The Mechanical Properties of Some Bioplastics Under Different Soil Types for Use as a Biodegradable Drip Tubes

Mostafa, H. M.[1], Sourell, H.[1] and Bockisch, F.J.[2]

[1]Institute of Agricultural Technology and Biosystem Engineering,
Federal Agricultural Research Centre (vTI), 38116 Braunschweig, Germany.
[2]Professor and Head, Institute for Application Techniques in Plant Protection, Federal Research Centre for Cultivated Plants (JKI), 38104 Braunschweig, Germany.
Corresponding author's email: harby_sorour@yahoo.com

ABSTRACT

A lack of degradability and the closing of landfill sites, as well as growing water and land pollution problems, have led to concern about plastics. With the excessive use of plastics and increasing pressure being placed on capacities available for plastic waste disposal, the need for biodegradable plastics and biodegradation of plastic wastes has assumed increasing importance in the last few years. Awareness of the waste problem and its impact on the environment has awakened new interest in the area of degradable polymers.

The biodegradation of five different types of commercial bioplastics available on the market as agricultural mulch film (Bioflex, Ecoflex, Mater Bi, Chitosan and Bi-OPL foil) was evaluated under different soil types (Sandy, Sandy Loam and Loamy soil) to study the material stability and life expectancy, and to establish which is better to use in the production of biodegradable drip tubes for drip irrigation system. Weight loss, tensile strength (TS) loss and loss of percentage elongation (%E) were measured in 0, 1, 2, 3, 4, and 5 months.

Bi-OPL appears to possess a high resistance to soil types and, as indicated by lower changes in tensile strength, weight losses and with maximum 26% decrease in elongation at break. At the end of experiments, Chitosan films were completely degraded in all soil types and both surface and subsurface positions. The starch contained in Mater Bi samples was degraded after 60 days with 4% weight losses and lead to 3% observed losses in tensile strength. Weight losses of Ecoflex and Bioflex were greater after three months (more than 30%) than previously (5 to 10%). The tensile strength of both Ecoflex and Bioflex films decreased about 4% and 3% respectively in loamy soil and loamy sand soil by Week 12,. More than 40% of the elongation capacity of the films was lost by Month 3 in both soil types. The decrease of %E in both films was slightly faster in loamy and loamy sand soil than in sandy soil.

Keywords: biodegradation, soil, Bi-OPL, Chitosan, Mater Bi, Bioflex, Ecoflex, drip tubes

1. INTRODUCTION

Because of their positive characteristics and benefits, bioplastics are often a viable alternative to conventional plastics made out of fossil resources. Since many conventional plastics can be substituted with bioplastics, features of and predictions within the conventional plastic market are also relevant for the bioplastic market. In the recent times, there has been tremendous interest in the use of bioplastic and biodegradable polymers. There were many attempts to use a bio-filler in thermoplastic polymers because it is a natural polymer, abundant, and a renewable resource.

The use of biopolymers can be an important tool in environmentally- friendly management because of the large amount of polymers used in many applications (Grifin, 1994). Conventional polymers, indeed, can be replaced - in some applications - with biodegradable polymers; for instance, an interesting application is the formulation of biodegradable mulching film to be used for vegetable crops. These films do not need to be removed off the fields and do not have any environmental impact. In order to be used in this application, the bioplastic film must possess specific mechanical and optical performance similar to those of the traditional films for agriculture, like polyethylene and poly [ethylene-co-(vinyl acetate)]. Concerning durability, biodegradable mulch films are made to be biodegraded in soil at the end of crop cycle; therefore durability cannot be compared with traditional mulch films. Durability should cover the initial cultivation stages, which may vary from 1 month up to a few months (3-4) depending on the crop (Dintcheva and Mantia, 2007).

