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Short communication

# Policy considerations for limiting unintended residual plastic in agricultural soils

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ABSTRACT

Growing crops under high-intensity agriculture entails the use of numerous plastic products, especially polyethylene plastic films used as crop mulches. As a result, some of the world's most productive agricultural soils are now being affected by plastic pollution, seriously threatening soil health and food security. Plastic film mulches designed to biodegrade in soil provide an appealing alternative to polyethylene films. What may be surprising, however, is that biodegradable plastic films do not necessarily represent a long-term solution to the problem of contaminating soil with plastic residues. Transformative science and policies are needed to mitigate uncertainty of biodegradable plastic residue accumulation in agricultural soils.



## 1. Introduction

To meet the world's increasing demand for food, and global development goals for food security, modern agriculture relies heavily on plastic products, especially plastic films, which are used for applications including crop mulches, greenhouse coverings, labels, and silage wraps. The global market for agricultural plastic films, worth more than U.S. $5.8 billion (2012), is projected to grow 7.6% per year through 2019 (Transparency Market Research, 2019).

Plastic films used as crop mulches are composed typically of low-density polyethylene, or LDPE (Lamont, 1993), and play an essential role in fruit and vegetable production. Short-term benefits provided to growers by plastic film mulches include fewer weed problems, reduced soil water evaporation, earlier and higher yields, and higher-quality produce (Lamont, 1993). Because of their tremendous utility in agriculture, the use of plastic film mulches is increasing worldwide, while simultaneously exposing some of the world's most productive and valuable soil resources to plastic residue. The extent to which agricultural soils are mulched with plastic film on a global scale is uncertain and represents a critically important information gap that remains to be filled. Nonetheless, in China in 2011, nearly 20 million hectares were reported to be mulched, with use projected to grow 7.1% or more annually (Liu et al., 2014).

The expanding use of LDPE plastic films for crop mulching can be associated with significant costs to farmers and broader society. Once degraded via weathering, plastic film mulch fragments often are incorporated or left behind in agricultural soils, risking pollution of the broader terrestrial environment and, via run-off, the marine environment (Jambeck et al., 2015). Additionally, removal of plastic film mulch from the field is labor-intensive, disposal is costly, and recycling and reuse are difficult because soil particles often adhere tightly and plastic film mulch easily tears into small pieces due to weathering. Socially undesirable disposal methods include burning or tilling used plastic film mulch directly into the soil. Because open burning of agricultural plastics threatens air quality and public health, regulations banning this activity have been enacted in various parts of the world. And, where plastic film mulches have been used and tilled into fields repeatedly in China, plastic residue ranges from 72 kg/ha to 260 kg/ha (Liu et al., 2014). Plant growth is inhibited at these levels, and the accumulated plastic residue may affect soil moisture, nutrient

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transport, and secondary salinization (Liu et al., 2014). A recent and comprehensive review by Steinmetz et al. (2016) catalogs benefits (such as those listed above), detriments (e.g., increased runoff of sediments and pesticides), and variability of the agroecosystem impacts of LDPE mulch films. However, knowledge about the long-term effects of plastic residues in agroecosystems is sparse (Rillig, 2012; Steinmetz et al., 2016), as are policy solutions, signifying a poorly recognized environmental problem.

Plastic film mulches designed to biodegrade in soil provide an appealing alternative to LDPE crop mulches. Several products claiming biodegradability are now on the market. There is great interest in these products among specialty crop growers, agricultural extension agents, agricultural input suppliers, and other stakeholders (Goldberger et al., 2015). Yet, even more than with LDPE mulch films, the social and environmental costs associated with long-term use of biodegradable materials are unknown. Specifically, it is unclear how much residue might remain in soils from biodegradable plastic film mulches, and what effects such residues might have on soil ecosystems.

The major reason why in-soil breakdown cannot be predicted is that many plastic mulch products are certified to meet the standards of biodegradation only under the conditions of industrial composting. While biodegradation in soil could be inferred from the products' labels, compostability cannot necessarily be extrapolated to biodegradability under the field soil conditions of commercial agriculture. A standard that ensures biodegradation of plastic film in soil has yet to be established, although significant efforts are in progress. From a policy perspective, *developing a new standard would provide a credible mechanism to test products with uncertain environmental outcomes*, thereby enhancing protection of terrestrial and downstream marine environments from the risks posed by plastic film mulch residues that may not fully biodegrade.

