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Agronomic performances of biodegradable films as an alternative to polyethylene mulches in vineyards

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Abstract

The use of polyethylene (PE) mulch at planting ensures the successful and homogeneous establishment of vineyards and also leads them to produce one year earlier. However, as they are rarely removed from the vineyards, the aesthetic and environmental impact of those films is devastating. In addition, the long-term stability of conventional plastics appears disproportionate with respect to the material lifespan required in mulching practices. To face up this issue biodegradable films already used in horticulture would be an environmentally friendly alternative provided that they meet the requirements of the perennial crop and associated farming practices *i.e.* remain intact in the field long enough to provide its expected positive effects on the crop and then, biodegrade on the soil surface without additional ploughing.

The performance and environmental impact of a commercially available biodegradable mulch films displaying different thicknesses were studied through two consecutive full-scale field experiments conducted in the south of France. The impact of mulching on soil properties and agronomic performance was measured during the three first crop cycles by monitoring vine growth and fruiting yield concomitantly with film ageing and fate in field. In parallel, respirometric tests were undertaken to evaluate the impact of field ageing on the biodegradation rate.

As a result, the use of biodegradable films for vine mulching provide similar agronomical performances as PE; grapevine growth and harvest yield were found to be significantly higher for the mulched modalities than for the bare-soil. This positive mulch-induced effect appeared from the first growing season and was maintained three years later even if the biodegradable mulch started deteriorating 5 months after planting. Thus, in spite of the early loss of integrity of the studied biodegradable mulch films, a significant positive effect on the vine growth, the rootstock development, the earliness of the first harvest and the yield (and quality) of the two first harvests have been evidenced. This leads to reconsider the required life expectancy of mulch film in the case of vineyard and constitutes encouraging results towards the possibility of substituting PE films with biodegradable ones.

Keywords: Vineyard, mulch, biodegradable films, vegetative growth, fruiting yield, rootstock, soil properties

INTRODUCTION

The successful establishment of a new vineyard strongly depends on the first growing years, grapevines generally starting producing during the third season. The use of polyethylene (PE) mulch films in the vine row is sometimes used in newly planted vineyards, not only for a herbicidal effect and to ensure their successful and homogeneous establishment, but also to deliver earlier production. Indeed, mulched vines may produce a crop one year earlier than unmulched vines (Godden and Hardie 1981; Moore 1963;

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Pinamonti 1998; Van der Westhuizen 1980). Such films lead to a better preservation of soil moisture, more uniform soil temperatures, less leaching of fertilizers, lower soil compaction, weed control, an increased growth and a higher survival rate (Van der Westhuizen 1980). Moreover, an increase in vegetative growth and yield were observed up to three years after planting when the film was removed after the first season (Moore 1963), or up to five years after planting when it was maintained 18 months (Van der Westhuizen 1980).

However, despite the described benefits from the use of mulch films, they are not widely used by most European winegrowers. Among the cited reasons, a clear disadvantage of PE films is that they are not easily removed from vineyards, leading to significant waste disposal issues often resulting in an environmental pollution. Indeed, there is a discrepancy between the long-term stability of PE and the material lifespan required in mulch applications (Martin-Closas and Pelacho, 2011). In the case of long-term perennial crops such as grapevines, the mulch lifetime needs to be further studied, considering that the reported effects mainly focus on the early crop cycles. In this context, the performances of biodegradable mulch films, which constitute an environmentally friendly alternative to the currently used polyethylene film (Briassoulis, 2006), have to be assessed in vineyard field experiments. Minuto *et al.* (2008) reported a preliminary study on the use of Mater-Bi-based mulch films in vineyards. According to the authors, film thickness and formulation are key parameters for the efficiency of the film. They report a reduction of weeds growth over a 12 month period improved vine establishment with mulching vineyards compared to an unmulched treatment. In a vine nursery situation, a comparison between mechanical tillage, PE and Mater-Bi mulch films was conducted by Tarricone *et al.* (2011) who concluded that mulching should not be recommended due to the impact of water status on grafting. However, the Mater-Bi mulch film proved to have positive effects on the vine growth (both on aerial parts and roots).

Despite the low number of available studies on the use of biodegradable mulch films in vineyards, there is a strong need for further research activities on the topic. The present work is part of the AGROBIOFILM European project, which aimed at developing biodegradable mulch films fitting specific regions and crops requirements. The impact of mulching on soil properties and agronomic performance was measured during the three first crop cycles by monitoring vine growth and fruiting yield concomitantly with film ageing and fate in field. In parallel, respirometric tests were undertaken to evaluate the impact of field ageing on the biodegradation rate.

MATERIALS AND METHODS

Experimental design.

Two full-scale field experiments were set up with an interval of one year both in a vineyard located in Southern France near Carcassonne (43°12 N-02°36 E). The first experimental field test was initiated in 2010 (April the 1st) and was conducted over 3 years with Chardonnay cultivars grafted on SO4 rootstocks. The second experimental field test consisted of Cot cultivars (red grapevines) grafted on SO4 rootstocks was launched in 2011 (February the 25th) and was conducted over two years. In both vineyards, the inter-vines and inter-rows distances were of 0.8 and 3 m, respectively. Vines were mechanically mulched 10 days after planting and each treatment tested was applied through a complete randomized block design with three replicates with five guard vines in the row between

each modality to prevent potential border effects. Each treatment consisted of an average of 115 vines, grown in 5 consecutive rows, with guard rows and vines between each treatment for the first experiment, and an average of 165 vines grown in 8 consecutive rows, with 5 guard vines between each treatment for the second experiment. The soil contained 19% clay, 42% silt and 39% sand and had a pH of 8.46. The biodegradable mulch film tested (BF) was made of Mater-Bi® CF04P grade (Novamont, Italy) with different thicknesses (BioBag, Askim, Norway). For comparison, PE film (Agripolyane, Saint Chamond, France) and bare soil (BS) were used. All the mulch films were 110 cm wide, of which 80 cm was exposed at the soil surface. In the case of BF, three thicknesses were tested: 40 μm , 25 and 70 μm whereas for PE only film of 40 μm thick were tested.

