Soil Solarization with Biodegradable Plastic Film: Two Years of Experimental Tests

G. Russo, A. Candura and G. Scarascia-Mugnozza
University of Bari, Department PROGESA, Via Amendola, 165 A, 70125, Bari
Italy

Keywords: soil solarization, biodegradable plastic film, environmental sustainability

Abstract

Soil solarization is an "environmentally-friendly" pest and weed control method utilized in agriculture. While the use of plastic films for soil solarization provides for an increased level of agricultural productivity and a reduction in the use of chemicals, there is however a serious drawback regarding the disposal of used traditional plastic materials. A possible solution to this problem is the use of biodegradable plastics, which degrade gradually when plowed-down due to the action of microorganisms. Current trends towards the use of environmentally-friendly products have contributed to the commercial development of plastic materials based on renewable agricultural resources marketed as biodegradable. Examples are plastics based on starch, and synthetic polymers. The comparison between biodegradable, EVA based and coextruded multilayer films for soil solarization in field is the aim of this research. Field experiments were carried out from Febrary 2001 to July 2003. The climatic parameters and soil temperatures at different depths under each of these materials have been evaluated. Measuring the laceration, tensile strength and the radiometric properties every 15 days tested the performance of the materials. Soil samples were analysed in order to verify the reduction of infesting load soilborne pathogens. EVA and multilayer films produced higher soil temperatures, longer duration, and better phytopathological results were obtained in comparison to the biodegradable film. The reached thermal levels in the soil and the mortality of the pathogenic are enough comparable for the three material used.

Therefore, the use of biodegradable films, if their radiometric and mechanical properties are improved, should be increased due to their high level of environmental compatibility.

INTRODUCTION

Plastic films are widely used in agriculture to increase growth of the crops as well as for covering greenhouses, small and large tunnels, mulching and soil solarization. The disinfection of agricultural soil is necessary in order to reduce the level of microorganisms present that can damage crops both from a quality and quantity point of view. In fact, Italy ranks second worldwide for the use of methyl bromide, which will be illegal from December 2004 (O.J. of E.U., 2000), as a fumigant in the disinfection of agricultural soil (Minuto and Gullino, 1999). As a procedure for the partial disinfection, soil solarization can be utilized in combination with other methods in order to reduce energy costs and environmental impact while reaching the required results (Lazzeri and Mancini, 2001; Picuno and Scarascia, 1993). Soil solarization is a physical method for partial disinfection of soil that consists in covering agricultural soil, which has been watered until saturated, with sheets of transparent or photoselective plastic film in the summer. The plastic film, increases superficial soil temperatures and decreases heat loss by convection, irradiation and evaporation (Scarascia et al., 1992). Soil solarization was introduced in the 1970's (Katan, 1983) and in temperate areas is utilised in the warmer months with the highest solar radiation in order to reach the efficient thermal threshold that can vary from 38 to 43.5 °C (Stapleton et al., 1993; Bollen, 1985; Pullman et al., 1981). It has been observed that when superficial soil temperatures reach 40°C for a few hours, pathogen agents are noticeable reduced but not eliminated while, when the temperature reaches at least 50°C for at least one hour, the result is lethal for most pathogen micro organisms (De Vay et al. 1990; Katan, 1983). In addition, solarization does not leave toxic residues in the soil and saves on irrigation seeing as it impedes the normal evaporation of water (Stapleton et al., 1993). Solarization can be carried out with either transparent or photoselective plastic films (Candura et al., 1999; Failla et al., 1990) of either single or double layer (Scarascia and Picuno, 1992) which can be left on the ground even after the end of the hot season as a form of mulch (Cascone et al., 1999). Traditional plastic films are currently on the market and provide varying results depending on the type of use and amount of time left on the soil. These films however present problems regarding their gathering and disposal after use. The disposal of traditional plastics is governed by regulations which foresee disposal at dumpsites or by incineration but unfortunately these materials are often abandoned or illegally burned on the same soil where they were utilized bringing about serious negative consequences for both man and the environment (Scarascia and Picuno, 1992). If you take into account that the use of plastic films is seasonal, with usage ranging from 1 to 3 years, it can be estimated that the total amount of agricultural plastics waste amounts to approximately 100000 t/year (Scarascia, 1995). In order to control the disposal of these materials in Italy, consortia that gather and recycle agricultural plastics have been created but they are unfortunately not present in all regions. A possible solution is the substitution of traditional materials with biodegradable plastics that would reduce the environmental damage should the physical and mechanical characteristics allow for it (Briassoulis, 2004b) but not at zero cost. In fact biodegradable plastics currently cost three times as much as traditional plastics and the current disposal costs are substituted by composting costs (Ren, 2002). Current trends towards the use of environmentally friendly products have contributed to the commercial development of plastic materials based on renewable agricultural resources marketed as biodegradable. Examples are plastics based on starch, polyhydroxyalkanoates (PHA) and polylactides (PLA), cellulose derivatives, lignin, polyesters from vegetable oils such as poly (glutamic acid), etc. In addition to these agricultural resources, synthetic polymers are also used for biodegradable products including polyamides, polyurethanes, aromatic anhydrides, poly (vinyl alcohol) and poly (epsilon-caprolactone). Even though R&D and sales are in continuous development, the degradable films currently utilised in agriculture can be divided into three categories: starch-based polymers, polyhydroxybutyrate (PHB) polymers, and polylactides (PLA) (Briassoulis, 2004a). The goal of this research was to test and compare three types of plastic films for agricultural soil solarization: traditional EVA film, Polydac-photo-selective film and Mater-Bi, a starch-based film not yet available commercially.

