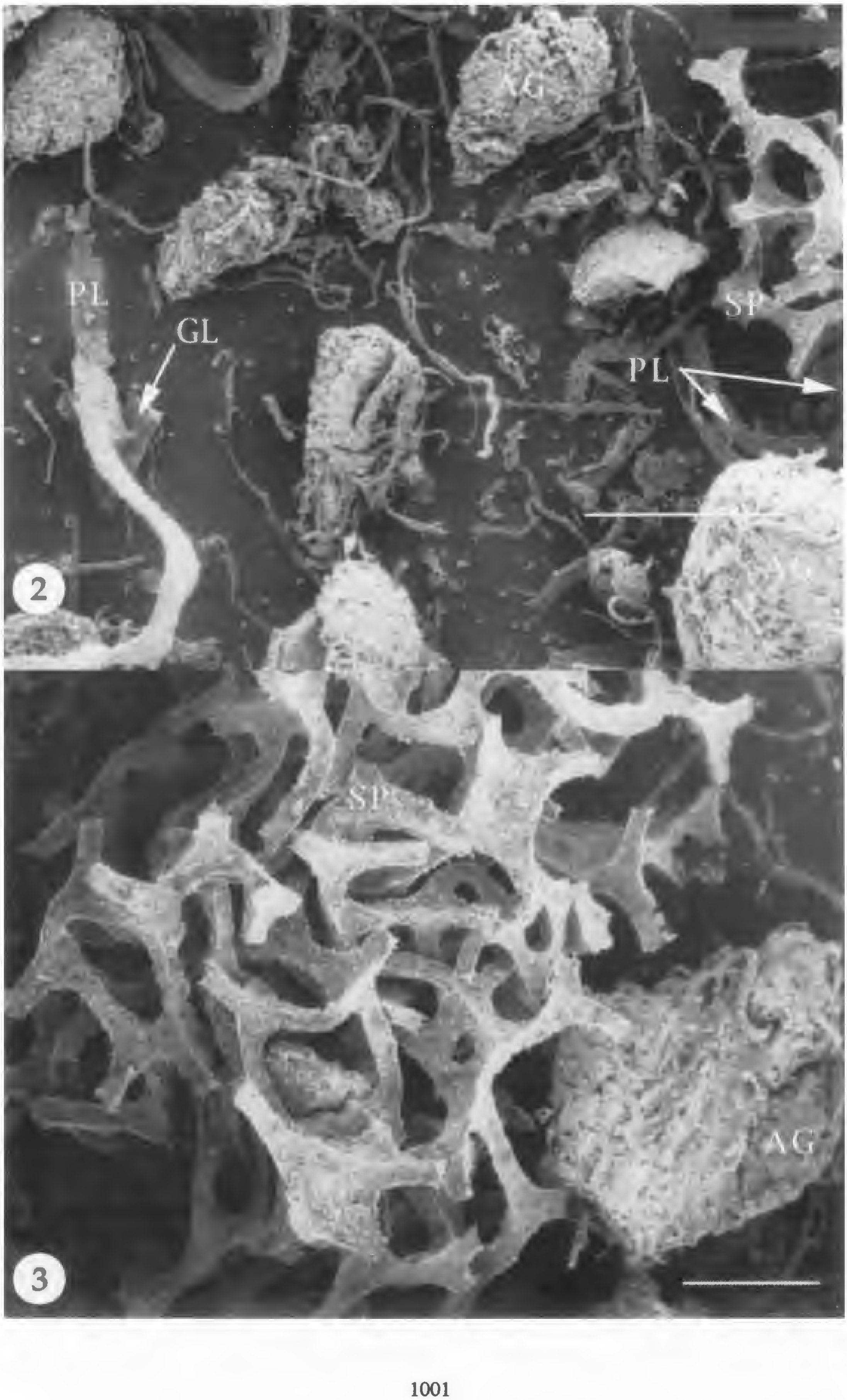
and local economics. Littering on beaches and along water fronts has resulted in localized economic losses (O'Hara and Iudicello, 1987).

Application of MSW composts containing plastic debris to land causes problems because fields treated many times eventually become littered with these materials (Segall, 1992). Plastic film residues incorporated into soils as contaminants in MSW composts eventually migrate to the surface due to tillage-related and possibly other activities. This has been observed in field plots at the Ohio State University, to which MSW compost had been applied several years earlier (He *et al.*, 1992). These film particles float on puddles and would eventually accumulate along fences or in drainage channels, potentially causing problems there, as described above, for marine conditions. It is common knowledge that the greenhouse and nursery industries experience problems with styrofoam used in potting mixes. This material is used less frequently in those substrates because it accumulates in drainage channels and clogs sprinklers of irrigation systems.

Although quantitative information on the fate of plastic residues in soil is not available, Stamatiadis and Dindal (1983, 1990) examined the impact of small plastic and glass particles on the coprophilous arthropod decomposers and earthworms under modeled landfill conditions. They demonstrated that these materials do not have a negative effect until very high concentrations are reached, and that sharp pieces of glass caused hemorrhaging in earthworms. Conclusive evidence for a direct negative effect caused by plastic particles likely to occur after years of application in MSW compost-treated soils were not discovered by Stamatiadis and Dindal (1983, 1990). Aesthetic factors may pose the greatest concern.

We conclude that plastic film residues of all sizes must be considered in any analysis of compost quality. Furthermore, a light microscope or hand-held magnifying lens must be utilized in this process. Substitution of non-biodegradable plastics with biodegradable products may eventually solve part of this problem (Barak *et al.*, 1991; Pettigrew *et al.*, 1995; Shimp, 1993). This seems particularly important for foam plastics that readily disintegrate into small particles during processing of MSW.


