University of Alberta

Foreign Matter in Municipal Solid Waste Compost

by

Natasha Tanya Page ©

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ABSTRACT

This study investigated foreign matter (FM) particles from non-source separated municipal solid waste (MSW) compost. Finished compost was either collected directly from curing piles (unscreened) or subject to an additional screening (screened). Compost samples contained FM particles including glass, metal, plastic, and synthetic fibres. Fourier Transform Infra Red analysis found that plastics included polystyrene and polyethylene. No significant difference ($p>0.05$) was found between percentage of FM in the screened compost (2.17 ± 0.11%, mass/mass) and unscreened compost (2.01 ± 0.40%). The compost was applied to gray luvisolic soil and subjected to simulated runoff conditions. No significant difference was measured between the total masses of eroded FM for screened and unscreened compost (0.349g and 0.337g respectively), despite the higher runoff volume for screened compost treatments ($p<0.05$). Topdressing either compost led to significantly higher masses of eroded FM than tilling ($p<0.05$), despite the significantly higher volumes of runoff for the tilled treatments.

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Introduction and Literature Review

1.1 Introduction

Composting is a controlled process involving thermophilic microbial degradation of organic material. Aerobic microbes break down organic matter while emitting carbon dioxide and water. Pathogens present in the feedstock are inactivated by the heat, and the volume of material is reduced to approximately half of its original size. At the end of the process the starting feedstock is no longer recognizable. Compost, the resulting material, is an organically stable, humus like product. When properly managed, composting will create organic matter that may be added to soil without causing any detriment to plant life present there (Cardenas 1979, Epstein 1997).

Composting is a logical method of waste management for urban centres since it decreases pathogens and reduces the volume of refuse to be landfilled. A wide variety of materials may be successfully composted including organic food wastes, paper products, biodegradable textiles, sewage sludge, and other municipal solid waste (MSW) products. If mixtures of biodegradable and non-biodegradable materials are processed together, the resulting compost is considered non-source separated, and will require further refining to remove impurities. Biodegradable material can be sorted from a mixture of MSW to produce source-separated MSW compost with fewer impurities.

Composting non-source separated MSW requires specific considerations due to the contaminants present in the feedstocks. The non-biodegradable materials including plastic, metal and glass are known as foreign matter (FM), and are often mixed with the refuse. These materials are not desirable in the final product, as they reduce compost quality and marketability (Hyatt 1995). Despite a variety of technologies for refining MSW compost, FM cannot be easily removed once mixed with the biodegradable feedstock (de Blignieres 1986, Mato *et al.* 1994, Skinner 1995).

This research project examined the amount and type of FM particles in compost produced by the Edmonton Waste Management Centre (EWMC). The Canadian Council of Ministers of the Environment (CCME 1996) defines FM as non-biodegradable material over 2mm. This study also included particles from 0.5 to 2mm in all FM analysis. The MSW compost was also examined under simulated runoff, with an intense rainfall rate, to determine any possible erosion of the FM once it has been applied to the soil. The movement of FM was measured in soil topdressed with compost, and in compost/gray luvisolic soil mixes.

This thesis is organized in four chapters and is written in paper format. The introduction and literature review are in Chapter 1. Chapter 2 provides details on the compost analysis, and results for the types and percent of FM particles present in the EWMC compost samples. Chapter 3 describes the experimental measurement of erosion behaviour of the FM. Chapter 4 summarizes the research project.

1.2 Composting as a Municipal Waste Management Strategy

Municipal waste managers must collect a heterogeneous mix of materials and dispose of them in a sanitary, environmentally sound, and economically viable manner. In the past, household refuse was dumped in open pits and covered with soil. There was little understanding of the environmental consequences and health concerns from the resulting leachate and gases. The dumps became environmental liabilities as leachate seeped from the buried waste and into the surrounding soil and water (Golueke and Diaz 1996). The common perception of dumps was generally negative, and public concerns included potentially foul odours, biological health hazards, and the growth of bird and rodent pest populations. This led to the "Not in my backyard", or NIMBY syndrome, where people understood the need for garbage disposal as long as it was not located in their community (Hall 1995).

Sanitary landfills were designed to prevent health and environmental concerns. Some key differences between a dump and a landfill include thick clay liners and extensive monitoring equipment to determine if the landfill is leaking contaminants (Westlake 1997). Despite the positive changes in the management of waste, the NIMBY syndrome continued and potential sites for sanitary landfills were met with opposition from the local communities (de Bertoldi 1993b, Hall 1995). Futhermore, the long term cost of building meticulously designed landfills and monitoring leachate encouraged waste managers to seek alternative methods of handling refuse. This trend was coupled with a growing awareness of the importance of recycling "waste" materials into a reusable form (Bidlingmaier 1993, Golueke and Diaz 1996).

Composting recycles organic material, and therefore decreases the volume of waste to be landfilled. MSW composting is defined as composting using solid household waste as the main feedstock. This material may be presorted to remove all nonbiodegradables, or be a complete mixture of urban refuse. The goals of MSW composting include minimizing the volume of waste landfilled, significantly decreasing pathogens, and recycling organic material into a marketable product (Cardenas 1979). Waste managers will find composting financially beneficial if they sell the resulting compost, although not all facilities will be able to recover production costs through compost sales (Herolzheimer and Colom 1999).

1.2.1 Challenges Arising from Composting Non-source Separated Feedstock

A challenge with MSW compost is finding the proper compost recipe to efficiently break down the waste. The large volumes of household waste collected daily from urban centres may not contain a mixture of ingredients optimal for composting. Several parameters must be adhered to for the efficient breakdown of the refuse. These parameters include a carbon to nitrogen ratio close to 30, moisture content of 60-65%, and sufficient levels of oxygen to maintain aerobic microbial activity (Epstein 1997, Zucconi and de Bertoldi 1987). These conditions can be difficult to maintain when using MSW feedstock, as it may be high in paper waste and therefore too high in carbon content. Conversely, compost operators can periodically receive high amounts of fresh yard trimmings, especially in seasonal climates. These wastes contain high levels of nitrogen, which must be balanced with a source of carbon. If key composting parameters are not met, the material produced may not be of high quality (Zucconi and de Bertoldi 1987).

Non-source separated MSW is a mixture of biodegradable and non-biodegradable material and may include paper, building materials, metals, glass, plastics, ceramics, and other waste materials. The variety of plastics found in MSW includes synthetic textiles and packaging materials like polyethylene films and polystyrenes. Although nylons can degrade from ultraviolet radiation, the majority of plastic in MSW is recalcitrant to degradation and therefore will become FM if not removed during processing (Brinton and Evans 2002, de Bertoldi 1993b, Hatch 1993).

A variety of technologies is employed to remove FM from non-source separated feedstock. Density separation and destoners are designed to remove material with a higher or lower density than the organic aggregates. Ferrous and eddy current magnetic separation removes ferrous and non-ferrous metals, while debaggers remove the polyethylene bags that contain the MSW (Purman 1998). It stands to reason that particles with a similar size, shape, and magnetic properties as organic matter are the most problematic to remove from the compost. Despite the compost refining technologies, le Bozec and Resse (1987) found that 28 to 43% inerts (dry wt) can remain in the compost at the end of the process, with stones and non-biodegradable fines <2mm making up 75% of the total mass of inerts.

MSW composting facilities must take care to create a product that provides agronomic benefits while meeting consumer expectations (Hyatt 1995). Therefore, it is of utmost importance that the MSW compost produced be of high enough quality to warrant consumer demand. FM in the final product is aesthetically displeasing and may pose concerns for the workers handling the product and the receiving ecosystems (Krause *et al.* 1996).

1.3 History of Municipal Solid Waste Composting

Composting of agricultural wastes has occurred throughout history from as long ago as the Greek and Roman civilizations (Epstein 1997). The emergence of large scale MSW composting occurred when scientific understanding of composting was in its infancy (de Bertoldi 1993a). First attempts did not optimize the microbial process as important parameters and effective compost recipes had not yet been identified. In fact, in the early 1930s there were debates on whether efficient microbial breakdown of feedstock was anaerobic or aerobic, and if thermophillic temperatures were an acceptable part of composting (Epstein 1997). Numerous scientific studies have laid the groundwork for the thermophillic, aerobic microbial process as composting is presently defined (Cardenas 1979, Epstein 1997).

One of the first facilities that produced non-source separated MSW compost on a large scale was located in the Netherlands, in 1932 (Epstein 1997, Oosthoek and Vam 1987). Using the Van Maanen process, refuse was piled in windrows and turned by overhead cranes to facilitate aeration. Trainloads of garbage were brought to a ramp and dumped to form the piles. The final product was screened to create several different grades of compost. This method of dealing with refuse grew in the Netherlands until approximately one-third of all MSW produced was managed by two large-scale composting plants (Epstein 1997). Throughout Europe, composting MSW became more common after World War II; the number of facilities creating non-source separated MSW compost increased and peaked in the 1960s (Brinton 2000, de Bertoldi 1993b).

Questions arose over the heavy metal concentrations and levels of FM in non-source separated MSW compost, and resulted in negative public perception of compost (Brinton 2000, de Bertoldi 1993b, Golueke and Diaz 1995). Plant operators discovered problems with removing non-biodegradable materials after they had been mixed during processing (de Bertoldi 1993b, de Blignieres 1987). Because of these aesthetic and environmental concerns, many facilities experienced difficulty in marketing the final product and shut down as they could not recover their capital costs (Golueke and Diaz 1995, Kashmanian and Spencer 1993). At present, there is approximately a 50% decline in the number of facilities found in Europe compared to the number operating in the 1970s (Brinton 2001).

The present trend in some European countries is to compost source separated wastes, or biowastes, as there are fewer concerns with product quality. In Spain, the contamination of the final product associated with polyethylene plastic bags encouraged facilities to accept only source separated wastes in biodegradable bags (Herbolzheimer and Colom 1999). One region passed a law in 1993 that source separation and treatment of all organic MSW was mandatory for towns with a population greater than 5000 people (Herbolzheimer and Colom 1999). This has increased the growth of composting plants in Spain, with 30 more proposed plants in 1999.

Both Europe and North America followed similar patterns in their development of compost technology (Golueke and Diaz 1995). Within North America, municipal waste managers compost urban refuse despite the fact that compost facilities must compete with the relatively inexpensive tipping fees at landfills. In the United States, MSW composting was not common until legislation and economic conditions made composting an attractive alternative to landfills (Renkow and Rubin 1998). New MSW composting facilities were created in the 1960s throughout North America. High quality processing plants were expensive to create, and not all plants were designed to maximize the removal of inert particles (Golueke and Diaz 1995). Bans on landfilling yardwaste encouraged the growth of yardwaste composting facilities, while biosolids research in the 1970s aided the growth of biosolids compost facilities (Epstein 1997). However, in 1994, a waste flow control law was appealed at the U.S Supreme Court, and facilities in that country were no longer guaranteed a constant volume of feedstock. Instead, waste managers were encouraged to haul MSW long distances to landfills with low tipping fees (Satkofsky 2001).

As in Europe, some of the facilities failed to produce compost of high enough quality to be readily accepted in the marketplace. Many of these facilities failed because of the economic pressure to compete with the price of landfilling, and the difficulty with marketing the final product to recover capital costs (Brinton 2000, Golueke and Diaz 1995). Even if MSW compost was able to meet local restrictions for FM and heavy metals, the public's perception was that MSW compost was of poor quality, and could potentially harm the soil (de Bertoldi 1993b). According to a 2001 MSW composting projects survey, there are presently 16 facilities operating in the United States, and seven more projects being implemented (Satkofsky 2001). Five of the present facilities accept source separated MSW, while the rest accept mixed MSW.

Large-scale MSW facilities also exist across Canada. In 1993, only 2 facilities composted non-source separated MSW and both facilities were located in Quebec (CCC 1993). By 1994, approximately 300,000 metric tonnes of organic material were composted annually in 137 facilities, and 12 were located in Alberta. A 1999 survey found that the number of facilities increased to over 300 (Antler 2000). By the year 2000, the city of Toronto diverted 25% of their residential waste stream through organic recycling and composting programs, and planned to divert higher masses of waste by composting more MSW (Barrett 2000a). In Canada, the volume of waste composted has increased to 1.65 million metric tons annually (Antler 2000). As illustrated by these figures, composting will continue to play an important role in waste management.

As seen in other countries, some compost facilities in Canada are also moving towards source separation to increase the quality of their compost. For instance, the province of Prince Edward Island is following an integrated waste management plan that encourages local residents to separate their waste into recyclables, organics, and trash (Barrett 2000b). With this strategy, they have diverted 65% of their MSW from entering the landfill. A similar program is found in Nova Scotia, where since 1998 there was a province wide ban on landfilling or burning organics. Within one year of implementing the ban, 44% of residential wastes were diverted from landfills. Local residents were provided with specially designed carts to collect the organic material. The participation rate has been positive: only 0.7% of the carts were returned by residents (Friesen 2000).

1.3.1 The Edmonton Waste Management Centre

The Edmonton Waste Management Centre (EWMC) is responsible for managing

225,000t of waste annually (Edmonton Waste Management 1999). To decrease the amount of waste entering the local landfills, this municipality uses a multi-pronged approach. They use an integrated waste management program, including recycling, ecostations for hazardous wastes, extensive education programs, and co-composting of MSW and biosolids. The present waste management strategy of composting non-source separated MSW was adopted on the basis of economics and user acceptance. A Blue Bag Recycling program collects recyclable materials separately from the residential MSW collection, and processes them in a Materials Recovery Facility, rather than the co-composter. These integrated programs decrease the volume of non-biodegradable and hazardous waste that is sent to the co-composter. As a result of these initiatives, approximately 70% of residential MSW is diverted from the landfill.

The EWMC opened the co-composter in March 2000. This facility covers an area of 23,000m^2 and is capable of processing 200,000T of MSW and 100,000T of biosolids annually. At present, the co-composting facility produces 125,000T of compost per year. When yard waste is plentiful, the co-composter relies solely on MSW to provide the appropriate C/N ratio. When the C/N ratio of the MSW is too high to successfully compost the refuse, dewatered biosolids are added to increase the nitrogen levels. The resulting material is marketed as a soil amendment to be used in horticulture, home gardens, and agriculture.

The co-composting facility is capable of producing Type A and Type B compost (see section 1.4.2), depending on the composition of the feedstock. The plant is designed to remove the maximum amount of non-biodegradable material from the final product through a variety of technologies. First, the waste is collected from households and dumped at the tipping floor. Workers remove large, non-compostable items before the remaining material is fed into mixing drums. The retention time of the drums is 24h. The mixture is then screened to remove all material greater than 80mm, and ferrous metals are removed using an electromagnet. The remaining feedstock is moved on conveyor belts to the aeration hall, where it is turned regularly and gradually moved across the hall. The compost remains in the aeration bays for 14 to 28 days.

After the aeration hall, the compost is moved out to be refined. A trommel screen removes all particles greater than 25mm. Destoners separate the material into three different waste streams. High density and heavy particles like glass shards and stones are residuals, and are landfilled. Light density plastics, dust, and foil are separated into the light fraction. Compost is guided to the third stream. The light fraction is further refined into material greater or less than 10mm. All material that is smaller than 10mm is returned to the compost stream, while the larger objects are landfilled. The compost stream is then processed through an eddy current magnetic separator to remove non-ferrous metals. The compost is moved to curing piles, where it is stored until deemed mature by CCME standards (CCME 1996) and further refined with a ball screener; it is then ready to be marketed as a soil amendment.

1.4 Foreign Matter/Inerts

Foreign matter (FM), or inerts, is material that is undesirable in the final product from composting mixed MSW. FM refers to inert, non-biodegradable material that is resistant to microbial degradation. The different types of FM include glass, plastic and metal. Stones and naturally formed non-biodegradable substances may or may not be defined as foreign matter depending on the regulating agency and country.

Generally, the amount of FM is determined by the mass of non-biodegradable material found in the "overs" at a specified screen size, expressed as a percentage of that fraction of compost (Brinton 2000, Brinton 2001, de Blignieres 1986). Several acceptable methods exist for determining the level of FM in a compost sample. Most procedures include drying a mature compost sample, sieving the material, and sorting the "overs" from a specified sieve size. The percent FM is then determined by the following formula:

$$\%FM = \left(\frac{FM_{drywt}}{FM_{drywt} + Compost_{drywt}} \right) \times 100 \qquad (1.1)$$

FM may be difficult to see when it is mixed with organic material, so Brinton and Evans (2002) recommend wet sieving compost samples to make the FM more visible, and to use polarized light microscopy to aid in the detection of smaller particles. Le Bozec and Resse (1987) used a methodology that includes soaking the compost in sodium hypochlorite solution to remove organic material, followed by density separation to characterize the type of FM. German standards also require a surface area estimation of the FM contamination to measure the visibility of the FM in the compost (Brinton and Evans 2002).

Composting concentrates the organic matter fraction, so immature compost will contain lower levels of FM than the same material that has degraded to maturity. Craul and Switzenbaum (1996) recommend that FM should not be visible, and should not exceed 1% dry weight of the cured compost. Other proposed limits can be found in de Bertoldi (1993a), who divided FM into categories. He recommended maximum levels of glass ranging from 0.1 to 3% dry wt, and plastic particles from 0.2 to 1.6%.

