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Standard Guide to Assess the Compostability of Environmentally Degradable Nonwoven Fabrics[1]

This standard is issued under the fixed designation D 6094; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide covers suggested criteria, procedures, and a general approach to establish the compostability of environmentally degradable nonwoven fabrics and products.

NOTE 1—The assessment of degradable plastics and nonwoven fabrics or products is considered similar. Consequently, this guide contains only minor changes in technical content from this guide developed by Subcommittee D20.96 on Environmentally Degradable Plastics of Committee D-20 on Plastics.

1.2 The values stated in SI units are to be regarded as the standard. The inch-pound units given in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 123 Terminology Relating to Textiles
D 883 Terminology Relating to Plastics
D 1776 Practice for Conditioning Textiles for Testing
D 3593 Test Method for Molecular Weight and Molecular Distribution of Certain Polymers by Liquid Size Exclusion Chromatography (GPC) Using Universal Calibration
D 3776 Test Methods for Mass per Unit Area (Weight) of Woven Fabrics
D 3786 Test Method for Hydraulic Bursting Strength of Knitted Goods and Nonwoven Fabrics-Diaphragm Bursting Strength Tester Method
D 5034 Test Method for Breaking Strength and Elongation of Textile Fabrics (Grab Test)
D 5152 Practice for Water Extraction of Residual Solids from Degraded Plastics for Toxicity Testing
D 5209 Test Method for Determining the Aerobic Biodegradation of Plastic Materials in the Presence of Municipal Sewer Sludge
D 5247 Test Method for Determining the Aerobic Biodegradability of Degradable Plastics by Specific Microorganisms
D 5338 Test Method for Determining Aerobic Biodegradation of Plastic Materials Under Controlled Composting Conditions
D 5509 Practice for Exposing Plastics to a Simulated Compost Environment
D 5512 Practice for Exposing Plastics to a Simulated Compost Environment Using an Externally Heated Reactor
D 5734 Test Method for Tearing Strength of Nonwoven Fabrics by Falling-Pendulum (Elmendorf) Apparatus
D 5988 Test Method for Determining the Aerobic Biodegradation In Soil of Plastic Materials or Residual Plastic Materials After Composting
D 5951 Practice for Preparing Residual Solids Obtained After Biodegradation Standard Methods for Plastics in Solid Waste for Toxicity and Compost Quality Testing
D 6002 Guide to Assess the Compostability of Environmentally Degradable Plastics
E 1440 Guide for an Acute Toxicity Test with the Rotifer Brachionus (and with Microcrustacean Thamnocelphalus)
E 1720 Test Method for Determining Ready, Ultimate, Biodegradability of Organic Chemicals in a Sealed Vessel CO_2 Production Test
G 22 Practice for Determining Resistance of Synthetic Polymeric Materials to Bacteria

2.2 *ORCA Standard:*

Guidelines for the Evaluation of Feedstock for Source Separated Biowaste Composting and Biogasification, 1994[3]

2.3 *OECD Standards:*

OECD Guideline 207, Earthworm, Acute Toxicity Tests[4]
OECD Guideline 208, Terrestrial Plants, Growth Test[4]

[1] This guide is under the jurisdiction of ASTM Committee D13 on Textiles and is the direct responsibility of Subcommittee D13.64 on Non-Woven Fabric.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards*volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Organic Reclamation and Composting Association (ORCA), Avenue E. Mounier 83, Box 1, B-1200 Brussels, Belgium.

[4] Organization for Economic Development (OECD), OECD Guidelines for Testing of Chemicals, Available from Director of Information, 2 rue André Pascal, 75775 Paris Cedex 16, France.

2.4 *Other Documents:*

Guidelines for the Use of Environmental Marketing Claims, 1992[5]

Towards Common Ground, The International Workshop on Biodegradability, 1992[6]

2.5 *Compositing Documents:*

Compost Facility Operating Guide, 1995[7]

Recommended Test Methods for the Examination of Compost and Composting[7]

U.S. Solid Waste Composting Facility Profiles—Volume II, 1993[8]

3. Terminology

3.1 *Definitions:*

3.1.1 *biodegradable material*, *n*—a material in which the degradation results from the action of naturally occurring micro-organisms such as bacteria, fungi and algae.

