The Effect of Moisture and pH on the Biodegradability of Packaging Materials

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Abstract

The U.S. produces 268 million tons of waste, of which over 140 million go into landfills, with paper and cardboard accounting for 23.05% and styrofoam at 30%. Landfills contribute to 14.5% of methane emissions due to their process of waste compaction then covering the waste with soil (decomposition). An alternative method, biodegradation, incorporates soil but instead absorbs waste while emitting fewer greenhouse gasses; therefore, I hypothesize the higher the moisture (controls available oxygen in soil) and the higher the acidity (impacts enzyme activity and weakens the biological properties of paper-based materials) in soil paired with a significantly compostable material or paper, then that material will biodegrade the fastest, determined through mass over one month. To experiment, paper, cardboard, and styrofoam will be enclosed in soil paired with three levels of DV: pH 8–14, 1-6, and 7 (IV: granulated lime, increases pH, and soil sulfur, decreases pH); moisture content: 0 mL, 627.46 mL—the average rainfall in Virginia—and 1,254.92 mL—double. Samples (Paper, cardboard, styrofoam): 0mL and pH-10- 3-7 produced a mass of [0.50-4.6-0.05], [0.50-4.6-0.05], and [0.50-4.6-0.05] after one month. 627.46mL and pH-10-3-7 produced a mass of [0.4-4.50-0.05], [0.27-4.45-0.05], and [0.43-4.55-0.05]. Lastly, 1,254.92mL and pH-10-3-7 produced a mass of [0.38-4.48-0.05], [0.24-4.41-0.0495], and [0.41-4.52-0.05]. My hypothesis that paper degrades the fastest and the greatest mass lost after one month, was supported. My experiment concludes biodegradation can produce similar results to landfills while being a natural process that emits less methane.

Billions of pounds of packaging waste that pile up from consumer products sit in landfills, releasing carbon and methane into the atmosphere due to improper disposal. These emissions increase the gap in the ozone layer, leading to global warming and the extinction of certain ecosystems. According to the EPA, the average person produces about 5.91 pounds of trash and 1.51 pounds recycled; therefore, about 4.40 pounds average daily waste per person. Additionally, companies produce more than 90% of plastic and overall waste. Once again, these pounds of trash are often sorted improperly, therefore not disposed of correctly. My experiment on the effect of moisture and pH on the biodegradability of packaging materials, tests if styrofoam, cardboard, and paper can be degraded to discover the most sustainable material for packaging. Additionally, I tested the speed of the materials' biodegradation. Thus, the purpose of my experiment is to use biodegradation to show companies and communities a more sustainable way to degrade organic materials. As a result, my hypothesis concludes that if I add moisture and acidity to the soil with the most compostable material, that material will biodegrade the fastest because increase in moisture and acidity breaks down materials faster, depending on their composition.

Cambridge Dictionary defines biodegradation as a natural process where organic materials in the environment are converted into simpler compounds, then mineralized and redistributed through the elemental, carbon, nitrogen, and sulfur cycles. Factors that affect biodegrading are as follows: presence of substates, water activity, temperature, the redox environment, and pH. However, styrofoam is not biodegradable; therefore, I do not know how these factors will affect this material, but this product will still be tested. Additionally, this product’s content, polystyrene foam, was banned in eight US states and one territory. The main question here could be why, which is also something my experiment will reveal. On the other hand, paper and cardboard *are* biodegradable, so I infer that my previous factors will have a large impact on their composition.

To further the factors' impact, I will enclose the items in soil. Soil's conditions can easily be changed and often inhabit substates, which is not a part of the testing but increases the product's chances and speed in the biodegradation process.

Materials: Similarly, the first factor in my experiment will be moisture content. Moisture affects the physical and biological properties of soil as it controls the available oxygen—oxidative degradation is a main factor in paper decay; the higher the moisture content, the higher the oxygen level. Furthermore, moisture has an immediate impact on the molecular structure of paper and cardboard, weakening it. The item becomes brittle and distorted, which makes it easier to degrade without the use of industrial methods but may have little effect on styrofoam's structure. Therefore, in this experiment, there will be three different levels of water volume to test which amount is most effective. I hypothesize that a higher moisture content, combined with increased dissolved oxygen, will speed up the rate of an item's biodegradation.

