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Research article

Deterioration pattern of six biodegradable, potentially low-environmental impact mulches in field conditions

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ABSTRACT

Polyethylene plastic mulches are widely used in agriculture due to the countless advantages they have. However, the environmental problems associated with their use have led us to look for alternative mulch materials which degrade naturally and quickly, impact the environment less and function satisfactorily. To this end, biodegradable plastics and paper mulches are being used, but aspects related to their degradation should be studied more in-depth. This work provides the deterioration pattern of six biodegradable mulch materials (i.e. vegetable starch, polylactic acid plastic films or paper mulches) in horticultural crop in the edaphoclimatic conditions of Central Spain in two situations: over the lifetime of the mulches and after being incorporated into the soil. In the first situation, the deterioration levels were evaluated by recording the puncture resistance, weight and area covered in the above-soil and the in-soil part, and after soil incorporation by the number of fragments, their surfaces and weight. In the above-soil part, biodegradable plastics experienced further deterioration, particularly with no crop, while the paper mulch remained practically intact. However, the in-soil paper experienced complete and rapid degradation. At 200 days after soil incorporation, mulch residues were scarce, with the environmental effects it entails. These findings offer practical implications regarding the type of crop. The measurement of the surface covered, rather than the weight, was shown to be a more reliable indicator of the degradation of mulches. Furthermore, visual estimation was found to underestimate the functionality of mulches in comparison to that of the measurement of the surface covered.

1. Introduction

1.1. The use of degradable and non-degradable mulches in agriculture

Mulching is a technique widely used in agriculture consisting of modifying the condition of agricultural soils by covering the soil surface, totally or partially, with different kinds of materials. The benefits of mulching can be summarised as earlier harvest as a result of increasing soil temperature, weed control, enhancing the efficiency of fertilisers and water levels, improving total soil porosity (Nawaz et al., 2016) and crop yield and quality (Scarascia-Mugnozza et al., 2006; Moreno and Moreno, 2008). Additionally, mulches are suitable for afforestation by increasing survival of afforest seedlings under semi-arid conditions (Jiménez et al., 2013), for reducing soil erosion, restoring soil fertility and increasing soil water retention capacity (Calatrava and Franco, 2011; Nishigaki et al., 2016). However, the modification of the microclimatic conditions under plastic mulches not only enhances plant productivity but also increases biological degradation of organic matter in the soil, which has recently been discussed as a trigger to rapid depletion of soil nutrients in general and carbon stocks in particular (Steinmetz et al., 2016). A complete review about the positive and negative impacts of mulching can be consulted in Kader et al. (2017).

For decades, many different types of mulches have been tested worldwide. However, plastics of different composition, thickness and colour have been the most commonly used, especially black polyethylene (PE), a petroleum-based plastic, due to its low price and the positive effects on crop yields (Haapala et al., 2014). The lifetime of mulch PE exceeds the duration of crop cycles, and for this reason, together with its difficult removal and later recycling, it is

Abbreviations: Polyethylene, PE; Biodegradable, BD; Mater-Bi®, MB; Sphere 4, Sp4; Sphere 6, Sp6; Bioflex®, BFx; Ecovio®, Eco; MimGreen®, MG; Days after transplanting, DAT.

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commonly left on the field to be further broken down by successive tillage operations (Moreno et al., 2014). This may generate important environmental pollution by progressive accumulation of plastics in the agricultural soils, given its repeated use. However, the long-term impact of plastic mulching as a standard agricultural practice is still relatively unknown in terms of potentially deteriorating soil quality or its post-crop fate (Steinmetz et al., 2016). Additionally, in the case of PE, due to its hydrophobic nature as an adsorbent and adsorbate, the residual waste may adsorb pesticides, hence increasing localised pesticide concentrations (Hayes et al., 2012).

To overcome these environmental problems, we can find alternative materials that can degrade and/or come from renewable sources such as photodegradable, biodegradable, oxo-degradable or oxo-biodegradable films, paper mulches or crop residues. A detailed description of all these mulch materials can be consulted in Kyrikou and Briassoulis (2007), Saponaro et al. (2008), Martín-Closas and Pelacho (2011), Kasirajan and Ngouajio (2012) or Haapala et al. (2014).

The degradation can be defined as an irreversible process leading to a significant change of the structure of a material, characterised by a loss of properties (e.g. integrity, molecular weight, structure or mechanical strength) and/or fragmentation. Because the term "polymer degradation" involves a deterioration in the functionality of polymeric materials, "degradation" and "deterioration" are often used interchangeably (Schnabel, 1992). The main causes of degradation of agricultural plastics during their lifetime are photodegradation, oxidation and biodegradation (a degradation process resulting from the action of naturally occurring microorganisms such as bacteria, fungi, and algae, degrading into products such as carbon dioxide or methane and water) (Kasirajan and Ngouajio, 2012).

The major reason why in-soil breakdown cannot be predicted when using biodegradable mulch materials is that many of them are certified to fit the standards of biodegradation only under the conditions of industrial composting. Additionally, it is unclear to know how much residue might remain in soils from biodegradable plastic film mulches, and what effects such residues might have on soil ecosystems (Brodhagen et al., 2017).

