Physical Properties of Innovative Biodegradable Spray Coating for Soil Mulching in Greenhouse Cultivation

E. Schettini and G. Vox
Dipartimento di Progettazione e Gestione dei Sistemi Agro-zootecnic i e Forestali (PROGESA) - University of Bari
Via Amendola 165/a, 70126 Bari
Italy

M. Malinconico, B. Immirzi and G. Santagata
Istituto di Chimica e Tecnologia dei Polimeri (ICTP) – CNR
Via Campi Flegrei 34, Comprensorio Olivetti, 80078 Pozzuoli (NA)
Italy

Keywords: radiometric properties, mechanical properties, mulch films, biodegradable polymers, tomato

Abstract
In order to overcome to the serious drawback of huge quantities of plastic waste obtained at the end of the life of agricultural plastic mulching films, researches on innovative biodegradable materials have been developing. The paper examines a new sustainable approach in which a water solution of natural biodegradable polymers is sprayed on a cultivation area in order to form a mulch coating. The material used is a blend of two polysaccharides, such as Guar Gum and Locust Bean Gum activated with glycerol. A protected field experiment was conducted to test the effectiveness of spray black biodegradable mulching coating in a tomato crop in Southern Italy. Field performance and physical properties, evaluated by means of laboratory tests, are compared to those of commercial low density polyethylene and biodegradable starch based mulch films. The spray mulching coating is opaque in the solar radiation range and behaved as a black body. The tested spray coating showed much lower values of tensile stress and elongation at break in comparison with the values of commercial low density polyethylene and biodegradable starch based mulch films. Such innovative coatings were characterised by functionality during their use in field. Results indicate that the biodegradable spray coatings could be a sustainable alternatives to plastic films based on fossil raw materials.

INTRODUCTION
Petroleum derived plastic films, like low density polyethylene (LDPE) or ethylene-vinyl acetate (EVA), are widely used in agriculture for soil mulching. The world consumption of plastic mulching films is about 650000 tons per year (Jouët, 2001). The use of plastic films for soil mulching increases yield and quality of horticultural products, contributes to clean products, reduces water evaporation from the soil and then water consumption, controls weeds and allows the presence of products in longer period of the year, providing greater benefit and cost effectiveness to the grower. At the same time the oil based materials have the serious drawback of large quantities of post-consumption plastic materials, causing environmental negative consequences connected to their collection, disposal and reuse. In recent years researches (Halley et al., 2001; Krochta and De Mulder-Johnston, 1996; Tocchetto et al., 2002) have been focusing on developing biodegradable polymers to be applied in agriculture that should not generate wastes to be disposed of. Besides, the innovative materials should be characterised by suitable mechanical and physical properties in order to be used from planting to harvesting applying the same cultivation techniques currently used for plastic mulching films (Briassoulis, 2004; Scarascia- Mugnozza et al., 2004). The introduction of water solutions of natural biodegradable polymers to be sprayed on a cultivation area in order to form a coating as mulch can be a solution. Spray mulching coatings by using natural polymers deriving from marine biomasses represent the further development of biodegradable starch based films which have been recently introduced at experimental level (Immirzi et al., 2003). At the end of the cultivation, the waterborne spray mulching coatings can be
disposed incorporating them into soil by tilling the field at the end of cultivation. Biodegradation in the soil is a natural process due to the action of micro-organisms such as bacteria, fungi and algae. Residual breakdown products of spray biodegradable coatings after the cultivation period should be completely mineralised into carbon dioxide or methane, water and biomass by means of soil micro-organisms in a reasonable time frame (Chandra and Rustgi, 1998; Kaplan et al., 1994; Narayan, 2001).

The aim of this paper is to evaluate the physical properties and field performance of innovative biodegradable spray mulch coating casted directly on the soil in order to replace the based petroleum mulch films. An experimental test using biodegradable spray mulching coating, in comparison with biodegradable starch based and non biodegradable mulching films, was carried out in a tunnel protected cultivation of tomato in Southern Italy.