Viticultural practices and parameters.

Vineyard management practices were typical of those used in the region. In the two experimental field tests, vines were pruned from the end of the first season with a single cane as to a Guyot system. In both cases, only vigorous vines were pruned in this manner whereas for the weakest ones, the main cane was shortened to two buds. In order to quantify the canopy development, the pruning woods of a representative number of vines (30 per treatment) were yearly collected and weighed. To quantify the fruit production the vines (30 per treatment) were manually harvested 17.5 and 29 months after planting. Fruit quality parameters were evaluated by measuring the total solids content of the grapes using a Convex refractometer (Medline Scientific Limited, Oxfordshire, UK) and pH using a CONSORT C833 pH meter (Consort. Turnhout, BE). The development of the vine rootstock was monitored for the 25 months-old vines of the first field experiment. For this purpose, the roots of three representative vines per treatment were excavated and manually collected in the first 60cm-thick soil horizon from a quarter of the Voronoi polygon (Figure 1), which is the elementary space defined by the half distances between the sampled vine and its neighbours on the row or inter-row (Snowdon et al. 2002). The roots were washed and their morphological parameters (length and diameter) were characterized using WinRhizo software (Regent Inc. Canada).

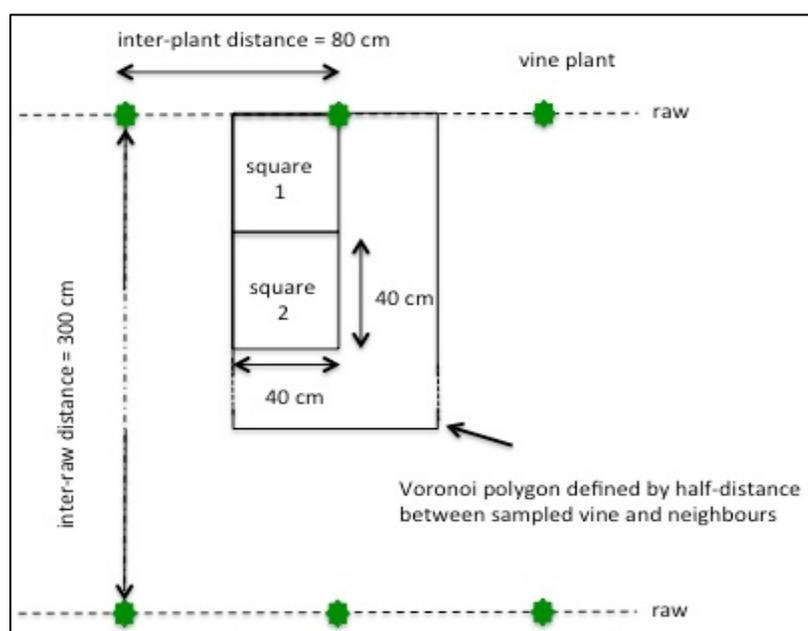


Figure 1. Description of the experimental design where the vine roots were sampled

Soil analysis.

Soil samples were taken from the superficial layer of the soil (0-20cm) and analysed for their physical, chemical and biological properties. They were collected at planting date (t0) and 24 months later (t24 months). The apparent density was evaluated according to the cylinder method (ISO 11272,1998). Organic carbon and nitrogen contents were evaluated according to NF ISO 13878 and NF ISO 13878. Organic matter content was deduced from the organic carbon, using a ratio of 1.72. The microbial biomass was evaluated using the Fumigation-extraction method (Wu, Joergensen et al. 1990). The nematofauna was analysed according to Oostenbrink (1960) and NF ISO 23611-4 as reported in Villenave et al. (2010). Nematode taxa were then assigned to trophic groups (Yeates, Bongers et al. 1993).

Film ageing

Tensile properties of mulch films were monitored on a tensile machine (ZWICK Roell type BZ 2.5/TN1S) using a 5kN force sensor. Samples (13x70mm) were razor-blade cut along the parallel direction. Tests were conducted according to EN ISO 527-3 standard at 500 mm/min crosshead speed.

Biodegradability assessment

Respirometric tests in standardized aerobic conditions were conducted firstly at 28°C to evaluate the biodegradability of initial BF film, and then, in compost medium at 58 °C to evaluate the rate of biodegradation of mulch films before and after 18 months spent in field. The methods were adapted from the US standard ASTM D5988-96 to determine the aerobic biodegradation of plastic materials in Soil and in compost medium. The released CO₂ being proportional to the percentage of biodegraded substrate, CO₂ evolution quantifies the ultimate degradation (i.e. mineralization) during which a substance is broken down to its final products. Beforehand, materials were cut into 1-2 mm bits and their carbon contents were measured with an elementary analyser (ThermoQuest NA 2500) in order to precisely set the plastic dose to either 2 mg of carbon per g of soil and 16 mg of carbon per g of compost. Biodegradation tests were carried out in a soil collected at the location of the field experiments and in real and mature compost. Distilled water was initially added to the solid media and then regularly added all along the experiment to maintain the moisture content of the medium around 80–100%.