Materials: Correspondingly, the second IV in my experiment is the pH level of the soil. According to Palmisano, degradation rates increase at 7–7.5 and begin to slowly decrease again afterwards (Biodegradability of Plastics, BioScience). This directly correlates with a higher bacterial population and greater enzyme activity, which help break down materials into a natural compost. Hence, I will be using granulated lime to increase the pH and soil sulfur to decrease the pH of the soil. As the soil pH becomes alkaline, the acidity substrates attack the cellulose chains, causing the paper to become more brittle or weak; similarly, this condition does the same to cardboard. In contrast, polystyrene, or styrofoam, is resistant to both acids and bases. Therefore, I hypothesize that an alkaline or neutral pH will degrade the items the fastest or have the most impact.

As touched upon in the introduction, improper disposal of waste creates large amounts of carbon emissions; about 5% of global greenhouse gas emissions come directly from landfills. Additionally, landfills release methane and carbon dioxide, which together make up 90% of landfill gasses; the remaining 10% consists of nitrogen, oxygen, ammonia, sulfides, and hydrogen (EPA, Basic Information About Landfill Gas). Methane is described as a potent greenhouse gas that is 28–36% more effective at trapping heat in the atmosphere. Furthermore, landfills are the third-largest source of methane emissions in the United States, contributing approximately 14.5% of these emissions in 2020. Consequently, these emissions contribute to climate change, which is related to respiratory diseases, extreme weather, food supply disruptions, and increased wildfires. As a result, my experiment helps to reduce this impact by finding natural ways—biodegradation—to break down organic waste.

Method used to conduct experiment: paper, cardboard, and styrofoam are enclosed in 10 containers each. Before the materials/DV(s) are enclosed, their initial mass is collected in g/m^2. The first 3 containers are classified as the control, consisting of only the selected materials and potting soil. The second set (3 total): materials, 0mL, and a pH of 9. The third set (3 total): materials, 627.46mL, and a pH of 9. The fourth set (3 total): materials, 1,254.92mL, and a pH of 9. The fifth set (3 total): materials, 0mL, and a pH of 3. The sixth set (3 total): materials, 627.46mL, and a pH of 3. The seventh set (3 total): materials, 1,254.92mL, and a pH of 3. The eighth set (3 total): materials, 0 mL, and a pH of 7. The ninth set (3 total): materials, 627.46mL, and a pH of 7. The tenth set (3 total): materials, 1,254.92mL, and a pH of 7. The additional masses of the DV(s) are collected every week for a month to detect any decreases related to the different environments.

The results are as follows: Samples (Paper, cardboard, styrofoam): 0mL and pH-10- 3-7 produced a mass of [0.50-4.6-0.05g/m^2], [0.50-4.6-0.05], and [0.50-4.6-0.05] after one month.

627.46mL and pH-10-3-7 produced a mass of [0.4-4.50-0.05], [0.27-4.45-0.05], and [0.43-4.55-0.05]. Lastly, 1,254.92mL and pH-10-3-7 produced a mass of [0.38-4.48-0.05], [0.24-4.41-0.0495], and [0.41-4.52-0.05]. These results lead to the conclusion that supports my hypothesis, paper was the fastest to decay/ had the highest mass decrease compared to the other DV(s). Significantly, as there is not much data online pertaining to my experiment, I question why that is. There are accounts of the effect of pH and moisture on the rates of biodegradation, but no experimented data correlating to testing certain materials and them being affected by these factors. Although, this makes sense as landfills are too populated and condensed with materials that biodegradation has a hard time occurring but would be done if given the right resources, energy, and effort put into my landfill companies. Despite the paper and cardboard biodegrading, there were no long-term effects on the styrofoam — although having a slight change at the end due to the concentrated acidity of the soil. Another study could dig deeper into organic ways, has been done through inorganic processes, to make styrofoam break down without negatively impacting the environment or ecosystems. There is a large percentage of styrofoam in landfills so a continued experiment about styrofoam could significantly help to lower landfills' effect on the environment and climate change. Ultimately, furthering research into this topic could decrease climate changes effects as it directly deals with correctly landfills emission issues. Studying a new way to degrade materials that emit little to no harmful gasses and protect microplastic impacting soil quality, could provide gateways into more in-depth research relating to landfills impact on the environment and well-being of those in neighboring areas.