1.2. Methods for evaluating the degradation of mulches

In **field conditions**, the degradation rate of mulches is widely measured as the material weight loss over time, although the process requires a thorough but not overzealous cleaning to be sure that no material is lost, therefore favoring its degradation, or no foreign matter is added (Calmon et al., 1999; Shah et al., 2008). In the case of soil-buried materials, it is common to place the film samples into small nets in order to facilitate their recovery from the soil and later cleaning and weighing (Shah et al., 2008; Rudnik and Briassoulis, 2011), although the presence of this framework could interfere with the natural development process in real conditions. Another method for determining the deterioration rate of mulch materials is through photographic monitoring and subsequent analysis by using image processing programs (Calmon et al., 1999; Cowan et al., 2013; Moreno et al., 2014).

According to Shah et al. (2008), the visual effects used to describe mulch degradation in field conditions include the progressive roughening of the surface, formation of holes or cracks, fragmentation or changes in colour. Additionally, the monitoring of mulch degradation has been often carried out by using subjective, qualitative and easy-to-apply numerical scales that assess the degree of the soil cover or the film resistance (Martín-Closas et al., 2016). These qualitative scales can in turn be related to more objective quantitative tests, both under field and laboratory conditions.

Under **laboratory conditions**, the degradation of mulches has been previously studied by changes in the mechanical (Scarascia-Mugnozza et al., 2006; Martín-Closas et al., 2008) and optical properties (Calmon et al., 1999; Martín-Closas et al., 2008; Schettini et al., 2011; Barragán et al., 2016), by scanning electron microscopy (Liu et al., 2010) or atomic force microscopy (Ikada, 1999), through the CO_2 evolution/O_2 consumption ratio (Hoffmann et al., 1997), the amount of carbon assimilated by the microbial community (CO_2 released) (Narayan, 2010) or by soil enzymatic measurements (Barragán et al., 2016; Wang et al., 2016).

Therefore, the aim of this study was to evaluate the deterioration pattern of six biodegradable mulch materials in real conditions and to quantify its deterioration rate after soil incorporation. This would deepen the knowledge of mulch degradation and help to assess its potential suitability as an alternative to mulch PE in order to reduce environmental pollution in the agricultural fields.

2. Material and methods

2.1. Research site and experimental design

The field experiment was conducted at the Agrarian Research Centre "El Chaparrillo" (39°0′N-3° 56′W, altitude 640 m) (Regional Institute Research and Food Industry Development and Forest, IRIAF), Ciudad Real, Spain, from May 2014 to June 2015. This area is low-sloped (<5%), no-windy and with a high solar exposure in summer.

A randomised complete block design with four replicates and seven treatments consisting of mulch materials of different composition was adopted. The mulch materials tested, all of them black in colour and 1.20 m in width, were: (1) Standard linear low density polyethylene (PE, 15 μm, Siberline); (2) Biodegradable plastic Mater-Bi® (MB, corn thermoplastic starch, co-polyester, 15 μm, Novamont S.p.A.); (3) Biodegradable plastic Sphere 4 (Sp4, 15 μm, potato thermoplastic starch and biodegradable recycled polymers bioplastic, Sphere Group Spain S.L.); (4) Biodegradable plastic Sphere 6 (Sp6, idem); (5) Biodegradable plastic Bioflex® (BFx, polylactic acid [PLA], co-polyester, 15 μm, Fkur-Oerlemans Plastics); (6) Biodegradable plastic Ecovio® (Eco, polylactic acid [PLA], ecoflex, 15 μm, BASF); (7) Biodegradable paper MimGreen® (MG paper, 85 g m^{-2}, long fibre paper, MimCord S.A.).

All these materials (with the exception of PE) are susceptible of degradation in field conditions as result of several factors (microorganisms, temperature, moisture and light). The starch-based and paper materials are especially sensitive to the moisture, while the PLA-based materials require, in addition to high humidity levels, higher temperatures for a fast degradation process (information obtained by the suppliers).

Each experimental plot consisted of a single crop row, 25 m long, with rows spaced 1.5 m apart. Mulches were placed mechanically on 22 May 2014, forming central beds ≈0.8 m wide. The remaining ≈0.2 m on both sides were buried in the soil. The sweet fresh bell pepper crop cv. Infantes was used. Planting took place on the mulch beds using a manual seedling transplanter on 26 May 2014. Plants were arranged in double-rows in each bed separated by a distance of 0.33 m, resulting in an average crop density of 38,000 plants ha^{-1}. The crop was drip-irrigated daily until 26 September (126 days after transplanting, DAT) with a drip-line located below the mulches. The irrigation quantities were calculated following the FAO methodology proposed by Allen et al. (2006), and the soil moisture was maintained near field capacity values in all the treatments. Harvests were done periodically and the last one took place on 16 Oct 2014 (146 DAT).

In each experimental plot, approximately 1 m was left with no