Data analysis.

Data were subjected to analysis of variance using Statgraphics Plus 5.0 software. If not mentioned, a confident level of 95% was considered. In all the tables, mean values followed by mean standard error are given.

RESULTS AND DISCUSSION

1. Overview

The performance and environmental impact of a commercially available biodegradable mulch films displaying different thicknesses have been assessed through two full-scale field experiments set up with an interval of one year in the south of France. The impact of mulching on soil properties and agronomic performance was measured during the three first crop cycles by monitoring vine growth, roots development and fruiting yield

concomitantly with film ageing and fate in the field. In parallel, respirometric tests were undertaken to evaluate the impact of field ageing on the biodegradation rate.

2. Research Data

Ageing of mulch film under field conditions

The biodegradable mulch film (BF) started deteriorating about 5 months after the films installation with the apparition of small holes and perforations. This early degradation of the biodegradable films occurred whatever the thickness of the film and was mainly attributed to a decrease in elongation at break (ϵ_B) as evidenced by the evolution of the mechanical properties of the films 4 months after planting (Table 1). This embrittlement of the biodegradable material (-90% for ϵ_B) was much marked than these of the PE film (-25% for ϵ_B). Indeed, as already reported by Touchaleaume et al. (2017), UV-light can be considered as the major ageing factor responsible for the mulch film degradation on top of the soil since in two field experiments, successively launched at one-year interval, the first signs of deterioration of the biodegradable mulch films occurred for approximately the same value of cumulated solar radiations.

Table 1. Evolution of the mechanical properties of the mulching films (PE and BF) after 5 months field exposure.

	Film thickness μm	σ_B^1 (MPa)		ϵ_B^2 (%)	
		t_0	$t_{4 \text{ months}}$	t_0	$t_{4 \text{ months}}$
PE	40	18.5 \pm 0.6	14.3 \pm 0.4	409 \pm 23	311 \pm 25
BF	40	20.4 \pm 0.8	11.7 \pm 0.8	487 \pm 18	159 \pm 65
BF*	40	16.9 \pm 1.2	11.2 \pm 0.7	428 \pm 27	51 \pm 17
BF	25	16.9 \pm 0.1	12.8 \pm 0.5	299 \pm 10	57 \pm 9
BF	70	14.8 \pm 0.5	10.4 \pm 0.4	574 \pm 50	113 \pm 7

¹ ϵ_B : elongation at break in parallel direction

² σ_B : stress at break in parallel direction

As a result of the field exposure (rain, animals, tractor, etc.), one year after mulch installation, when comparing the aspect of the films in the raw, it could be noticed that all the films appeared very degraded (Figure 2). BF degradation was such that the film did not cover totally the soil after 12 months, whereas the PE film remained still intact, the BF*40 being the most damaged and the BF70 the less damaged (Figure 2). For a same thickness, the biodegradable film that contains 10% scraps (BF*40*) would be more prone to degrade on the top of the soil than the one which does not contain any (BF40). After apparition of the first signs of film deterioration, it seemed that the rate of damaging would be higher in the case of the BF*40 than for the BF40. In contrast, the introduction of 10% recycled material in the formulation had no effect on its degradation once buried in soil. The use of thinner film (25 instead of 40 μm) would have no significant influence on its degradation on the top of the soil. Paradoxically, the use of a thicker film (70 μm) would delay the film deterioration on the top of the soil whereas it would not prevent it to degrade once buried in soil. Nevertheless, this fast damaging of the films (that is expected to increase the surface area in contact with soil) combined with the fact that they are all partially recovered by the

soil might be seen as positive when considering their further end of life and expected biodegradation in vineyard.

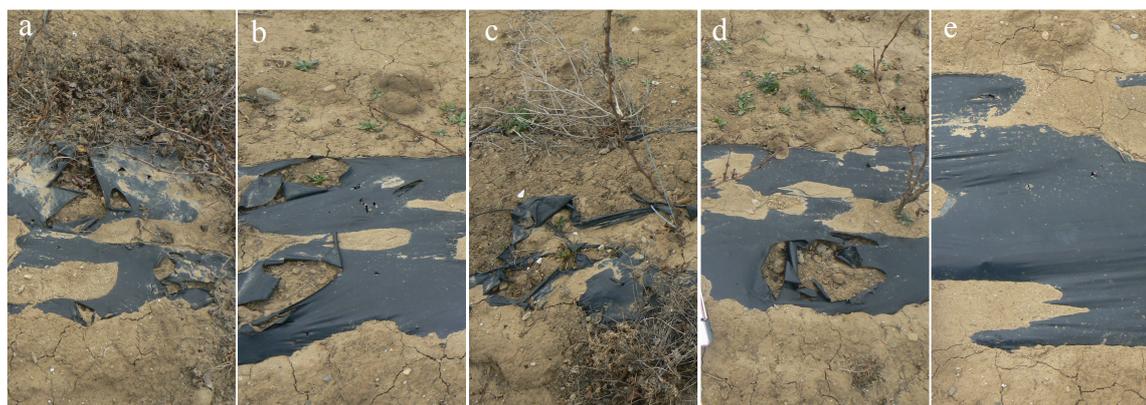


Figure 2. Comparison of the mulch films degradation 12 months after vine planting; a) BF 40 μm ; b) BF 40* μm ; c) BF 25 μm ; d) BF 70 μm ; e) PE 40 μm

