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Analysis of the mechanical and degradation performances of optimised agricultural biodegradable films

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Abstract

The introduction and the expanding use of biodegradable materials represent a really promising alternative for enhancing sustainable and environmentally friendly agricultural activities in mulching and low-tunnel cultivation. The main challenges for the development of agricultural films biodegradable in the soil concern primarily the effects of ageing and degradation during the useful lifetime, which may cause premature losses in their mechanical performance. A set of Mater-Bi based biodegradable films was developed and tested, following the selective optimisation of some processing parameters of the film manufacturing along with the optimisation of the structural low-tunnel system design. The behaviour experienced during the experiments suggests that the so optimised biodegradable films perform in a way comparable to the corresponding LDPE films, within the period of their useful lifetime. Experimental investigation indicates that water and high temperatures do not affect the mechanical behaviour of the biodegradable films significantly, as it is experienced during the first period of their exposure to real field conditions. A high dose of UV radiation has detrimental effects, however, on the elongation at break of both mulching and low-tunnel films. These films are shown to be readily degraded within 4–6 months under irrigated agricultural soil conditions, indicating a high biodegradability rate.

Keywords: Biodegradable materials; Agricultural films; Biodegradation; UV artificial ageing; Mechanical performance; Degradation performance

1. Introduction

Polymers have been used in agriculture and horticulture since the middle of the last century. In the past, plasticulture (that is the use of plastics in agriculture) was introduced primarily in developed countries, but is recently spreading to developing countries as well. Growth is particularly strong in areas with limited farmland, such as in Europe, Japan and Korea. The growing use of plastics in agriculture has enabled farmers to increase their crop production and to alleviate the dependence of their production on the climatic conditions. Today, the use of plastics in agriculture results in increased yields, earlier harvests, less reliance on herbicides and pesticides, better protection of food products and more efficient water conservation. As a consequence, the use of plastics in agriculture is growing globally, following the transformation of the agriculture into a technical industry.

A large proportion of the plastics used in agriculture are agricultural films. Plastic films are used in greenhouses, as tunnels over crop rows, as silage covers, as bale-wrap films, and mostly as mulching films to cover the soil of crop rows [1]. In particular, the expanding use of mulching films and the combination of low-tunnel films along with mulching films for protected cultivation, aims at elimination of weeds, conservation of water and fertilisation and also, with the use of both films, in providing a better micro-environment for the plants and protection against adverse climatic conditions. The conventional agricultural plastic films used today are low density polyethylene (in some cases high density polyethylene HDPE, or linear low density polyethylene LLDPE), poly(vinyl chloride), polybutylene or copolymers of ethylene with vinyl acetate.

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According to the International Committee for Plastics in Agriculture (Comité International des Plastiques en Agriculture or CIPA [1]) about 500,000 hectares are under greenhouse globally and 4,500,000 hectares are using mulch film. An estimated 2–3 million tons of plastics are used each year in agricultural applications. Based on the report of [2], agriculture consumes 2.5% of the global plastic production (4 million tons in 2000). In Western Europe 956,000 tons of plastic were used in agriculture in 2000 (Association of Plastic Manufacturers in Europe, 2002) [3]. The main agricultural uses of plastic in Western Europe in 2000 were [4] greenhouse and low-tunnel films (230,000 tons), mulching film (70,000 tons), silage film (70,000 tons).

A serious negative side effect associated with the steadily growing use of plastics in agriculture concerns the parallel growing disposal problem of thousands of tons of agricultural plastic wastes produced each year. Unfortunately, a large portion of these is left on the field or burnt uncontrollably by the farmers releasing harmful substances with the associated obvious negative consequences to the environment [5]. Aesthetic pollution and landscape degradation of regions of natural beauty represent an additional negative environmental impact. Furthermore, another 'disposal option', burying of these materials in the agricultural land, represents an imminent threat for an irreversible soil contamination and possibly for the safety of the food produced in such fields. Both practices are illegal based on the Landfill Directive (Directive 99/31/EC) [6] which forbids the uncontrolled burying of the waste and the Incineration Directive (Directive 2000/76/EC) [7] which states that uncontrolled burning is prohibited. There are several reasons, however, for all these environmentally dangerous practices. The main reasons are the lack of cost efficient systematic disposal techniques available to the growers along with the high labour cost for the proper collection of the plastic films and other plastic wastes following the end of the cultivation [8]. Recycling is not considered as a cost efficient solution for the thin and dirty mulching and low-tunnel films.

Accordingly, the degradation and possibly biodegradation, of agricultural plastics are very important subjects with economical and environmental aspects. The possibility to use materials biodegradable in the soil appears as a very attractive alternative to the conventional (mostly polyethylene) agricultural plastics, a real challenge for enhancing sustainable and environmental friendly agricultural activities, especially in mulching and low-tunnel cultivation applications. The emphasis with regard to agricultural biodegradable films, at the moment, is placed on developing thin biodegradable mulching films and, currently at the experimental stage, biodegradable low-tunnel and direct cover films.

A successful development of high performance biodegradable agricultural films mainly depends on meeting three critical design requirements: achieving good mechanical behaviour of the original films, retaining a satisfactory mechanical performance during the useful lifetime and achieving 100% biodegradation in the soil after the end of the useful lifetime, preferably before the next cultivation season. A literature review on the mechanical behaviour of various types of biodegradable materials is presented in [8]. The mechanical design requirements for low-tunnel films were defined in [9], where a new methodological approach for designing low-tunnel films was developed.

In the framework of a European research project[1] a series of experimental Mater-Bi based thin low-tunnel and mulching films were developed, evaluated and optimised (Mater-Bi is a material based on starch complexed with biodegradable polyesters). Several biodegradable films made of different grades of Mater-Bi material and additives (including transparent and coloured mulching films), different thickness and processing parameters exposed in the experimental field under real cultivation conditions in four different locations in Europe, were tested in the laboratory, analysed systematically and compared against the performance of the corresponding conventional polyethylene films. A detailed analysis of the laboratory based testing of the evolution of the critical mechanical properties of these experimental Mater-Bi based biodegradable mulching and low-tunnel films with respect to the time of their exposure to real field conditions is presented in [10]. The overall mechanical behaviour of the same series of experimental Mater-Bi made thin low-tunnel films, was analysed in the work of [11] with respect to the combined effect of two major factors: optimisation of selected processing parameters during manufacturing of the film along with the design of the low-tunnel structural systems. The procedure introduced in [9] for the mechanical design requirements of low-tunnel biodegradable and conventional films was revised, as a result of the work of [11], specifically for the case of biodegradable low-tunnel films [11].

The evaluation of the first three sets of experimental films [10,11], confirmed the feasibility of developing thin biodegradable low-tunnel and mulching films of satisfactory performance, while the need to further optimise the processing parameters to be used for the development of a final optimised set of biodegradable films was identified in technical terms.

Subsequently, a fourth set of optimised Mater-Bi based biodegradable and mulching films was developed and tested in the field and the laboratory, following the optimisation of selected processing parameters of the film manufacturing along with the optimisation of the structural low-tunnel system design. In the present work, the overall mechanical and degradation performance of the optimised set of biodegradable films is presented and compared against the performance of conventional polyethylene films. The biodegradable mulching and low-tunnel films after their use may be rototilled into the soil along with the cultivation remains [10–12]. These materials are completely biodegraded in soil, leaving no remains, and without any negative environmental impact.

[1] *Bioplastics*: 'Biodegradable plastics for environmentally friendly mulching and low tunnel cultivation', QLK5-CT-2000-00044.