1.4.1 International Standards

Compost standards and voluntary guidelines are a reflection of the available technology, political climate, social and environmental concerns, and scientific research available during the respective time period (Bidlingmaier 1993, de Bertoldi 1993a, Epstein 1997). Countries vary in their compost standards but there are some main trends evident when examining different international standards (Table 1-1). Safety, stability, heavy metal content, and FM content are the key parameters measured to assess compost quality (Brinton 2000). Both voluntary and mandatory standards exist for many countries, with a trend towards clean, source separated compost. Many countries include stones and naturally occurring materials in a separate category, as a type of inert material restricted by an additional limit.

TABLE 1-1.

International Foreign Matter Standards.

Country*	FM limits	Stones
Australia	• FM < 0.5% dry wt for compost fraction >2mm	• Mass < 5% of compost fraction > 5mm
Austria	• FM < 2% dry wt for compost fraction >2mm	• Mass < 3% of compost fraction > 11mm
Belgium	• FM < 0.5% dry wt for fraction >2mm • No visible contaminants	• Mass < 2% of compost
France	• Maximum 20% dry wt • FM < 6% for fraction > 5mm	• No specified limit
Germany	• Free of FM: <0.1% dry wt • Relatively free of FM: <0.5% dry wt • Moderately contaminated: >0.5% • Very significantly contaminated: >2%	• Mass < 5% of compost fraction > 5mm
Italy	• FM < 3% of total compost	• No specified limit
Netherlands	• FM < 0.5% dry wt for fraction > 2mm	• Mass < 3% of compost fraction < 5mm
Spain	• "free of contamination"	• No specified limit
Switzerland	• FM < 0.5% dry wt for fraction > 2mm • Plastics < 0.1% dry wt	• Mass < 5% of compost fraction > 5mm
United Kingdom	• FM < 1% dry wt for fraction > 2mm • Plastics < 0.5% dry wt	• Mass < 5% of compost fraction > 2mm
United States	• No specified limit	• No specified limit

*For Canadian standards, see Table 1-2, pg. 17.

1.4.2 Canadian Standards

Within Canada, there are presently three different agencies that define guidelines for FM levels in compost. These guidelines range from voluntary standards to legislation specifying grades of compost and their suitable applications. The Canadian Council of Ministers of the Environment (CCME) guidelines define FM as material that matches all of the following criteria (CCME 1996):

- any matter over a 2 mm dimension
- results from human intervention
- organic or inorganic constituents such as metal, glass and synthetic polymers (e.g., plastic and rubber)
- excluding mineral soils, woody material and rocks

The Fertilizers Act regulates products that are sold as soil amendments or fertilizers, and is administered by the Canadian Food Inspection Agency (CFIA). This act is valid for regulating compost sales if the compost is sold as a plant nutrient or soil supplement to create more favourable soil conditions for plant growth (Antler 1997). Also, the compost is subject to regulation under the Fertilizers Regulations, where the compost must not contain, "any substance in quantities likely to be generally detrimental or seriously injurious to vegetation (except weeds), domestic animals, public health or the environment when used according to directions". Therefore, compost may not contain any FM that would be considered hazardous to the workers handling the product, and not cause any foreseeable environmental problems.

The Bureau de normalisation du Québec (BNQ) has developed consensus standards that are accredited by the Standards Council of Canada (CAN/BNQ 1996). These standards are designed to build consumer confidence in the quality of products produced in Canada, and to help them compete in national and international markets. The standards grade compost based on a variety of criteria, including heavy metals content, percent weight of FM, and size of FM. These grades are designated: Type AA, type A, and type B. Type B is considered the minimum acceptable grade for good quality compost (Antler 1997). The differences in the three grades are the different allowable concentrations of FM and trace elements (Table 1-2). Compost not conforming to these standards will not be certified by the BNQ standards.

The CCME guidelines for compost quality preclude compost from containing any sharps greater than 3mm in any dimension, and no FM greater than 25mm in any dimension (CCME 1996). Despite meeting product quality criteria, the compost may still contain FM that could result in decreased aesthetic appeal, become a hazard to people handling the compost, or a potential threat to receiving ecosystems. The CCME guidelines specify two different grades of compost, Category A and Category B. Category A contains low levels of trace elements in the compost and can be used for a wide variety of applications, while Category B is allowed to contain slightly higher levels of trace elements but is restricted in use; this may be controlled by provincial or territorial regulations (Antler 1997).

TABLE 1-2.

Summary of Canadian Foreign Matter Standards.

Regulating Agency	FM limits
Canadian Council of Ministers of the Environment	• Sharps < 3mm in any dimension • FM < 25mm in any dimension • At present, no weight restriction
Standards Council of Canada /Bureau de normalisation du Québec	• Type AA: < 0.01% dry wt, < 12.5 mm • Type A: < 0.5%, < 12.5 mm • Type B: < 1.5%, < 25 mm
Canadian Food and Inspection Agency	• Sharps < 3mm in any dimension

The CFIA classifies compost based on criteria for safe handling. It follows the 1996 CAN/BNQ limits for Type B compost for trace elements, maximum levels of pathogens, maturity levels, and limits the presence of sharp objects (Antler 1997, CCME 1996).

1.5 Potential Concerns Related To Non-Source Separated MSW Compost

By using a "cradle to grave" model, one can trace the fate of potentially troublesome compost feedstock to determine at what rate it may erode into the environment (Narayan 1993, Shimp 1993). If MSW compost is applied to agricultural areas or other lands, the FM present in the compost will become part of the soil ecosystem. This will expose plant life, soil mesofauna, and other organisms to the FM. Once applied to agricultural soils, the FM in compost would be subject to the same erosive forces as the soil aggregates themselves. These particles are subject to wind and water erosion, soil mixing from agricultural practices, and movement from soil mesofauna. These erosive forces could move FM particles into the surrounding environment.

Little data exist on the impact of non-biodegradable materials eroded in the ecosystem, so present knowledge is limited to anecdotal evidence and reports of troublesome plastic debris in marine ecosystems. Hoitink (2001) reported concerns with FM particles from MSW compost that moved from agricultural fields, causing blockages to irrigation pipes and eventually collected on nearby water bodies. For plastic eroding into the environment, a key concern is that organisms may ingest the material (Curlee and Das 1991, Krause *et al.* 1996). Ingestion of small polyethylene pellets and styrofoam beads by marine animals can result in intestinal blockages or nutrient deficiencies, as the animal may cease eating because of the false feeling of satiation. Other potential concerns include intestinal ulceration and intestinal injury (Curlee and Das 1991).

Organisms known to consume plastic particles include birds, mammals, and turtles (Bjorndal *et al.* 1994, Robards *et al.* 1995). Birds have been found to ingest plastic pellets ranging from 0.5 to 28mm, primarily consuming particles from 3.5 to 4.5mm (Robards *et al.* 1995). The likelihood of an animal mistaking a plastic particle for a prey item is linked to the animal's normal feeding behaviour. If the debris resemble an organism's food, or if the particles become covered with natural prey items, the organisms are more likely to ingest the material. For example, marine birds that feed by skimming food particles floating on water could ingest drifting plastic particles (Curlee and Das 1991, Robards *et al.* 1995). Similar feeding behaviour can be observed in animals frequenting inland lakes, so similar concerns are realistic if plastic pieces of FM move to these wetlands. It is important to also note that economic losses have been measured for marine environments that were contaminated with plastic, for both the cost of cleaning up the area and from the lost tourism (Ballance *et al.* 2000, Ryan 1996).

Even if the FM particles do not migrate from the original area of application, large volumes of sharps could be a potential hazard to workers handling the material and animals feeding in the amended sites. For example, it has been reported "We have had a few cases where lawns glistened because of the amount of glass in compost applied to the soil" (Anon 1997). Such large volumes of glass would undoubtedly be a potential hazard and aesthetically unpleasing to the consumer.

Despite these concerns, some research points to MSW compost as an environmentally friendly method of disposing of non-biodegradable material/mixed waste to decrease pressure on landfills (Wolkowski 1996, 2002), so long as the application rates do not exceed 17.8T ha^{-1} (40t ac^{-1}). Using mature MSW compost containing FM levels of 13.4% glass, 3.1% plastic, 0.5% metal, and 1.7% other, Wolkowski (2002) found no detrimental impact on corn yields or other environmental concerns despite the high levels of FM. However, the report recommends reducing the level of glass to increase compost quality.

Preliminary field trials of the EWMC compost demonstrated a positive crop response to MSW compost applications on local sites of poor quality agricultural soil.

These trials evaluated crop growth and nutrient uptake following compost applications of 50 to 200T ha^{-1}, and measured substantial increases in wheat, barley, and canola yields at a financial benefit to the farmer (Zhang *et al.* 1999, 2000). Furthermore, the compost continued to provide agronomic benefits for the crops planted the next year (Zhang *et al.* 2000). This is in agreement with Dick and McCoy (1993), who determined that compost can be utilized as a soil amendment to enhance agricultural soil quality and generally have a positive influence on plant growth.

No amount of screening or presently known technology can completely remove all FM particles from mixed MSW compost (Brinton and Evans 2002, de Blignieres 1986). Compost producers have found two key problems when dealing with the non-biodegradable materials: some FM, like plastic film, can clog up machines and cost money from the "down time" of the equipment (Gamble 2000). Furthermore, the presence of the visible inert materials decreases compost quality due to its lower marketability (Bidlingmaier 1993, de Bertoldi 1993a).

1.6 Summary

Whatever impacts the FM particles in MSW compost may have, they can be expected to occur over a long term. FM particles like polyethylene and polystyrene plastics are extremely slow to degrade and will persist in the receiving ecosystems long after the original application of compost (Ohtake *et al.* 1998). In hindsight, if there are environmental problems, there are obvious difficulties in collecting FM particles once they have entered the environment.

Composting reduces the amount of biodegradable waste entering landfills by recycling organics into a marketable product. This has made MSW composting become increasing popular as a form of waste management (Sequi 1995). MSW compost quality is correlated with the amount of non-biodegradable material in the feedstock. The actual environmental concerns related to the compost may be real or perceived by consumers. In either case, FM in non-source separated MSW compost reduces the marketability of the product and poses a challenge for compost producers.

Some differences exist between FM standards in different countries, and even different regions within a country. It is important to note that the variation in standards has led to uncertainty and hesitancy in buyers, as they are not certain as to what standards are needed for high quality compost, thereby limiting the growth of the industry (de Bertoldi 1993b).

For the long term success of MSW composting as a waste management strategy, consumers must purchase the final product, and feel assured that MSW compost will increase the soil's productivity, foster plant growth, and have no detrimental environmental impacts. Therefore, it is imperative to have an understanding of what is contained in the final product and what implications it may have for the soil environment.

This study examined the type and mass of FM found in EWMC compost, and determined the behaviour of the FM particles under simulated runoff conditions with an intense rainfall rate. Size and type of FM content were measured in compost samples to determine the mass fractions of each category. Although FM is traditionally defined as material over 2mm (CCME 1996), inorganic manmade material from 0.5 to 2mm was also included in the analysis. The movement of FM was measured in soil topdressed with compost, and in compost/gray luvisolic soil mixes.

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CHAPTER 2

Compost Analysis

2.1 Introduction

The City of Edmonton, Alberta, Canada is composting residential municipal solid waste (MSW) and sewage treatment biosolids as an alternative to landfilling the material. Through an aerobic microbial process, the biodegradable organic matter is converted to chemically stable humus that can be utilized as a soil amendment to enhance agricultural soil quality and generally have a positive influence on plant growth (Dick and McCoy 1993). The Edmonton Waste Management Centre (EWMC) presently produces 125,000T of compost per year. Local residents collect recyclables separately for the Blue Bag Recycling program, and this waste is processed in a Materials Recovery Facility. The remaining residential MSW is treated in the co-composter. The present waste management strategy of composting non-source separated MSW was adopted on the basis of economics and user acceptance.

Foreign matter (FM), or inerts, is undesirable material remaining in the final product that results from composting mixed MSW. FM refers to inert, non-biodegradable particles that are resistant to microbial degradation. The different types of FM include glass, plastic and metal. Stones and naturally formed non-biodegradable substances may or may not be defined as FM depending on the regulating agency and country.

According to Canadian regulatory agencies, FM is defined as "any matter over a 2mm dimension that results from human intervention and having organic or inorganic constituents such as metal, glass and synthetic polymers (e.g., plastic and rubber) that may be present in the compost but excluding mineral soils, woody material and rocks." (CAN/BNQ 1996). Present Canadian guidelines for compost quality preclude compost from containing any sharps greater than 3mm in any dimension, and no FM greater than 25mm in any dimension (CCME 1996). Despite meeting product quality criteria, the compost may still contain FM that could result in decreased aesthetic appeal, become a hazard to people handling the compost, or a potential threat to receiving ecosystems.

This study was designed to compare the type and mass of FM found in two treatments of cured EWMC compost. Size and type of FM content were measured in compost samples to determine the mass fractions of each category. Although FM is traditionally defined as material over 2mm (CCME 1996), manmade material from 0.5 to 2mm was also included in the analysis.

2.2 Materials and Methods

2.2.1 Description of Composts

The composts in this study were created from MSW and yard waste collected in the early spring of 2000 from single family dwellings and processed through the co-composter at the EWMC (see section 1.3.1). Although a full waste sort was not done to characterize the feedstock, an approximation of starting materials was deemed close to a winter sort of Edmonton MSW for single family dwellings from 2001, as listed in Table 2-1 (Schubert 2001).

At the EWMC, several procedures were followed to decrease the level of contaminants remaining in cured compost. Residential MSW was collected and deposited at a tipping floor, where it was hand sorted to remove large non-compostable items. During the composting, the remaining material was further refined by trommel screens, destoners, eddy current, and magnetic separators; the rejected particles were recycled or landfilled. After processing, the refined compost was piled in windrows and cured, where it was monitored for biological activity based on pile temperature readings until considered mature. The compost was then suitable to be marketed as a soil amendment.

TABLE 2-1.

Waste sort for single family dwellings in Edmonton, winter 2001 (Schubert 2001).

Material	Percent by Mass	Potential FM
Paper	20.56	0.39[1]
Food	37.59	0
Other Organics	15.37	0
Yard Wastes[2]	0.70	0
Metal	2.95	2.95
Aluminum	0.89	0.89
Glass	5.15	5.15
Plastics	8.66	8.66
Textiles	1.62	1.62
Other wastes[3]	5.31	2.46
Household Hazardous Wastes	1.20	0
Total	100	22.12

[1] Plastic coated paper
[2] Mass higher during summer months
[3] Carpet and construction demolition

This study compares two treatments of cured EWMC compost that originated from the same waste feedstock. One batch of compost was collected directly from the curing pile and is referred to as unscreened compost (UC). Another batch of compost was taken from the curing pile and subject to one more screening with a 18.75mm (0.75in) trommel screen (MCB 621R, McCloskey Bros, Peterborough, ON), producing screened compost (SC).

On April 16, 2001, 65L a composite sample of UC was collected from four randomly picked locations in the curing piles, including the surface and interior of the windrows. The compost sample was mixed with a shovel in a 76L plastic bin, where it was stored for the duration of the experiment at ambient room temperature (20°C). The compost had cured for over 12 months to assure biological stability. The same procedure was used to collect SC, which was taken from the same batch of original MSW in order to decrease variation due to the feedstock.

2.2.2 Compost Analysis

Four 500g samples each of UC and SC were oven dried for 24h at 65°C (Despatch Industries Ltd. Model V-31 Std, Style II, Mississauga ON, Canada) to determine initial moisture content (MC). To determine aggregate size distribution, dried samples were then run through a sieve shaker (Ro Tap, W.S. Tyler Company, Cleveland, OH) for 15min with 25mm, 12.5mm, 2mm screens, and a catch pan. The material remaining in each sieve was weighed to determine the total mass for each size fraction.

The percent and type of FM was measured for the UC and SC composite samples. Three 500g subsamples were taken from each of the storage bins. Each subsample was shaken in a 2L polyethylene bag, and then one 10g sample was collected from each bag for a total of three 10g samples for each of UC and SC. These samples were dried for 24h at 65°C. Each sample was placed in a 95mm diameter petri plate and hand sorted under a 20x light microscope (KYOWA Optical Co. Ltd., SD-2AL, Japan) to visually identify all FM fractions: plastic film, plastic chip, synthetic fibre, metal, and glass.

Since the visual identification of the FM particles was subjective, four different observers examined the EWMC compost to compare the ease of sorting FM from the humic material in the compost. The definitions of plastic chip, plastic film, metal, glass, and synthetic fibre were agreed upon. The categorization of small rocks posed some confusion, so the recommendations of the National Standards of Canada were followed, and rock and other naturally occurring materials were not included as FM (CAN/BNQ 1996).

A pair of forceps was used to collect the FM particles from the petri plate. Organic material adhering to the particles was gently removed by hand to avoid an inflated percent of FM. Plastic film and chips were further divided into the size categories of 0.5 to 2mm, 2 to 12.5mm, and 12.5 to 25mm. Material that was folded upon itself was not manipulated to determine its size if fully stretched. Material smaller than 0.5mm was not included in the analysis.

Any material that was shiny and metallic in appearance or resembled metal foil was classified as metal. Glass particles were translucent or clear, brittle, and had obviously sharp edges. Plastic film was particulate remnants of plastic bags, sheets, and wrap. As defined by Krause *et al.* (1996), film particles are generally flexible, translucent, and less than 0.05-0.8mm in width. Plastic chips have a more rigid structure, are generally opaque, and are greater than 0.8mm in width. Sponge like material was also classified as plastic chips. Synthetic fibres described all long, thin non-biodegradable particles with a constant diameter no greater than 0.10mm.