Effect of mulching on physical, chemical and biological soil properties

Soil analyses were undertaken to describe the impact of mulching on soil physical, chemical and biological characteristics (Tables 2 and 3). Actually, the effects of soil management on the soil characteristics are expected to partially explain the mulch-induced effect on viticultural parameters. However, because the chemical properties of a soil are characterized by a great inertia, they are not expected to significantly change in a short time scale. Moreover, the different additions of foliar fertilizers made in the field are supposed to render difficult the interpretation of the results. As a consequence, only the most relevant mulching-induced changes observed two years after vine planting are presented (Tables 2 and 3).

Table 2. Evolution of soil physical (bulk density), chemical parameters (organic matter and C/N ratio) and biological (microbial biomass) parameters for unmulched soil (BS) and soil under PE and BF during the two first years after vine planting

		Bulk density (g/cm ³)	Organic matter (g/kg)	C/N	Microbial biomass (mgC/kg dry soil)
t₀		1.46 ^a ± 0.05	10.38 ^a ± 0.49	11.97 ^a ± 0.60	55.2 ± 9.3
	BS	1.39 ^a ± 0.06	11.90 ^{aba} ± 0.89	14.07 ^{ab} ± 1.46	171.0 ± 7.2
t_{24m}	PE	1.38 ^a ± 0.03	12.30 ^{aba} ± 0.99	14.90 ^{ba} ± 0.28	175.7 ± 28.4
	BF	1.42 ^a ± 0.07	12.90 ^{ba} ± 1.32	16.00 ^{ba} ± 1.40	171.6 ± 32.4

Values with different subscripts are considered as significantly different at p=0.05

The initial chemical properties of the soil are representative of those of a vineyard soil of this region. No significant changes in bulk density were observed suggesting that the texture of the soil was not influenced by the presence of mulch film during the two first years following vine planting. In contrast, the soil organic matter content and its C/N ratio slightly increased with time, especially for both mulching treatments (BF and PE) as compared to bare soil. Given that the same amount of fertilizers was supplied whatever the

treatment considered, those changes may be attributed to a higher biological activity in mulched soils. This was supported by recent findings by Liu et al. (2015), who showed that the carbon stocks decreased only in the top soil (<20 cm depth), but increased in the rooting zone (20–40 cm depth) after four years of plastic mulching. This could be due to higher water retention in the mulched modalities, especially in the case of PE film whose water vapour permeability is 10 fold lower than these of BF. The soil organic matter content and its C/N ratio slightly increased with time, especially for BF and PE treatments.

The values of the biological parameters *i.e.* the microbial biomass and the nematode abundance at planting time (t_0) revealed a rather low biological activity (Tables 2 and 3, indicative of a disturbed soil, which is also poor in nutrients as typically observed in the location of the present experimental field. A significant increase in the microbial biomass (+220%) was observed two years after vines planting but without link with mulching since recorded for all the treatments. Actually, according to Kapanen (2008) and Chen et al. (2014), plastic mulching are known to exert no significant impact on the total microbial diversity compared to bare soil. This was expected to favour the ultimate bio-assimilation of the biodegradable film by the soil at the end of the crop, the soil microbial biomass content being a key indicator of its biodegradation ability.

Regarding the nematofauna two years after planting, it could be noted that the abundance of total nematodes increased in all treatments (Table 3). This rise was notably higher in the case of BF treatment due largely to an increase in the plant-feeding nematode group, mainly Tylenchidae et Pratylenchidae, both known to be harmless against vinegrape. These results suggest a more diversified soil biological activity with the BF treatment, possibly a result of the progressive decomposition of BF film leading to an enrichment of the soil with carbon components potentially available to the nematodes (Salome et al. 2016).

Table 3. Evolution of the abundance of the nematode according to trophic groups for unmulched soil (BS) and soil under PE and BF during the two first years after vine planting

		Bacterial-feeders	Fungal-feeders	Omnivores and carnivores	Plant-feeding	Free-living nematodes	Total nematodes
t_0	BS	110 ^a ±26	56 ^a ±9	19 ^a ±3	180 ^a ±40	186 ^a ±34	365 ^a ±68
	BS	151 ^a ±34	75 ^a ±24	26 ^a ±10	105 ^a ±23	251 ^a ±48	356 ^a ±65
t_{12m}	PE	189 ^a ±17	91 ^a ±18	20 ^a ±7	236 ^a ±32	299 ^a ±20	536 ^b ±51
	BF	131 ^a ±49	52 ^a ±4	15 ^a ±1	152 ^a ±61	198 ^a ±52	350 ^{ab} ±99
t_{24m}	BS	159 ^a ±46	121 ^a ±17	5 ^{ab} ±3	244 ^a ±35	285 ^a ±63	530 ^a ±98
	PE	117 ^a ±52	93 ^a ±29	1 ^a ±1	338 ^{ab} ±34	211 ^a ±82	549 ^{ab} ±115
	BF	191 ^a ±60	130 ^a ±36	21 ^b ±6	538 ^b ±141	342 ^a ±79	879 ^b ±98