3.1.2 *compostable material*, *n*—a material capable of undergoing biological decomposition such that the material is not visually distinguishable and breaks down into carbon dioxide, water, inorganic compounds, and biomass, at a rate consistent with known compostable materials **(1)**.[9]

3.1.3 *composting*, *n*—a managed process that controls biological decomposition and transformation of biodegradable material into a humus-like substance called compost; the aerobic mesophilic and thermophilic degradation of organic matter to make compost; the transformation of biologically decomposable material through a controlled process of bio-oxidation which proceeds through mesophilic and thermophilic phases, and results in the production of carbon dioxide, water, minerals and stabilized organic matter (compost or humus).[10]

3.1.3.1 *Discussion*—Composting uses a natural process to stabilize mixed decomposable organic material recovered from municipal solid waste, yard trimmings, biosolids (digested sewage sludge), certain industrial residues and commercial residues (see 2.4).

3.1.4 *degradable material*, *n*—a material designed to undergo a significant change in its chemical structure under specific environmental conditions resulting in a loss of some properties that may be measured by standard methods appropriate to the plastic and the application in a period of time that determines its classification.

3.1.5 *fragmentation rate*, *n*—the rate at which a material fractures during testing as a result of mechanical agitation, chemical degradation, or biodegradation.

3.1.6 *mesophilic*, *adj*—a descriptive term for a phase in the composting process that occurs between temperatures of 20 to 45°C (68 to 113°F) and is characterized by the presence and activity of organisms capable of thriving at these temperatures (see 2.5).

3.1.6.1 *Discussion*—Rates of biodegradation are typically dependent upon the temperature of the medium and on the organism populations in the compost. (See *thermophilic*.)

3.1.7 *nonwoven fabric*, *n*—a textile structure produced by bonding or interlocking of fibers, or both, accomplished by mechanical, chemical, thermal, or solvent means and combinations thereof (*syn. nonwovens*).

3.1.8 *thermophilic*, *adj*—a descriptive term for a phase in the composting process that occurs between temperatures of 45 to 75°C (113 to 167°F) and it is associated with specific colonies of microorganisms that accomplish a high rate of decomposition (see 2.5).

3.1.9 For definitions of other textile terms used in this guide, refer to Terminology D 123. For definitions of other plastic related terms used in this guide refer to Terminology D 883.

4. Summary of Guide

4.1 This guide utilizes a tiered criteria-based approach to assess the compostability of environmentally degradable nonwoven fabrics and products, which includes, in tier one, biodegradation testing of materials used in the nonwoven fabric or product. In addition, the nonwoven fabric or product must be compostable in its finished form, meaning that the rate of disintegration of the nonwoven in actual compost proceeds at an acceptable rate. The second and third tiers of testing address this issue.

4.1.1 Focus is directed to applying resources on materials of greatest interest and potential. The tiers progress from rapid screening of nonwoven fabric and products (including all materials comprised therein) to relatively long term, more complex/higher cost evaluations.

4.1.2 This guide includes methods that simulate mesophilic and thermophilic phases that are representative of composting processes and compost end use.

NOTE 2—The availability of other test methods appropriate for this guide is acknowledged.

5. Significance and Use

5.1 The nonwoven fabric or product can be formed from a combination of materials (natural or manufactured fibers, continuous or staple fibers, film laminate, binder resins, etc.). Each material may be comprised of more than a single component, for example, natural or synthetic polymers, dyes or pigments, surfactants, and other additives. All components and materials which are organic in nature must be evaluated and determined to be biodegradable and to cause no toxic or negative effect in the compost medium. Inorganic fillers or additives (except for heavy metal salts, which are separately regulated) are assumed to be neutral to the composting process. Biodegradation of the materials is demonstrated only through carbon dioxide evolution tests and is considered to be the first and one of the most important steps in establishing the ultimate compostability of the nonwoven.

5.2 Nonwoven fabrics and products that are designed to degrade after use have been developed. These nonwovens are intended to enhance existing solid waste landfill diversion

[5] Federal Trade Commission, 6th Street & Pennsylvania, NW, Washington, DC 20580.

[6] Workshop proceedings can be obtained from the Institute for Local Self-Reliance, National Office, 2425 18th St., NW, Washington, DC 20009-2096.

[7] The Composting Council, 14 South Pitt Street, Alexandria, VA 22314.