The world consumption of low density polyethylene (LDPE) mulching films in horticulture is at present around 700 000 tones per year (Espi et al., 2006). After use, the films can be dirty with soil, organic matter and agro-chemicals. As a result, they must be collected after use and either be disposed of or recycled. Because of the high costs related to the regular process of gathering and discarding films and the recycling process, plastic films are often discarded in a dump or burned with the subsequent emission of toxic substances both to the atmosphere and to the soil (De Prisco et al., 2002). Suitable alternative methods are presented by the use of biodegradable materials in agriculture (Malinconico et al., 2002; Imam et al., 2005; Kyrikou and Briassoulis, 2007; Tzankova Dintcheva and La Mantia, 2007; Kijchavengkul et al., 2008a, 2008b; Malinconico et al., 2008). At the end of their life, biodegradable materials can be integrated directly into the soil where bacterial flora transforms them into carbon dioxide or methane, water, and biomass. Because biodegradable materials do not produce wastes that require disposal, they could represent a sustainable ecological alternative to LDPE films (Immirzi et al., 2003 and Kapanen et al., 2008).

Natural biodegradable plastics are based primarily on renewable resources. Biodegredation is degradation caused by biological activity, particularly by enzyme action leading to significant changes in the material's chemical structure. The biodegradability of plastics is dependent on the chemical structure of the material. The biodegradation of plastics proceeds actively under different soil conditions according to their properties. Biodegradation of starch based polymers occurred between the sugar groups leading to a reduction in chain length and the splitting off of mono-, di-, and oligo- saccharide units by a result of enzymatic attack at the glucosidic linkages (Demirbas, 2007).

With the development of degradable plastics, a group of materials was created with consideration for their disposal. However, for economic reasons, the use of degradable plastics is still negligible. These plastics are suitable for waste management to close circular flow, save oil reserves, stabilize CO2 emissions and offer consumers an environmentally-sound option (Tien et al., 2000).

According to Mostafa et al, (2009), The equilibrium moisture content of Chitosan and Mater-Bi was higher than Ecoflex and Bioflex and it was the lowest for Bi-OPL by changing the relative humidity from 43 to 95% under different conditions of temperature (10, 20, 30, 40 and 50Co). The temperature and relative humidity play an important role in the microorganism activity which can attach and degrade the bio materials, so each of following: Ecoflex, Bioflex and Bi-OPL, may hold for a longer period of time than Chitosan and Mater-Bi as a mulch film. It may be better to use the same materials which are used to produce Ecoflex, Bioflex and Bi-OPL to produce the degradable drip tubes for drip irrigation system.

Plastic films currently used for soil mulching have two serious drawbacks: they are manufactured with non-renewable oil-based raw materials and produce large amounts of plastic wastes that require disposal. Biodegradable coatings that can be sprayed represent an ecologically friendly alternative to synthetic petro-chemical polymers for soil mulching (Immirzi et al., 2009).

Degradation of an acylated starch-plastic mulch film was evaluated by Frenando et al., (2002) in two soil types, grey lowland (A) and volcanic andosol (V) soil. In both laboratory and field experiments, the weight loss of the plastic films was on the average 50% greater in soil V than in soil A. The significantly large loss of weight of films in soil V, which was nearly two and a half times that observed in soil A, was assumed to be due to the effects of some different properties of soil V from those of soil A.

Measurement of the mechanical properties of polymers is a convenient way to estimate the degree of degradation of plastics (Swift, 1993 and Orhan et al., 2000)). The percentage elongation value of LDPE/starch blend film started to decrease in inoculated soil after 1 month, whereas it remained constant for at least 3 months in non-inoculated soil. LDPE/starch blend films showed a 56% reduction (range, 20±56%) in percentage elongation in inoculated soil compared to a 12% reduction in non-inoculated soil, suggesting that LDPE/starch blend film degraded faster in the inoculated soil than in the non-inoculated soil

The initial breakdown of a polymer can result from a variety of physical and biological forces. Physical forces, such as heating/cooling, freezing/thawing, or wetting/drying, can cause mechanical damage such as the cracking of polymeric materials (Shah et al., 2008).

Degradation of plastic and bioplastic in general, is defined as a detrimental change in its appearance, mechanical, physical properties and chemical structure (Grifin, 1994), so the main aim of this work was to obtain the biodegradability and the life expectancy of some bioplastic materials under different conditions of soil types. In order to develop new sustainable technologies that can be used as biodegradable drip tubes, a series of studies will be done to identify the properties of these materials and the possibility to use them as biodegradable drip tubes for developing and managing micro irrigation systems.

