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Disparity between the Terms "Biodegradability" and "Biobased" Pertaining to Biodegradable Mulch Films

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Summary

"Biobased" and "biodegradable" are essential and helpful terms when it comes to understanding biodegradable mulch films; yet, these terms are often poorly understood, hence mis-communicated. Biobased does not entail biodegradability nor does it imply that fossil-based materials are not biodegradable. It is then essential to understand that biodegradability is an inherent property of a material that is independent of its feedstock source, but depends on the molecular structure of its polymeric constituents and their ability to be utilized by microorganisms.

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USDA United States Department of Agriculture National Institute of Food and Agriculture

1. Introduction

For many years, the terms *biobased* and *biodegradable* have been poorly understood by many audiences, including current and potential users of biodegradable mulches (BDMs). Products labeled as "biobased" are oftentimes misperceived by consumers as being biodegradable because their constituents were derived from renewable resources. Yet, biobased products do not necessarily have *inherent capability* to biodegrade, and many fossil-derived materials are readily biodegradable. *Biobased* (*defined in Table 1*) [1] only pertains to the beginning stage of plastic mulch`s life cycle, particularly to its feedstock sources. In contrast, *biodegradable* (*defined in Table 1*) [2] refers to the mulch's end-of-life. *Figure 1* compares the life cycle of biobased and fossil derived polymeric components of BDMs. The former and latter can be represented by polylactic acid (PLA) and polybutyrate adipate terephthalic acid (PBAT), respectively. Their molecular structures are given in *Figure 2*.

Both polymers undergo nearly identical life cycles except for the initial stage, i.e., during sourcing and preparation of feedstock. After the completion of their useful-life stage in specialty crop production, during which they reduce weeds, retain soil moisture and modulate soil temperature, BDMs can be tilled into the soil or composted [3, 4]. Despite being derived from diverse feedstocks, PBAT and PLA are biodegradable. Their carbon atoms are consumed by microbes and returned to the environment in two forms: CO_2 which is a new carbon input that can be recaptured by plants, with the remaining balance going to biomass which contributes to the organic content of the soil.

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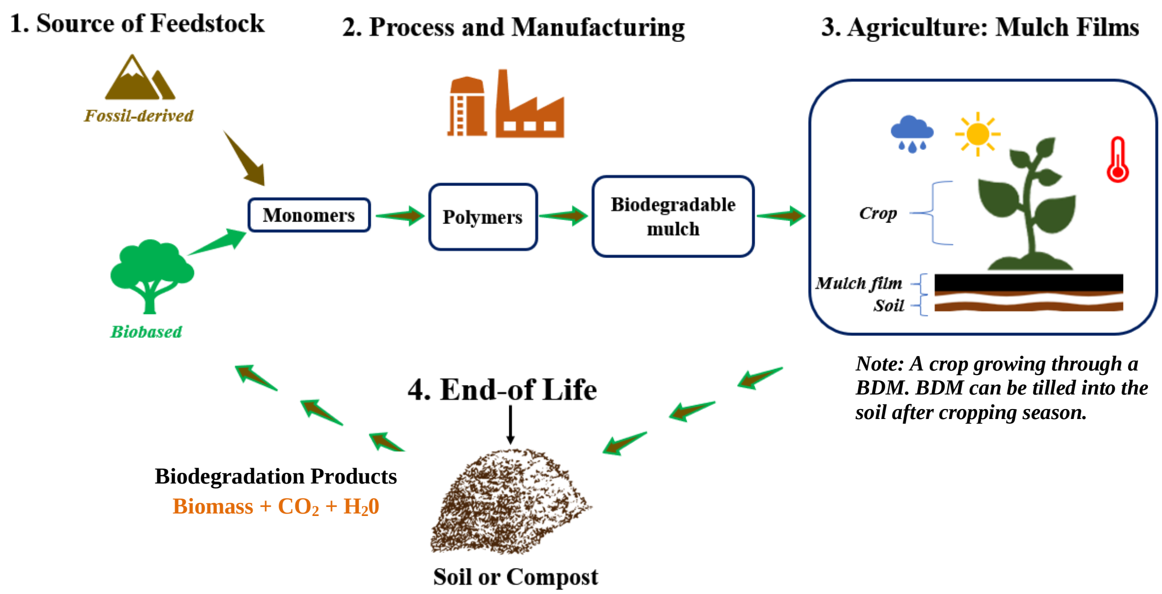

Figure 1. Comparison of the life cycle of polymers employed for biodegradable mulches. Green arrows indicate pathway for biobased-biodegradable polymers while brown arrows represent fossil-based biodegradable polymers.

Image source: https://www.1001freedownloads.com/free-clipart/compost-pile (compost image only)

Table 1. Definition of terms frequently used that relate to biobased and biodegradable plastics.