[8] The National Composting Program, The United Conference of Mayors, 1620 Eye Street, NW, Washington, DC 20006.

[9] The boldface numbers given in parentheses refer to a list of references at the end of the text.

[10] Definition as given in the Compost Facility Operating Guide referenced in Footnote 13.

programs by allowing difficult to recycle materials to be collected and processed in alternative solid waste disposal systems. Biological waste management, such as composting, has emerged as a viable approach to process these compostable nonwovens along with the organic fraction of municipal solid waste (MSW). A comprehensive testing program is needed to establish the compostability (for example, fragmentation rate, biodegradation rate and safety) of these materials.

5.3 Each tier in this guide includes objectives and a summary which presents potential test methods, method principles, test duration, implication of results and recommended priority.

5.4 This guide can be adapted to generate product specific evidence for substantiation of compostable claims and obtaining classification as a compostable product. State and local regulations should also be considered.

6. Tier 1: Biodegradation Screening Tests

6.1 *Summary*—In this tier, rapid screening-level studies are performed, under mesophilic conditions, to obtain information unavailable from literature review. The objectives are to determine whether biodegradation of the materials in the nonwoven fabric or product can occur, where biodegradation is based upon carbon dioxide (CO_2) production, and expand the understanding of the degradation mechanism.

6.2 The following test methods are recommended for initial screening of materials in the nonwoven fabric or product.

6.2.1 *Test Method D 5209 (Sturm Test)*—This aqueous test method utilizes a fresh sample of activated sewage sludge that has been aerated, homogenized and settled. The supernatant is used as the inoculum. It contains primarily a mixed bacterial population which promotes rapid biodegradation under mesophilic conditions. Metabolism of test materials produces CO_2, that is trapped in alkali solution and quantitated by titration. Test length is typically 30 days, but can be extended if the medium is reinoculated. A positive result (recovery of ≥60 % of theoretical CO_2) usually indicates the material will also biodegrade in a composting environment. A negative result should be confirmed by a lab thermophilic composting test such as Test Method D 5338. The contribution of non-microbial degradation can be quantified by including sterile or poison controls and comparing changes in molecular weight or mass of the samples.

6.2.2 *Test Method D 5988*—This static test uses a defined sand/soil/mature compost matrix to provide a consortium of mesophilic and thermophilic bacteria and fungi. Biodegradation is measured in a manner similar to the Sturm test based on the amount of material carbon converted to gaseous carbon (CO_2). Readily biodegradable materials can be screened in 30 to 60 days. A negative result should be confirmed by a thermophilic composting test (Test Method D 5338).

6.3 The following test methods are recommended to obtain additional evidence of inherent biodegradability of materials.

6.3.1 *Test Method D 5247 (Specific Microbe Test)*—This aqueous test utilizes pure microbial cultures to assess the biodegradability of materials under mesophilic conditions based upon mass loss or molecular weight changes. Test duration is 7 to 14 days. Microbes indigenous to the composting or soil environment can be evaluated with this method.

6.3.2 *Practice G 22 (Bacteria Growth Resistance)*—In this practice solid materials are placed in inoculated molten agar and the extent of microbial growth is rated. Test duration is about 14 days. A positive result indicates the test material is potentially biodegradable.

6.3.3 *Clear Zone Assays*—Opaque test material is dispersed into solid agar. A given quantity of microorganisms is applied to form a lawn. Degradation of a material is indicated by formation of clear zones in the solid medium. Test duration is 3 to 14 days. A positive result indicates the test material is potentially biodegradable. Microbes indigenous to the composting or soil environment can be evaluated with this method. Biodegradability of non-opaque organic materials can be assessed by adding the indicator 2,3,5-triphenyl-tetrazolium chloride (TTC) to the media. If microbial colonies can oxidize the material, their electron-transport pathways will reduce the TTC. Reduced TTC is detected by its deep red color, whereas oxidized TTC is colorless **(1)**.

6.3.4 *Test Method E 1720 (Biodegradability in a Sealed Vessel)*—Ready aerobic biodegradability of organic materials is assessed in small sealed vessels inoculated with sewage microbes. Gaseous CO_2 is monitored by head space analysis. This method represents a simpler approach relative to Practice D 5209. A positive result (≥60 %) usually indicates that the material will also biodegrade in a composting environment.