2. EXPERIMENTAL PROCEDURES

The biodegradability of five different types of commercial bioplastics available on the market as agricultural mulch film (Bioflex, Ecoflex, Mater Bi, Chitosan and Bi-OPL foil) was assessed per DIN EN 13432 (2000) and ASTM D5988 (2003) under different soil type conditions (Sandy, Sandy Loam and Loamy soil) to study the material stability and life expectancy, and to find the type most suitable for producting the biodegradable drip tubes.

The bioplastics under study were:

1- Ecoflex® F BX 7011, a biodegradable aliphatic-aromatic copolyester based on the monomers 1,4-butanediol, adipic acid and terephthalic acid for film extrusion. It has been developed for conversion to flexible films using a blown film or cast film process. Typical applications are packaging films, agricultural films and compost bags (BASF, 2007).

2- Bio-Flex® film compounds are innovative PLA / copolyester blends. The excellent processing qualities stem from the outstanding compatibility of the polymeric components polylactic acid (PLA) and the biodegradable copolyester. Bio-Flex ® film compounds do not contain starch or derivatives of starch (FKUR, 2008).

3- Chitin, a polysaccharide of animal origin, is obtained from seafood industrial waste material. It occurs in the skeletal material of crustaceans such as crabs, lobsters, shrimps, prawns and crayfish. Chitosan is the deacetylated product formed by treatment of chitin with concentrated (50%) caustic alkali. Thus Chitosan is safe (nontoxic), biocompatible and biodegradable (Yadav et al., 2004 and Radhakumary et al., 2005).

4- Mater - Bi® is a biodegradable thermoplastic material made of natural components (corn starch and vegetable oil derivatives) and of biodegradable synthetic polyesters. The material is certified as biodegradable and compostable in accordance with European Norm EN 13432 and with the national regulations UNI 10785 and DIN 54900 (Novamont, 2008).

5- Bi-OPL is biodegradable film mulching and produced from polylactic acid (PLA which made of degradable materials (corn) and compostable in accordance with DIN EN13432 (Oerlemansplastics, 2008).

Three types of soil were used in this study. The first was a sandy soil, the second a sandy loam soil, and the third a loamy soil. The soil samples were collected from three different sites in Braunschweig, Germany. The physical and chemical characteristics of the soil types are summarised in Table 1.

Table 1: The physical and chemical analysis of the different soil types.

Texture	**Sand %**	**Silt %**	**Clay %**	**PH**	**CaCO3 ppm**	**N %**	**C %**	**P ppm**	**K ppm**	**Mg ppm**
Sand	91,4	6,1	2,5	5,4	4,4	0,028	0,42	4,8	42,5	26
Sandy loam	59,4	32,3	8,3	6,3	1,7	0,095	1,5	3,8	53,9	98,8
Loam	9,7	77,5	12,8	7,2	4,4	0,093	1,1	3,7	41,0	53,1

A climate chamber measuring 3.5 x 2.75 x 3.0 m and capacitive humidity sensors (Aluminum 12 mm $\phi \pm 2$ % for RH, and 1 K for temperature accuracy, made in Germany) were used to control the temperature and relative humidity conditions.

The soils were sieved with a 2-mm mesh screen to remove gravel and plant materials. Water content of the soils was adjusted to 55% of their maximum water-holding capacity. Bioplastic strips (6 x 6 cm) of all films (90 strips for each bioplastic film) were weighed before being placed in the soil. Seventy five polypropylene bags with a 6 liter volume were filled with soil (25 bags for each soil type). Three bioplastic strips were placed separately on the soil surface and the other three bioplastic strips were placed separately in the soil at 10 cm depth and ensured good contact over the whole surface. Fifteen bags were prepared for each bioplastic mulch film (five bags for each soil type) to measure the weight loss, losses of tensile strength (TS) and elongation (%E). All of the bags were kept in climate chamber at 25 ^{o}C and 70% relative humidity and each of the bags was irrigated every 10 days. The bioplastic strips were retrieved after 1, 2, 3, 4, and 5 months of incubation, and were gently rinsed with water to remove the soil particles. They were then air-dried for 24 h, photographed and weighed. TS an %E were measured with a tensile testing machine (Daiei Kagaku – Arimoto Kigyo Co., Ltd. Japan). Each strip was cut into tensile pieces 6x2 cm in size. Weight losses for the materials were measured according to **(**Khan, et al. 2006) by the following equation:

$$\text{Weight losses}\left(\%\right)=\frac{\left(W_2 - W_1\right)}{W_1}*100$$

Where:

W_1 and W_2 are the films weight before and after treatment.