Values with different subscripts are considered as significantly different at $p=0.05$

Effect of mulching on vine growth and crop performance

At the end of the first growing season, Vines were pruned with a single cane as to a Guyot system. However, only vigorous vines were pruned in this manner in the first season, whereas for the weakest ones, the main cane was shortened to two buds. The first pruning

is an important step for the vineyard since closely related to its capacity to be harvested. As a general way, vines in the mulched treatments had similar vigour, while the vines grown on BS were weak and exhibited variable growth, as previously reported (Moore 1963; Van der Westhuizen 1980). These observations on growth were confirmed by the amount of pruning wood, which was significantly higher for PE- and BF-mulched treatments compared to the BS treatment (Table 4). It is worth noting that differences in pruning weight between the PE and BF treatments were not statistically significant despite the early degradation of the BF mulch film. As a result 97% and 94% of the vines mulched with PE and BF respectively had sufficient vigour to be pruned with a cane (*i.e.* vines reached bearing size) while only 13% of the unmulched vines met this requirement. The yields at the first harvest (2011) confirmed this trend (Table 4). It is important to underline that vines grown under PE and BF produced significant quantities of grapes 17 months after planting while it was necessary to wait for an extra year in the case of BS treatment. Although yield differences were not significantly different between the mulching treatments, the BF treatment produced higher must soluble solids than the PE treatment (20.4°B and 18.5°B respectively) and had a lower pH (3.3 and 3.5 respectively).

Table 4. Effect of vine mulching on the viticultural performances (pruning and fruiting production and quality) during the three first growing seasons¹ (planting in)

		Pruning wood (g/vine)	Fruiting production (kg/vine)	Soluble solids (°Brix)	pH
	BS	23.1 ^a ± 17.2	0.39 ^a ± 0.03	- -	- -
2011	PE	102.3 ^b ± 73.0	5.06 ^b ± 0.87	18.5 ^a ± 1.5	3.46 ^a ± 0.04
	BF	83.9 ^b ± 64.2	4.24 ^b ± 1.23	20.4 ^b ± 0.6	3.33 ^b ± 0.03
	BS	225.7 ^a ± 144.3	4.34 ^b ± 1.57	21.5 ^a ± 0.1	3.30 ^a ± 0.09
2012	PE	427.6 ^b ± 136.5	3.34 ^a ± 1.49	21.6 ^a ± 1.6	3.44 ^a ± 0.03
	BF	411.5 ^b ± 206.1	3.06 ^a ± 1.35	22.0 ^a ± 1.5	3.42 ^a ± 0.13

Values with different subscripts are considered as significantly different at p=0.05

¹ vine planted in April 2010; first pruning in March 2011 and second in 2012; first harvest in August 2011 and second in September 2012

The yields of the second harvest (2012) also indicated no significant difference in terms of fruiting yield and quality of the must between the BF and PE treatments (Table 4). In contrast, the unmulched vines (BS), for which it was the first harvest, led to a significantly higher yield than the two mulched treatments. The decrease in fruiting yield observed for the two-mulched treatments is probably due to their exceptionally high production yield the year before while it was the first time they bore grapevines. However, the fruiting yield of the un-mulched vines is in the same range of order than these obtained for the first harvest of the mulched vines. Thus, despite the early loss of BF film integrity, which occurred before the end of the first crop cycle, it is worth noting that the mulch-enhanced effect on vine growth was maintained during the second and third crop cycles. This suggested that the presence of a mulch film during the 5 months following planting would be sufficient to bring

the vines to fruiting age during the second season and too lead them to higher production than un-mulched vines.

In order to attest the durability of the films in the climate conditions of the experimental area and verify if BF films with different thicknesses or containing a certain percentage of recycling material (10wt%) could lead to similar results, a second field test was launched in 2011. Six months later, all the mulched vines had similar vigour and no difference in vine growth between the different mulch film treatments was observed at this stage. In contrast, vines grown on bare soil had a lower development. At the end of the first growing season (March 2012), vines were pruned as previously mentioned and the pruning woods of a representative number of vines were collected and weighed (table 5). Results indicated a positive effect of mulching on the wood production during the first crop cycle confirming the observations previously made even if significant differences between PE and BF mulch films were observed. However, it is worth noting that the thickness of the film had no significant effect on the pruning yield (Table 5), the thinnest one (BF25) leading to a yield comparable with the three others BF films tested (BF40, BF*40 and BF70).

Regarding the first harvest of this second trial, the fruiting production of the mulched vines (whatever the treatment considered) was significantly higher than these of the un-mulched vines (Table 5). No significant difference was also observed between the different film thicknesses of the biodegradable films with reference to the quality of the must in terms of soluble solids, pH and acidity. The lower soluble solids recorded for the BS treatment was directly related to its lower fruiting production. Thus, it can be assumed that the film thickness of BF films had no impact on the fruiting yield leading to question the use of a thicker film that necessarily would induce an unjustified over-cost.