All fibres that were not earthy brown, had a constant diameter and shape from end to end, and over 1cm in length were considered synthetic or manufactured; both terms are used interchangeably throughout this report. Strands of fiberglass were included in this category. Due to the low weight of fibres, they were counted rather than weighed. Three fibre counts of three different $225mm^2$ areas were taken for each sample, and the average number of strands per gram of compost was determined. This average was then extrapolated for the entire area of the petri plate ($7087mm^2$). The diameters of fibres was determined at 100x magnification under a light microscope (Reichert, model 239 523, Cave and Company Ltd., Vancouver, Canada).

Chemical composition of plastic particle and fibre samples was determined through the Spectral Services & Microanalytical Laboratory (University of Alberta, Edmonton, Canada) using Fourier Transform Infra Red (FTIR) analysis (Nic-Plan IR Microscope, Nicolet Magna-IR Spectrometer, Model 750, Wisconsin, USA) and comparing their respective spectra using the Omnic computer-based search (Synthetic Fibers by Microscope 1991-1992, National Bureau of Standards Synthetic Fibers; Hummel Polymer and Additives 1989-1992, Nicolet Instrument Corp., Cologne, Germany). Manufactured fibres were also analyzed through solubility tests, as outlined in the Technical Manual of the American Association of Textile Chemists and Colorists

(AATCC 1988).

Due to the diversity of FM collected from both compost treatments, only the particles that appeared "common" were analyzed through FTIR and solubility tests. The particles were grouped together based on similarities in their appearance including texture, colour, thickness, and shape.

Field emission scanning electron microscopy (JEOL, JSM-6301FXV) was conducted for compost and fibre samples to obtain magnified images, and to find any evidence of degradation. Two aluminum stubs (12mm, pin type, Cambridge) were prepared for each compost treatment. Glue (Colloidal Silver Liquid, Ted Pella Inc., Redding, CA, USA) was applied to the surface of the stubs, and compost was sprinkled on the surface. Manmade fibres were collected from the compost and adhered to stubs with double sided carbon tape (STR Tape Paint Company). Particle elemental composition was confirmed using energy dispersive x-ray analysis (Princeton Gamma Tech Inc, NJ, USA). The operational parameters used included an acquisition time of 60s, accelerating voltage of 20kV, and a working distance of 12 to 15mm. The SEM and x-ray analysis was conducted at the Scanning Electron Microscope Laboratory at the Department of Earth and Atmospheric Sciences (University of Alberta, Edmonton, Canada).

According to American Society for Testing and Materials (Satkofsky 2002), plastics are biodegradable if they show evidence of intense microbial activity, and the material must physically and visually fragment while under conditions conducive to microbial growth. In this study any FM that was noticeable with the unaided eye, or showed no evidence of microbial activity under SEM analysis, was considered non-biodegradable.

2.2.3 Statistical Analysis

The compost subsamples were assumed to be representative of the composition of the original MSW compost. Physical differences in percentage FM between UC and SC were determined using a two-tailed t-test, with $p<0.05$ considered a significant difference, and $p<0.10$ deemed a statistical trend. The SAS proc glm procedure (SAS Institute Inc., Cary, NC, USA. 1999-2000) was used to analyze the data. Values are reported as means ± standard errors of replicated trials.

2.3 Results and Discussion

2.3.1 Compost Analysis

A significantly higher percentage ($p<0.05$) of SC was composed of aggregates ranging from 0 to 2mm when compared to UC (82.6 ± 0.1% and 78.0 ± 0.5%, respectively), measured on a dry weight basis. There was also a significant difference ($p<0.05$) between the 2 to 12.5mm size fractions, with the SC containing 17.3± 0.1% and the UC containing 20.6 ± 0.5%. For the SC, no aggregates were found in the 12.5mm screen, while the UC contained 1.2 ± 0.7%. The moisture content was not significantly different at 29 ± 0.5% and 30 ± 0.7% for UC and SC, respectively. A small percentage of material classified as plastic chips was sponge like in appearance, but too low to warrant an additional category of FM.

Visual inspection with the unaided eye confirmed the presence of synthetic fibres, plastic film and chips in both types of MSW compost (Figures 2.3-1 & 2.3-2). Metal and glass fragments were minute and not noticeable without the aid of a microscope. Particles composed of film plastic or metal foil were often folded upon themselves into an accordion shape, and were measured in that form. Therefore, the stretched length of the particles may have been larger than what was actually measured. This may cause some error in determining the mass of material for each size category, although the overall mass would be accurate. Although some aggregates were found to contain FM, the aggregates were not actively broken to search for all covered FM (Figure 2.3-3).

No differences were found in the percent mass fractions of FM for SC and UC, except for 12.5 to 25mm plastic film particles. UC was found to contain 0.209 ± 0.050%

of plastic film, while SC contained 0.013 ± 0.010% film. This suggests that the final screening process effectively removed film plastic over 12.5mm and large aggregates from the MSW compost. Both composts contained over 2% FM. A summary of all the FM found in the composts is provided in Table 2-2.

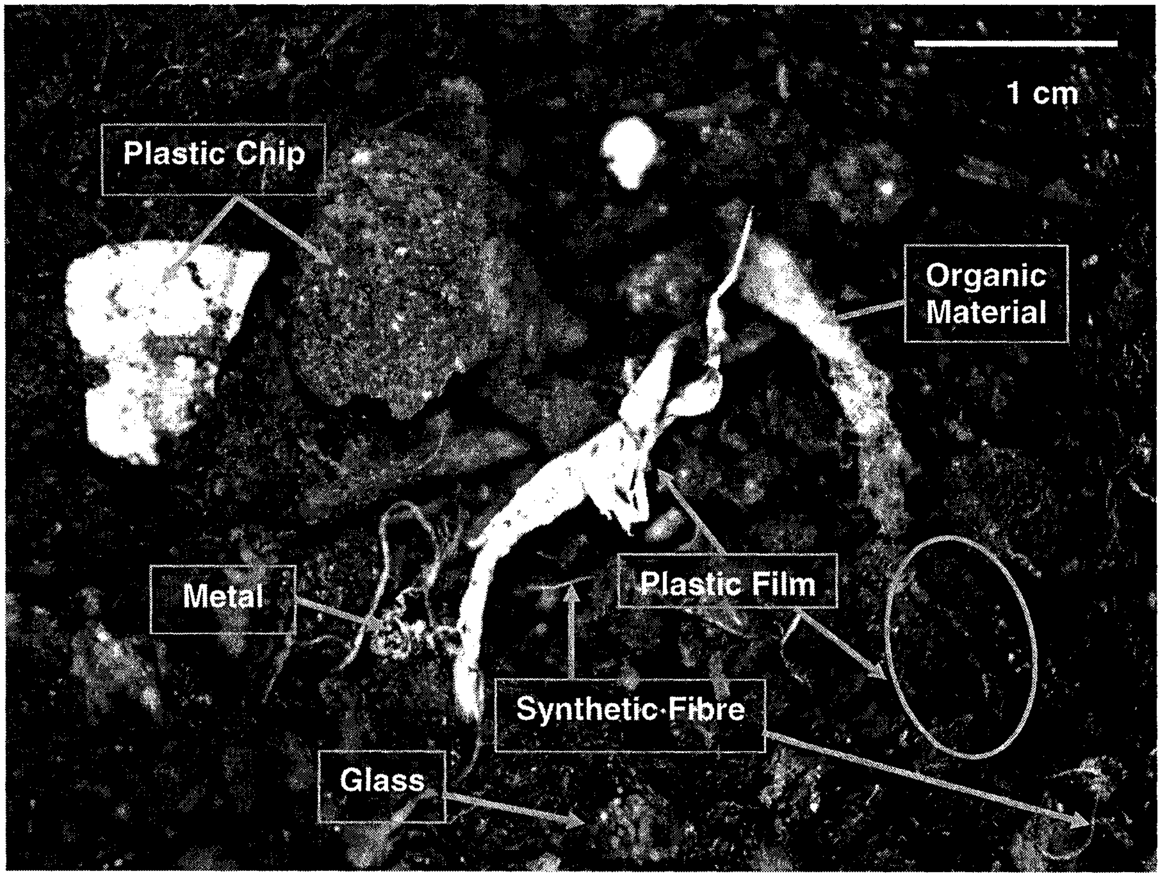

Figure 2.3-1. Examples of the different categories of FM found in the finished compost. This is a not a representative sample of EWMC compost.

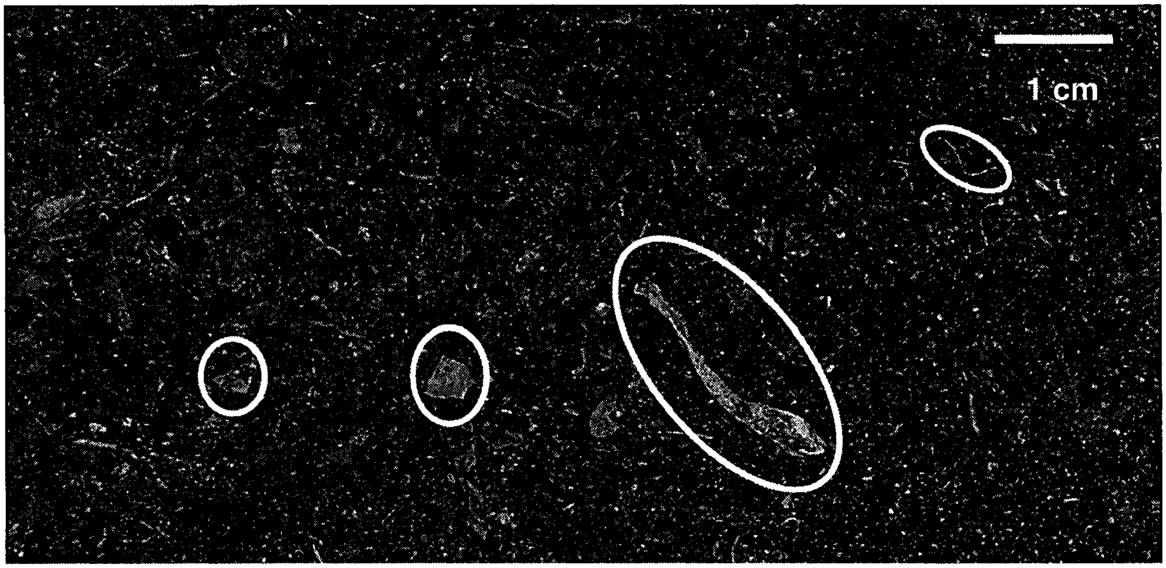

Figure 2.3-2. Cured compost from the Edmonton Waste Management Centre, with plastic film and chips apparent on surface.

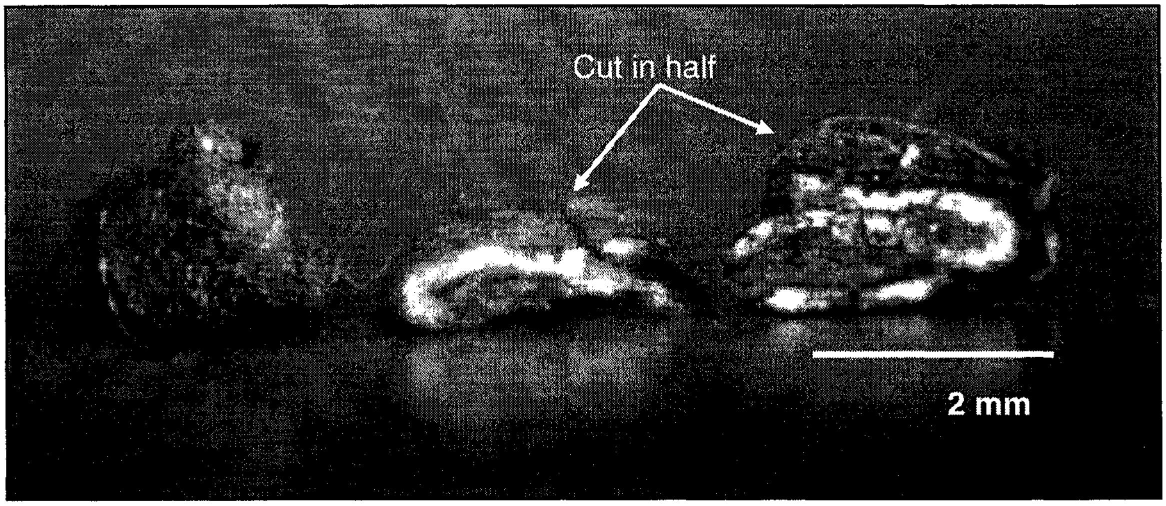

Figure 2.3-3. Close-up of plastic chip embedded inside an aggregate.

TABLE 2-2.

Mean percent ± standard error of foreign matter (FM) present in Edmonton Waste Management Centre compost, expressed as dry weight.

Type of Material	Percent Foreign Matter	
	Screened Compost (SC)	Unscreened Compost (UC)
Plastic Chips		
0.5 - 2mm	0.091 ± 0.018	0.074 ± 0.013
2 - 12.5mm	1.156 ± 0.280	1.421 ± 0.385
12.5 - 25mm	0.013 ± 0.008	0.008 ± 0.008
Plastic Film		
0.5 - 2mm	0.029 ± 0.014	0.002 ± 0.002
2 - 12.5mm	0.330 ± 0.023	0.393 ± 0.042
12.5 - 25mm	0.013 ± 0.010 b[1]	0.209 ± 0.050 a
Glass	0.456 ± 0.225	0.296 ± 0.035
Metal	0.081 ± 0.036	0.143 ± 0.068
Total FM	2.169 ± 0.114	2.425 ± 0.238
Synthetic Fibres*	18.2 ± 1.3	15.6 ± 1.2

[1] Means with different letters denote significant differences within FM category ($p<0.05$).

*Number of fibres per g compost, expressed as a dry weight basis.

2.3.2 Composition of Plastic Film and Chips

The greatest mass of FM present in both compost treatments was plastic chips that ranged in size from 2 to 12.5 mm, with 1.156 ± 0.280 and 1.421 ± 0.385% in the SC and UC, respectively. Low masses of plastic chips were also found in the larger and smaller size categories (Table 2-2); no significant differences were found in the percentages of plastic chips in the different compost treatments. The majority of these particles were opaque, light green in colour, flexible, and a minimum of 1mm in thickness, as measured under the microscope. All the plastic chip samples sent for FTIR analysis fit this physical description. The computer-based search comparing FTIR spectra identified these particles as polystyrene (Figure 2.3-4).

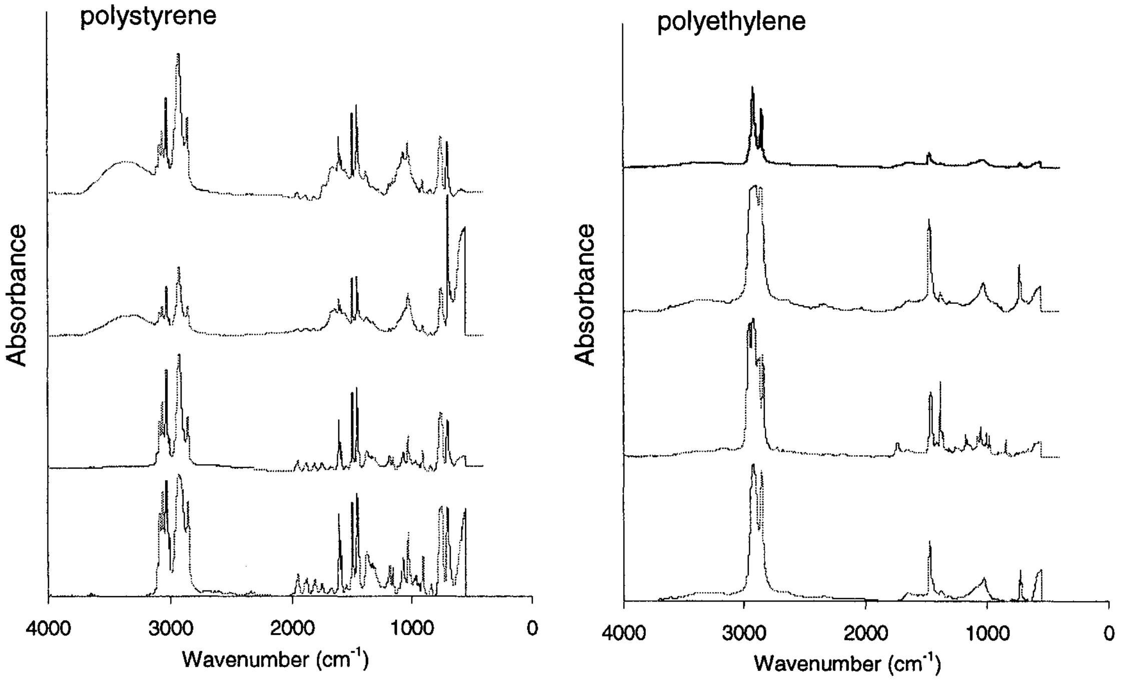

Figure 2.3-4. FTIR spectra for plastic chips (polystyrene) and plastic film (polyethylene).