RESULTS

1. Biodegradation on soil surface

1.1 Sandy soil

The weight loss of plastic films during degradation in sandy soil is shown in Figure 1. The change of weight of Bi-OPL film was not observed, but the weight of Chitosan film was reduced significantly - as much as 16%, after two months and reached to 100% after four months of the treatment. The weight loss of Ecoflex, Bioflex, and Mater-Bi films in the soil started without an apparent lag phase and reached approx. 3, 4, and 3.8% respectively after two months and approx. 3.8, 8, and 9.6% after three months of the treatment.

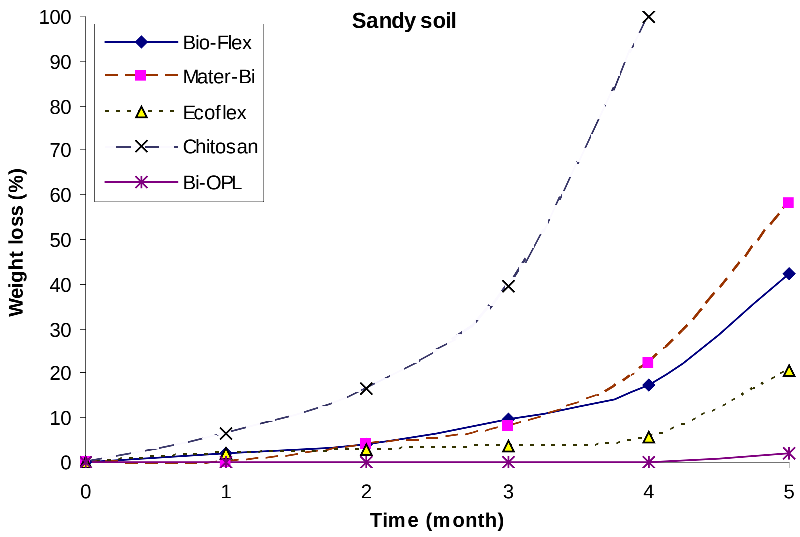

Figure (1): Weight loss (%) of biodegradable plastic in sandy soil

In most applications envisaged for films or fibres in contact with the soil, loss in tensile properties is the most relevant practical criterion to determine its degradation (Orhan et. al, 2004).

Tensile strengths for bioplastic samples are shown in Figure 2 and the elongation losses were showed in Table 2. Chitosan was remarkably susceptible (100% loss of tensile strength after four months), while Ecoflex, Mater-Bi, and Bioflex remained relatively resistant after three months (3, 4, and 3% loss of tensile strength 27, 30, and 37 % loss of elongation capacity respectively). Mater-Bi remained slightly resistant at the fourth month (63% loss of tensile strength and 51.6 % loss of elongation capacity). On the other hand, Bi-OPL was more resistant than the others, where the loss of tensile strength was only 2.8% and 26 % loss of elongation capacity at the end of the treatment.