Table 5. Effect of vine mulching on the viticultural performances (pruning production, fruiting production and grapes quality) during the two first growing seasons¹

	Thickness (μm)	Pruning wood (g/vine)	Fruiting production (kg/vine)	Soluble solids ($^{\circ}\text{Brix}$)	pH	Acidity (g tarttric acid/l)	
2012	25	94 ^a ± 85	3.28 ^a ± 1.51	20.3 ^a ± 1.6	3.20 ^a ± 0.13	6.08 ^{ab} ± 0.75	
	40	88 ^a ± 45	3.16 ^a ± 1.35	19.8 ^a ± 0.7	3.21 ^a ± 0.06	6.30 ^{ab} ± 0.62	
	40 *	103 ^a ± 40	3.60 ^a ± 1.17	19.8 ^a ± 1.6	3.18 ^a ± 0.14	6.24 ^{ab} ± 0.50	
	75	106 ^a ± 76	4.51 ^a ± 1.54	19.9 ^a ± 1.5	3.16 ^a ± 0.05	6.14 ^{ab} ± 0.31	
	PE	40	141 ^b ± 81	4.10 ^a ± 0.99	19.8 ^a ± 0.7	3.15 ^a ± 0.05	6.63 ^a ± 0.47
	BS	-	35 ^c ± 49	1.13 ^c ± 1.68	21.3 ^b ± 1.5	3.25 ^a ± 0.12	5.85 ^b ± 0.45

Values with different subtitles are considered as significantly different at p=0.05

¹ vine planted in March 2011; first pruning in March 2012 and first harvest in September 2012

Effect of mulching on rootstock development

To better understand the impact of mulching on vine growth during the first growing season and confirm the positive effect observed on the aerial parts, the rootstock development of 25-months old vines was studied after excavating and manually collecting

the vine roots in the first 60cm-thick soil horizon from a quarter of the Voronoï polygon. The morphological parameters (length and diameter) of the collected roots were then characterized and their dry weight determined (Table 6 and Figure 3).

Table 6. Root growth of mulched (PE and BF) or unmulched (BS) 2 years-old vines.

		Total root¹ dry weight (g)	Total root¹ length (cm)	Fine root² length (cm)	Medium root³ length (cm)
t_{24m}	BS	40.93 ^a ± 5.87	3416 ^a ± 457	3111 ^{ab} ± 409	305 ^a ± 104
	PE	47.05 ^a ± 3.48	4479 ^a ± 359	4062 ^{ab} ± 506	417 ^a ± 173
	BF	78.23 ^b ± 7.89	4683 ^a ± 1425	4168 ^b ± 761	515 ^b ± 187

¹Cumulated root dry weight and root length for a total soil volume of 96 dm³ corresponding to the first 60cm thick soil horizon.

²Fine root were ascribed to roots having a diameter d<2cm

³Medium root were ascribed to roots having a diameter ranging between 2mm<d<10mm

Values with different subscripts are considered as significantly different at p=0.05

As evidenced by the total dry weight of roots developed between the soil surface and 60 cm depth, vines mulched with the BF film developed significantly twice more roots than the unmulched treatment (Table 6) and this repartition appeared quite well distributed in the space when considering the three horizons and two squares (Figure 3). This behaviour specifically observed the BF treatment was also confirmed by the total root length that was higher for BF despite a rather weak statistical reliability of the results due to the low number of replicates. The root distribution according to size (Table 6) indicated that mulching treatments (PE and BF) produced more fine roots (diameter < 2mm), which control water and nutrient uptake from soil than for un-mulched treatment. In the first horizon, which is the closest to topsoil, the PE treated vines developed more fine roots than the BF ones (results not shown) probably because the PE mulch film was still intact 25 months after vine planting whereas the BF film had already lost its integrity. Regarding the medium size roots (2mm < diameter < 10mm), which control not only water and nutrients transport but also soil exploration, the root development of the BF treatment appeared higher than these of both PE or BS treatments in most of the depths and squares considered (results not shown). It is worth being underlined that even in the farthest horizon, the root development of the un-mulched vines appeared lower.

Hence, in spite of the high variability of the values obtained, the development of vine rootstock appeared to be favoured with the BF treatment and this specific behaviour might be related to the progressive degradation of the mulch film that occurred at the end of the first growing season. This result is in agreement with Van der Westhuizen (1980) who reported a higher root mass of Chenin Blanc vines mulched with a plastic film disintegrating 18 months after planting as compared to un-mulched vines. This could be explained by an adaptation of the root system consecutive to the loss of mulch integrity and the resulting changes in the soil water content. In the case of permanently mulched vines, it is well known that the rootstock develops first close to the soil surface, which is a drawback to the newly planted vines in terms of nutrient and water uptake by roots. In contrast, with the BF treatment, it is likely that there would be loss of water after the film degradation with a reduction in the water content of the soil close to the surface, favouring root development deeper in the soil profile in search of water. To conclude, the vines treated with BF mulch

film would be able to firstly adopt the behaviour of the PE-treated vines at the soil surface, and then, the behaviour of the un-mulched vines in depth. As a result, the rooting of vines grown under BF would be more vigorous and better distributed as shown by the roots distribution in the different horizon studied (Figure 3). This assumption is also in agreement with a higher turnover of the fine roots and the specific development of plant-feeding nematodes two years after vine planting with the BF treatment

