# EXPERT STATEMENT

# (BIO)DEGRADABLE MULCHING FILMS

This expert statement tackles two aspects related to the (bio)degradation of agricultural mulching films in soil. The first part discusses the biochemical pathway of biodegradation and more particularly the meaning of complete biodegradation in soil. The second part of the statement touches on the possible accumulation of plastics in the soil as a result of repetitive use of both non-biodegradable and biodegradable mulching films.

## Executive summary

- The only (scientifically correct) parameter to quantify biodegradation is the conversion of organic carbon to carbon dioxide ($CO_2$).
- In terms of biodegradation, 'complete' does not mean '100% conversion to $CO_2$' as part of the organic carbon is also used for microbial growth (which cannot be quantified precisely). This biomass yield typically ranges from 10% to 40%, depending on the substrate.
- Conventional polyethylene (PE) mulching films do not biodegrade in soil and accumulate over time, resulting in an average accumulation of 462.5 kg mulching film (fragments) per hectare per decade, assuming one cultivation period per year and a film thickness of 20 µm.
- Soil biodegradable mulching films, on the other hand, do biodegrade in soil and reach complete biodegradation within a maximum of 2 years under laboratory conditions. This results in a maximum accumulation level at the plateau phase of 281.3 kg per hectare, returning to no accumulation whatsoever if cultivation is to be ceased for two years. On the other hand, the accumulation level of non-biodegradable films continues to increase and does not decrease when cultivation is stopped.
- Non-biodegradable PE mulching films cannot be downgauged as this increases the relative level of contamination. Biodegradable mulching films, however, can be downgauged without any negative effect on plastic accumulation in soil.
- PE mulching films are acceptable, yet, only in a thickness (far) above 25 µm so that the recovery rate after harvesting can be kept as high as possible.


OWS nv Tel.: +32 9 233 02 04 mail@ows.be
Dok Noord 5, B-9000 Gent, Belgium Fax.: +32 9 233 28 25 www.ows.be

## ‘Complete’ biodegradation in soil

Just like any natural, organic material like leaves or straw, soil biodegradable polymers are assimilated as food and energy source by the microbial population present in soil. Bacteria and fungi use the organic carbon present in the biodegradable polymer to extract biochemical energy for driving their life processes by aerobic oxidation of the readily utilizable organic carbon. Equation 1 shows that the majority of this organic carbon is converted into carbon dioxide ($CO_2$), while a minor part is converted into microbial carbon (the so-called biomass yield or $C_{biomass}$ in the equation). This biomass yield is typically between 10% and 40% depending on the substrate which is converted. The $C_{residual}$ consists of (partially) undegraded polymer but can also be metabolites (to be considered as in-between degradation products).

$$C_{polymer} + O_2 \quad \Rightarrow \quad CO_2 + H_2O + C_{residual} + C_{biomass} \qquad \text{[Eq. 1]}$$

Biodegradation of a polymer is not a uniform process. Instead, both the rate and the maximum level of biodegradation of a specific polymer are very much determined by the environmental conditions on micro-level. These environmental conditions can differ with regard to moisture content, oxygen availability, pH-value, temperature, types of microorganisms (bacteria, fungi and/or actinomycetes), etc. While temperature and the presence or absence of fungi can have a big impact on the level of biodegradation, other factors mainly have an influence on the rate of biodegradation.

In other words, while the general opinion considers ‘complete’ to be identical to ‘100%’, it must be noted that, when it comes to biodegradation, the word ‘complete’ should be interpreted slightly different, as only the amount of $CO_2$ in Equation 1 can be quantified. $C_{residual}$ and $C_{biomass}$ cannot be quantified, since it is technically and analytically not possible to carry this out precisely. Hence, based on carbon to carbon dioxide conversion, which is already for many years the one and only parameter to quantify the level of biodegradation of a material, 100% biodegradation does not exist. Nonetheless, this should not incorrectly be interpreted as incomplete biodegradation as the ‘missing’ carbon is being used for microbial growth, meaning that $C_{polymer}$ is completely consumed.