EXPERIMENTAL TEST

The research had the scope of providing a comparison of the thermal and biological effects of the above three film types and evaluate their mechanical and radiometric properties as well as variations over time. From February 2001 through July 2003, experiments were carried out near Foggia (Borgo Cervaro) on a total area of 5000 m^2 (Fig. 1), that was divided into two areas of approximately 2500 m^2 each. In February 2002, on one of the two areas 10 Kg of rape seeds (*Brassica napus f. oleifera*) were sown, while the other area was bare soil without sowing seeds. In May 2002 while the rape was in bloom, it was cut and plowed-down (Gamliel and Stapleton, 1997). Both areas were then treated with the same standard agricultural practices in order to refine and homogenize their structure. At the same time an experimental station was set up in order to gather climatic data such as air temperature with ventilated PT100 sensor, wind speed and direction, solar radiation with a Piranometer MS-402 (0,3-3 mm). In June 2002 after having placed the temperature probes in the soil, the areas were irrigated until they reached their water capacity and the films were then placed. The duration of the solarization has been of 25 days. Four experimental parcels of 5m x 40m (200m^2) were set up in each area in order to gather phyto-pathological data and statistics regarding the wear and aging of the films. Soil temperature was measured with PT100 sensors at depths of 2, 10, 20, 30 and 40 cm in the film covered parcels as well as in the uncovered parcel (one parcel was left uncovered and served to validate the experiment results). At the end of July 2002 both areas were then cultivated with vegetable crops in order to carry out phyto-pathological tests. In February 2003 the procedures were once again repeated in the same area. During the experiments soil samples were taken in order to determine the texture composition and weight. In the two years, for each experimental parcel (with and without green manure) the following films were put in place: 20µm Polydak photoselective, 35µm EVA, and 40µm biodegradable Mater-Bi. Samples of the film were taken when it was put in place and every 15, 30 e 45 days during the two years of the experiment. These samples then underwent mechanical tests as well as spectroradiometric in order to evaluate eventual alterations caused by atmospheric agents and solar radiation. Radiometric tests on the film were carried out utilising Perkin-Elmer UV-VIS Lambda 2 spectrophotometer with a integrating sphere at wavelength ranges of 200-1100nm, and Perkin-Elmer FT-IR 1760 spectrophotometer at wavelength range of 2000-25000nm. The resistance tests: extensibility percentage; tensile strength; tear strength (degradable film) were carried out with a computerised universal press PMA10 - Galdabini after having taken the samples with a steel hand punch, while material was gathered with a test tube for the laceration tests. After soil sterilization, on the field seedlings of marrow, cucumber, watermelon and melon were planted. During the productive phase the fruits was picked and weighed. At the end of the of cultivation cycles all the plants have been uproot and on the radical apparatus and on the collar was pointed out the presence of darkening and suberifications by means of empirical evaluation (Table 1). For the phyto-pathological tests, soil samples were taken at depths of 2, 10, 20, 30 and 40 cm with an auger two days before the film was laid and after approximately 40 days for microbiological analysis. From each 5 Kg sample of soil, 10g were taken and 90ml of sterile Agar-acqua (0,1%) were added and agitated for at least 15 minutes. One ml of this solution was then taken to carry out a decimal dilution at a concentration of $1x10^{-4}$. From each dilution of $1x10^{-2}$, $1x10^{-3}$ e $1x10^{-4}$, 1ml of suspension was taken and placed on slides according to Martin medium PCNB nash e snyder and PDA modified (streptomycin 500ppm, neomycina 100ppm and benlate 0.5 mg). For each dilution has been prepare three repetitions. The inoculated slides were then incubated in the dark at 21°±2 °C for 10 days. After the incubation a total fungus colony count was taken, enlarged on all three substratum of isolation. The data gathered were expressed in logarithm values and were subsequently elaborated statistically through a variance analysis (ANOVA) comparing the averages with a Duncan Test. The fungin flora more frequently isolate from the soil has been: *Fusarium oxysporum* Schlect. Emend. Sn. E Hans., *F. avenaceum* (Corda ex Fr.) Sacc., *F. solani* (Mart.) Sacc., *F. equiseti* (Corda) Sacc., *F. culmorum* (W.G. Smith) Sacc., *Acremonium cucurbitacearum* Gams et al., *Acremonium* spp., *Plectosporium tabacinum* (van Beyma) Palm, Gams et Niremberg, *Macrophomina phaseolina* (Tassi) Goidànich, *Pyrenochaeta lycopersici* Schneider et gerlach, *Verticillium nigrescens* Pethybridge, *Rhizoctonia solani* Kühn., and species of the genus *Trichoderma* spp., *Phoma* spp., *Phitophthora* spp., *Pythium* spp. and *Alternaria* spp. (Lops et al., 2003).