## 2. Revisiting current standards

Nearly complete biodegradation (microbial conversion into carbon dioxide and/or methane and water) of the polymers typically used to manufacture biodegradable plastic film mulches can be achieved under industrial composting conditions. In part, the conversion relies on high temperatures not typically found in agricultural soils. Existing standards for industrial composting of biodegradable materials such as ASTM D6400 (ASTM International, 2012) employ a test method that inherently assumes soil microbial respiration to produce 44 g $CO_2$ for every 12 g C consumed. ASTM D6400 requires that ≥90% of theoretical $CO_2$ evolution be achieved within 180 days under controlled laboratory conditions (nutrients, pH, soil moisture, temperature) for plastics or for single organic constituents that comprise >1% of the product. ASTM D6400 permits persistence of fragments that are ≤2 mm (classified as microplastics). Thus compost, if used as a soil amendment, may be a source of residual microplastic.

The fate and transport of microplastics is largely unstudied in soil ecosystems (Rillig, 2012). ASTM D6400 and other compostability standards do not address biodegradation in soil. It is important to note that non-degraded plastic fragments and microplastics that accumulate in soil are not necessarily biologically inert. In marine systems, microplastics have been shown to adsorb hydrophobic toxicants, which can be released and absorbed into living cells upon ingestion (Bergmann et al., 2015). Biodegradable plastic film mulches also are typically hydrophobic, and have the potential ability to adsorb certain pesticides or other compounds commonly used in crop production.

Many fruit and vegetables grown in mulched cropping systems are annual plants and consequently most biodegradable plastic film mulches are designed for single-season, but repeated use. Soil-biodegradable plastic film mulches could be applied and tilled into the same field each succeeding crop year. Even with a 90% biodegradation benchmark (as per ASTM D6400 and other compostability standards), repeated soil incorporation of biodegradable plastic film mulches could result in significant, unsustainable soil accumulation of plastic film fragments and microplastics, affecting agricultural ecosystems in as-yet uncertain and undefined ways. The effects of accumulated plastic mulch fragments on soil-dwelling microflora and fauna, or on soil physical and chemical properties, are not addressed by the compostability standards currently used to certify them. Thus, the environmental repercussions of plastic accumulation in soils are largely unknown, in contrast to the increasing documentation of the harmful impacts of plastic waste to marine environments (Kershaw, 2015). Given the known harm plastics cause in the marine ecosystem, we are advocating rigorous examination of the long-term effects of plastic on agroecosystems before a global-scale adoption of plastic intended for incorporation into soils.

## 3. Developing a new standard

An opportunity exists to develop a new standard for biodegradation of plastic film mulch in soil that takes into account the unique conditions encountered in terrestrial systems, and accomplishes the long-term, ecosystem-level monitoring not achieved by compostability standards. Developing a new standard could clarify the uncertainty regarding soil pollution resulting from long-term and repeated mulch use, providing the necessary knowledge to guide agricultural practices that could mitigate such uncertainty. Preemptive action on this front by creating a standard that subscribes to a relevant risk assessment could help to avert a potential agricultural soil crisis similar to the one facing the marine environment.

### *3.1.* In situ *testing*

While laboratory tests are convenient because they are easily standardized, passing a requisite laboratory test does not guarantee biodegradation across a diversity of soil ecosystems. In agricultural settings, soil and environmental conditions vary broadly across sites and seasons. Weathering of mulch (degradation by sunlight, temperature extremes, water, wind, etc. prior to removal or tillage into the soil), directly affects the rate of breakdown. An in-soil biodegradation standard needs to include a reasonable testing range of soil moisture and temperature, crop and soil types, and associated microbial communities, and the testing should be carried out under selected field conditions that simulate typical farming practices and biodegradable plastic film mulch weathering. Because biodegradable plastic film mulches are likely to be re-applied and tilled into the soil on an annual or semi-annual basis, long-term assessments about the number, size, character, and fate and transport of the fragments, along with effects on the soil ecosystem, need to encompass repeated mulch laying and tilling-in over multiple years. Accurately characterizing biodegradation of plastics in the chemically complex environment of soil, admittedly, is difficult. The scope and timeframe of such long-term studies might fall under the purview of federal agencies, industry, academia, and/or other organizations that support research on agricultural and environmental safety.

### *3.2. Biodegradable film mulch labels*

Plastic film mulch labels should not conflate "compostable" and "biodegradable." It is not unusual to see the term "biodegradable" used solely, without "compostable" also listed on product labels, implying *in situ* soil degradation—misleading information that can lead to inappropriate soil incorporation of certain products. As an