The best known test method for the determination of the biodegradation of a polymer in soil is the international standard ISO 17556 *Plastics – Determination of the ultimate aerobic biodegradability of plastic materials in soil by measuring the oxygen demand in a respirometer or the amount of carbon dioxide evolved* (2012). This method prescribes that testing is considered valid only if the degree of biodegradation (based on carbon to carbon dioxide conversion) of the reference material cellulose has reached 60% or more at the plateau phase or at the end of the test.

A standard specification on the biodegradation of polymers in soil does not (yet) exist on ISO level. However, developments are ongoing at European (CEN) level and certification schemes for soil biodegradable polymers are already available on the market for many years. Both the draft CEN standard specification as well as the available certification schemes consider a polymer to be completely biodegradable if at least 90% (absolute or relative to cellulose) of the organic carbon present in the polymer ($C_{polymer}$) is converted to carbon dioxide within a period of maximum 2 years.

Between 2003 and 2015, OWS has run 79 biodegradation tests in soil in line with ISO 17556 varying in duration between 95 days and 1,811 days (see Figure 1). On average, cellulose reached a biodegradation level of 90.5% ± 9.6% at the end of the test, with 73.0% as a minimum and 112.8% as a maximum. The biodegradation percentage above 100% can be explained by a synergistic effect, also called priming.

From Figure 1 it can be concluded that, on average, 90% of the organic carbon in cellulose is converted into $CO_2$, while 10% is used for biomass production and is hence converted into $C_{biomass}$. Straw, on the other hand, shows biodegradation levels (at plateau) between 67.0% and 78.3%, while wood fibres and other natural materials like birch leaves and pine needles, which contain relatively high levels of lignin and hence biodegrade (much) slower, only reach biodegradation levels of approximately 60%.

OWS also has ample data on soil biodegradation of biopolymers, including, for instance, data obtained within the EU project Open-BIO which received funding from the European Union Seventh Framework Programme under grant agreement n° 613677 (see Figure 2). While cellulose reached a biodegradation level of 84.9% after 141 days, which falls within the abovementioned range of 90.5% ± 9.6%, polyhydroxybutyrate (PHB) and polybutylene sebacate (PBSe) show biodegradation levels of 86.3% after 120 days and 74.0% after 141 days, respectively.

Given that both PHB and PBSe are close to their plateau phase, it can (again) be concluded that not all $C_{polymer}$ is converted to $CO_2$ and part is used for biomass production as well. PHB shows a biodegradation profile similar to cellulose, with approx. 10-15% of $C_{polymer}$ used for biomass production, while PBSe biodegrades slower and more $C_{polymer}$ is used for biomass.