RESULTS AND DISCUSSION

The on-field tests allowed for the monitoring of thermal trends in the soil at varying depths (Fig. 2), while the spectroradiometric exams allowed for a careful analysis of the radiometric properties of the films (Fig. 3-7) and their variation over time. The results of the mechanical tests are shown in Figures 8-9. Results of the tear strength tests carried out on the degradable Mater-Bi film are highlighted in Figure 10. The spectro-radiometric tests carried out periodically on samples highlighted a progressive decrease in the total transmissivity by the three plastic films in the ultraviolet wavelength range (up to 380nm wavelength), throughout the experiment, while the visible wave range of the EVA and photoselective films showed a less emphatic decrease in the total transmissivity and a negligible difference in the wavelength range between 760nm and 1100nm. The degradable film on the other hand presented a progressive decrease in the total transmissivity in proportion to its degradation both in terms of visible wave range (Fig. 4) and short infrared wavelength range. Differing performances, based on the individual nature of each film were registered at wavelengths above 15000nm. The performance of the EVA film during mechanical tear strength tests and the extensibility percentage tests did not vary significantly during the two months testing. After 30 days of tests, the photo-selective film showed an increase in the tensile strength that declined at the end of the experiment to values lower than those at the beginning. On the other hand, the extensibility percentage of the same film increased during the first 15 days to then reduce slowly as the plastic properties decreased (Fig. 8, 9). The degradable film showed less resistance during tensile strength testing during the first 15 days and then decreased and remained constant until the end of the tests (Fig. 8). During the extensibility percentage tests and tear strength tests, the resistance property of the film decreased after the first 15 days to almost inexistent values as the degradation process was already underway (Fig. 9-10). The outcome of the statistical elaboration of data from the microbiologic analysis carried out on the soil samples after 40 days with the collaboration of the University of Foggia can be found in Tables 2-3. In the parcel covered with degradable film Mater-Bi, the results of the microbiologic exams at the end of the experiment were similar to those found in the soil samples (with or without green manure, Table 2-3). The effects of degradation of the Mater-Bi film were verifiable after approximately 30 days with a thermal behaviour similar to that of the uncovered validation parcel (Fig. 2). The various thickness of the films tested influenced the transmission of solar radiation and the increased thickness of the Mater-Bi film was chosen in order to allow for a compromise between the duration of the material and its transmissivity. Plastic film EVA and Polydak utilised with green manure have reduced the gravity of the illness on the roots of all the cultivated species (Table 2). The production of cultivated plant with or without green manured soil was been similar (Table 3).