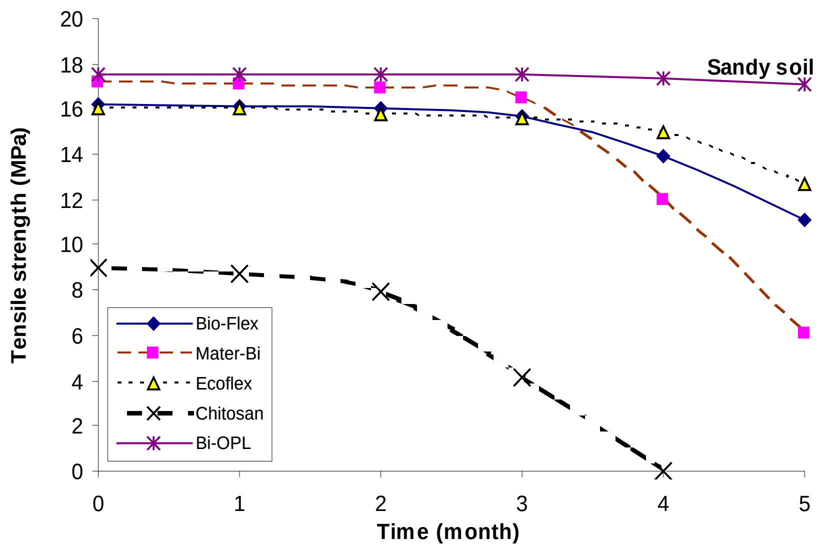

Figure (2): Tensile strength (MPa) of biodegradable plastic in sandy soil

According to the loss in physical properties, the films can be ranged in order of decreasing susceptibility: Chitosan >>>> Mater-Bi > Ecoflex and Bioflex > Bi-OPL. It could be that the hydrophobicity of PLA (Bi-OPL) is the main reason of its resistance to microbial enzymatic systems (Orhan et. al, 2004) . It is likely that the starch in Mater-Bi films allowed water adsorption and provided suitable conditions for microbial colonization and degradation of starch and esters, resulting in the disintegration of Mater-Bi. Degradation of mechanical properties might result from attack by microorganisms or from the soil chemistry.

Table (2): Elongation loss (%) of biodegradable plastic in sandy soil

Time (month)	Elongation (%)				
	Bio-Flex	Mater-Bi	Ecoflex	Chitosan	Bi-OPL
0	33	62	86	236	513
1	31	58	72	66	491
2	28	55	69	31	458
3	24	43	54	23	419
4	19	29	41	0	392
5	10	12	36	0	379

1.2 Sandy loam soils

Within the time frame of the experiments, a Bi-OPL film appeared to possess a high resistance to sandy-loam soil. The Bi-OPL materials recovered from the soil demonstrated very little degradation, indicated by lower changes in weight.

The data plotted in Figure 3 shows that the weight losses of Bi-OPL film were not more than 3.4 % during the time. For all of Ecoflex, Mater-Bi, and Bioflex materials, a lag phase of two months, after which a slight weight losses (3.8, 6, and 7.7 % respectively) were observed, but after that high weight loss values were recorded, where the losses were faster in the fourth month (16.9, 58, and 19.2 % respectively) and reached to 51, 71.4, and 45.1 % respectively at the end of the treatment.

Chitosan films appeared to possess very low resistance. There, the weight loss was approx. 21 % after two months and more than 60% after three months and ultimately reached to 100 % in the fourth month.

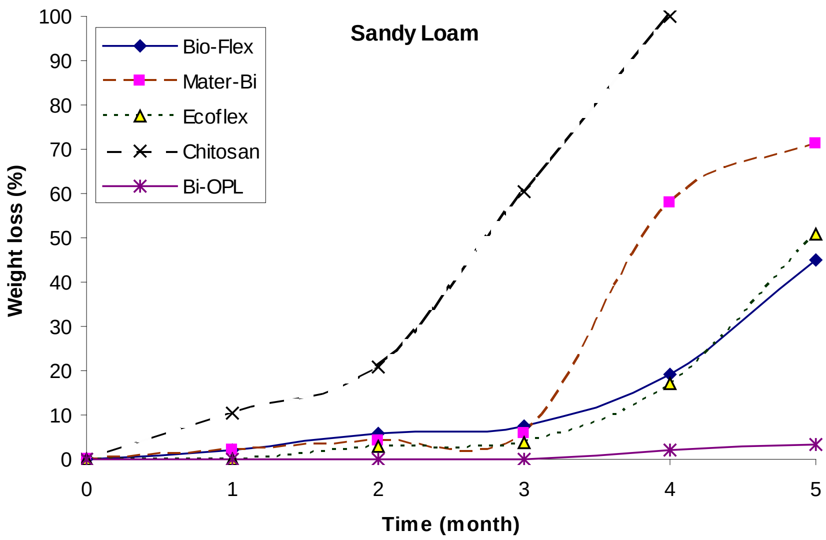

Figure (3): Weight loss (%) of biodegradable plastic in sandy-loam soil

The tensile strengths of the films were plotted in Figure 4 and the elongation losses were showed in Table 3. The tensile strength of all films except Chitosan showed a lag phase and no significant decrease until the third month, but Ecoflex and Bioflex showed a significant decrease at the end (41 % and 39 % respectively) and more than 63 % and 78 % losses in elongation capacity respectively.