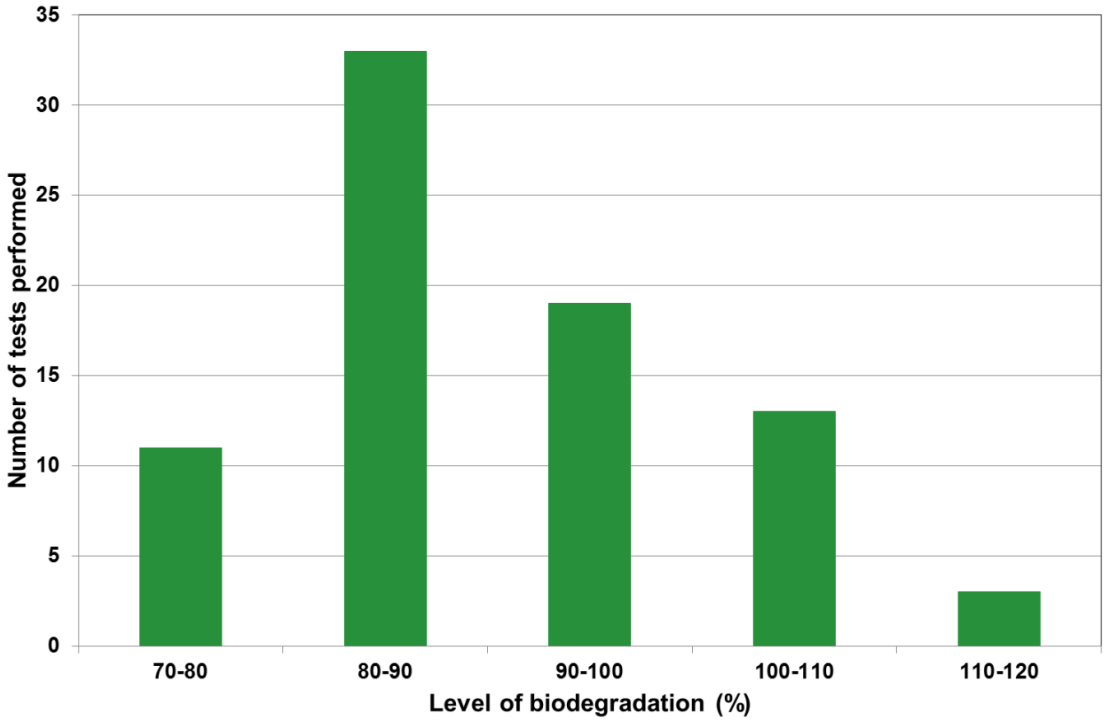


*Figure 1. Level of biodegradation (at plateau phase) obtained for cellulose in ISO 17556 testing performed at OWS in the period 2003-2015*

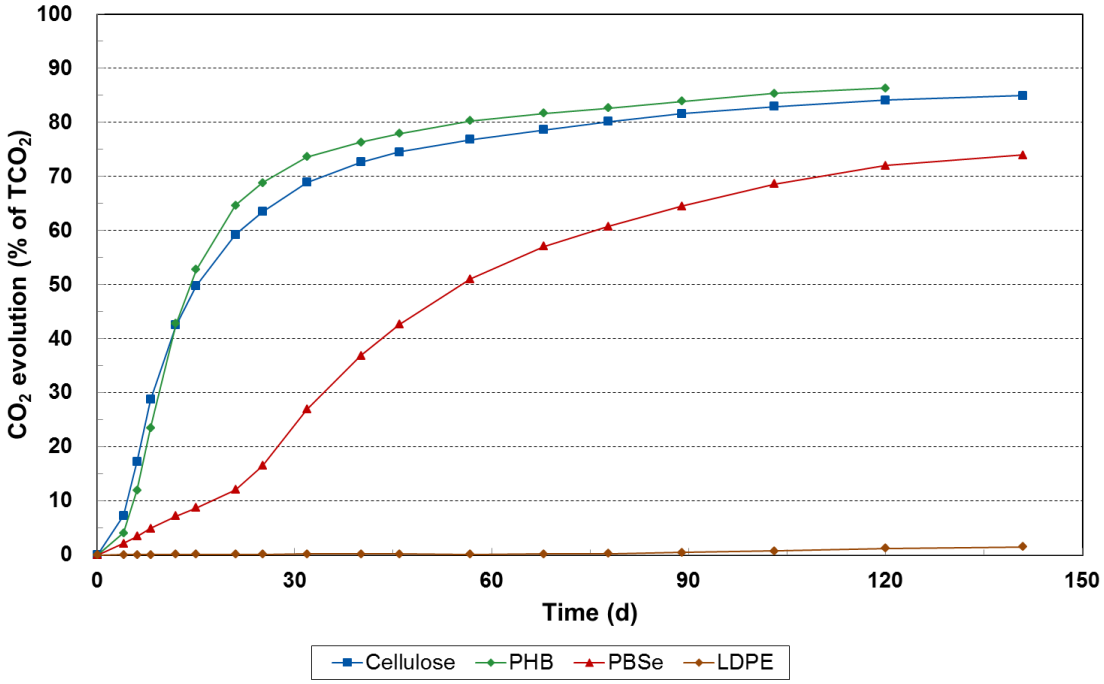


*Figure 2. Level of biodegradation obtained in soil in ISO 17556 testing performed at OWS on PHB, PBSe and LDPE*

A similar conclusion can also be made for polybutyrate adipate terephthalate (PBAT). After 181 days, an absolute biodegradation of 94.4% ± 1.7% was measured, proving that (again) part of $C_{polymer}$ was converted into biomass and not all is converted to $CO_2$ (see Figure 3).

