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Performance and environmental impact of biodegradable polymers as agricultural mulching films

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HIGHLIGHTS

- Assessment of in-use performances of PBAT-based films suitable for mulching.
- PBAT-based materials exhibit better radiometric properties than PE.
- PBAT-based mulch films lead to agronomical performance as high as PE.
- The early ageing of PBAT-based films is not detrimental to the vine performances.
- The material lifespan required for long-term crops mulching is questioned.

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ABSTRACT

In the aim of resolving environmental key issues such as irreversible soil pollution by non-biodegradable and non-recoverable polyethylene (PE) fragments, a full-scale field experiment was set up to evaluate the suitability of four biodegradable materials based on poly(butylene adipate-co-terephtalate) (PBAT) to be used as sustainable alternatives to PE for mulching application in vineyard. Initial ultimate tensile properties, functional properties during field ageing (water vapour permeability and radiometric properties), biodegradability and agronomical performance of the mulched vines (wood production and fruiting yield) were studied. In spite of their early loss of physical integrity that occurred only five months after vine planting, the four materials satisfied all the requested functional properties and led to agronomic performance as high as polyethylene. In the light of the obtained results, the mulching material lifespan was questioned in the case of long-term perennial crop such as grapevine. Taking into account their mulching efficiency and biodegradability, the four PBAT-based studied materials are proven to constitute suitable alternatives to the excessively resistant PE material.

1. Introduction

Mulching is an agricultural practice commonly used for crop production since the mid-1950s with among other benefits: weed control, soil moisture conservation and soil temperature regulation. The consequences for the plant growth are an increased survival after planting and an enhanced vigour, which drive to higher fruiting yields. In the case of vineyard, an extra advantage provided by mulching is to reach grapes bearing age one year earlier (Moore, 1963; Agulhon, 1975; Van der Westhuizen, 1980). Even if less often used than for short-term crops, mulching films made of polyethylene (PE) have also been used for decades in long-term crops such as vineyards. However, non-biodegradable plastic mulch films ended up degrading in the field and progressively broke up into small pieces that are not recoverable at the end of the crop and consequently led to an irreversible and detrimental environmental contamination. Hence, biodegradable polymer films are more and more considered as eco-friendly alternatives to polyethylene (Briassoulis, 2007).

Among biodegradable polymers, poly(butylene adipate-co-

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terephthlate) (PBAT) is a synthetic aliphatic-aromatic polyester displaying similar mechanical properties to low density polyethylene (ca. 30 MPa as tensile strength and 700% as elongation at break) (Kijchavengkul et al., 2008), which can be processed using same facilities as polyethylene. The soil-biodegradability of PBAT (Saadi et al., 2013; Muthuraj et al., 2014), which is provided by the butylene adipate group (Witt et al., 1997), makes it as a potential alternative to PE for mulching applications. Nevertheless, this promising co-polyester has not reached the expected industrial success because it is relatively expensive (ca. 6 $ per kg) and highly sensitive to UV radiation. Indeed, PBAT is known to undergo severe crosslinking phenomena making it brittle and thus hardly suitable for mulching applications. As a consequence, it has been recommended only for short term crops (Kijchavengkul et al., 2010). In order to overcome such limitations, blending PBAT with other biodegradable polymers, such as poly(lactid acid) (PLA) or polypropylene carbonate (PPC) and starch is considered as a promising way to extend its lifetime and thus consider it as a suitable candidate to replace PE for mulching applications (Briassoulis, 2006; Kasirajan and Ngouajio, 2012).

In addition to obvious economic advantages, PLA exhibits some interesting features, making it strongly appropriate for PBAT-blends. In PBAT/PLA blends, PBAT is usually introduced in the range of 5–20wt% into the PLA bio-based matrix in order to improve its toughness (Coltelli et al., 2008; Sirisinha and Somboon, 2012) and film-processability (Al-Itry, 2012). Studies devoted to blends where PLA is the minor phase dispersed within the continuous PBAT phase are scarce (Sirisinha and Somboon, 2012), but allow identifying several advantages. First, the introduction of PLA could reduce the consumption of non-renewable resources. Moreover, PLA hydrolytic degradation products could even catalyse the degradation of PBAT, which allows to tune the biodegradability of the material (Oyama et al., 2011). PLA/PBAT blends have already been tested through several field experiments as mulch films for horticulture (Yang and Wu, 1999; Martin-Closas et al., 2008) or as drip irrigation system (Briassoulis et al., 2011) and have led to promising results.