Polystyrene was found to change its form during the initial stage of the composting process. After 24 to 36h in a mixing drum of the co-composter, a large piece of polystyrene appeared to have melted: it became smooth and rounded in form (Figure 2.3-5). Closer inspection revealed that the inside of the particle retained the typical "spongy" structure of packaging polystyrene, while the outer layer was greenish and hardened. The change may have occurred due to the heat and pressure from the feedstock in the digester, or perhaps due to non-polar chemicals that dissolved the surface of the polystyrene. From this observation, it is reasonable to assume other polystyrene reacted in a similar fashion from the composting process since no foam formed polystyrene was found as FM in either cured compost treatment. For comparison, a 50mm piece of polystyrene was placed in an oven at 65°C for 48h. This was to subject the polystyrene to temperatures similar to the internal temperature of the mixing drum at the EWMC. No visible changes were noted in the sample. Therefore, the polystyrene in the compost was likely changed from factors other than the temperature of the digester.

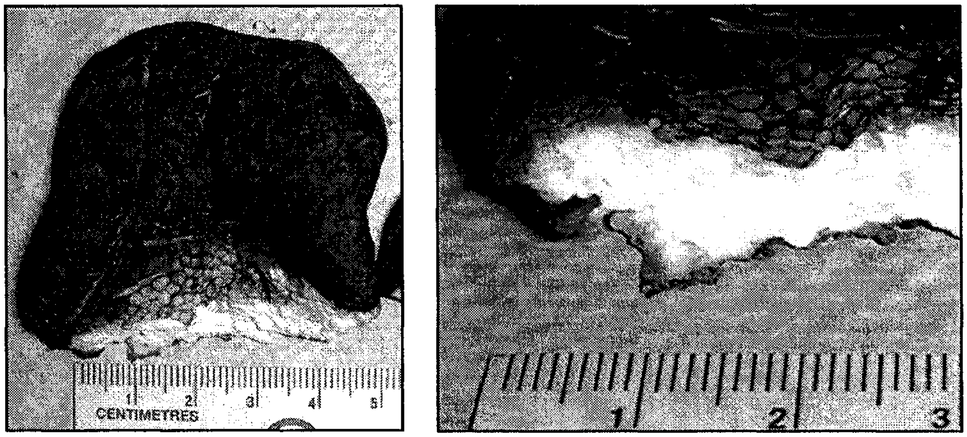

Figure 2.3-5. Polystyrene after 24-36 hrs in the beginning stages of the composting process.

The greatest fraction of plastic film was material that ranged from 2 to 12.5mm in length, with 0.330 ± 0.023 and 0.393 ± 0.042% in SC and UC, respectively. Although the percent of the material is low, the plastic film was thin and therefore covered a large surface area compared to the mass of the material; it was easily visible to the unaided eye, and could be an aesthetic concern to consumers (Figure 2.3-2). There was a significant difference ($p<0.05$) in the amounts of 12.5 to 25mm plastic film, with UC containing $0.209 \pm 0.050\%$ compared to $0.013 \pm 0.010\%$ in SC. It is evident that the final trommel screen was effective in removing larger pieces of plastic film from the compost.

FTIR spectra confirmed plastic film samples to be polyethylene, a material highly resistant to microbial degradation (Ohtake *et al.* 1998). Polyethylene is made of long, single bonded carbon chains. A high amount of energy is required to break the carbon backbone; microbes cannot easily degrade this material due to the large size of the molecules (Stein 1995). For instance, Ohtake *et al.* (1998) reported that a polyethylene bottle buried in microbial active soil for 37 years was still recognizable when unearthed, although there was some evidence of degradation of the surface of the bottle.

SEM micrographs can reveal physical evidence of microbial degradation by active microbial populations on the material in question (Krause *et al.* 1996). The SEM images showed little evidence of microbial activity on the polyethylene film (Figures 2.3-5a &2.3-5b), and the surface appeared smooth. There was no evidence of any form of degradation of the film. No microbial activity was evident for the sponge material in Figures 2.3-5c & 2.3-5d, although the cracked surface may be due to weathering or mechanical breakdown of the material. Figure 2.3-5e shows a different sponge-like particle with some bacteria present on the surface. In comparison, biodegradable debris like plant material had an abundance of microbial activity including bacteria and actinomycetes (Figure 2.3-5f); similarly thriving populations were not found on the FM particles.

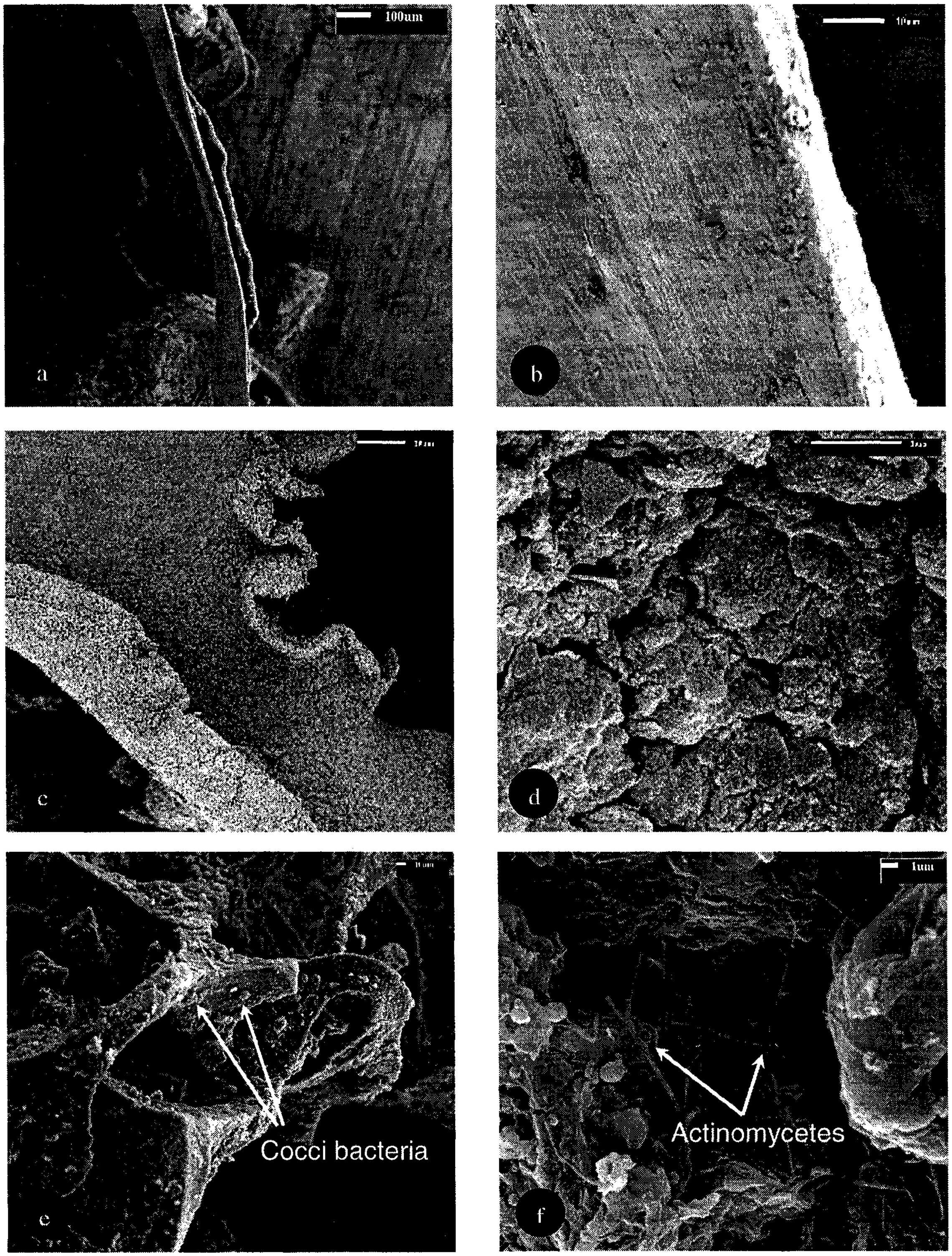

Figure 2.3-5. SEM micrographs of (a) plastic film (b) close up of plastic film, with no evidence of microbial activity, and (c) sponge material with no microbial degradation, (d) close up of sponge (e) sponge with some microbial activity and (f) actinomycetes and cocci bacteria degrading plant material.

Elemental analysis of the sponge material from Figures 2.3-5c & 2.3-5d shows it is composed of silicon, magnesium, calcium, and potassium. This is in comparison to the elements found in plant material (Figure 2.3-6). Soluble salts in the compost may adhere to other particles, so the high concentration of chloride ions found in the plant residue may be contamination from the compost feedstock.

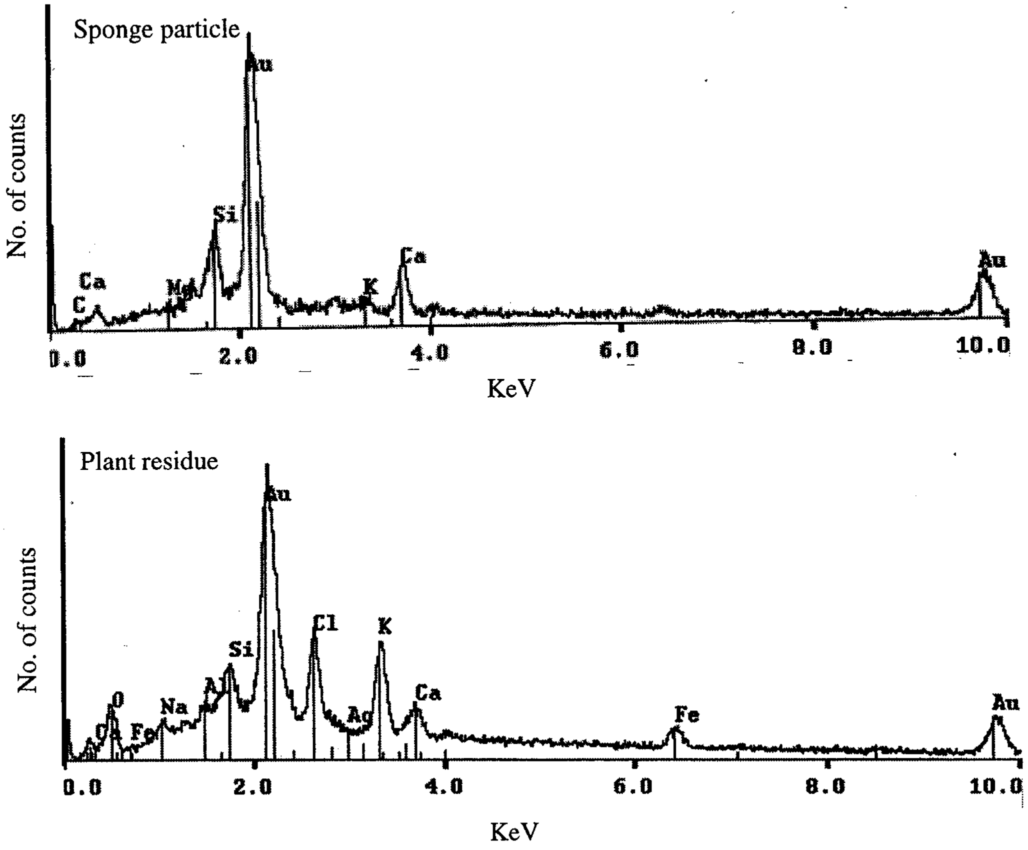

Figure 2.3-6. Elemental analysis of sponge material and plant residues remaining in Edmonton Waste Management Centre compost.

2.3.3 Composition of Synthetic Fibres

Synthetic and naturally formed fibres were common throughout both compost treatments (Figure 2.3-7). The SC contained 18.2 ± 1.3 strands of fibre per gram compost (dry wt), while UC contained 15.6 ± 1.2 strands. Three basic shapes were found: round, trilobal, and bilobal (Table 2-3). Round, colourless fibres (Table 2-3, Figure 2.3-8a) appeared to be the most common throughout the compost. Some strands had a distinctive flattened spot (Figure 2.3-8b) as seen in fibres that are heat annealed to create a plastic "sheet", as the material found in diapers (Brinton and Evans 2002, Hatch 1993). Trilobal nylon fibres are commonly found as face fibre in carpets and rugs, with some use in apparel and industrial textiles (Hatch 1993). These fibres were approximately twice as thick as the bilobal and round fibres, and were easily found under the light microscope at 20x (Table 2-3). An example of a less coarse trilobal fibre from the compost is seen in Figure 2.3-8c. Bilobal and round fibres are common in textiles and other applications (Hatch 1993). These fibres are smaller in diameter than the trilobal, but could also be easily seen with the aid of a microscope.

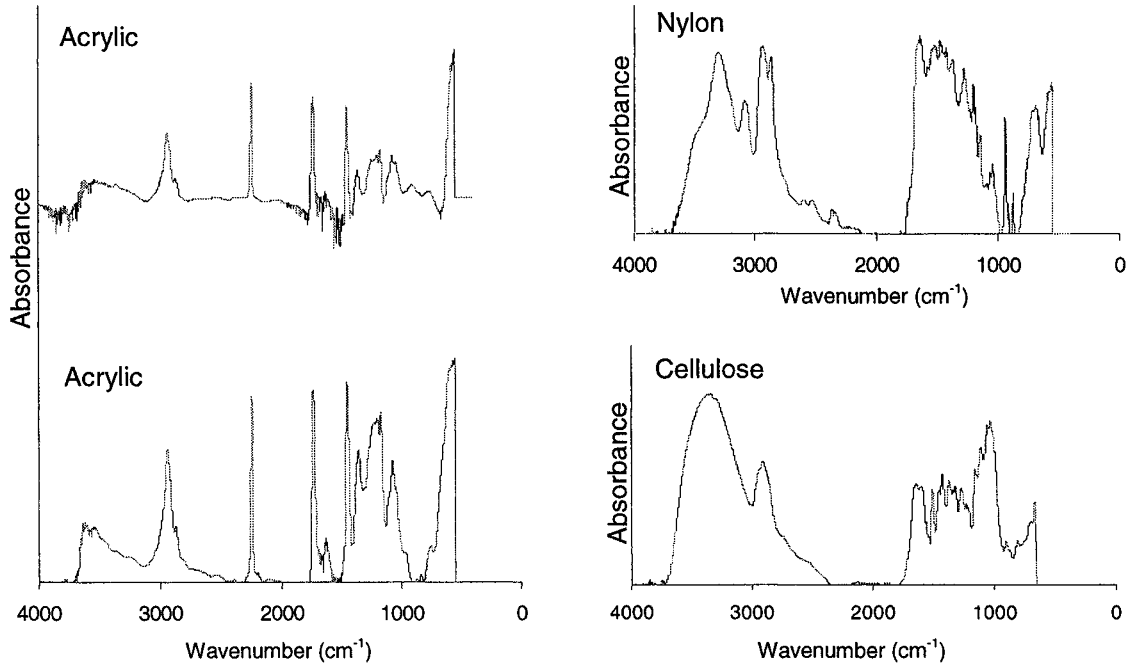

Figure 2.3-7. FTIR spectra from various fibres found in the compost.

Solubility tests confirmed a minimum of three different types of fibres remained after the composting process: polyester, nylon, and acrylic (Table 2-3). Since a limited number of strands were analyzed, a larger diversity of synthetic fibres may have been present in the compost.

Table 2-3.

Mean diameter ± standard error of synthetic fibres analyzed in solubility tests.

Description of Material	Diameter (μm)	Composition
Flat strand[1]	140	polyester
Trilobal	59.5 ± 7.7	nylon
Bilobal, reddish	25	acrylic
Smooth, round, colourless	33.1 ± 6.2	polyester

[1] Diameter greater than defined for fibres.

Polyester is the most common manufactured fibre in production, and is used primarily in apparel, and industrial and consumer textiles; it is understandable that polyester fibres were common in the compost (Hatch 1993). The chemical structure of polyester can vary, but by definition it is a long chain, synthetic polymer that must contain "at least 85% by weight of an ester of a substituted aromatic carboxylic acid" (Hatch 1993). The chemical components of polyester include methylene and carbonyl groups, ester links, and benzene rings. These chemical groups are biodegradable, but polyester fibres are strongly hydrophobic; little moisture can adhere to their surface, making it difficult for microbes to create a biofilm and degrade the material. Polyester is also classified as highly resistant to degradation from ultraviolet light, and invertebrates. Therefore, the polyester fibres found in the compost will not easily degrade either during the composting process or after application to soil.

Nylon fibres were also prevalent in the compost (Table 2-3). These are most commonly used as face fibre in carpet, with many applications to industrial and consumer textiles, and apparel (Hatch 1993). Nylon has a variety of chemical structures, although nylon 6,6 and 6,10 are the most commonly used. It is defined as “any long-chain synthetic polyamide in which less than 85% of the amide linkages are attached to two aromatic rings”. The key chemical group is a polar amide group, and therefore is not hydrophobic. Nylon is not resistant to ultraviolet light, but is classified as resistant to microbial and invertebrate decay. The nylon fibres in the compost therefore would not degrade during the composting process, but can degrade if applied to agricultural soils where they would be exposed to UV light.

Acrylic fibres are commonly used for apparel, and are bilobal in shape, so they appear like a "dogbone" or kidney bean in cross section. These fibres are mainly used for apparel and household textiles, and are also considered highly resistant to microbial and ultraviolet degradation. The acrylic molecule contains one of the longest carbon backbones found in synthetic fibres, which makes it physically difficult for microbes to digest the material (Hatch 1993). The FTIR spectra of acrylic fibres (Figure 2.3-7) found in the compost show a functional group at the wavenumber 3600 cm^{-1}, suggesting that some of the fibres contained the co-polymer acrylic acid (Hatch 1993).