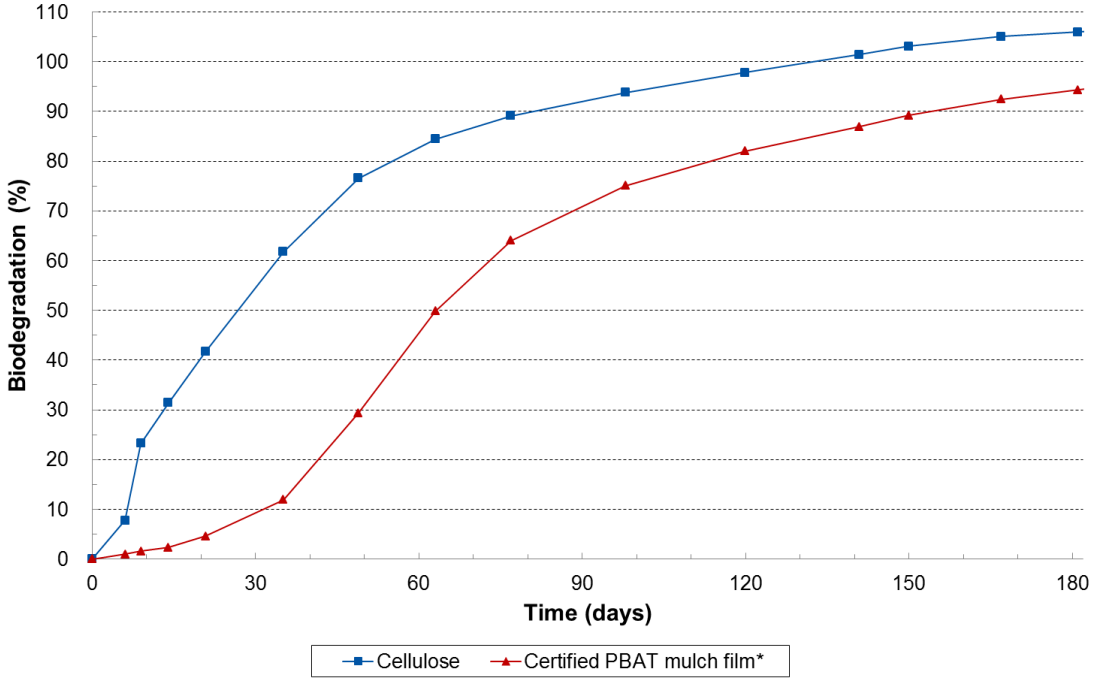


*Figure 3. Biodegradation in soil of a certified PBAT mulching film*[*]

In other words, the amount of carbon used for biomass production depends on the substrate and, as mentioned above, varies between 10% and 40%. A reliable method to measure biomass formation during biodegradation testing does, however, not yet exist.

[*] The certified PBAT mulching film referenced in Figure 3 concerns an ecovio® mulching film certified as biodegradable in soil.

## Accumulation of plastics in soil

Traditionally, mulching films are produced from non-renewable petroleum-based polymers, like polyethylene (PE). In particular, low-density polyethylene (LDPE) is the most widely used PE grade by vegetable growers due to its relatively good mechanical and optical properties. These LDPE mulching films vary in thickness between 15 µm and 50 µm.

Normally, the service life of mulching film exceeds the duration of crop cycles, allowing proper removal after harvesting. Nonetheless, it is estimated that, depending on the thickness of the applied mulching film, as much as 68% of the mulching film is not removed from the field as removal is time-consuming (about 16 hours per hectare) and disposal expensive (up to € 300 per hectare). Mulching films are therefore usually broken into pieces during soil preparation for the next crop, leaving pieces of plastic buried in soil as well as on the soil surface.

Pieces of PE mulching film buried in soil will not fragment further, while pieces on the soil surface will become brittle because of solar irradiation and consequent oxidation and subsequently fragment with a rate varying in function of the thickness of the mulching film, precise composition of the PE and weather conditions. As a result, in the end, also these pieces will end up buried in the soil and will accumulate over time.

According to a note in the European standard EN 13655 *Plastics – Mulching thermoplastic films for use in agriculture and horticulture* (2002), the observed levels of contamination of mulching films with soil and vegetal residues can vary from 70% to 90%. In other words, the thinner the mulching film, the higher the relative level of contamination and hence the more difficult (and expensive) the removal, recovery and/or recycling. Therefore, downgauging is not an option for PE mulching films. It can be concluded that while for 25 µm mulching films a collection rate of 90% can be guaranteed, this collection rate significantly drops due to the relative level of contamination to respectively 75% and 32% in the case of 20 µm respectively 10 µm mulching film.