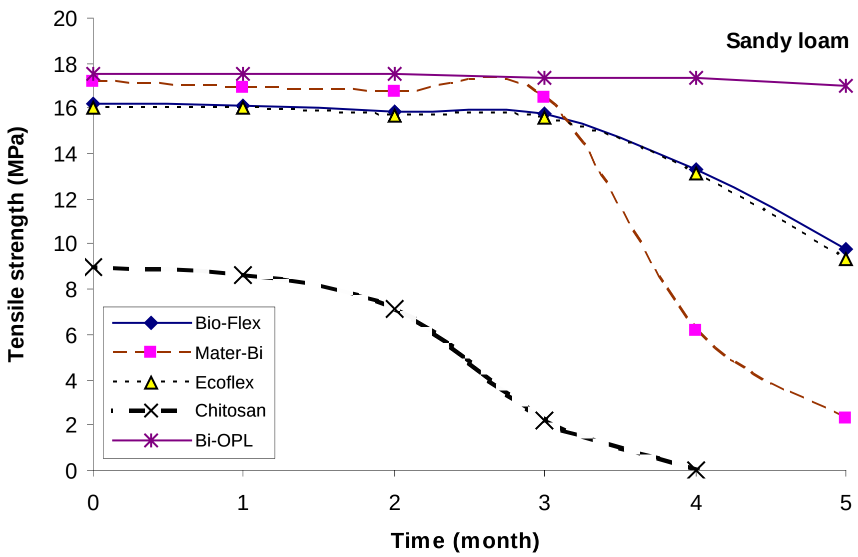

Figure (4): Tensile strength (MPa) of biodegradable plastic in sandy-loam soil

Also the tensile strength and elongation capacity of Mater-Bi decreased more quickly than Ecoflex and Bioflex at the end of the treatment (86 % loss of tensile strength and 87 % loss of elongation capacity). The tensile strength of Bi-OPL showed no significant additional decrease until the end of soil treatment, but more than 27 % of the elongation capacity was lost, while Chitosan was remarkably susceptible (76 % loss of tensile strength and 90 % loss of elongation) in the third month.

Table (3): Elongation loss (%) of biodegradable plastic in sandy-loam soil

Time (month)	Elongation (%)				
	Bio-Flex	Mater-Bi	Ecoflex	Chitosan	Bi-OPL
0	33	62	86	236	513
1	32	41	83	26	484
2	27	35	77	17	461
3	21	27	61	12	417
4	17	14	42	0	390
5	9	8	31	0	375

1.3 Loamy soils

Average weight loss in Bi-OPL and Bioflex at the second month was approx. 0 % compared with 56.3 % for Chitosan (Fig. 5), but Mater-Bi and Ecoflex showed small losses (4 % and 3.8 % respectively). Weight losses were 100 % for Chitosan at the fourth month, while Bi-OPL remained relatively resistant (2.8 %). At the end of the treatment, each of Bioflex, Mater/Bi, and Ecoflex all showed high weight losses (69.2, 80.1, and 77.4%, respectively) but there are no significant losses for Bi-OPL (3.9 %).

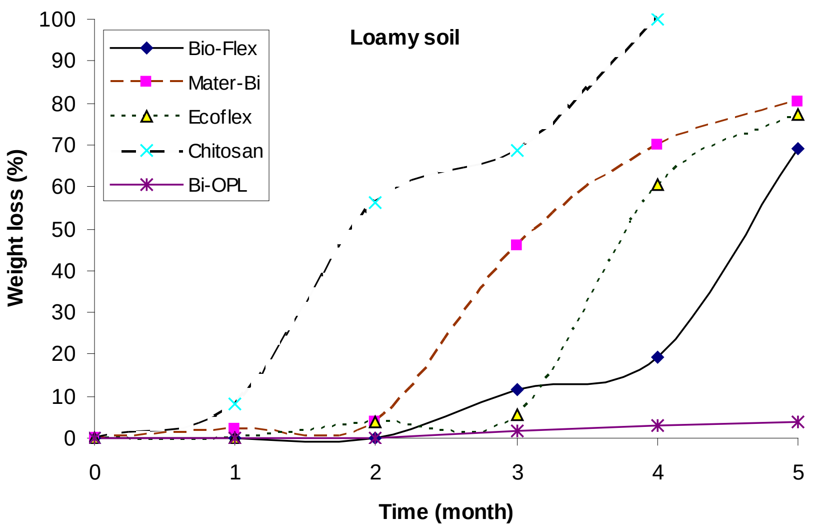

Figure (5): Weight loss (%) of biodegradable plastic in loamy soil

The tensile strength losses and the elongation capacity showed nearly the same trend for both Bioflex and Ecoflex (Fig. 6 and table 4), the tensile strength losses were 8 % and 3 % in the third month and reached 80 % and 87 % at the end of the treatment respectively, while the elongation capacity loss was 45 and 54 % and increased to 87 and 76 % respectively. A faster decrease in the tensile strength of Chitosan was observed in the second month (44.1 %) and reached 100 % in the fourth month.