6.4 *Substrate Utilization*—If it appears a material is being colonized or utilized as a growth substrate by microorganisms, a more fundamental understanding of the degradation process can be obtained. This typically involves preparation of purified microbial cultures capable of utilizing the material as a carbon source. The pure cultures can then be used for isolation and characterization of cellular enzyme systems contributing to degradation of the material **(2)**.

6.5 *Cress Seed Germination Bioassay*—This test method is used to assess the potential effect of materials on plant germination. This step may be especially valuable for screening processing additives used at 1 % or less in the nonwoven. Soils from the above soil contact test (see 6.2.2) may be evaluated at the beginning and end of the test to establish the potential effect of microbial degradation products. In the cress test, soil or compost is extracted with water and filtered. The supernatant is used for the germination test. Various dilutions of the supernatant are prepared and aliquots are added to petri dishes lined with filter paper. Cress seeds are placed into the petri dishes. The percentage of germinated seeds is determined after four days and compared to a water control. Soils containing test materials should be not significantly different from the blank soil at 95 % confidence interval.

7. Tier 2: Laboratory and Pilot Scale Composting Assessment

7.1 *Summary*—The objectives of this tier are to:

7.1.1 Establish the degradation rate (change in chemical structure, decrease in mechanical properties, fragmentation or mass loss) of the nonwoven fabric or product under lab scale thermophilic composting conditions.

7.1.2 Confirm the biodegradability of the materials in the nonwoven fabric or product under lab scale thermophilic composting conditions.

7.1.3 Determine whether any residual material continues to biodegrade in a lab scale simulation of compost-amended soil.

7.1.4 Obtain additional evidence with regard to the environmental safety of the materials of a nonwoven fabric or product using compost obtained from lab scale studies.

7.1.5 Establish the degradation rate of a nonwoven product or finished article under pilot scale composting conditions prior to full scale composting studies described in Tier 3.

7.2 The following test methods are recommended to establish the degradation rate of the materials in the nonwoven fabric or product under lab scale composting conditions.

7.2.1 The degradation rate of test materials under lab thermophilic composting conditions may be obtained by using Test Method D 5338 without the CO_2 trapping component. Test materials are exposed to an inoculum that is derived from stabilized compost from municipal solid waste. Aerobic composting takes place in an environment where temperature, aeration, and humidity are closely monitored and controlled. The degradation rate of materials may be established with the current Test Method D 5338 temperature profile or constant 58°C that has been adopted by the European standards organization—Comité Européen de Normalisation (CEN). Test duration is 45 days, but may be extended to simulate field conditions. At various time intervals, materials may be removed from the compost, cleaned and dried.

7.2.1.1 Changes in material chemical structure may be quantitated based upon in molecular weight distribution (Test Method D 3593). More sophisticated techniques such as Fourier transform infra red (FTIR) and nuclear magnetic resonance may also be appropriate **(3)**. Loss of material integrity due to material degradation may be quantitated by using Test Method D 5734 for tear strength, Test Method D 3786 for bursting strength, and Test Method D 5034 for breaking strength and elongation. Material degradation may also be established based upon mass loss (Test Method D 3776). Surface damage may be evaluated using tools such as scanning electron microscopy (SEM).

7.2.1.2 Degradation rates of materials may also be established using simulated MSW matrixes in externally heated and self-heating controlled lab scale composting environments according to Test Methods D 5512 and D 5509.

7.2.1.3 Sieve analysis can be included in the above tests to obtain additional fragmentation information. Compost containing fragmented material may be passed through a U.S. Standard Sieve with a 9.51 mm (⅜ in.) opening. This simulates the final screening step used to produce high quality compost products. National, state and local regulatory requirements should also be consulted.

NOTE 3—Agitation from compost turning equipment at full scale facilities may give faster fragmentation rates relative to lab scale methods.

7.3 The following test methods are recommended to establish the biodegradation rate of a nonwoven fabric or product.

7.3.1 Test Method D 5338 is suggested to establish the biodegradability of materials of a nonwoven fabric or product in a composting environment. The biodegradability is based upon the amount of material carbon recovered as gaseous carbon (CO_2) relative to the amount of material carbon originally added to the compost. Product organic components, at levels of 1 % or less, generally do not require retesting in this step if a positive result was obtained in Tier 1, 6.1. This test can be performed separately, or concurrently with 7.1. Biodegradation rates or end points should meet national, state or local regulations or be compared to reference materials described in 7.2.2.