Term	Definition
Biobased	*Materials that contain renewable plant, marine, and forestry-based resources not derived from petroleum [1]*
Biodegradable	*Capable of being broken down via microbial activity, as opposed to degradable, which refers to materials that can be broken down by abiotic factors such as heat, UV light, or mechanical stress. Complete biodegradation (i.e., mineralization) refers to the oxidation of the parent compound (an organic molecule) to carbon dioxide and water. Biodegradation provides both carbon and energy for the growth and reproduction of cells [2]*
Biodegradable plastic mulch	*Biodegradable plastic mulch: Manufactured alternative to plastic mulch. Ideally, biodegradable mulch provides the same benefits as plastic mulch (weed control, soil temperature moderation, reduced soil-borne pathogens, soil moisture retention, and soil conservation) and provides the added benefit of being 100% biodegradable, either in the field, soil or in composting, with no formation of toxic residues [7]*
Composting	*Process where biodegradable materials are decomposed and transformed into compost, CO_2, water, inorganic compounds and biomass through a controlled biological process [19]*
Degradation	*Irreversible process leading to a significant change of the structure of the material, typically characterized by loss of properties [14]*

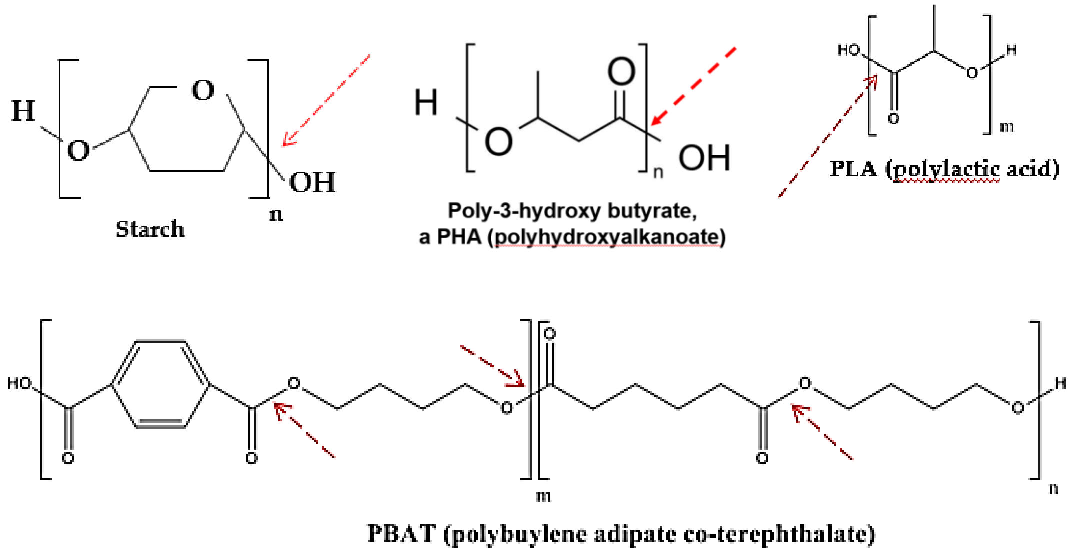

Figure 2. Molecular structure of commonly used polymeric components for biodegradable mulch films. Red arrows indicate hydrolyzable chemical bonds that undergo breakdown during microbial attack.

2. Differentiation of the terms Biobased and Biodegradable

Biobased: A Term Referring to Feedstock Source

Biobased materials contain carbon atoms derived *wholly or partially* from renewable feedstocks. Based on this definition, some but certainly not all BDMs are biobased [5, 6, 7]. Even though fossils and renewable products are based on carbon, the age of the carbon can be measured. The biobased content of BDMs is determined based on the levels of carbon isotopes, measured through the ASTM D6866 standardized method [8]. For instance, carbon-14 (^{14}C) can be detected in higher levels in biobased products than fossils [9]. The most common fully biobased polymers used for BDMs are polysaccharides (e.g. starch and cellulose), PLA (a polyester prepared via chemical polymerization of lactic acid, which is readily prepared from maize and other biomass via fermentation), and polyhydroxyalkanoates (PHA), which are polyesters that are synthesized directly by microorganisms (*Figure 2*).

Currently, a 100% biobased BDM that meets functionality and mechanical property benchmarks needed during the growing season is not commercially available. PBAT, for instance, is traditionally 100% fossil-based. However, a biobased 1,4-butanediol is now prepared on a commercial scale through fermentation. The incorporation of fully biobased 1,4-butanediol into PBAT increases the biobased content. In addition, the adipic acid group ($-OOC(CH_2)_4COO-$), can also be substituted by fully biobased azelaic acid ($-OOC(CH_2)_7COO-$), derived from fatty acids of crops rich in oil content [10]. Yet, increasing the biobased content often increases the market costs to the farmers, with no added benefit in mulch performance or biodegradation. In the U.S., BDMs can be certified for organic agriculture only if a soil biodegradable mulch contains 100% biobased polymer feedstock [11]. However, to develop a soil biodegradable plastic mulch entirely from biobased sources remains a continuing endeavor [12].