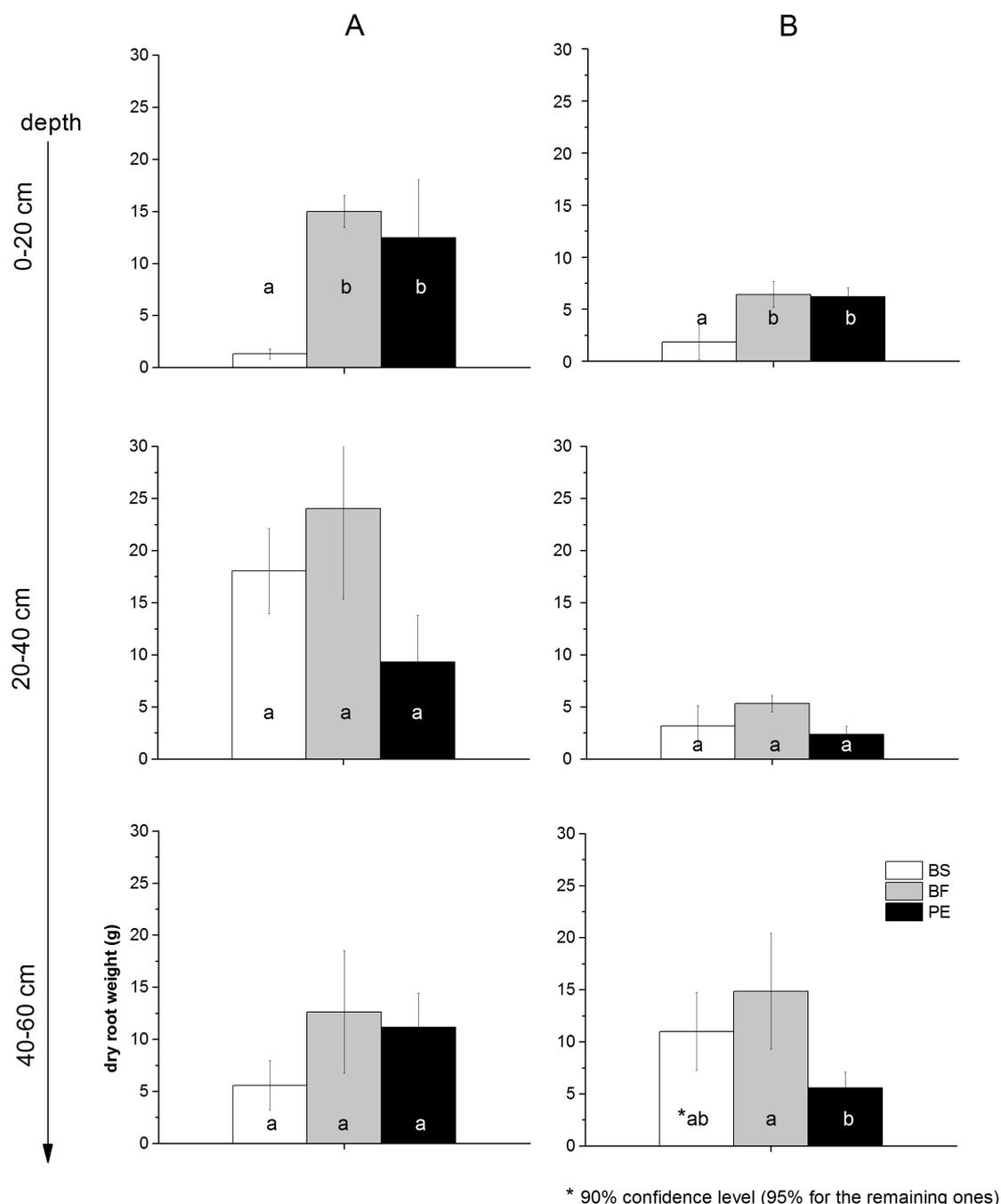


Figure 3. Effect of mulching treatment (BF, PE and BS) on the dry weight of roots collected at different depth and distance from the vine 24 months after planting (Values with different subscripts are considered as significantly different at $p=0.05$)

End of life and biodegradability assessment in standardized conditions

The sustainable requirement expected for the BF film were quantified as the biodegradation level through two respirometric test conducted in a vineyard soil at 28°C (Figure 4) and in a compost medium at 58°C (Figure 5).

Results obtained in soil measurements indicated that both biodegradable films (BF and BF*) reached a mineralisation threshold higher than 60% after two years (Figure 4). This indicated that they were both able to biodegrade in the standardized conditions of temperature and humidity claimed by one of the NF U52001 standard requirements despite the content in recycled material. However, it is worth noting that, even if the tests have been undertaken using the vineyard soil as incubation medium, known to be poor in organic matter and microbial biomass, the kinetics of biodegradation would be even slower in real field conditions. Indeed, temperature and humidity in use certainly differ from the standardized ones. In spite of that, based on the lifespan of a vineyard (several decades), the biodegradation process is expected to be complete before a new crop would be planted even without burying step.