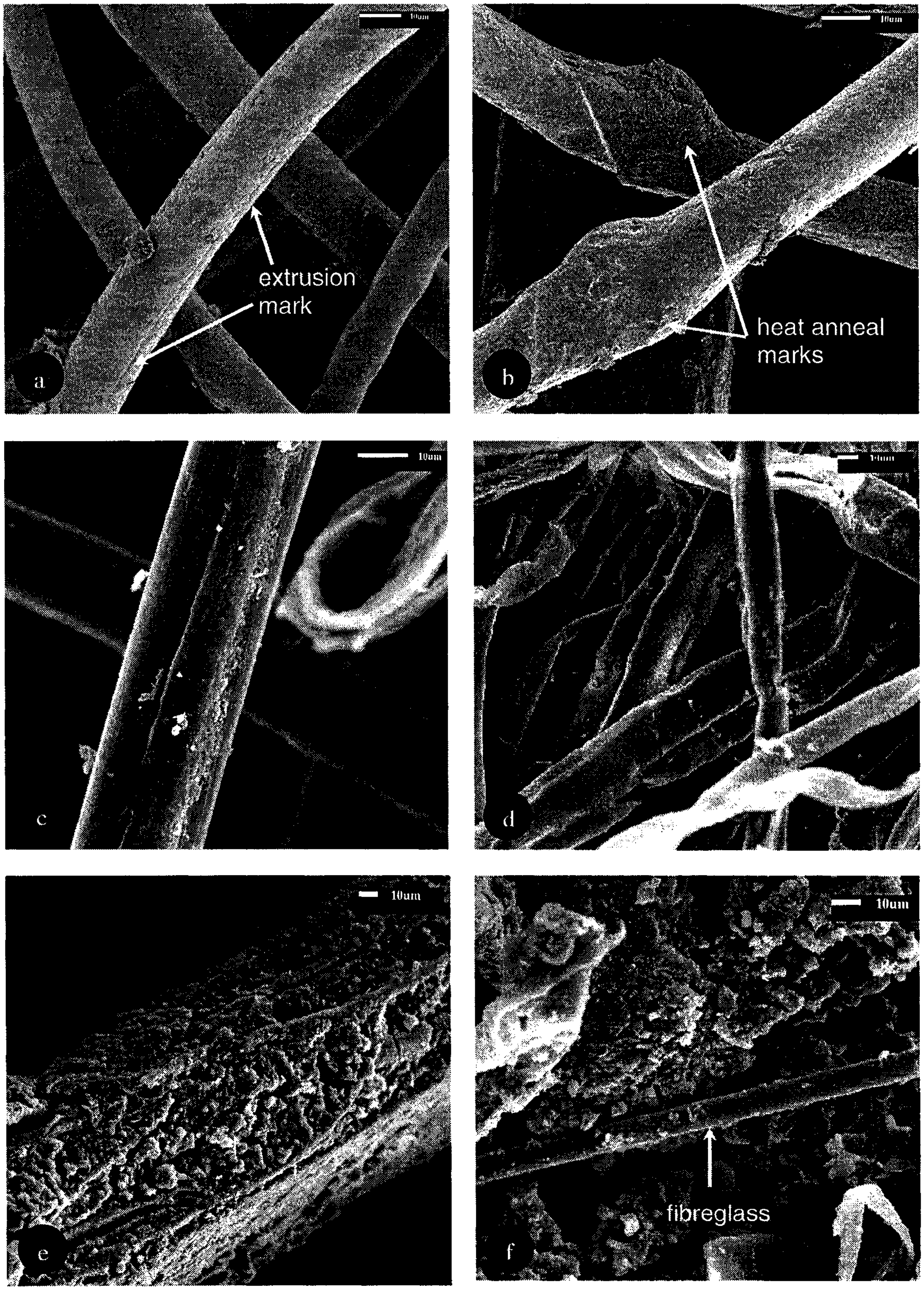

Figure 2.3-8. Fibres in compost (a) round synthetic, (b) round fibre with flattened points, (c) trilobal synthetic, (d) cellulose and lignin, (e) degraded plant material, and (f) fibreglass.

Earthy brown fibres (Figure 2.3-8d) in the compost were determined to be variants of cellulose and lignin (Figure 2.3-7), and appeared to be in various states of decay. Overall, the synthetic fibres found in the compost did not match the degraded appearance of plant tissue (Figure 2.3-8e) or naturally formed fibres (Figure 2.3-8d). Although fiberglass was not commonly found in the compost, it was seen under the SEM (Figure 2.3-8f).

X-ray analysis of various fibres confirmed the presence of fibreglass and synthetic fibres (Figure 2.3-9). The fibreglass was identified by the high amount of silicon. The synthetic fibre analyzed contained carbon and little else. The fibreglass was found to contain primarily silicon.

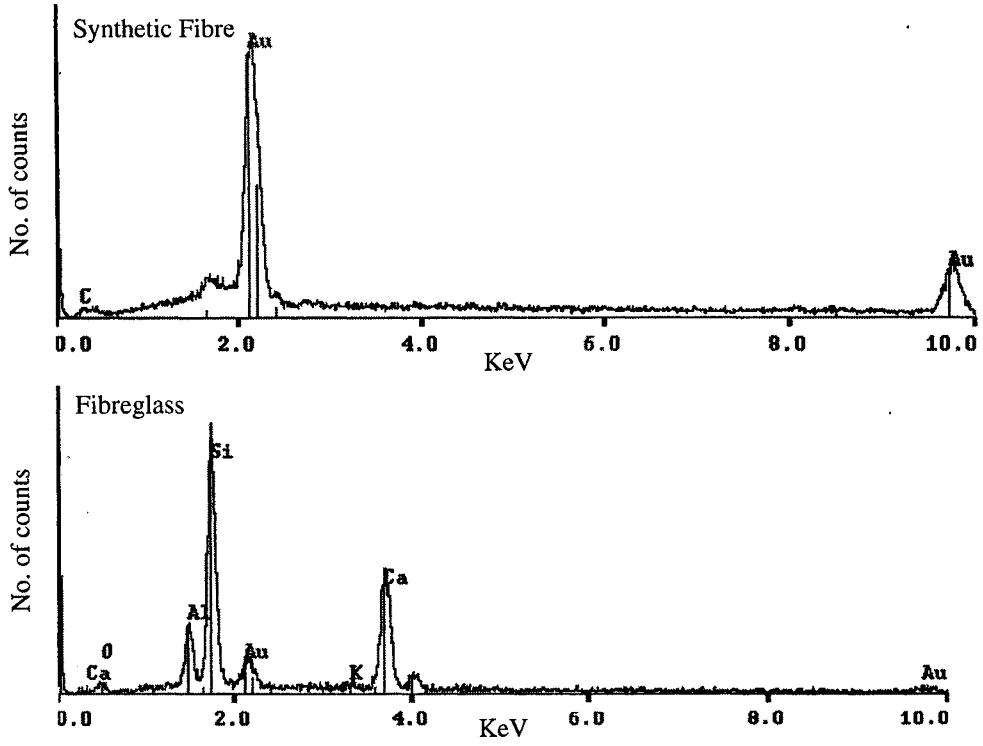

Figure 2.3-9. Elemental analysis of synthetic fibre and fibreglass found in Edmonton Waste Management Centre compost.

2.3.4 Metal

Although UC contained a higher percent of metal 0.143 ± 0.068% compared to 0.081 ± 0.036% in SC, there was no significant difference found between the treatments ($p > 0.05$). The mass translated into a small volume of metal as FM, so it was unlikely to be apparent to the casual observer. Most metal appeared as pieces of crumpled foil, and was thin and flexible in appearance. No sharp or potentially hazardous metals like razor blades or needles were found in either compost treatment. No metal particles were found during SEM analysis. Due to the low masses of material found, no FTIR analysis was conducted on the metal.

2.3.5 Glass

Sharp glass particles can be a concern due to the potential hazard for compost handlers. The greatest particle sizes ranged from 0.5 to 3mm in length. No significant differences in percent of glass were found between the compost treatments, with 0.456 ± 0.225% in SC compared to 0.296 ± 0.035% in UC (Table 2-2). No glass fragments were apparent under SEM. Due to the low masses of material found, no further analysis was conducted.

2.4 Conclusions

Non-source separated feedstock at the EWMC results in compost that contains approximately 2% FM, which cannot be removed with the present level of technology at the EWMC. Additional screening and refining reduced the amount of plastic film in the compost, but not the overall level of FM. The type of FM found in the compost varied considerably within the compost treatments, suggesting that future compost quality standards should specify limits for the different categories of material remaining in the compost.

There was no evidence of microbial degradation of the polyethylene, and it is reasonable to assume little degradation will occur in the soil. The synthetic fibres seen under SEM showed no evidence of microbial degradation from the composting process. These fibres could be expected to remain intact for an indefinite time period, unless other forms of degradation (UV light, mechanical wear from soil processes) break down the material.

Based on this study, the material that appeared to be most troublesome to remove was plastic pieces with a density and particle size similar to the compost aggregates. The most common type of FM was polystyrene chips, ranging in size from 2 to 12.5mm. Removal of plastic wastes before they enter the co-composting waste stream should lead to significant decreases in the amount of plastic in the final product.

2.5 References

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CHAPTER 3

Erosion Behaviour of Foreign Matter

3.1 Introduction

Like many other municipalities throughout North America, the City of Edmonton, Alberta, Canada is composting residential municipal solid waste (MSW) and sewage treatment biosolids as an alternative to landfilling the material. Little is known about the long term behavior of non-source separated MSW compost as a soil amendment. In this respect, one of the unknowns is the fate of the small particles of foreign matter (FM) that remain in this type of compost. FM is defined as "any matter over a 2mm dimension that results from human intervention and having organic or inorganic constituents such as metal, glass and synthetic polymers (e.g., plastic and rubber) that may be present in the compost but excluding mineral soils, woody material and rocks." (See Chapter 1) (CAN/BNQ 1996). In this chapter, types of FM are further broken down into metal, glass, plastic film, plastic chips, and synthetic fibres.

FM residues can erode from the soil, causing aesthetic concerns from debris that collect on ground and water surfaces (Krause *et al.* 1996) and become a threat to the natural ecosystem. Small synthetic fibres may be ingested by small aquatic organisms, resulting in malnutrition and internal blockages (Curlee and Das 1991, Krause *et al.* 1996, Robards *et al.* 1995). A proposed guideline to limit the potential of FM to be troublesome is to restrict FM to not be visible to the naked eye (Craul and Switzenbaum 1996). Other proposed guidelines include maximum limits of 0.1-0.3% dry weight for glass and 0.6-1.6% dry weight for plastic particles (de Bertoldi 1993). Research is still needed to determine the full impact of foreign matter in compost (Krause *et al.* 1996).

By using a "cradle to grave" model, one can trace the fate of potentially troublesome compost feedstock to determine at what rate it may erode into the environment (Narayan 1993, Shimp 1993). Once applied to, or incorporated with agricultural soils, the FM in compost would be subjected to the same erosive forces as the soil aggregates themselves. Agricultural soil aggregates are subject to water erosion by overland flow and particle dispersion by raindrop splash. The particulate movement in surface runoff is influenced by the rainfall intensity, soil surface texture, surface material, angle of slope, and soil type (Römkens 1990).

All soils have a runoff coefficient, a relative measure of the rate of overland flow, which is associated with the soil type and its physical properties. Porous, well drained soils containing high amounts of organic matter and large particles have a low runoff coefficient and would be expected to have a high water infiltration rate in a rainstorm event. Soils made of small particles and are rich in clay do not drain water well and have a high runoff coefficient. Furthermore, soils with smaller particles readily undergo surface sealing, decreasing water infiltration. This occurs during rainstorm events when the unstable soil surface degrades and forms a thin crust in the soil. This "seals" a layer in the soil and prevents downward water movement (Römkens 1990).

Compost added to soil as an amendment appears to increase the stability of the soil structure, and help maintain the aggregate framework. It also maintains the surface structure of unstable soil (Bresson *et al.* 2001). Therefore, it is reasonable to assume compost applications to poor quality agricultural soils will favourably change soil properties to decrease runoff and erosion. Bresson *et al.* (2001) verified this behaviour; MSW compost added at a rate of 15g kg^{-1} to silty clay loam soil delayed runoff events and significantly decreased sediment concentrations under simulated runoff conditions.

Particle movement in runoff is governed by the forces acting upon the particle. These physical forces include lift, drag, cohesion, and gravity (Torri *et al.* 1990). The lift on the particle is related to its density compared to the fluid it is resting in. Drag is related to the soil surface, and cohesive forces refer to the strength with which the particle adheres to the soil surface. Therefore, small FM particles with low surface areas and low densities are expected to erode at the highest rates.

This study was designed to determine the behaviour of the FM particles found in the Edmonton Waste Management Centre (EWMC) compost under simulated runoff conditions with an intense rainfall rate. The movement of FM was measured in soil topdressed with compost, and in compost/gray luvisolic soil mixes. As described in Chapter 2, size and type of FM content were measured in compost samples to determine the mass fractions of each category. Although FM is traditionally defined as material over 2mm (CCME 1996), inorganic manmade material from 0.5 to 2mm was also included in the analysis.

3.2 Materials and Methods

3.2.1 Description of Composts

The composts used in this study were manufactured from residential MSW and yard waste and processed by the EWMC. This facility produces grade A or grade B compost

A detailed description of the methodology used to analyze the compost and FM is included in Chapter 2. Four 500g samples each of UC and SC were dried for 24h at 65°C to determine initial MC and aggregate size distribution. Dried samples were then run through a sieve shaker (Ro Tap, W.S. Tyler Company, Cleveland, OH) for 15min with 25mm, 12.5mm, 2mm screens, and a catch pan. Screened samples from each sieve were weighed to determine total mass for each size fraction.

The FM was measured by collecting three 10g samples of UC and SC, and drying them for 24h at 65°C. Each sample was placed in a 95mm diameter petri plate and hand sorted under a 20x light microscope to visually identify all FM fractions (plastic film, plastic chip, inorganic fibre, metal, and glass). Plastic film and chips were further divided into the size categories of 0.5 to 2mm, 2 to 12.5mm, or 12.5 to 25mm. Material that was folded upon itself was not manipulated to determine its size if fully stretched.

All fibres that were not earthy brown, had a constant diameter from end to end, and were over 1cm in length were considered synthetic. Three fibre counts of three different 225mm^2 areas were taken for each sample, and the average was determined. This average was then extrapolated for the entire area of the petri plate (7087mm^2).

Water holding capacity was measured with 137g compost samples (520kg m^{-3}), which formed a layer equivalent to an application rate of 50t ha^{-1}. The compost was gently poured in a 70 micron mesh soil sieve, with a 200mm diameter. The sieve was placed in a round polyethylene container with a 250mm diameter that contained 1.8L distilled water. The compost was allowed to wick up water through the bottom of the sieve. After 15min, 500mL of water were gently poured on top of the compost to ensure hydrophobic fibres at the top of the sample would also be wetted. After a total of 30min the sieve was removed from the water and excess fluid was drained from the sieve for 1min, while the sieve was kept horizontal. The remaining compost was removed from the sieve, weighed, dried, and weighed again to calculate water holding capacity. This procedure was replicated three times for SC and UC.

3.2.3 Soil sample collection

On July 11, 2001, 1.0m^3 gray luvisolic soil from 0-250mm depth was collected from Bruderheim, Alberta, from the same experimental area that had shown an increase in crop productivity from MSW compost (Zhang *et al.* 2000). A 20L polyethylene container was placed randomly in a 6m x 30m vegetation free area. The soil was shoveled from three areas located within 2m of the container. The soil was then unloaded into a 100L wheelbarrow until the wheelbarrow was full, and then deposited into the back of a truck and transported to the rainfall simulator facility. Soil was unloaded onto a polyethylene sheet and covered with a waterproof tarpaulin for the remainder of the experiment. An additional 0.4m^3 of soil was collected two weeks later from the same location and following the same procedure. The soil was air dried and sieved with a 1cm x 1cm metal screen to remove all large aggregates and rocks, to homogenize the soil for experimental purposes. After screening, the soil was temporarily stored in an open wooden bin before being placed in the rainfall simulator soil trays. During handling, all soil was examined to verify the absence of FM. A detailed physiochemical analysis of the soil is presented by Zhang *et al.* (1999).

3.2.4 Rainfall Simulator and Soil Tray Setup

The design of the rainfall simulator is fully explained by Humphry *et al.* (2002). The device used in this study is a paired chamber rainfall simulator with two soil trays per chamber (Figure 3.2-1). The dimensions of each tray were 0.95m x 0.5m x 0.1m. Each set of trays rests on an adjustable slope, with a range from 0° to 30°. A nozzle is located 2.9m above each pair of soil trays and is calibrated to rain at 65mm hr^{-1} to create runoff conditions (ref). The soil trays have two drainage areas. One is located at the bottom of the tray to allow drainage of water that has percolated through the soil tray. Another drainage area is level with the soil surface, and collects the runoff from the overland flow.