CONCLUSIONS

The partial sterilization of agricultural soil through soil solarization is a widely tested and used practice that can be easily integrated with other disinfestation procedures in order to lower the weed load in agricultural terrain. One limit to the diffusion of this practice is the environmental sustainability of the practice due to the use of non-renewable resources for the production, disposal and recycling of the plastic materials. This research was conducted in order to evaluate and compare the thermal, mechanical and phytopathological performance of plastic and biodegradable films. While the integrity of the Mater-Bi film lasted 13 days, it was possible to verify, its insufficient solarizing capacity. The Polydak film provided for the absolute highest soil temperatures while the EVA film registered a greater solarization capacity. Based on the thermal trends registered in the soil, it is possible to correlate the efficiency of the film to the microbe load registered. In fact, the higher soil temperatures reached with the Polydak film had a positive effect on the reduction of pathogenic flora, especially in the upper soil levels. The use of biodegradable films can greatly assist in limiting environmental impact as the decomposed material can be completely plowed-down at the end of use and at the same time reduces the disposal costs of plastic materials avoiding any eventual possibility that these materials can be dumped in the environment. Based on the outcome of two years of tests and experiments, the fact that biodegradable films doesn't reach sterilization effects of the soil, in comparison with the EVA and Polydak, can safely be confirmed. Degradable film could be able be used as mulching material. Green manure has influenced partially on the reduction of the fungin species and on the production. The use of the degradable film for the soil solarization will be possible only when will be increased the duration and the mechanical properties.

ACKNOWLEDGEMENTS

Work carried out within the Italian funded MIUR project (2001):“Materiali plastici innovativi per la protezione delle colture e per la solarizzazione del terreno” Special thanks to Prof. Salvatore Frisullo of the Università di Foggia who was responsible for the

phytopathological aspects of the research. All authors contributed equally to the planning and carrying out of this project.

Literature Cited

Bollen, G.J. 1985. Lethal temperatures of soil fungi. Ecology and management of soil-borne plant pathogens, Wong and J.F. Kollmorgen Editors, American Phytopathological Society. St. Paul, Minnesota, USA, 191-193.

Briassoulis, D. 2004a. An Overview on the Mechanical Behaviour of Biodegradable Agricultural Films. Journal of Polymers and the Environment, Vol. 12, 2:65-81.

Briassoulis, D. 2004b. Mechanical Design Requirements for Low Tunnel Biodegradable and Conventional Films. Biosystems Engineering, 87, 2:209–223.

Candura, A., Scarascia Mugnozza, G., Russo, G. and Vox, G. 1999. Modello numerico di solarizzazione e prove con film fotodegradabile. Colture Protette, 28, 3:79-86.

Cascone, G., Arcidiacono, C. and D'Emilio, A. 1999. Influenza dell'apprestamento di protezione e della natura del terreno sui regimi termici della solarizzazione. Proceedings of congress AIIA "Le colture protette: aspetti agronomici, territoriali e tecnico costruttivi", Ragusa (ITALY), 24-26 Giugno, 137-148.

DeVay, J.E., Stapleton, J.J. and Elmore, C.L. 1990. Soil solarization. Food and agricultural organization, United Nation. FAO report # 109. Rome, Italy.

Gamliel, A. and Stapleton, J.J. 1997. Improvement of soil solarization with volatile cogenerated from organic amendments. Phytoparasitica 25 (suppl.) 3 I S-38S.

Failla, A., Fichera, C.R. and Cascone, G. 1990. Simulazione dei processi termici attivati dalla solarizzazione del terreno sotto serra e in pieno campo. Colture Protette, 19:133-138.

Lops, F., Carlucci, A., Ciuffreda, G., Mucci, M., Colatruglio, L. and Frisullo, S. 2003. Efficacia della solarizzazione nel controllo delle malattie funginee delle cucurbitacee. Proceedings of Congress "Materiali plastici innovativi per la protezione delle colture e la solarizzazione del terreno" Potenza 28 November 2003 (submitted to).

Katan, J. 1983. Soil solarization. Acta Hort. 152:227-236.

Lazzeri, L. and Manici, L.M. 2001. Allelopathic effect of glucosinolate-containing plant green manure on Pythium sp and total fungal population in soil. HORTSCIENCE 36, 7:1283-1289.

Minuto, A. and Gullino, M.L. 1999. Le alternative al bromuro di metile per la disinfestazione del terreno. Videotape, Università di Torino – Di.Va.P.R.A., Gallo Audiovisivi S.n.c. Savona, n.cat. 001/99.