Biodegradable: End-of Life Option of a Material

Role of Polymeric Structure

Biodegradability refers to a material-related property that does not depend on the nature and origin of feedstock. The inherent chemical properties of a polymeric material (e.g. chemical bonds) determines availability and susceptibility to break down during microbial attack (*Figure 2*) [13]. For example, PBAT, whether fossil-based or partially biobased, is readily biodegradable due to its labile ester bonds building blocks.

Biodegradation Is a Misunderstood Term

Biodegradation is the desirable path for the end-of-life of BDMs. But, in fact, this term represents several unique biodegradation pathways that a polymeric material can undergo. Each pathway is controlled by the biodegradation environment, including the set of biotic and abiotic environmental conditions employed, and physicochemical changes that occur during the material's service life (e.g., environmental weathering). Moreover, the term "biodegradation" should not be used as a stand-alone term, but should be associated with a specific environmental type (e.g., composting vs. soil), percent conversion of carbon atoms into carbon dioxide (per ASTM D6400 and EN 17033), and a definite duration.

A polymeric material's exposure to environmental weathering (e.g., solar radiation and fluctuations in soil moisture, soil and ambient air temperature) during its service life has a strong impact on biodegradability. Moreover, environmental weathering causes the mulch to undergo degradation (*defined in Table 1*, [14]) through chemical reactions that cause chemical bond scission and subsequent chemical transformation [15]. Weathering often causes embrittlement of mulch films, which as a result, further break down into smaller pieces that ultimately will be too small to be visible to the naked eye. The size reduction of soil biodegradable mulch fragments will accelerate the rate of biodegradation by increased surface area exposure to the microorganisms.

The type of biodegradation environment and the parameters which control it play an important role in controlling the rate of biodegradation (*Figure 3*). In addition, the microbial communities associated with the biodegradation environment differ greatly between types (e.g. soil vs. compost), geographical regions, and management practices. During *composting* (*defined in Table 1)*, inherently biodegradable components, either bio- or fossil-based, are transformed into compost, CO_2, water and minerals through microbial action under aerobic conditions [16]. The rate of biodegradation in an industrial composting facility is typically faster because of the ability to control temperature, moisture and aeration to assist the microorganisms to work in their most optimum level of performance than in the field and would therefore yield higher rate of biodegradation. In the soil, biodegradation can be slower than in compost operations due to several factors: lower temperature, soil moisture level, degree of aeration, and concentration of microorganisms in soil [17]. Hence, it is important to reference biodegradation to a specific biodegradation environment and its underlying properties.

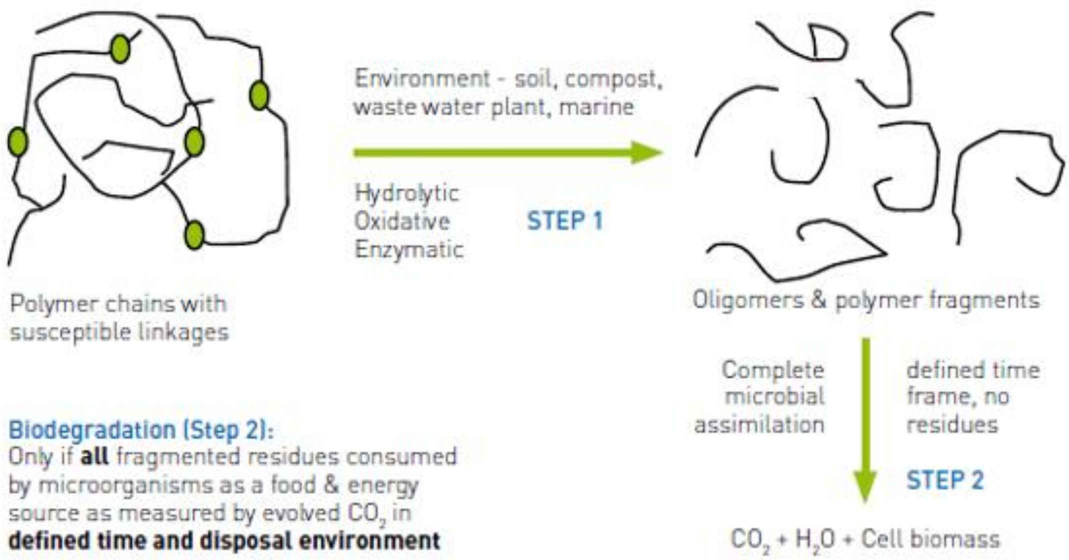

Figure 3 Biodegradation of carbon substrates. Source: Narayan, 2010 [17].

3. Conclusions

Understanding the terms biobased and biodegradable appropriately can aid farmers in properly selecting mulch films for specialty crop production using sustainable agriculture principles. It is vital to remember that a plastic mulch's biobased content does not control a mulch's biodegradability. Although the increase of biobased content in a soil biodegradable plastic mulch is a worthy pursuit, it does not affect biodegradability as long as the chemical structure or composition is not altered. The end-of-life is not dependent on feedstock but the polymeric structure.

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