Assuming an average thickness of 20 µm and an average density of 925 kg/m³ for LDPE, 185.0 kg of mulching film is needed per crop per hectare. With approx. 25% of the mulching film not being removed after harvesting, this converts to 46.25 kg of non-biodegradable inert PE mulching film (fragments) per crop per hectare remaining in the soil. The soil depth where these plastic fragments typically end up after use is presumed to be 20 cm, which corresponds to the normal depth of soil tillage. In other words, at the end of each cultivation period, 46.25 kg of (non-biodegradable) PE film fragments will end up in a volume of soil equal to 2,000 m³. This amount of soil weighs approximately 3,000 tonnes, considering a soil bulk density of 1.5 tonne/$m^3$, which means that the plastic accumulation rate would be, on average, 0.0015% per year (assuming only one cultivation period per year).

In case of a 25 µm PE mulching film and considering an average collection rate of 90%, 23.13 kg of mulching film (fragments) would remain in the soil per crop per hectare per year. However, if a 10 µm PE mulching would be used, characterized by an average collection rate of only 32%, 62.9 kg of mulching film (fragments) would remain in the soil per hectare per crop per year.

Without considering a potential growth of the mulching film industry, the level of accumulation when using 20 µm PE mulching films and one cultivation period per year increases to 462.5 kg mulching film (fragments) per hectare after 10 years, 2.3 tonnes per hectare after 50 years and even 4.6 tonnes per hectare after 100 years (see Figure 4). It must, however, be noted that these figures are average figures and the actual accumulation load depends on the thickness and density of the PE mulching film used and the number of crops cultivated and hence number of mulching films used per year. Figure 4 shows the increase in accumulation for 3 scenarios: one crop per year and a 20 µm film thickness, two crops per year and a 20 µm film thickness and two crops per year and a 10 µm film thickness.

According to several market studies, the mulching film market is expected to grow at a decent pace during the coming decade following the growing demand for high-quality crops and the need for (further) optimization of food production due to the increasing population. In the early 2000s, 'only' 2-3 million tonnes of mulching film was used on an annual basis, while in 2012 this was already 4.4 million tonnes. In the next years, it is estimated that this market will grow further at an average growth rate of 5.7% per year up to 2019.

Mulching films produced from biodegradable polymers can be ploughed into the soil at the end of the growing season without causing any plastic accumulation on long-term.

A typical biodegradable mulching film is 15 µm thick and has a density of 1,250 kg/m³. As such, 187.5 kg of mulching film is used per crop per hectare. If complete biodegradation in soil has been obtained under laboratory conditions, all organic carbon within the polymer ($C_{polymer}$) will be converted to carbon dioxide or used for biomass production. Under laboratory conditions (25°C), this means that at least 90% of the organic carbon has been converted to $CO_2$ within a period of maximum 2 years. In reality, the biodegradation rate will depend on the environmental conditions (temperature, moisture content, etc.). It must, however, be noted that one of the reasons of using mulching film is increasing soil temperature. Nevertheless, also at temperatures below 25°C complete biodegradation is expected to be reached. Considering a Q10 factor of 2, and assuming worst-case scenario, complete biodegradation would be obtained within maximum 4 years at 15°C.

The biodegradation profile of biodegradable polymers varies from one polymer to the other, making it impossible to calculate the level of temporary accumulation in soil. Based on an average thickness of 15 µm and an average density of 1,250 kg/m³, the top 20 cm (normal depth of soil tillage) of soil would contain 0.0063% of biodegradable mulching film fragments at the end of the cultivation period. Assuming the biodegradation profile follows a linear approach and average temperature of the soil during cultivation is 25°C, 50% of the plastic fragments would have been converted to $CO_2$ and biomass after one year. In other words, maximum accumulation level would be 0.0094% of biodegradable plastic fragments (0.0063% from cultivation period x + 50% of 0.0063% from cultivation period x-1), which corresponds to 281.3 kg per hectare. This is assuming a new year brings a new cultivation period and hence a new mulching film.