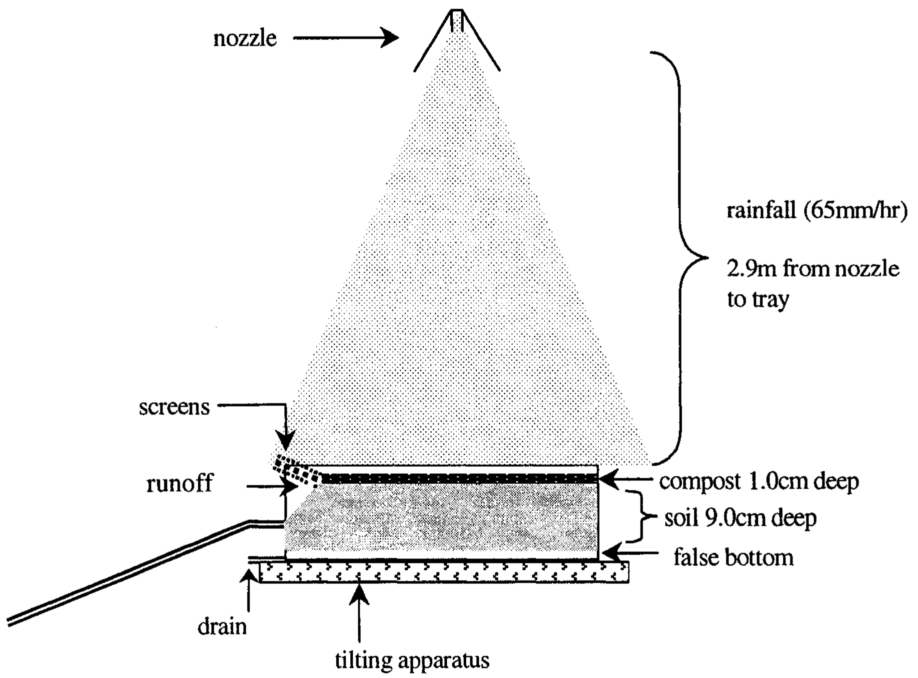


Figure 3.2-1. Soil tray setup for topdressed treatments. Water that infiltrates the soil goes out the false bottom and out the drain.

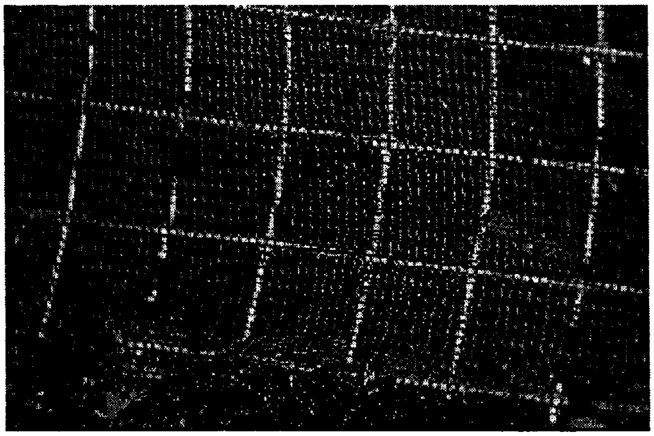


Figure 3.2-2. 1cm x 1cm wire mesh with insect netting

Five 16cm x 51cm fine insect mesh (No See Um®) screens, 90 holes cm^{-2}, were placed on a 10mm x 10mm wire mesh on the downstream lip of the tray (Figure 3.2-2). The screens were 1cm wider than the soil tray; the edges were bent along the sides of the soil tray to catch all eroded material travelling downstream. The wire mesh provided a stable physical structure so the screens would not collapse under the force of the water. It was assumed that while the screens caught eroded material, they did not impede flow, or otherwise impact runoff and erosion behaviour.

Three different treatments were examined: compost application: tilled versus topdressed; compost type: SC versus UC; and slope of soil tray: 5° or 12°. All compost applications were added to the soil trays at a rate of 50t ha^{-1}. This rate was chosen because it was deemed economically beneficial when applied to crops in silty loam gray luvisolic soil (Zhang *et al.* 2000), although it should be noted that the industry standard ranges from one tenth to one quarter of this rate (Rynk 2002). A total of 54.6kg (42L, 1300kg m^{-3}) of screened soil were added to each of the soil trays while they were set at 0° to the horizontal. The soil was transported in 20L pails and gently poured into the trays. The soil was then smoothed and leveled with a board. For the topdressed treatment, a mass of 2kg (3.7L, 540kg m^{-3}) compost (MC 30%, d.b.), equivalent to 50t ha^{-1}, was applied to the top of the soil. The compost was leveled until the entire soil surface was evenly covered. All soil treatments were brought to field capacity before starting the rainfall simulation to ensure equal moisture contents for all treatments. Water was added to all soil treatments by a prewet cycle, which immersed the trays in water from underneath for 24h, and allowed the water to wick upwards via capillary action (Humphry *et al.* 2002). Any excess water took no longer than 15min to drain, and the tilting apparatus was raised either to 5° or 12 ° to the horizontal, according to the appropriate treatment. The rainfall simulation was started within 10min after the excess water finished draining.

The same procedure was followed for the tilled treatment, except that the soil was premixed with the compost before being poured into the soil trays. A total of 109.2kg (84L) of screened soil were mixed with 4kg (7.4L) of compost to achieve the same ratio of soil to compost as used in the topdressed treatments. The soil and compost were mixed for 10min using a mortar mixer (12S Crown Construction Equipment, Winnipeg, Canada).

The rainfall rate was set at 65mm h^{-1} for 80min, a rate much higher than what is normally expected for natural rainfall in the Bruderheim area. Screens were collected by hand at 20min intervals and each was placed in an aluminum tray for drying. All eroded material collected was removed by hand from the dried screens and placed in polyethylene bags for sorting and weighing. A 100mm diameter soil core was taken from the centre of each tray immediately after the rainfall simulation, to examine any potential vertical movement of FM. These soil cores were air dried at room temperature for 96h, split in half, and examined under a 20x microscope (KYOWA Optical Co. Ltd., SD-2AL, Japan) for any evidence of vertical FM movement.

3.2.5 Sample Analysis

All dried samples from the screens were examined under a light microscope. Each sample was placed in a 95mm diameter petri plate and hand sorted under a 20x light microscope to visually identify all FM fractions (plastic film, plastic chip, inorganic fibre, metal, and glass). FM particles of each category were stored in respective polyethylene bags for further confirmation of their chemical composition. The number of inorganic fibres that eroded was determined using the same method outlined in the compost analysis in Chapter 2.2.2.

Field emission scanning electron microscopy (JEOL, JSM-6301FXV) was conducted at the Scanning Electron Microscope Laboratory at the Department of Earth and Atmospheric Sciences (University of Alberta, Edmonton, Canada) for compost and soil samples to obtain magnified images, and to closely examine the aggregate structure. Compost and soil mixtures representative of tilled soil treatments were taken from the surplus materials remaining after the rainfall simulations were finished, and were stored at room temperature. Two aluminum stubs (12mm, pin type, Cambridge) were prepared for each treatment. Glue (Colloidal Silver Liquid, Ted Pella Inc., Redding, CA, USA) was applied to the surface of the stubs, and compost or soil was sprinkled on the surface. The operational parameters used included an acquisition time of 60s, accelerating voltage of 20kV, and a working distance of 12 to 15mm.

3.2.6 Statistical Analysis

The compost subsamples were assumed to be representative of the composition of the original MSW compost. Physical differences in percentage FM and water holding capacities between UC and SC were determined using a two-tailed t-test, with $p<0.05$ considered a significant difference, and $p<0.10$ deemed a statistical trend. The experimental design for the rainfall simulation was a split-plot design with three replicates per treatment. The SAS proc glm procedure (SAS Institute Inc., Cary, NC, USA.1999-2000) was used to analyze the data, and a pdiff statement was used to separate the means. Values are expressed as means ± standard errors of replicated trials.

3.3 Results and Discussion

3.3.1 Compost Analysis

As outlined in Chapter 2, SC contained a significantly higher percentage ($p<0.05$) of aggregates ranging from 0 to 2mm when compared to UC (82.6 ± 0.1% and 78.0 ± 0.5%, respectively), measured on a dry weight basis. There was also a significant difference ($p<0.05$) between the 2 to 12.5mm size fractions, with the SC containing 17.3 ± 0.1% and the UC containing 20.6 ± 0.5%. For the SC, no aggregates were found in the 12.5mm screen, while the UC contained 1.2 ± 0.7%. The moisture content was not significantly different at 29 ± 0.5% and 30 ± 0.7% for UC and SC, respectively.

No differences were found in the percent mass fractions of FM for SC and UC, except for 12.5 to 25mm plastic film particles. UC was found to contain 0.209 ± 0.050% of the plastic film, while SC contained 0.013 ± 0.010% film. This suggests that the final screening process effectively removed film plastic over 12.5mm and large aggregates from the MSW compost. Both composts contained over 2% FM. A summary of all the FM found in the composts is provided in Table 3-1.

Visual inspection with the unaided eye confirmed the presence of synthetic fibres, plastic film and chips in both types of MSW compost. Metal and glass fragments were minute and not noticeable without the aid of a microscope. Particles composed of film plastic or metal foil were often folded upon themselves into an accordion shape, and were measured in that form. Therefore, the stretched length of the particles may have been larger than what was actually measured. This may cause some error in determining the mass of material for each size category, although the overall mass would be accurate.

TABLE 3-1.

Mean percent ± standard error of foreign matter (FM) present in Edmonton Waste Management Centre compost, expressed as dry weight.

Type of Material	Percent Foreign Matter	
	Screened Compost (SC)	Unscreened Compost (UC)
Plastic Chips		
0.5 - 2mm	0.091 ± 0.018	0.074 ± 0.013
2 - 12.5mm	1.156 ± 0.280	1.421 ± 0.385
12.5 - 25mm	0.013 ± 0.008	0.008 ± 0.008
Plastic Film		
0.5 - 2mm	0.029 ± 0.014	0.002 ± 0.002
2 - 12.5mm	0.330 ± 0.023	0.393 ± 0.042
12.5 - 25mm	0.013 ± 0.010 b[1]	0.209 ± 0.050 a
Glass	0.456 ± 0.225	0.296 ± 0.035
Metal	0.081 ± 0.036	0.143 ± 0.068
Total FM	2.169 ± 0.114	2.425 ± 0.238
Synthetic Fibres*	18.2 ± 1.3	15.6 ± 1.2

[1] Means with different letters denote significant differences within FM category ($p<0.05$).

*Number of fibres per g compost, expressed as a dry weight basis.

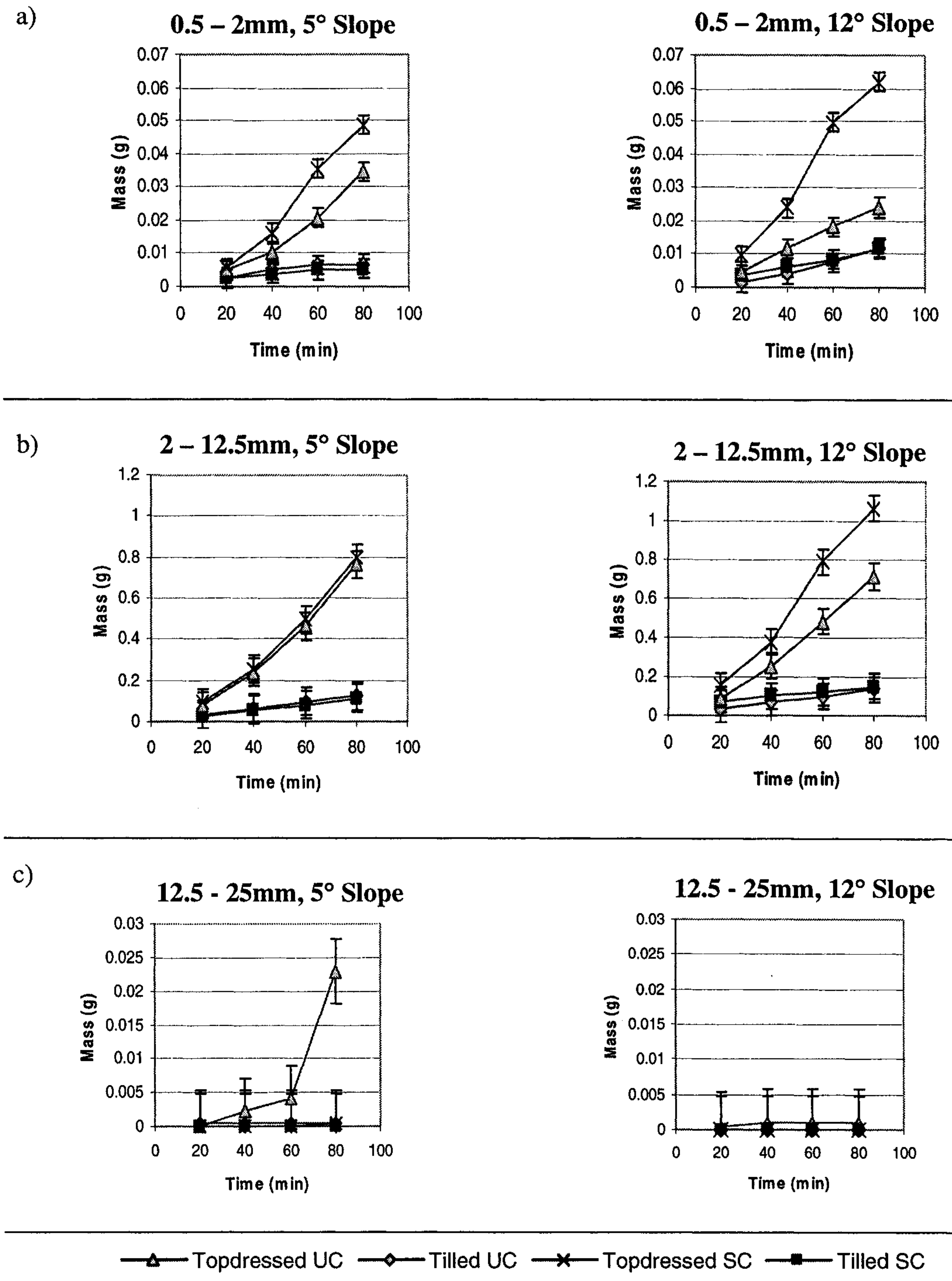
3.3.2 *Erosion Behaviour of FM*

Cumulative mass eroded vs. time graphs are presented for each type of FM in figures 3.1-1 to 3.3-3. The mass of eroded plastic chips was related to the original composition of the compost, and the particle size of the FM. All tilled treatments eroded a lower mass of plastic chips than the topdressed treatments (Figure 3.3-1). For the 0.5 to 2mm size fraction, the greatest mass of eroded chips was in the topdressed, SC treatment (Figure 3.31a). There was a significant interaction between compost type and rainfall time ($p<0.05$); SC eroded small plastic particles at a more rapid rate than UC. This may be due to the differences in runoff volumes from the compost treatments, as discussed in the next section. There was no significant difference between the compost types (Figure 3.3-1b) for plastic chips ranging from 2 to 12.5mm. This type of FM was the highest fraction of eroded FM measured in this project. This is intuitively logical when one considers the composition of the original material; the FM from both compost treatments was composed primarily of 2 to 12.5mm plastic chips. The lowest masses of eroded plastic chips were for particles greater than 12.5mm (Figure 3.3-1c). The original compost contained less than 0.013% plastic chips (dry weight), so it is reasonable to assume that few of these particles were on the soil surface, and therefore not subjected to the erosive forces of runoff. Any particles located lower than the soil surface were not likely to exhibit any vertical movement. Furthermore, relatively large plastic particles will require high amounts of energy to overcome the force of friction from the soil surface (Torri *et al.* 1993).

Extremely low masses of plastic film were found in the eroded material. All size categories exhibited a significant interaction between tillage and rainfall time, as tilled treatments contained significantly less eroded plastic film than topdressed treatments during the 80min of simulated rainfall. Final masses of eroded 0.5 to 2mm film were greatest for the topdressed SC, and they were no greater than 5.7 ± 0.6mg (Figure 3.3-2a). The greatest mass of eroded plastic film was measured within the 2 to 12.5mm size fraction (Figure 3.3-2b), with no significant difference measured for the type of compost. Plastic film fragments greater than 12.5mm eroded at the highest rate for topdressed UC, which exhibited a positive interaction of erosion rate and rainfall time for compost type (Figure 3.3-2c).

Synthetic fibres eroded readily in the runoff; fibre counts for the topdressed samples reached 329 ± 19 and 321 ± 19 fibres for UC and SC, respectively (Figure 3.3-3a). Screening the compost did not decrease the rate of erosion for the fibres, as no significant difference was measured between the compost types. Tilling the compost with soil decreased the rate of erosion, as the fibres would have been trapped in the soil and would be unable to move vertically through the soil profile.

Low masses of eroded glass were found in all treatments. The mass of glass from tilled samples was difficult to determine accurately, as the glass particles often became indistinguishable from small grains of fine sand. The mass of eroded sand increased for all treatments over the time period of the rainfall simulation (Figure 3.3-3b). No significant trends were determined for either tillage or compost type, perhaps due to the high variation of the samples. Minute masses of eroded metal foil were found in all treatments, with higher masses found in UC than SC. The amount of eroded metal increased over time for all treatments (Figure 3.3-3c).


a) 0.5 – 2mm, 5° Slope

0.5 – 2mm, 12° Slope

b) 2 – 12.5mm, 5° Slope

2 – 12.5mm, 12° Slope

c) 12.5 - 25mm, 5° Slope

12.5 - 25mm, 12° Slope

Figure 3.3-1. Mass of eroded plastic chips during 80min of simulated rainfall at rate of 65mm hr^{-1}: (a) 0.5 to 2mm (b) 2 to 12.5mm, and (c) 12.5 to 25mm. The highest erosion rate is from 2-12.5 plastic chips. Note differences in scale for mass.