Official Journal of the European Union, 2000. Regulation (CE) N. 2037/2000 of the European Parliament and Council of 29 June 2000

Picuno, P. and Scarascia Mugnozza, G. 1993. Prove sperimentali di solarizzazione in serra. Colture Protette, 22, 3:87-92.

Pullman, G.S., De Vay, J.E. and Garber, R.H. 1981. Soil solarization and thermal death: a logaritmic relationship between time and temperature for four soilborne plant pathogens. Phytopatology, 71:959-964.

Ren, X. 2002. Biodegradable plastics: a solution or a challenge?" Journal of Cleaner Production (2003) 11:27–40.

Scarascia Mugnozza, G. and Picuno, P. 1992. Prove di solarizzazione mediante pacciamatura con film plastici trasparenti. Colture Protette, 21, 9:121-126.

Scarascia Mugnozza, G., Russo G. and Vox, G. 1992. Modello numerico per l'analisi previsionale delle temperature nel terreno agrario solarizzato. Proceeding of congress of Accademia dei Georgofili "Informatica e Agricoltura" Firenze, 17-18 December 1992, 185-194.

Scarascia Mugnozza, G. 1995. Sustainable greenhouse production in mediterranean climate: a case study in Italy. Medit, 6, 4:48-53.

Stapleton, J.J., Paplomatas, E.J., Wakeman, R.J. and DeVay, J.E. 1993. Establishment of apricot and almond trees using soil mulching with transparent (solarization) and black polyethylene film: Effects on Verticillium wilt and tree health. Plant Pathol. vol. 42, 3:333-338.

Tables

Table 1. Empirical estimation of the damages to the cultivations.

Empirical evaluation	Presence of darkening and suberification
0	0%
1	10-30%
2	31-50%
3	>50%

Table 2. Solarization efficiency on seriousness of illness.

Covering with film used for solarization	Species	Seriousness of illness	
		With greenmanure	Without greenmanure
Biodegradable	Melon	2.225 A	1.795 B
Bare soil	Melon	2.075 A	2.162 A
Bare soil	Cucumber	2.012 AB	2.022 AB
Bare soil	Water melon	1.808 B	2.242 A
Biodegradable	Water melon	1.667 BC	1.620 CDE
Biodegradable	Cucumber	1.650 BCD	1.700 BC
Eva	Melon	1.585 BCD	1.468 DE
Bare soil	Marrow	1.528 BCD	1.665 BCD
Polydak	Melon	1.358 C	1.257 DEF
Polydak	Cucumber	1.350 CD	1.425 E
Biodegradable	Marrow	1.290 D	1.500 DE
Eva	Marrow	1.278 DE	1.00 G
Eva	Cucumber	1.253 DE	1.273 EF
Polydak	Water melon	1.205 E	1.205 F
Eva	Water melon	1.155 F	1.190 G
Polydak	Marrow	1.083 G	1.322 DEF

Table 3. Solarization efficiency on cucurbitaceous plant production.

Covering with plastic film	Species	Greenmanure Kg	No greenmanure Kg
Polydak	Marrow	56.51 A	42.78 A
Eva		53.24 AB	40.41 AB
Bare soil		50.71 BC	38.38 ABC
Biodegradable		47.81 C	35.6 C
Polydak	Melon	78.58 A	66.18 A
Eva		68.45 C	44.60 D
Bare soil		65.95 D	55.71 C
Biodegradable		70.83 C	63.2 B
Polydak	Water melon	113.11 A	82.40 A
Eva		91.27 B	70.7O B
Bare soil		81.80 C	65.33 BC
Biodegradabile		79.72 CD	63.30 C
Polydak	Cucumber	115.42 A	92.35 A
Eva		107.50 A	87.15 B
Bare soil		88.78 C	68.43 C
Biodegradable		97.16 B	63.32 D

Figures

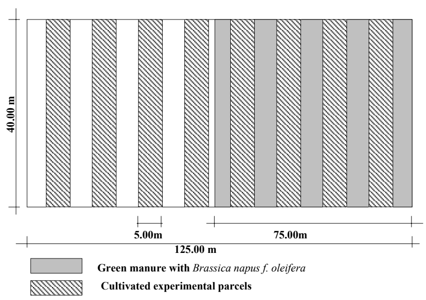

Fig. 1. Experimental field.