However, if the field would not be used for 2 years, using no new mulching films, the remaining mulching film (fragments) would biodegrade further and would have been completely biodegraded at the end of the 2 years period, leaving no accumulation whatsoever. In the case of non-biodegradable PE fragments, however, the accumulation level increases each year and also remains even if no new mulching films are being used. Figure 5 shows the accumulation of mulching film (fragments) over time, assuming a cycle of 2 years with one crop per year, following by two years of no cultivation.

Finally, it should also be noted that in reality the film itself needs to biodegrade in soil while under laboratory conditions testing is performed using powder (obtained through milling of pellets). Figure 6, however, shows that the biodegradation rate at start is actually higher for film compared to powder. This is also not surprising as film samples have a thickness of approximately 15 µm, while powder samples obtained through milling of pellets usually have a particle size of a couple of hundreds of microns. In other words, in reality, biodegradation of mulching films is expected to proceed quicker compared to laboratory conditions (assuming moisture content and temperature are identical in both conditions).

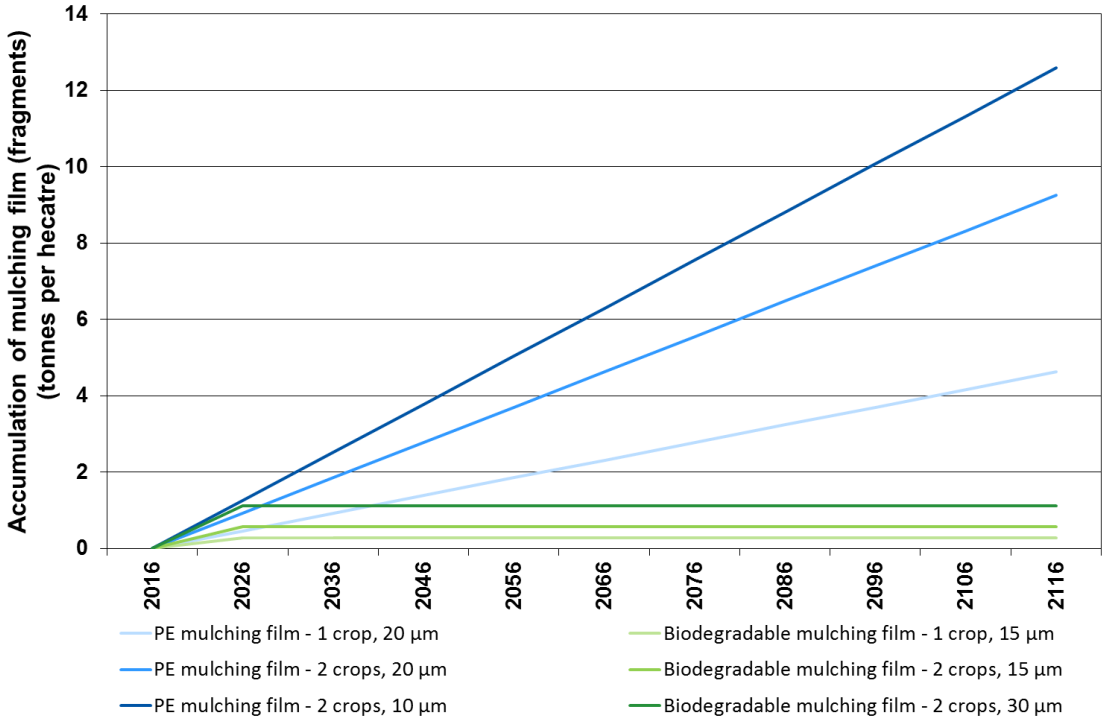


*Figure 4. Schematic overview of the increase in accumulation of PE and biodegradable plastic fragments in soil (not considering the expected growth rate of the mulching film industry)*