	Intial Mass (g)/m	1st Week	2nd Week	3rd Week	4th Week	Average
Paper (Control, just in soil)	0.50 g/m^2	0.50 g/m^2	0.50 g/m^2	0.50 g/m^2	0.50 g/m^2	0.50 g/m^2
Cardboard (Control, just in soil)	4.6 g/m^2	4.6 g/m^2	4.6 g/m^2	4.6 g/m^2	4.6 g/m^2	4.6 g/m^2
Styrofoam (Control, just in soil)	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2
Paper (No water, PH Base)	0.50 g/m^2	0.50 g/m^2	0.50 g/m^2	0.50 g/m^2	0.50 g/m^2	0.50 g/m^2
Cardboard (No water, PH Base)	4.6 g/m^2	4.6 g/m^2	4.6 g/m^2	4.6 g/m^2	4.6 g/m^2	4.6 g/m^2
Styrofoam (No water, PH Base)	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2
Paper (627.46 mL, PH Base)	0.50 g/m^2	0.48 g/m^2	0.45 g/m^2	0.42 g/m^2	0.38 g/m^2	0.43 g/m^2
Cardboard (627.46 mL, PH Base)	4.6 g/m^2	4.59 g/m^2	4.58 g/m^2	4.5 g/m^2	4.52 g/m^2	4.55 g/m^2
Styrofoam (627.46 mL, PH Base)	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2
Paper (1,254.92 mL, PH Base)	0.50 g/m^2	0.46 g/m^2	0.43 g/m^2	0.39 g/m^2	0.34 g/m^2	0.41 g/m^2
Cardboard (1,254.92 mL, PH Base)	4.6 g/m^2	4.57 g/m^2	4.53 g/m^2	4.50 g/m^2	4. 47 g/m^2	4.52 g/m^2
Styrofoam (1,254.92 mL, PH Base)	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2
Paper (No water, PH Acidic)	0.50 g/m^2	0.50 g/m^2	0.50 g/m^2	0.50 g/m^2	0.50 g/m^2	0.50 g/m^2
Cardboard (No water, PH Acidic)	4.6 g/m^2	4.6 g/m^2	4.6 g/m^2	4.6 g/m^2	4.6 g/m^2	4.6 g/m^2
Styrofoam (No water, PH Acidic)	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2
Paper (627.46 mL, PH Acidic)	0.50 g/m^2	0.44 g/m^2	0.36 g/m^2	0.25 g/m^2	0.05g/m^2	0.27 g/m^2
Cardboard (627.46 mL, PH Acidic)	4.6 g/m^2	4.57 g/m^2	4.50g/m^2	4.41 g/m^2	4.30 g/m^2	4.45 g/m^2
Sytrofoam (627.46 mL, PH Acidic)	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2
Paper (1,254.92 mL, PH Acidic)	0.50 g/m^2	0.42 g/m^2	0.32 g/m^2	0.20 g/m^2	0.045g/m^2	0.24 g/m^2
Cardboard (1,254.92 mL, PH Acidic)	4.6 g/m^2	4.55 g/m^2	4.47g/m^2	4.37 g/m^2	4.26 g/m^2	4.41 g/m^2
Styrofoam (1,254.92 mL, PH Acidic)	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2	0.048 g/m^2	0.0495 g/m^2
Paper (No water, PH Akiline)	0.50 g/m^2	0.50 g/m^2	0.50 g/m^2	0.50 g/m^2	0.50 g/m^2	0.50 g/m^2
Cardboard (No water, PH Akiline)	4.6 g/m^2	4.6 g/m^2	4.6 g/m^2	4.6 g/m^2	4.6 g/m^2	4.6 g/m^2
Styrofoam (No water, PH Akiline)	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2
Paper (627.46 mL, PH Akiline)	0.50 g/m^2	0.47 g/m^2	0.43 g/m^2	0.38 g/m^2	0.32 g/m^2	0.4 g/m^2
Cardboard (627.46 mL, PH Akiline)	4.6 g/m^2	4.57 g/m^2	4.52 g/m^2	4.48 g/m^2	4.42 g/m^2	4.50 g/m^2
Styrofoam (627.46 mL, PH Akiline)	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2
Paper (1,254.92 mL, PH Akiline)	0.50 g/m^2	0.46 g/m^2	0.42 g/m^2	0.35 g/m^2	0.30 g/m^2	0.38 g/m^2
Cardboard (1,254.92 mL, PH Akiline)	4.6 g/m^2	4.55 g/m^2	4.51 g/m^2	4.46 g/m^2	4. 40 g/m^2	4.48 g/m^2
Sytrofoam (1,254.92 mL, PH Akiline)	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2	0.05 g/m^2

*Data points of paper, cardboard, and styrofoam in each condition.

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