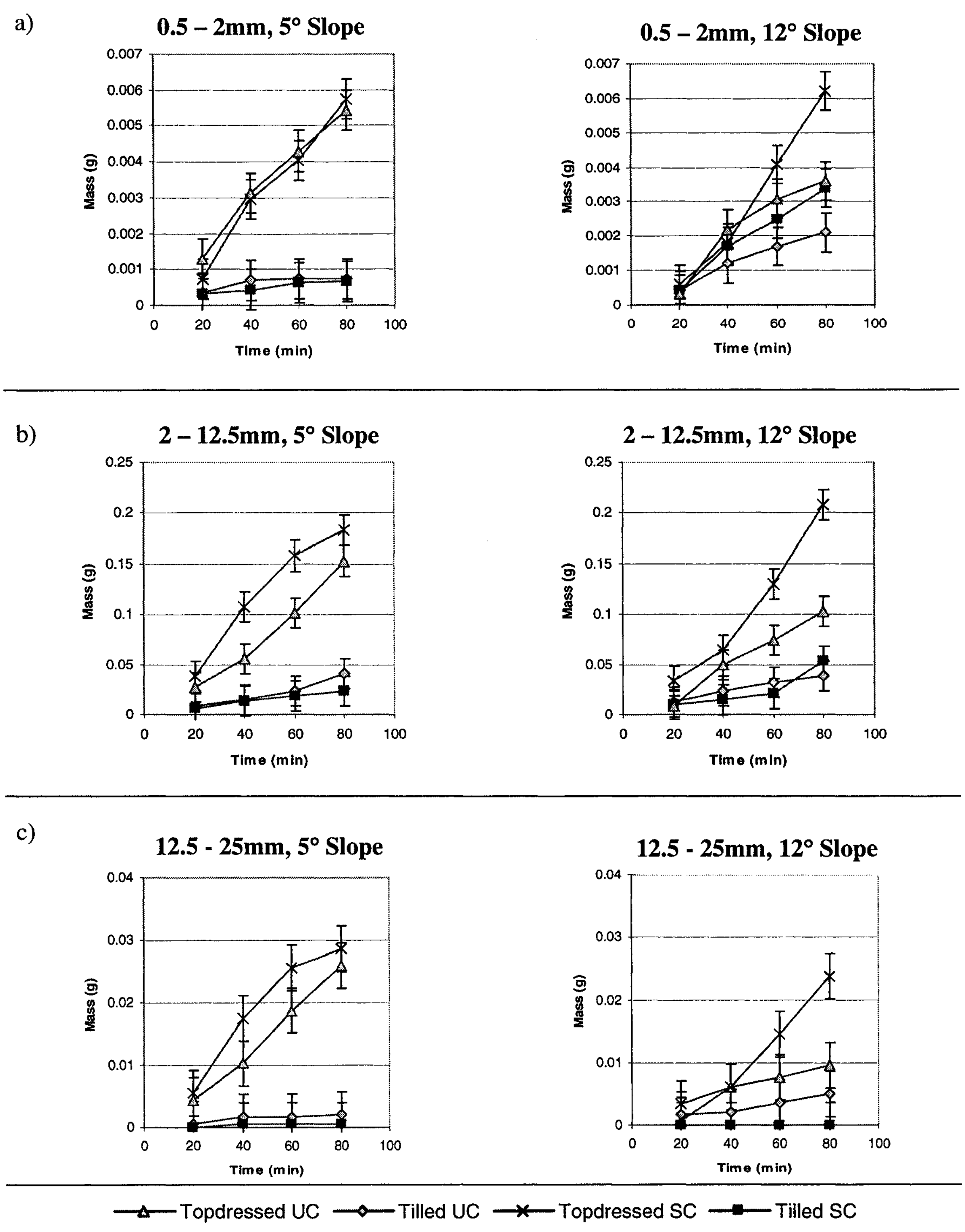


Figure 3.3-2. Mass of eroded plastic film during 80min of simulated rainfall at rate of 65mm hr^{-1}: (a) 0.5 to 2mm (b) 2 to 12.5mm, and (c) 12.5 to 25mm. The highest erosion rate is from 2-12.5 plastic chips. Note differences in scale for mass.

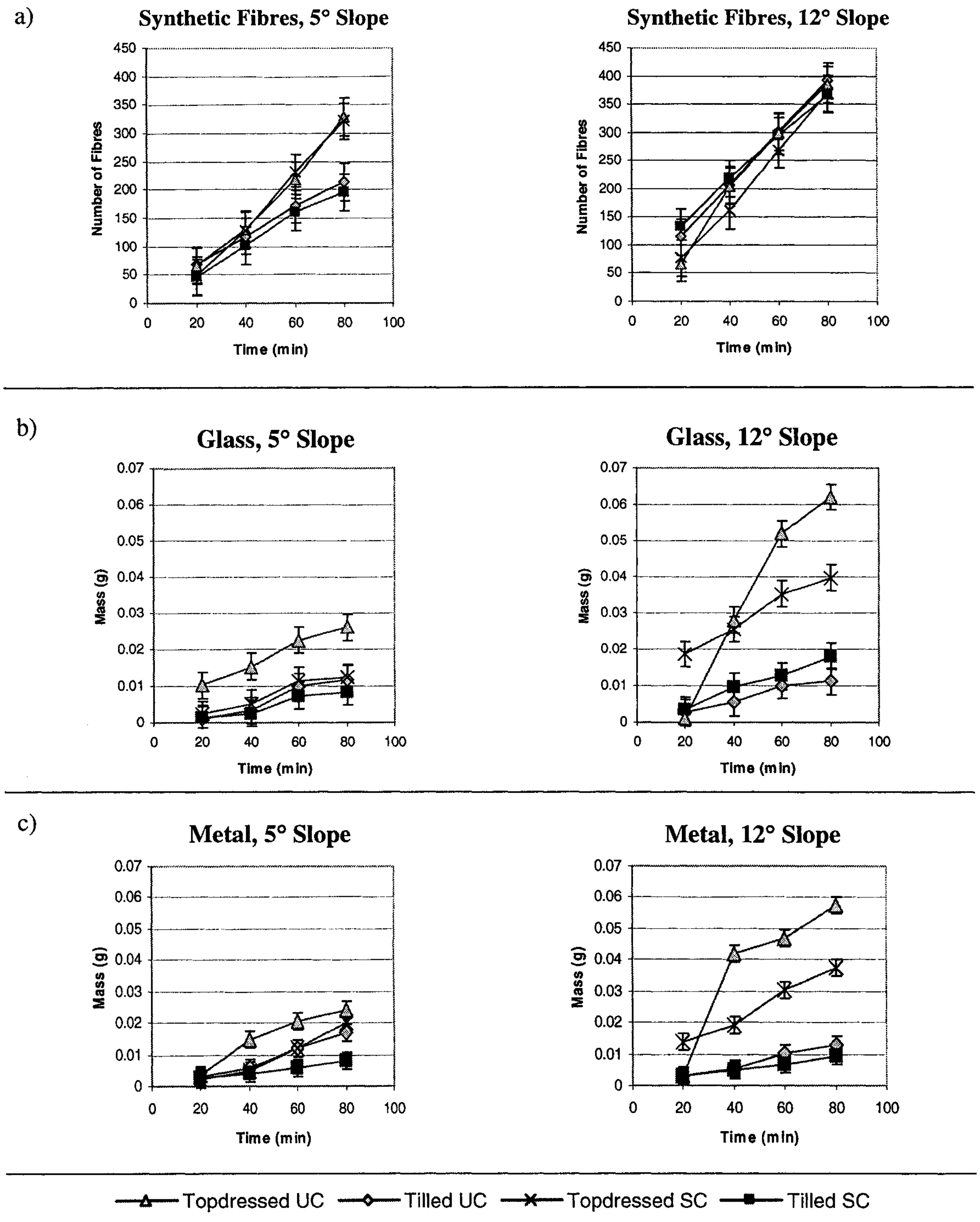


Figure 3.3-3. Erosion versus time during 80min of simulated rainfall at a rate of 65mm hr^{-1}: (a) strands of eroded synthetic fibres (b) mass of glass particles, and (c) mass of metal particles. Note differences in scale for amount of eroded material.

3.3.3 Impact of Compost Type

At the end of the 80min simulation, all SC treatments had yielded an average of 32.1 ± 0.7L runoff, significantly more than 28.3 ± 0.6L from UC treatments ($p<0.05$). This difference in the runoff data may be due to the physical differences between the compost treatments. SC contained a larger proportion of smaller aggregates, which resulted in slightly smaller macropores due to the smaller particles. These particles may have decreased pore size, impeded water flow in the soil tray and lowered rainfall infiltration rates. Furthermore, there may be a statistical trend ($p=0.07$) suggesting SC had a lower water holding capacity than UC (2.02 ± 0.04 and 1.86 ± 0.04kg kg^{-1}, respectively). This does not correspond with the observations of Raviv *et al.* (1987), who determined that decreasing particle size distribution increased water retention. Therefore, the increase in runoff may have been due to lower connectivity of macropores within the SC layer, as compared to the UC.

A summary of the data on eroded FM for the treatments SC and UC after 80min of simulated rainfall is found in Table 3-2. When comparing UC and SC, greater masses of eroded FM were measured from SC for both 2 to 12.5mm plastic film particles and 0.5 to 2mm plastic chips ($p<0.05$). The SC also showed a trend ($p=0.09$) for the interaction of tillage*compost, with the SC eroding a greater mass of 2 to 12.5mm plastic chips. The eroded SC treatment showed a trend ($p=0.08$) of less metal than the UC treatment (11.5 and 17.65mg, respectively). Although there was no significant difference measured between the SC and UC for the mass of metal, the compost samples showed a large variability, as confirmed by the high standard error (Table 3-1). Therefore, the higher mass of eroded metal from the UC treatment could be from greater masses of metal present in the compost samples used in the rainfall simulation.

TABLE 3-2.

Differences in eroded foreign matter (FM) for screened and unscreened compost treatments after 80min of simulated rainfall.

Type of Material	Foreign Matter Mass (mg)		Standard Error
	Screened Compost (SC)	Unscreened Compost (UC)	
Plastic Chips			
0.5<2mm	18.6 a[1]	10.9 b	1.1
2<12.5mm	296.2[†]	233.3	20.0
12.5<25mm	0.0	2.2	1.1
Plastic Film			
0.5<2mm	2.3	2.0	0.5
2<12.5mm	67.6 a	47.7 b	5.5
12.5<25mm	7.9	6.4	0.8
Glass	13.3	17.0	2.5
Metal	11.5[†]	17.6	2.0
Synthetic Fibre*	195.1	205.4	9.8

[1] Means with different letters denote significant differences within FM category ($p<0.05$).
[†] Statistical trend suggesting difference between means ($p<0.10$)
*Number of strands of fibres.

Significantly greater masses of plastic chips and film eroded from the SC compost samples than the UC soil treatments. The difference may be due to the smaller particle sizes found in the SC, as determined by the aggregate size distribution. The smaller particles are more likely to erode, as they are more buoyant, experience less drag, and require less force to carry them over a distance (Torri *et al.* 1990).

3.3.4 Impact of Tillage

A summary of data on eroded FM from the different tillage treatments is presented in Table 3-3. The tilled treatments showed a statistical trend ($p=0.06$) of higher masses of eroded soil (54.65 ± 7.34g) compared to the topdressed samples (12.84 ± 7.34g). Although there is a large difference in the averages, a statistical difference may not be apparent due to the high standard error calculated from the small number of samples. Furthermore, the tilled samples primarily contained sand, a much denser substance than the organic matter found in the topdressed treatments. No sand was present in any of the topdressed treatments.

The higher mass of the eroded tilled samples suggests that more energy was present in runoff from these treatments than the topdressed samples. This correlates with the significantly higher ($p<0.05$) volume of runoff from the tilled samples 38.7 ± 1.0L, compared to 24.1 ± 1.5L for the topdressed samples; a higher volume of runoff represents more energy to carry soil particles, which consequently can erode higher masses of material (Torri *et al.* 1990). Tilling the compost into the soil appeared to increase the water holding capacity of the soil from 0.44 to 0.48kg kg^{-1} soil. However, this increase is insignificant when compared to the water holding capacity of pure compost (1.85 to 2.05kg kg^{-1} compost), which may explain why the topdressed compost infiltrated greater volumes of water, and had less runoff. The runoff from the tilled samples was turbid from silt and clay particles.

TABLE 3-3.

Impact of tillage on mass of eroded foreign matter after 80min of rainfall.

Type of Material	Foreign Matter Mass (mg)		Standard Error
	Tilled Soil	Topdressed Soil	
Plastic Chips			
0.5<2mm	5.7 b[1]	23.7 a	1.5
2<12.5mm	85.8 b	443.6 a	40.7
12.5<25mm	0.1	2.1	1.0
Plastic Film			
0.5<2mm	1.1 b	3.1 a	0.3
2<12.5mm	22.0[†]	93.3	13.5
12.5<25mm	1.3	13.0	2.9
Glass	7.4[†]	23.0	3.6
Metal	7.1	21.9	7.1
Inorganic Fibre*	193.8	206.7	36.7

[1] Means with different letters denote significant differences within FM category ($p<0.05$).
[†] Statistical trend suggesting difference between means ($p<0.10$).
*Number of strands of fibres.

It is assumed that the impact of rainfall on the tilled treatments quickly illuviated clay and silt particles, and created a surface seal a few millimeters below the soil surface. This process can occur in a few minutes, depending on the rainfall event and storm intensity (Römkins 1990). Crop residues or other organic matter like compost on the surface of the soil will decrease the impact of the rainfall on the soil surface. Topdressed compost treatments absorbed some energy from the simulated rainfall and decreased the impact of the raindrops on the soil surface. This, coupled with the higher water holding capacity of the pure compost layer compared to the soil amended with compost, delayed surface seal formation and soil erosion. The higher masses of eroded soil correlate with the results from Bresson *et al.* (2001), who found soils amended with compost experience delayed surface degradation and decreased sediment runoff. It is important to note that most agricultural practices used today leave some amount of organic residue on the surface to decrease soil erosion. Therefore, the dramatic difference in runoff found between tilled treatments and topdressed treatments might not be found in most agricultural fields.

Less FM eroded for all tilled treatments when compared to topdressed treatments, and statistical differences were found for plastic chips ranging in size from 0.5 to 2mm, 2 to 2.5mm and for 0.5 to 2mm plastic film particles (Table 3-3). A statistical trend (p=0.07) was measured for the mass of 2 to 12.5mm plastic film particles (93.3 ± 13.5mg) eroded from the topdressed treatments, compared to 22.0 ± 13.5mg for the tilled compost. This can be explained when one considers that all the compost and FM were diluted throughout the soil tray in the tilled samples. Microscopic analysis of soil cores (Figure 3.3-4) taken from each soil tray found no downward movement of FM in the topdressed treatments. It was also noted that the soil pores appeared to be too small and discontinuous for any downward movement of FM larger than 0.5mm, since the soil contained high amounts of clay and few macropores (pores > 0.1mm). This is in agreement with Perret *et al.* (1999), who determined that the hydraulic radii of soil pores decreased when the soil was tilled. Therefore, it is reasonable to assume no vertical movement of 0.5 to 25mm FM occurred in the tilled samples; within the timeframe of this simulation, only FM on the surface of the soil trays would be subject to erosion from runoff.

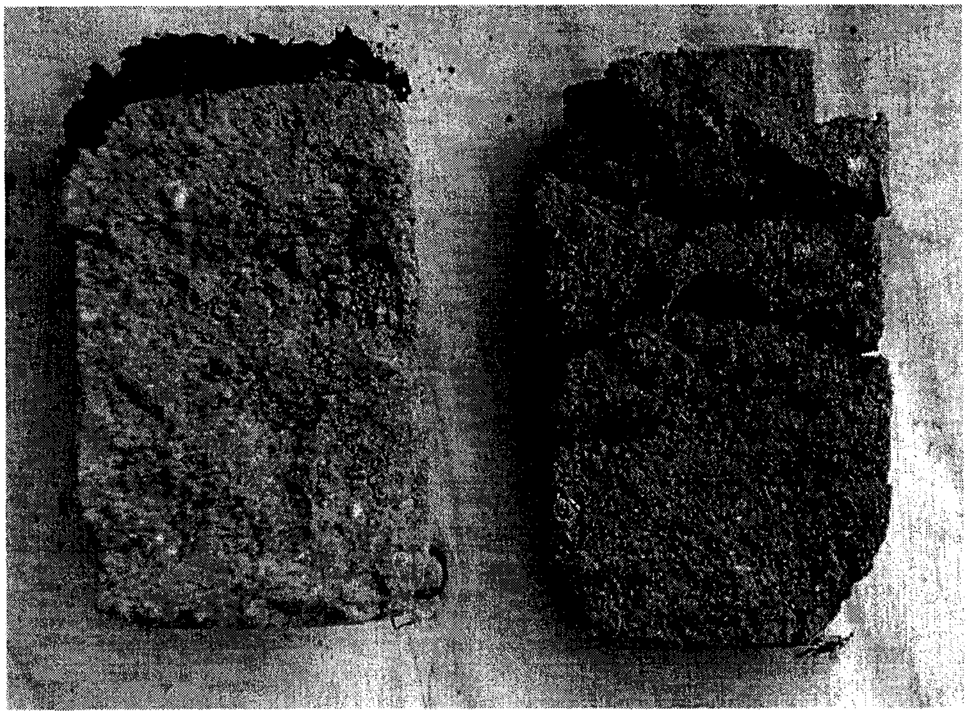


Figure 3.3-4. Soil cores from topdressed compost treatment (left) and tilled compost (right). A distinct layer of compost can be seen on the topdressed treatment, while the tilled treatment is darker from the additional organic material.