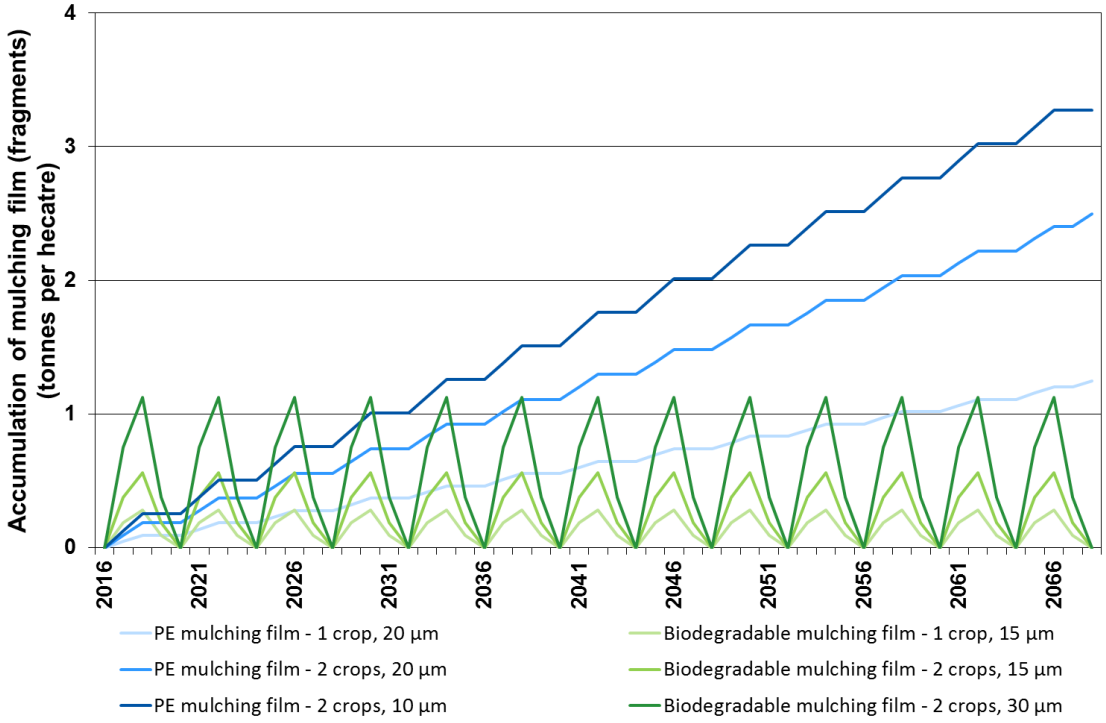


*Figure 5. Schematic overview of the accumulation of PE and biodegradable plastic fragments in soil assuming a cycle of 2 years of cultivation and 2 years of no cultivation (not considering the expected growth rate of the mulching film industry)*