AG
PL
GL
SP
PL
2
SP
AG
3

Such particles probably cannot be removed from composts by screening. Styrofoam particles were not recognized in this study, possibly because they were coated with biofilms on aggregates.

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(Figures 4 and 5 on facing page)

Figure 4. Scanning electron micrograph of composted pine bark with biofilm. Bar = 75 μm.

Figure 5. Scanning electron micrograph of a plastic film particle in composted municipal solid waste. Note the low density of microorganisms visible on the surface of this particle relative to the biofilm in Figure 4. Bar = 15 μm.

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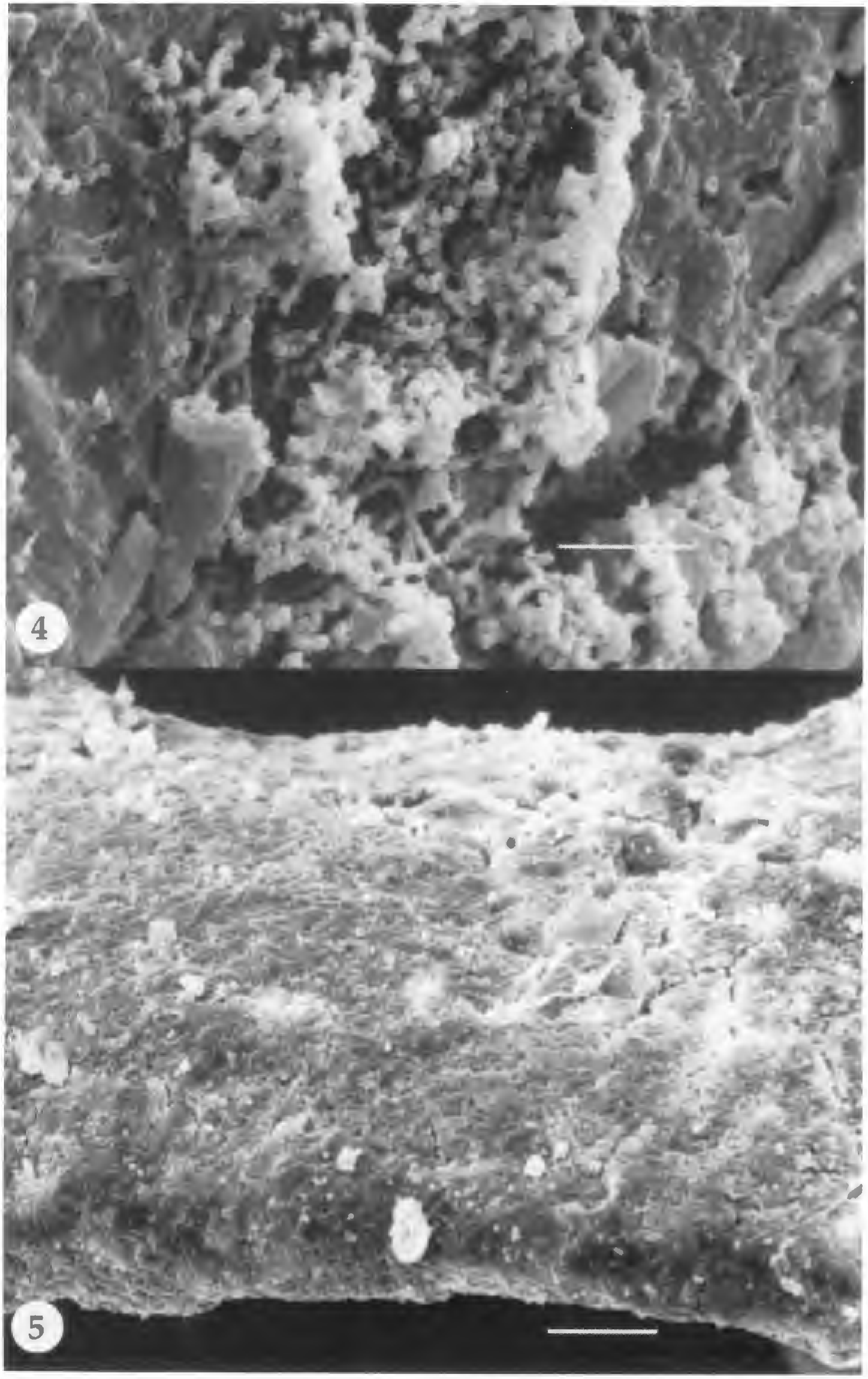
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Discussion with Reviewers

E.R. Walter: Do these sources of MSW composts represent those found in other areas?

Authors: MSW is highly heterogeneous in nature, and the compost produced thereof necessarily is as well. The composition of MSW changes with the season, and varies daily depending on the relative quantities of household wastes, industrial wastes, etc., discarded by society. The analysis presented in this paper is of a preliminary nature only, but presents an idea of what can be encountered in MSW composts relative to those prepared from separated wastes (see Franklin and Associates Ltd., 1989, for more details).

E.R. Walter: Is the cause of surface cracking on the plastic particle in Figure 5 due to ultraviolet (UV) degradation or microbial attack?

Authors: Any degradation of plastic particles in these samples is more than likely due to UV radiation or other physical factors. Plastics in these MSW composts were almost entirely non-biodegradable in nature.

E.R. Walter: Black polyethylene, which has not been UV stabilized, is now being used in agricultural applications where it tends to disintegrate by the end of the growing season. Do you see any problems with the use of this material?

Authors: While interesting, we did not investigate this aspect as it is outside the scope of this study.