BIODEGRADABLE SPRAY COATINGS

Because the traditional mulching films deposited on the soil are anchored on it, so that an air space between the soil and films generates, the films themselves must show strong mechanical performances to prevent wind and rain to break them. Sprayable mulching coatings based on polysaccharides are casted directly on the soil and during the drying process, a continuous coating is formed following the unevenness of the soil surface. Such a cover coating does not need a very good answer to mechanical properties, except for stability towards rain. In our case mulching coatings are realised spraying a blend of two available polysaccharides, coming from Leguminosae, i.e. Guar gum (Guar bean) and Locust bean gum (carob tree); because the polysaccharides films are generally brittle, to improve their flexibility and toughness, a certain amount of plasticizer like glycerol is added.

MATERIALS AND METHODS

Field Test

The full-scale field test was carried out using innovative biodegradable spray black coatings as mulch in a tomato crop. The trial started in Spring 2004 at the experimental farm of the University of Bari in Valenzano (Bari), Italy, having latitude 41° 05′ N. The tomato crop was grown in a steel-constructed tunnel (30.00 m x 8.00 m, ridge height of 3.20 m) North-South oriented. The tunnel was covered with a film EVA with the brandname of PATILUX, made by Pati Company (San Zenone degli Ezzelini, Treviso, Italy), having a thickness of 200 µm. The tunnel covering film was characterised by the following radiometric coefficients: solar radiation range (300-2500 nm) total transmissivity equal to 90.9 %, solar direct transmissivity equal to 56.7 %, solar reflectivity equal to 8.8 %, long wave infrared range (LWIR, 7500-12500 nm) transmissivity equal to 22.5 % and LWIR reflectivity equal to 3.2 %. The end sides were covered with corrugated rigid laminated plastic in reinforced plastic with fibreglass (GRP), having a thickness of 3 mm. The soil inside the tunnel was sandy loam (64.25% of sand, 21.72% of silt, 14.03% of clay) characterised by: pH in water equal to 7.50, conductivity of saturated soil paste equal to 16.37 g/kg and to 9.66 g/kg of fine loam, cationic exchange capacity equal to 18.52 meq/100g of fine loam and C/N ratio equal to 8.46. The ventilation system is composed by two fans in the south end side and two sliding shutters in the north end side; the system was controlled automatically in order to maintain internal air temperature under the set point value of 27 °C.

The spray treatment was casted directly on the soil by means of a high pressure, airless spray machine at 20 MPa of pressure. The soil of the raised beds, before the spray treatment, was moistened up to saturation in order to avoid any percolation of the spray. On 9 March 2004 black spray mulching coatings, with and without acetic acid addition, were executed: the former was named MYA, the latter MY. Task of the acetic acid is to inhibit weeds growth. Mulching coatings MYA were realised in two times: a clear composition and afterwards a black composition were sprayed on the raised beds (Fig. 1).
Coatings MY were executed spraying only the black composition. The clear composition was composed of a polysaccharide mixture (guar gum and locust bean gum) at a concentration of about 1.5% of each component with the addition of 10% of acetic acid. The black composition was composed of a polysaccharide mixture (guar gum and locust bean gum) at a concentration of about 1.5% of each component with the addition of 2% of carbon black. The black polysaccharide composition was sprayed uniformly at 0.6 L/m² on the top and on the edges of the raised beds. On 19 March 2004, the realised mulching coatings were further oversprayed with a second black spray coating at about 0.8 L/m², applying the same spray application procedure used during the first spray treatment for all the plots (Fig. 2). This was necessary in order to cover cracks appeared on the spray coatings.

Besides a biodegradable mulching film, named MB, and a LDPE mulching film, named MP, were installed for functionality and agronomical comparison. The black biodegradable mulching film MB, with a thickness of 12 µm, was manufactured by two industrial companies: the starch based raw material was supplied by Novamont Company (Novara, Italy), while the extrusion was made by Pati Company. The black commercial LDPE film MP was manufactured by Pati Company with a thickness of 40 µm. The biodegradable and LDPE mulching films were cut to the proper length and placed manually over soil raised beds covering the bed surface and were anchored around the edges with the soil.