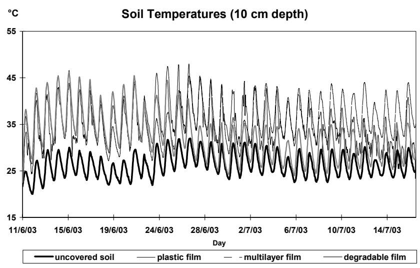

Fig. 2. Soil temperature at a depth of 10cm during tests conducted in 2003.

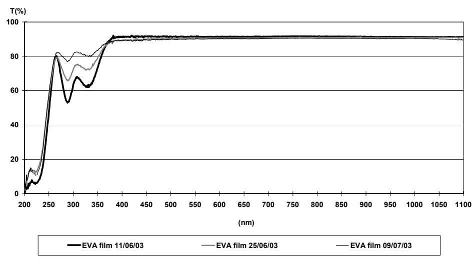

Fig. 3. Transmissivity in the visible and near infrared wave range of Eva plastic film

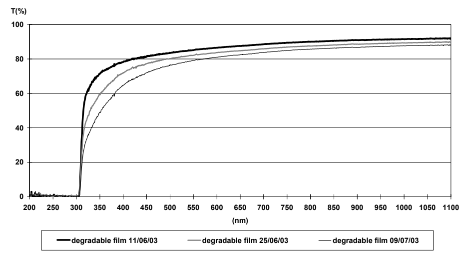

Fig. 4. Transmissivity in the visible and near infrared wave range of biodegradable film.

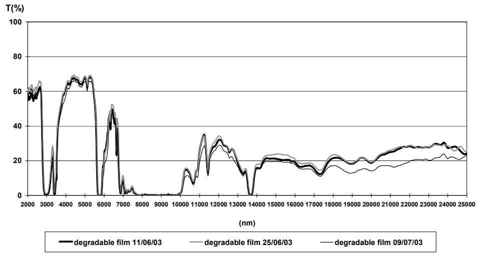

Fig. 5. Transmissivity in infrared wavelengths range of biodegradable film.

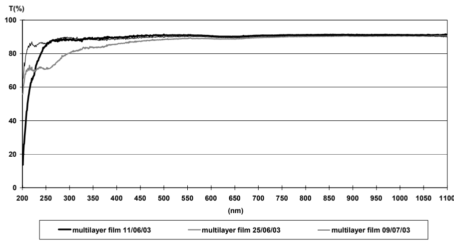

Fig. 6. Transmissivity in the visible and near infrared wave range of multilayer film.

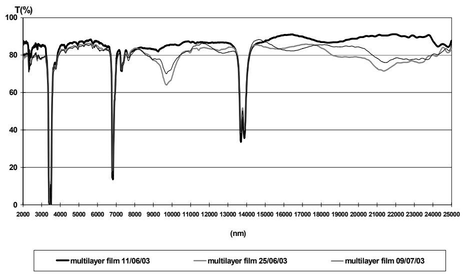

Fig. 7. Transmissivity in infrared wavelengths range of multilayer film.

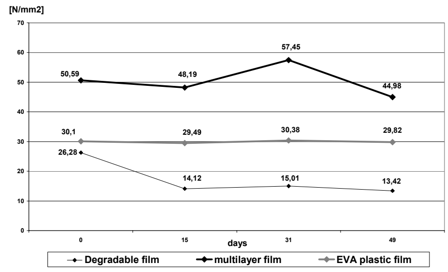

Fig. 8. Tensile strength of the films used for solarization.

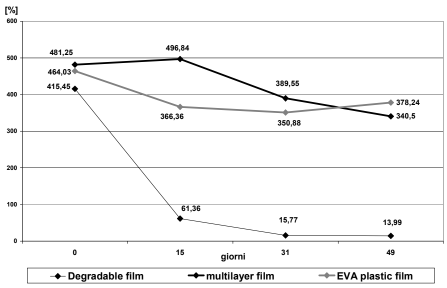

Fig. 9. Extensibility percentage of the films used for solarization.

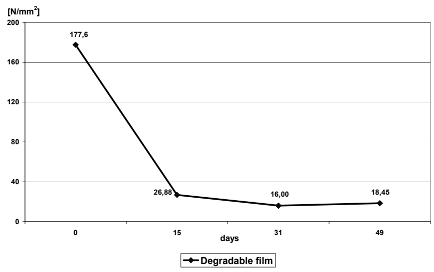

Fig. 10. Tear strength of the biodegradable film for solarization.