7.3.1.1 If a negative result is obtained, check the controls described in the method or repeat the test with a lower dose closer to field use levels (assuming that an acceptable signal to noise ratio is possible).

7.3.2 Nonwoven fabrics or products may be compared under identical conditions to natural reference materials known to be biodegradable in a composting environment (for example, cellulose or starch[4]). Other materials regarded as biodegradable in a composting environment are oak, maple and corn leaves, and kraft paper.[8] Unmodified polypropylene film or nonwoven, is generally considered a negative reference material.

7.3.3 Recovery of all material carbon as gaseous carbon (CO_2) may be impractical due to incorporation of material carbon into microbial biomass or stable humic substances. Materials labeled with the radioactive isotope of carbon, ^{14}C, may allow identification of carbon partitioned into the following: CO_2-C, residue-C, water soluble-C and microbial biomass-C. In this manner, a complete mass balance may be obtained. Use of radioactive isotope labeling allows testing at field use levels, in composts with high background CO_2. However, these definitive studies are comparatively expensive.

NOTE 4—There is currently no ASTM test method for ^{14}C-labeled materials.

7.3.4 The effect of a material on compost microorganisms may be evaluated as described by Schwab et al. **(4)**.

7.4 The following test methods are recommended to establish the rate at which the nonwoven fabric or product continues to biodegrade in compost conditioned soil.

7.4.1 If incomplete biodegradation is indicated in 7.2, the biodegradability of product or component residue in soil can be established with the soil contact method cited in 6.2.2. Test duration should be minimum of six months or until a regulatory specification is attained or results support calculation of a rate as indicated by lack of a plateau.

7.4.2 Materials from 7.2.2 can also be evaluated in soil to obtain additional comparative data.

7.4.3 Composts should be prepared according to Practice D 5957 prior to soil studies.

7.5 The following terrestrial and aquatic ecotoxicity tests are suggested to obtain evidence regarding product effects on plant and animal life. National, state and local regulatory requirements should be considered.

NOTE 5—The nonwoven fabric or product should not cause any negative ecotoxicological effects on the resulting compost.

7.5.1 Compost from 7.2 should be prepared according to Test Method D 5152 or the bridging practice in D XXX2 (see 7.4.3 above) prior to performing ecotoxicity tests.

7.5.2 The following ecotoxicity tests are suggested as a minimum prior to proceeding to pilot and full scale testing:

7.5.2.1 Aquatic toxicity test with rotifer Branchionus according to Test Method E 1440. Test duration is about one month.

7.5.2.2 Plant germination as described by the cress seed test in 6.4. Test duration is about one month.

7.5.2.3 Plant growth test as described by OECD Guideline 208. This test method determines phytotoxicity by mixing the compost containing the material with soil. Plant emergence survival and growth is evaluated. Generally three plant species are tested. Test duration is about 1 month. Results from compost containing material are compared to compost without material and to a soil control.

7.5.2.4 Earthworm test according to OECD Method 207. This test determines possible toxicity by mixing the compost containing the material with a specified soil. Earthworm mass change and survival are measured. Results from compost containing material are compared to compost without material and to soil controls.

7.6 Pilot-scale investigations are intended to confirm results from lab-scale composting tests. These tests may be used to evaluate the practical processibility, at anticipated field use levels, of a nonwoven fabric or product or full sized article by simulating larger scale operating conditions.[4] Pilot-scale tests may also be used to establish the impact of different waste matrices on degradation of a material **(4)**.

7.6.1 An ASTM standard pilot scale test method has not been developed. Pilot scale systems ranging from relatively simple to complex have been constructed by Industry **(4)** and commercial testing labs. Some systems include rotating drums (manual or mechanical) to simulate full scale feedstock homogenization and composting process initiation. Some systems control feedstock aeration and temperature. Vessel size ranges from 30 to 200 L. All systems are self-heating. The duration of the thermophilic composting phase ranges from a few days to a few weeks.

7.6.2 Externally-heated pilot scale systems may be required to simulate thermophilic conditions characteristic of full scale processes.

7.6.3 Product degradation, safety and microflora changes may be measured with the techniques described in 7.1, 7.2.4 and 7.4.