Five thesis were arranged: biodegradable mulching, MB; LDPE mulching, MP; black spray mulching with acetic acid addition, MYA; black spray mulching, MY; non-mulched bare soil as control. The thesis were replicated four times in a randomized block design in the tunnel. Planting raised beds were oriented in west-east direction. On 23 March tomato plants (cv Naxos) were transplanted as experimental crop. The tomato growing methods applied were the same for all the plots including drip irrigation.

Samples of spray coating were prepared in situ in order to carry out laboratory physical tests. The black polysaccharide composition, after being heated up at 45°C, was applied at about 1.4 L/m² by the spray machine on pieces of glass on which previously a thin layer of sunflower oil was put in order to avoid any attachment of the spray film on the glass surface. After few days the samples were peeled and tested in laboratory in order to assess the physical properties.

Laboratory Tests

The radiometric properties of the materials used were analysed by means of spectrophotometers, at the Department PROGESA of the University of Bari, in order to evaluate the capacity of materials to transmit, reflect and absorb radiation. The transmissivity and the reflectivity in the wavelength range between 200 nm and 2500 nm were measured by means of a Perkin-Elmer Lambda 950 UV-Vis-NIR spectrophotometer; an integrating sphere of 60 mm of diameter was used to evaluate the diffuse fraction of the transmitted and reflected radiation. The solar transmissivity coefficient was calculated as weighted average value over the wavelength interval between 300 nm and 2500 nm using the spectral distribution of the terrestrial solar radiation as weighting function (Papadakis et al., 2000). The transmissivity in the LWIR range between 2500 nm and 25000 nm, was measured by means of a Perkin-Elmer FT-IR 1760 X spectrophotometer. The near normal reflectivity in the LWIR range was measured at a fixed angle of 10°. The transmissivity and the reflectivity coefficients were calculated as average value over the wavelength interval between 7500 nm and 12500 nm (Papadakis et al., 2000).

Tensile and morphological analyses were conducted in order to study the mechanical behaviour of the coatings at the ICTP-CNRS of Pozzuoli. Among the many mechanical properties of the materials tested, tensile properties are important indicators of the material's behaviour under loading in tension. Stress-strain and Young’s modulus were evaluated using an Instron tensile machine 4301 on dumbbell specimens characterised by a width of 1 cm, a length of 4 cm and a thickness of 0.05 cm. Four samples for each
material were tested. Morphological Scanning Electron Microscopy analysis (SEM) was performed by using a Philips 501 SEM on a Au/Pd coated film surface.

RESULTS AND DISCUSSION

The values of the transmissivity and reflectivity coefficients of the black films tested during the tomato cultivation in the solar radiation and LWIR ranges are shown in Table 1. In the solar radiation range all the materials are opaque in fact both their total and direct transmissivity coefficients are very low, almost equal to zero. The innovative spray mulching coating absorbed more than 90% of the solar radiation and this behaviour was similar to those of the biodegradable starch based mulching film and of the LDPE mulching film. In the LWIR range the LDPE film showed a higher transmissivity in comparison with spray mulching coating which recorded a LWIR transmissivity equal to 0.2%. The LWIR reflectivity was low for all the materials. The black spray mulching coating behaved practically as a black body.