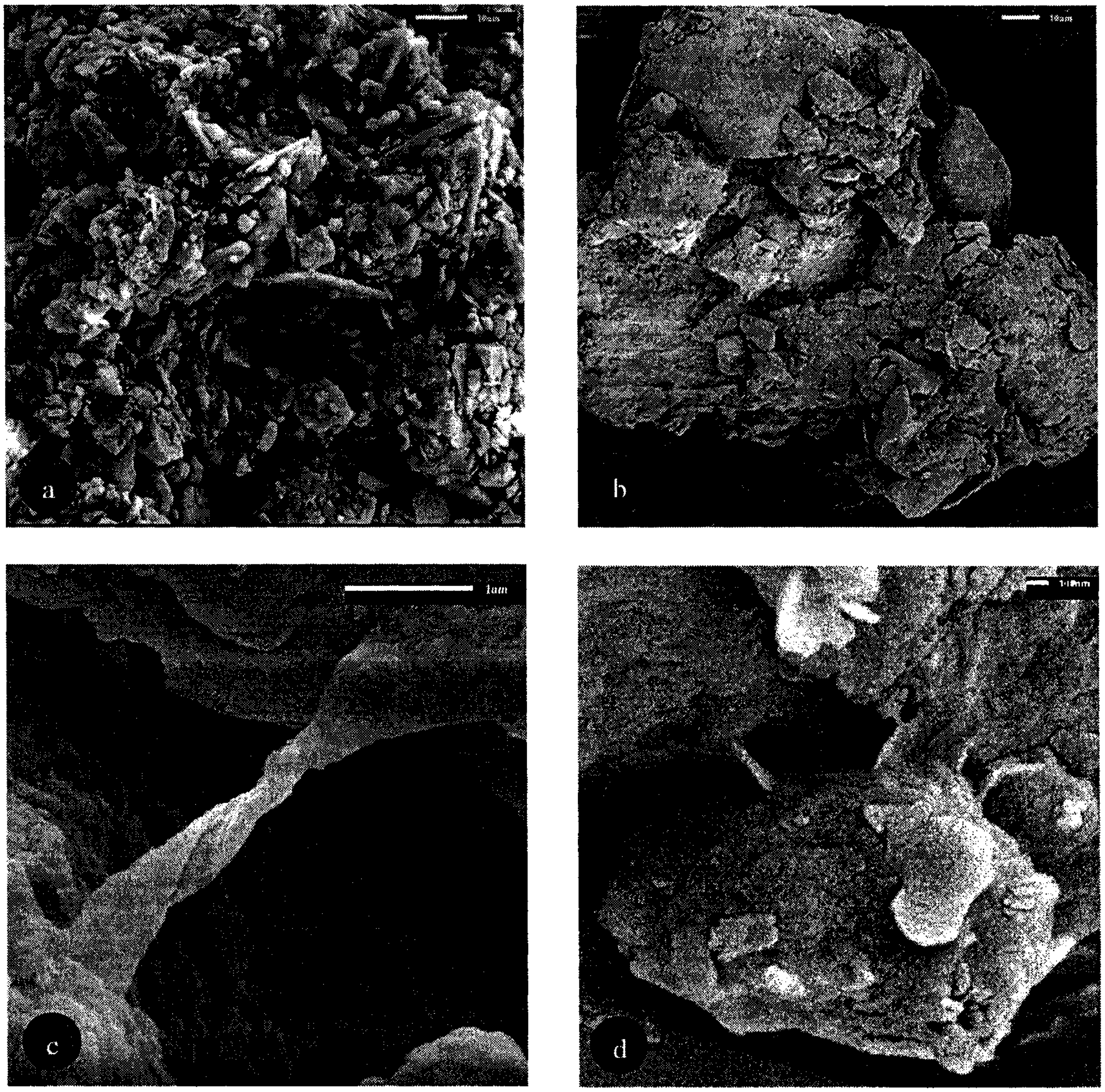


Figure 3.3-5. (a) Untreated soil (b) compost and soil mixture, showing microaggregation (c) bridge found in soil tilled with UC, and (d) bridge in soil tilled with SC.

SEM micrographs of the soil confirmed that little organic matter was present (Figure 3.3-5a). When compost was added to the soil, the structure of the aggregates changed from densely packed inorganic particles to aggregates with larger pores (Figure 3.3-5b). Soil samples mixed with compost showed minute "bridges" between aggregates (Figures 3.5-5c and 3.3-5d). Since the compost soil mixture was stored at room temperature for several months before the SEM micrographs were taken, it is unclear if this structure is from the mixture, or if it formed during an interaction between the soil and organic matter in the compost. Bresson *et al.* (2001) described changes in soil structure from organic matter: the bulk density decreased, which was attributed to the dilution of the materials, and also from an increase in aggregate stability. The structures in Figures 3.3-5c and 3.3-5d may be evidence of the soil processes. However, it is unlikely that these changes were present in the soil treatments used in the rainfall simulation, as the soil was used shortly after mixing.

3.3.5 Impact of Slope

A summary of data on eroded FM from the two soil tray slopes is presented in Table 3-4. A significant interaction between slope and tillage ($p<0.05$) was measured when comparing the total mass of eroded soil samples. The tilled compost treatments on the 12° slope eroded 72.2 ± 4.9g of soil, compared to 36.6 ± 4.9g from the 5° slope. The topdressed compost treatments eroded 15.8 ± 4.9g from the steeper slope, and 9.9 ± 4.9g from the 5° slope. This is intuitively logical, as the force of friction on a particle is related to the angle of the surface it is resting on. A steep angle will impart a lower force of friction on a particle travelling downstream compared to the same surface with a gentler angle (Torri *et al.* 1990). The topdressed compost treatments had significantly lower masses of eroded material for both slopes when compared to the tilled soil treatments, suggesting that a 50T ha^{-1} application of MSW compost is an effective form of erosion control for unstable soil slopes. This is in agreement with data from Bresson *et al.* 2001, who reported that compost amended soil decreased surface slumping in unstable soil surfaces.

Few statistical differences were found for the FM eroded from the steeper slope (Table 3-4). The highest masses of eroded FM were from 2 to 12.5mm plastic chips for both angles, with 236.5 ± 33.7mg from the 5° slope, and 292.9 ± 33.7mg from the 12° slope. Plastic film fragments also eroded at a high rate, with 60.1 ± 15.6mg for the 5° slope, and 54.6 ± 15.6mg for the steeper soil treatment. A statistical trend was found for the number of eroded synthetic fibres (p=0.07), with 159.7 ± 24.5 from the 5° slope, and 241.3 ± 24.5 from the 12° slope.

TABLE 3-4.

Differences in eroded foreign matter for 5° and 12° slopes after 80min of simulated rainfall.

Type of Material	Foreign Matter Mass (mg)		Standard Error
	5°	12°	
Plastic Chips			
0.5<2mm	13.3	16.1	1.5
2<12.5mm	236.5	292.9	33.7
12.5<25mm	2.0	0.2	1.0
Plastic Film			
0.5<2mm	2.0	2.2	0.5
2<12.5mm	60.1	54.6	15.6
12.5<25mm	9.0	5.3	4.0
Glass	9.4 b[1]	21.0 a	1.8
Metal	14.1	20.3	1.9
Synthetic Fibre*	159.7[†]	241.3	24.5

[1] Means with different letters denote significant differences within FM category ($p<0.05$).

*Number of strands of fibres.

[†] Statistical trend suggesting difference between means ($p<0.10$).

3.4 Conclusions

This study found that FM in compost applied to gray luvisolic soil and subjected to intense rainfall conditions may erode from the original area of application. The total mass of eroded FM is dependent on the type of material present in the original compost, and its location in the soil profile. Overland movement of FM is linked to the mass and shape of the particle, and the amount of energy required to move it.

In all cases topdressed compost resulted in more FM eroded than tilled treatments, but the topdressed application also decreased overall erosion rates and runoff volumes while increasing the amount of rainfall infiltrating the soil. A similar decrease in erosion rates could be expected from topdressing with other types of organic matter. Since most present day agricultural practices leave organic residue on the soil surface, tilling the compost in the soil would provide additional agronomic benefits while embedding the majority of the FM in the soil. The actual differences in decreased erosion from crop residue or from a topdressed layer of compost could be examined in future studies.

It should be noted that this study was limited to a laboratory rainfall simulator and did not examine the other forces influencing FM movement including wind erosion, soil tillage from mesofauna, soil temperature, and residual vegetation. Therefore, it would be premature to form any firm conclusions, based on this study, on the potential concerns arising from FM eroded from MSW compost applied to agricultural fields. Further research is required on the fate of FM from compost, including long term monitoring of field trials to determine actual erosion rates of FM particles.

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CHAPTER 4

Synthesis and Discussion

4.1 Synthesis

Municipal Solid Waste (MSW) composting is a sensible method of recycling organic wastes for the Edmonton Waste Management Centre (EWMC). Approximately 86% of Edmonton's residential waste stream is biodegradable, and can be processed into a marketable product to be used as a soil amendment. By removing the organics from the waste stream, the life expectancy of the local landfills will be extended for future use, and will delay the need for new suitable landfill space. At present, 70% of Edmonton's residential MSW is diverted from the landfill.

MSW compost from the EWMC can be added to poor quality agricultural soil to create favourable agronomic soil properties: by raising the level of organic matter, the soil particles exhibit increased soil aggregation and water infiltration, while decreasing runoff. Applications of as little as 20T ha^{-1} of compost have been shown to significantly decrease soil erosion and surface water runoff (Bresson *et al.* 2001). Previous studies also confirm increased crop productivity on soils amended with the EWMC compost (Zhang *et al.* 1999, 2000).

Despite these favourable aspects, some properties of the EWMC compost pose concerns. Depending on the processing method, non-source separated MSW compost may contain up to 43% FM (le Bozec and Resse 1987) including particles of glass, metal, and plastic, although advances in screening and separation technology can generate a cleaner product. Regardless of the process used, present refining methodologies cannot remove all the remaining FM to create "pure" compost (Brinton and Evans 2002, de Bertoldi 1993b).

The non-source separated MSW compost from the EWMC was examined for the type and amount of FM present. First, two compost treatments were collected from the EWMC curing piles. One was taken directly from the curing piles, while the other sample was screened with an 18.75mm (0.75") trommel screen. Subsamples from both composts were dried and analyzed under a 20x microscope to collect and sort all FM particles greater than 0.5mm. The differences in type and percent of FM present in each compost treatment were statistically analyzed. The identity of FM particles was determined using FTIR, solubility tests, and SEM micrographs with x-ray analysis.

The compost samples used in this study contained 2% FM, including plastic particles, metal, glass, and synthetic fibres. If this compost was applied to fields at the experimental rate of 50T ha^{-1}, approximately 100kg ha^{-1} of FM would be added to the soil. The types of synthetic polymers found, including polyethylene, polystyrene, and polyester, were primarily non-biodegradable and recalcitrant to degradation from microbes, ultraviolet light, and invertebrates. The smooth appearance of the synthetic fibres and other FM seen in the SEM micrographs is a validation of their non-degraded condition. Since they will remain in the soil for an unpredictable amount of time, compost applicators need an understanding of the long term impact of this material (Shimp 1993). Nylon fibres were also found in the compost, and these would be expected to degrade from ultraviolet light if the compost was applied to agricultural soil.

This project studied the erosion of the FM from its original area of application while under intense rainfall conditions. The compost was either tilled in, or topdressed on gray luvisolic soil, placed in soil trays, and treated with an intense precipitation rate from a laboratory rainfall simulator. Samples were collected at 20min intervals to obtain a cumulative mass and time graph for each category of FM. All sizes and types of FM moved downstream during the controlled simulation. The highest masses of eroded material were from numerous pieces of polystyrene, ranging in size from 2 to 12.5mm. These particles are similar in size and shape to the troublesome plastic particles found in marine environments.

4.2 Implications of Results

It is difficult to predict the exact impacts of the FM on soils or inland aquatic environments; researchers can only look to similar examples for guidance. It is reasonable to assume FM particles will be subject to the same erosive forces as the soil aggregates themselves, and could erode from their original area of application. Research of marine environments shows that similar debris can erode from inland streams, causing aesthetically unpleasing tourist areas from the litter. Plastic particles as small as 0.5-22mm in diameter can be ingested by wildlife, and may be benign, cause intestinal ulceration, or sometimes even death (Robards *et al.* 1995). Since similar wildlife species with similar feeding habits live inland, the ingestion of FM by these animals is a realistic concern.

Even if the environmental concerns are groundless, there are other problems stemming from non-source separated compost. Long term success of this waste management method hinges on the ability to sell the compost and recover production costs (Golueke and Diaz 1995). This is not possible if the compost is limited in its marketability due to real or perceived concerns about compost quality. Since the EWMC compost analyzed in this study contained more than 1.5% FM, it did not meet the voluntary FM standard established by the Bureau de normalisation du Québec (CAN/BNQ 1996). Therefore, this compost did not meet the minimum acceptable grade for good quality compost (Antler 1997). It should be noted that the EWMC has implemented new refining technologies since the co-composting plant has been in operation, and the compost sample used in this study may not be indicative of the present product quality.

There are several alternative methods of composting organic waste to create a product with less FM. Source separation of the feedstock would limit the level of non-biodegradable material fed into the co-composter, and should result in lower fractions of FM in the final product. Of the 2% FM found in the compost, the highest fraction of FM was composed of plastic chips for both compost treatments: 53.3% for screened compost, and 70.7% for the unscreened compost. These plastic chips were identified as polystyrene. At present, polystyrene is not collected through the Blue Bag recycling program; reduction of non-biodegradable waste added to the waste stream would decrease the FM in the final product. Lastly, biodegradable plastic would nullify the need to remove plastic as FM, as it would instead add humus to the final product and not need to be screened out.

4.3 Recommendations for Future Work

At the time the EWMC was under construction, surveys of local residents indicated that a non-source separated MSW composting facility would be the best form of waste management for Edmonton; public perception about these practices may have changed. A pilot project of sample communities could be tested to measure the willingness of residents to sort their waste into organics, recyclables, and other. This could be encouraged in conjunction with public education programs. The communities could be monitored for the effectiveness of the education programs, along with collection costs and the quality of the resulting compost. If the community projects were deemed successful and viable, the new collection system could be expanded throughout Edmonton.

Methods of decreasing the amount of non-biodegradable material used as feedstock for the co-composter should also be encouraged. A variety of different biodegradable plastic bags exist for compost bin liners and garbage collection.

Further research is required on the fate of FM from compost, including long term monitoring of field trials to determine actual erosion rates of FM particles. In plant productivity trials currently using EWMC compost, the soil could be monitored for vertical and horizontal FM movement and changes in the activity of soil micro and mesofauna. It would be prudent to also carefully monitor any water bodies in the vicinity of the compost applications, and to conduct laboratory trials on the feeding behaviour of aquatic organisms exposed to FM particles.

4.4 Conclusions

The use of non-source separated feedstock at the EWMC results in compost that contains approximately 2% FM, which cannot be removed with the present level of technology at the EWMC. Additional screening and refining reduced the amount of plastic film in the compost, but not the overall level of FM. The type of FM found in the compost varied considerably within the compost treatments, suggesting that future compost quality standards should specify and limit the different categories of material remaining in the compost.

The plastic FM found in the compost was recalcitrant to degradation. There was no evidence of microbial degradation of the polyethylene, and it is reasonable to assume little degradation will occur in the soil. The manufactured fibres also showed no evidence of degradation from the composting process. These synthetic fibres could be expected to remain intact for an indefinite time period, unless other forms of degradation (UV light, mechanical wear from soil processes) break down the material.

Based on this study, the material that appeared to be most troublesome to remove was plastic pieces with a density and particle size similar to the compost aggregates. The most common type of FM was polystyrene chips, ranging from 2 to 12.5mm. Removal of plastic wastes before they enter the co-composting waste stream should lead to significant decreases in the amount of plastic in the final product.

This study found that FM in compost applied to gray luvisolic soil and subjected to intense rainfall conditions may erode from the original area of application. The total mass of eroded FM was dependent on the type of material present in the original compost, and its location in the soil profile. Overland movement of FM is linked to the mass and shape of the particle, and the amount of energy required to move it.

In all cases topdressed compost resulted in more FM eroded than tilled treatments, but the topdressed application also decreased overall erosion rates and runoff volumes while increasing the amount of rainfall infiltrating the soil. A similar decrease in erosion rates could be expected from topdressing with other types of organic matter. Since most present day agricultural practices leave organic residue on the soil surface, tilling the compost in the soil would provide additional agronomic benefits while embedding the majority of the FM in the soil. The actual differences in decreased erosion from crop residue or from a topdressed layer of compost could be examined in future studies. It should be noted that this study was limited to a laboratory rainfall simulator and did not examine the other forces influencing FM movement including wind erosion, soil tillage from mesofauna, soil temperature, and residual vegetation. Therefore, it would be premature to form any firm conclusions, based on this study, on the potential concerns arising from FM eroded from MSW compost applied to agricultural fields.

4.5 References

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