PBAT can also be blended with PPC, a partially oil-based polymer. The two major interests of using PPC as a component of mulching films are its water-induced biodegradation (Varghese et al., 2010; Luinstra and Borchardt, 2012) and the fact that its synthesis consumes carbon dioxide. Those features render PPC environmentally friendly and an interesting candidate for renewable materials (Tao et al., 2009; Luinstra and Borchardt, 2012; Xing et al., 2013) even if its use for agricultural applications has not yet been investigated.

Finally, blends of PBAT and thermoplastic starch have been widely studied (Mani and Bhattacharya, 2001; Brandelero et al., 2012; Shirai et al., 2013), mainly due to the starch biodegradability and large availability at a competitive price. Starch/PBAT blends mainly known under the Mater-bi® brand (Novamont) are currently one of the most frequently used biodegradable materials especially for plastic bags and also mulching films (Briassoulis, 2006, 2007; Kapanen et al., 2008; Martin-Closas et al., 2008; Filippi et al., 2011). Blow extruding starch blends requires long and complex processing setup, generating some waste (Thunwall et al., 2008; Liu et al., 2009; Nafchi et al., 2013), which is an extra environmental issue. Introducing a part of such processing waste in the final material would reduce the environmental impact of the material before use.

However, to our knowledge, very few studies dedicated to the use of biodegradable materials for long-term crops mulching are available in the literature (Guerrini et al., 2008, Tarricone et al., 2011), most likely because of the discrepancy between those materials and the vineyard lifespans. Conversely, the long-term stability of conventional plastic such as PE is incommensurate with the material lifespan required in mulching practices (Martín-Closas and Pelacho, 2011). Yet, vineyard is a long-term crop commonly living over 50 years and it is reasonable to consider that any mulching film, even PE, will not remain intact for so long. There is then a real need to balance the agronomic benefits with the environmental impact of the film (Guerra and Steenwerth, 2012).

The aim of the present work was to evaluate the suitability of four biodegradable materials based on PBAT to be used as sustainable alternatives to PE for mulching application in vineyard. For this purpose, a full-scale field experiment was conducted to verify first that the materials were able to satisfy the initial requirements of a mulch film in terms of functional and environmental properties and then check if those properties were maintained in use conditions (field weathering) and led to the same agronomical performance as a conventional PE film.

2. Materials and methods

Four commercial biodegradable films of different composition were obtained by blow-extrusion in order to be used as vine mulches in comparison with a conventional PE film (Agripolyane, Saint Chamont, France): Mater-Bi® CF04P made of starch and PBAT (BioBag, Askim, Norway) both as a single extruded material and containing 10wt% of recycled material (named Starch/PBAT and Starch/PBATr, respectively), Bioflex F2110 made of PLA/PBAT in a 30/70 ratio (FKuR, Willich, Germany) and a PPC/PBAT blend in a 20/80 ratio (Hangzhou Xinfu Pharmaceutical, Zheijang, China). All the films were 40 μm-thick and carbon black (5%wt) was used as a colour additive using the masterbatch techniques, the latter being prepared with the same composition as the matrices.

2.1. Full-scale experimental design

Experiments were conducted over 2 years in a vineyard located in Southern France near Carcassonne (43°12 N-02 36 E). Cot cultivars grafted on SO4 rootstocks were planted in March 2011 (inter-vine and inter-row distances of 0.8 and 3.0 m, respectively) and were mechanically mulched 10 days later. Six different treatments (4 different biodegradable mulch films, PE film and bare soil, BS) were tested in a complete randomized block design with four replicates, each treatment consisting of an average of 220 vines. No permanent irrigating system was installed; vines have only been irrigated twice a summer during the first and second year after planting.

2.2. Agronomic performance assessment

Vineyard management practices were typical of those used in the region. From the end of the first season, vigorous vines were trained with a single cane as a Guyot system, whereas for the weakest ones the main cane was shortened to two buds. The pruning woods were collected and weighed 12 months after planting to quantify the canopy development and the vines were manually harvested 18 months after planting to evaluate the production and fruiting yield. For all measurements a representative number of vines (40 per treatment) were considered. Soil temperature along time was monitored by means of probes placed at 15 cm depth into the soil two weeks after the installation of the films.

2.3. Film characterization

2.3.1. Biodegradability

Respirometric tests in standardized aerobic conditions at 28 °C were conducted to evaluate the biodegradability of mulching films. The method was adapted from the US standard ASTM D5988-96 to determine the “Aerobic Biodegradation in Soil of Plastic Materials”.