The results of the mechanical tests carried out on the materials are reported in Table 2. As concerning black spray coating samples, it was very difficult to perform mechanical analysis because of the presence of micro-holes, so that the material itself teared before testing, and of the wrong measurement of the thickness of spray coating, due to the very large amount of carbon black inside, even 2% against 1.5% of polysaccharides components. The samples of spray coating MY, of biodegradable mulching film MB and of LDPE film MP were conditioned at 25°C and at 50% of relative humidity before testing. Other samples of spray coating (coded MY*) were tested after being conditioned at 25°C and at 16% of relative humidity. From the analysis of the data, we may observe a very different mechanical performance of MY and MY* films respect to the MB and MP samples. In particular, the values of Young Modulus, of the stress and of the elongation at break are very low. This may be in contrast with the evidence that, when a polymeric material is filled with carbon black, normally Young Modulus increases, while elongation at break decreases. In our case two synergetic effects may justify this different behaviour: the problem about the determination of thickness discussed before by one side, and the great capability of water absorbance by polymeric coating by the other side. The large amount of carbon black, not homogenously dispersed in the blend can create, on the coating surface, sites accessible to the water settling. In this case the water can not interact directly with the polymeric matrix, but acts apparently as a plasticizer so that the mechanical responses are lower than the expected values. The great un-homogeneity of carbon black particles dispersed in polymeric matrix is clearly showed in Fig. 3. The innovative spray coatings were characterised by functionality during their use in field and their field performance was good as the commercial LDPE film and biodegradable mulching film (Fig. 4). Due to the presence of some cracks on the surface of the spray coatings, two additional hand-weeding controls were necessary during the growing season in the plots with spray coatings with and without acetic acid addition. The weeding procedure was the same used for the non-mulched bare soil control plots. First results concerning tomato crop yield have shown comparable behaviour between spray mulching and LDPE film.

CONCLUSIONS

The experimental tests showed that the innovative biodegradable spray coatings can be a suitable alternative to the low density polyethylene films used for soil mulching. The biodegradable spray coatings present good radiometric properties, but research must be addressed in order to improve their mechanical characteristics. Besides parameters such as spraying techniques and the soil humidity during spray application must be carefully defined in order to obtain suitable soil coatings.
ACKNOWLEDGEMENTS

The present work has been carried out under the project LIFE Environment “Biodegradable coverages for sustainable agriculture - BIO.CO.AGRI” funded by the European Commission (LIFE03 ENV/IT/000377).

Authors thank M. Cosmo, technician of the Department PROGESA - University of Bari, for his cooperation in the spectrophotometric measurements.

The experimental tests, the data processing and the editorial work must be shared, within the competencies of the two research groups, equivalently among the Authors.

Literature Cited


Tables

Table 1. Radiometric coefficients of the spray mulching coating MY, of the biodegradable film MB and of the LDPE mulching film MP.

<table>
<thead>
<tr>
<th>Material</th>
<th>Solar total transmissivity (%)</th>
<th>Solar direct transmissivity (%)</th>
<th>Solar reflectivity (%)</th>
<th>LWIR transmissivity (%)</th>
<th>LWIR reflectivity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MY</td>
<td>0.1</td>
<td>0.0</td>
<td>4.7</td>
<td>0.2</td>
<td>1.2</td>
</tr>
<tr>
<td>MB</td>
<td>0.4</td>
<td>0.3</td>
<td>4.5</td>
<td>10.5</td>
<td>5.7</td>
</tr>
<tr>
<td>MP</td>
<td>0.1</td>
<td>0.0</td>
<td>5.5</td>
<td>18.9</td>
<td>4.2</td>
</tr>
</tbody>
</table>
Table 2. Mechanical parameters of spray mulching coating MY, of the biodegradable film MB and of the LDPE mulching film MP.

<table>
<thead>
<tr>
<th>Material</th>
<th>Young Modulus (MPa)</th>
<th>Stress at break (MPa)</th>
<th>Elongation at break (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MY*</td>
<td>62.7±7.5</td>
<td>1.06±0.1</td>
<td>3.01±0.9</td>
</tr>
<tr>
<td>MY+</td>
<td>48.8±6.4</td>
<td>2.45±0.2</td>
<td>4.10±1.2</td>
</tr>
<tr>
<td>MB+</td>
<td>247±70</td>
<td>15.2±1</td>
<td>413±200</td>
</tr>
<tr>
<td>MP+</td>
<td>160±25</td>
<td>15±1</td>
<td>230±70</td>
</tr>
</tbody>
</table>

* samples conditioned at 25°C and 16% of relative humidity
+ samples conditioned at 25°C and 50% of relative humidity

Figures

Fig. 1. Black spray treatment after the transparent pre-treatment with acetic acid (09/03/2004).
Fig. 2. Mulches were oversprayed with a second black spray coating (19/03/2004).

Fig. 3. SEM micrograph of black spray mulching coating MY as sprayed.
Fig. 4. Tomato plants on black spray mulching coating after 92 days after planting.