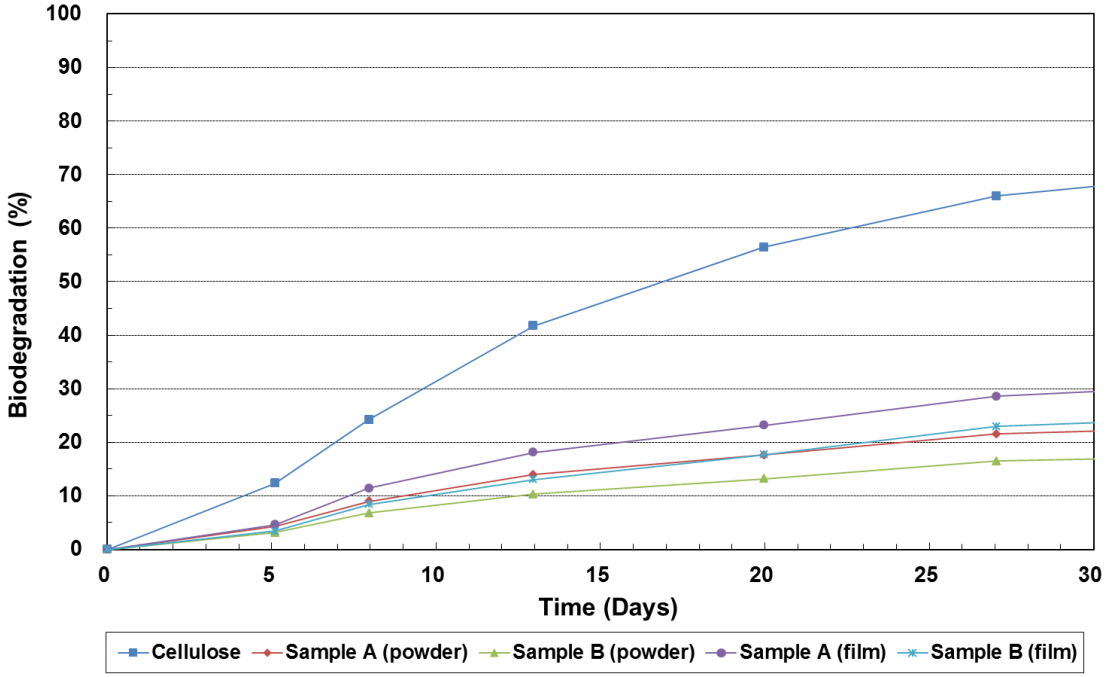


*Figure 6. Comparative biodegradation test on mulching film (powder versus film)*

Gent, Jan-30-2017

Bruno DE WILDE
Lab Manager
OWS nv

Sam DECONINCK
Lab Project Manager
OWS nv

## References


[1] Handbook of Biodegradable Polymers, 2nd Edition. Editor: Catia Bastioli. Smithers Rapra. ISBN: 978-1-84735-526-3

[2] EU project Open-Bio (www.open-bio.eu), received funding from the European Union Seventh Framework Programme under grant agreement n° 613677 and aims at increasing the uptake speed of standards, labels and harmonized product information lists for bio-based products.

[2] Kyrikou, I. and Briassoulis, D. *Biodegradation of Agricultural Plastic Films: A Critical Review*. J Polym Environ (2007) 15:125-150

[3] Ngouajio, M., Auras, R., Fernandez, R. T., Rubino, M., Counts Jr., J. W. and Kijchavengkul, T. *Field Performance of Aliphatic-aromatic Copolyester Biodegradable Mulch Films in a Fresh Market Tomato Production System*. HortTechnology (2008) 18:605-610

[4] Kasiraian, S. and Ngouajio, M. *Polyethylene and biodegradable mulches for agricultural applications: a review*. Agron. Sustain. Dev. (2012) 32:501-529

[5] *Ecological Benefits of Biodegradable Mulching film*. Presentation by Tijana Duric at the conference "Micro-plastics – Sources, impacts and solutions" in Cologne, 23-24 November 2015.

[6] *Global Warming Potential – Consideration of Different PE Mulch Film Thicknesses and Recycling Rates*. Presentation by BASF.

[7] Scarascia-Mugnozza, G., Sica, C. and Russo, G. *Plastic Materials in European Agriculture. Actual Use and Perspectives*. Journal of Agricultural Engineering (2011) 3:15-28

[8] *Agricultural Films (LDPE, LLDPE, HDPE, EVA/EBA, Reclaims and Others) Market for Greenhouse, Mulching and Silage Applications – Global Industry Analysis, Size, Share, Growth, Trends and Forecasts, 2013 – 2019*, Transparency Market Research, 2013

[9] *Agricultural Films Market by Type (LLDPE, LDPE, HDPE, EVA, Reclaim), Applications (Greenhouse, Sliage and Mulch) and Geography (North America, Asia-Pacific, Europe and RoW) – Global Trends & Forecast to 2020*, MarketsandMarkets, 2015

[10] TC 249 WI 00249875:2016 *Plastics – Biodegradable thermoplastic mulch films for use in agriculture and horticulture – Requirements and test methods*

## Expertise OWS

OWS nv is a private and strictly independent contract research laboratory based in Belgium with more than 25 years of experience in the field of biodegradability and compostability testing, covering different end-of-life options like industrial and home composting, soil biodegradation, fresh water biodegradation, seawater biodegradation, etc. Since 1988, OWS has tested 3,000+ materials and products for 800+ clients all over the world. Materials tested, at lab-scale and/or pilot-scale, include polymers, paper(board), packaging, mulching films, consumer goods, agricultural and horticultural products, food service ware, films and bags, inks, additives, adhesives, etc.

With an ISO 17025 certificate at hand, covering the overall laboratory operation and specific activity of compost analyses, OWS is recognized by all certification bodies active in the field of biodegradability and compostability.

OWS is also situated at the forefront of the industry through activities in standardization at international (ISO), regional (CEN) and national (ASTM and DIN) level, allowing co-development of new test methods and standards on biodegradability and compostability.