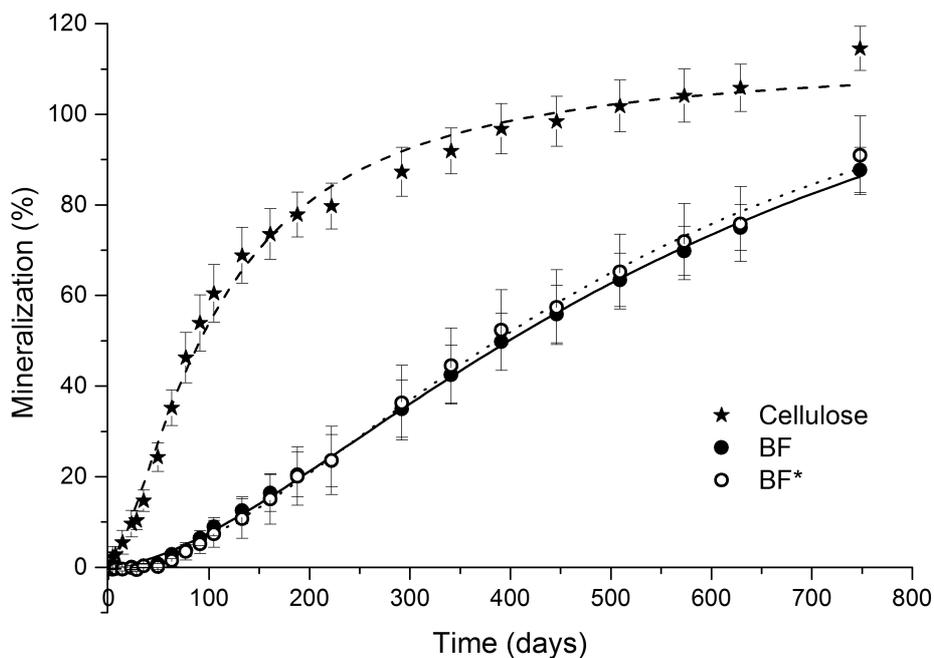


Figure 4. Biodegradation in soil (collected from vineyard) at 28°C of BF and BF*(10% of scraps included in the formulation)

To complete this study, a BF film sample collected from the field was subjected to a biodegradation test conducted in compost medium with the objective to evaluate how its rate of biodegradation might be affected by a 18 months field-weathering. According to Touchaleaume et al. (2017), this ageing duration corresponded to a cumulated solar radiations received by the film of 953 kJ/cm². The biodegradation curves (Figure 5) indicated that field ageing had few impact on the biodegradation pattern of the biodegradation of BF despite a 10% decrease in the percentage of mineralization was noticed for the aged film compared to the un-aged one at the end of the experiment, Hence,

the changes in the biodegradation rate induced by field ageing were closely linked with the level of crosslinking undergone by each material (Touchaleaume et al. 2017). However, the biodegradable character of BF could not be questioned even after undergoing photo ageing in field conditions during 18 months.

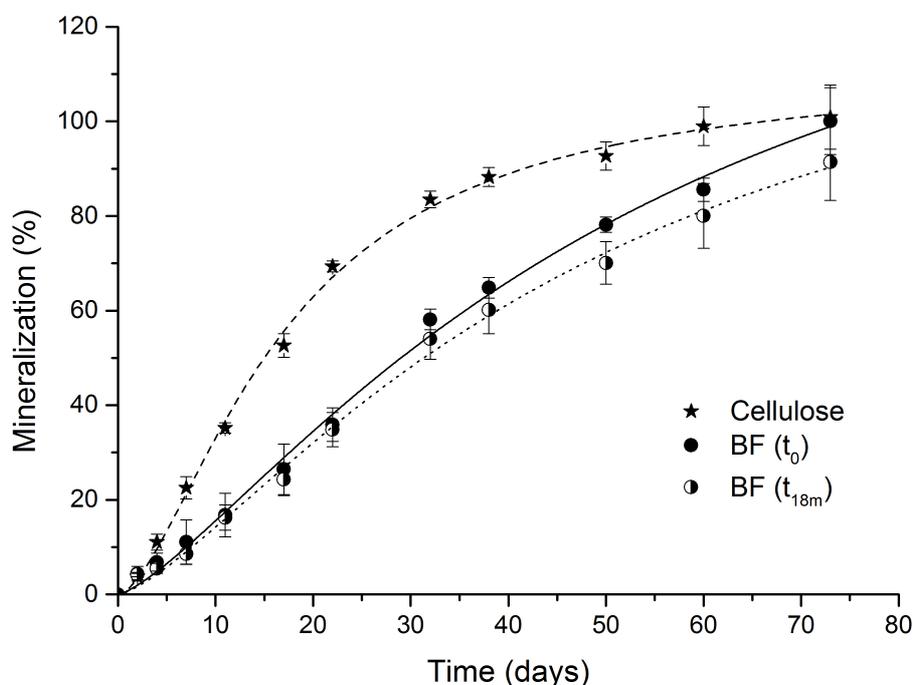


Figure 5. Kinetics of biodegradation in compost medium at 58°C of BF film before and after 18 months field-ageing.

CONCLUSION

Mulching has a noticeable effect onto the vine growth, starting from the first growing season and enabling one year earlier production than unmulched vines. During the three growing seasons after planting, vines initially grown on BF and PE mulches were both more vigorous and productive than BS ones, with a similar behaviour in terms of vegetative growth and production. In addition, root development was favoured in the case of the BF treatment compared to PE and BS treatments.

Thus, despite the early loss of integrity of the BF film, which occurred before the end of the first crop cycle, it is worth noting that the mulch-enhanced effect on vine growth was still noticeable during the second and third crop cycles. This suggested that the presence of mulch film at the critical early stage of growth would be as efficient as permanently mulching, *i.e.* it allowed the plant to grow fast enough to reach economically significant fruiting production. Based on these results, the long-term stability of PE appeared over-estimated, the material lifespan required for mulching application in the case of vineyard being probably around 4-5 months from the planting of the vines. The biodegradable mulch film tested fulfilled the requirements of vineyard mulching and its correlated farming practices *i.e.* remain intact in the field long enough to provide its expected positive effects on the crop, and be able to be biodegraded afterwards.

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