7.7 In addition to ecotoxicity, a product may not have a negative effect on the quality of the compost based upon standard chemical and physical tests. National, state and local regulations should be consulted.

7.7.1 The quality of pilot scale composts containing degraded nonwoven fabric or product should be compared to pilot scale nonwoven-free composts based upon chemical analysis. Suggested analyses include EPA 503 heavy metals, pH, compost maturity, density, porosity and conductivity as described in Recommended Test Methods for the Examination of Compost and Composting (2.3).

8. Tier 3: Field/Full Scale Assessment

8.1 *Summary*—In this tier the compostability of products in the field is established based upon full scale composting studies and backyard composting environments. The backyard studies have been included in response to current Guidelines for the Use of Environmental Marketing Claims (2.3).

8.2 Field assessment of products in full scale systems should include a range of technologies. Technologies range from unmanaged piles (municipal yard waste) to turned aerated static piles with temperature control to tunnel/agitated bay systems with temperature control. Consult the Compost Facility Operating Guide (see 2.3) to obtain descriptions of facility technologies in the United States. The need for full scale assessment may be reduced as composters, solid waste managers, and degradable nonwoven fabric and product suppliers gain experience with their products.

8.2.1 Ideally, the test nonwoven should be added to the feedstock at anticipated exposure levels. It should be exposed to the entire process to establish the compatibility with turning equipment and to ensure that it is not screened-off early in the process. Other goals are to ensure that the test material does not have an adverse effect on the process (that is, biological activities, litter, odor, pH, etc.) and that the test material is not visually distinguishable after curing and final processing is completed.

8.2.2 A useful technique to quantitate the degradation rate in full scale systems which do not grind feedstock, is through the placement of fiberglass pouches containing the product in the feedstock. The pouches may be removed periodically to measure the fragmentation rate and to quantify product degradation as described in 7.1.

NOTE 6—A full scale procedure which includes use of the pouches has been developed by ASTM Institute for Standard Research Degradable Polymer Advisory Committee. The procedure may be submitted to ASTM for standardization.

8.2.3 Limited plant growth studies using compost containing degradable products are also recommended. The intent of these studies is to confirm previous lab/pilot scale results.

8.3 According to the Guidelines for Environmental Marketing Claims, an unqualified compostable claim is considered deceptive if the product is not compostable in a “home” or “backyard” environment. The compostability of nonwoven fabrics or products in backyard composting environments can be established, if needed. The composting process tends to be slower due to a relatively short thermophilic composting phase. Loss of heat due to the relatively small pile or bin size is a significant factor. The approach described in 7.5 and 7.6 will likely provide sufficient evidence.

8.3.1 The compostability of products should be established in both bins and free-standing piles based upon typical home composting practices.

9. Report

9.1 State that the samples were tested as directed in Guide D 6094. Describe the materials or products sampled and the method of sampling used.

9.2 Report the following information:

9.2.1 A summary of the results from all three tiers, and

9.2.2 Conclusions regarding compostability of the materials, including biodegradation, fragmentation and safety.

10. Keywords

10.1 biodegradation; composting; ecotoxicity; nonwoven fabric

REFERENCES

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(**2**) Skipper, H. D., et al., "Microbial Degradation of Herbicides," in *Research Methods in Weed Science, 3rd Ed.*, N. D. Camper, ed., Southern Weed Science Society, Athens, GA, 1986, pp. 457–462.

(**3**) Jendrossek, D., et al., "Degradation of Poly(3-hydroxybutyrate), PHB, by Bacteria and Purification of a Novel PHB Depolymerase from *Comamonas* sp.," *Journal of Environmental Polymer Degradation*, 1993, Vol 1, pp. 53–63.

(**4**) Seal, K. J., "Test Methods and Standards for Biodegradable Plastics," in *Chemistry and Technology of Biodegradable Polymers*, G. L. Griffin, ed., Blackie Academic and Professional, Glasgow, 1994, pp. 116–134.

(**5**) Schwab, et al., "Characterization of Compost from a Pilot Plant-Scale Composter Utilizing Simulated Solid Waste," *Waste Management and Research*, 1994, Vol 12, pp. 289–303.

(**6**) Zucconi, et al., "Cress Seed Germination Bioassay," *Biocycle*, Vol 22(2), 1981.