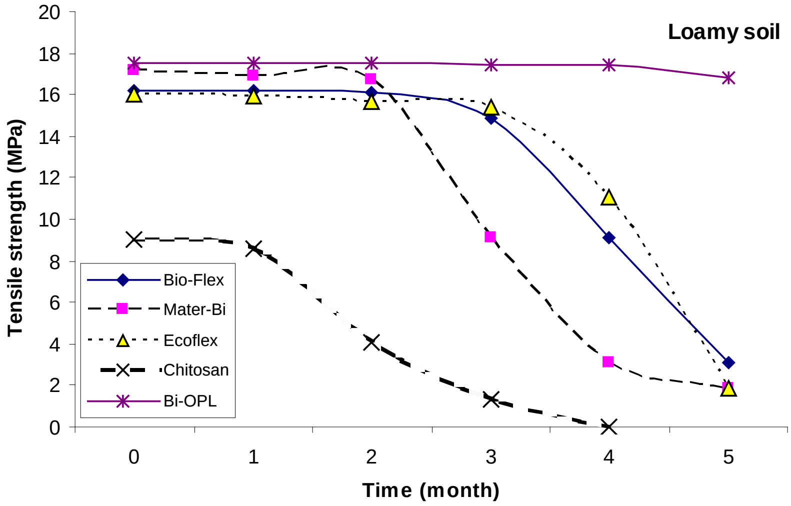

Figure (6): Tensile strength (MPa) of biodegradable plastic in loamy soil

Mater-Bi retained good resistance at two month (2 % loss of tensile strength and 50 % loss of elongation capacity) but was only slightly resistant at the end of the treatment (89 % loss of tensile strength and 92 % loss of elongation capacity). On the other hand, Bi-OPL was more resistant than the others, where the loss of tensile strength was 4 % and 25 % loss of elongation capacity at the end of the treatment.

Table (4): Elongation loss (%) of biodegradable plastic in loamy soil

Time (month)	Elongation (%)				
	Bio-Flex	Mater-Bi	Ecoflex	Chitosan	Bi-OPL
0	33	62	86	236	513
1	27	47	66	39	488
2	25	31	51	21	459
3	18	25	39	3	427
4	11	11	31	0	394
5	4	5	21		381

1.4 Multiple regression analysis

Multiple regression analysis was carried out on biodegradation data as average percent of weight, tensile strength, and elongation losses for the materials (Bioflex, Mater-Bi, Ecoflex, Chitosan, and Bi-OPL) as a function of time. The best fit of the data was obtained as the following equation:

$$BD = \mathrm{a}\ \mathrm{T}^{\mathrm{b}}$$

Where,
BD : Biodegradation, (%)
T : Time, (month)
abc : Constants are listed in Table (5)

Table (5): the constants for the different materials

Material	**Soil type**	**constants**		**R^2**
		a	**b**	
Bioflex	**Sandy**	2,4499	1,701	0,971
	Sandy-Loam	1,8978	2,0107	0,993
	Lomy	4,3749	1,6195	0,902
Mater-Bi	**Sandy**	1,8292	2,0889	0,961
	Sandy-Loam	10,022	1,2189	0,898
	Lomy	8,5955	1,498	0,970
Ecoflex	**Sandy**	5,0936	1,047	0,929
	Sandy-Loam	1,0866	2,3391	0,994
	Lomy	6,643	1,4071	0,926
Chitosan	**Sandy**	24,527	0,9063	0,927
	Sandy-Loam	31,677	0,778	0,929
	Lomy	33,984	0,8224	0,973
Bi-OPL	**Sandy**	1,4839	1,2257	0,996
	Sandy-Loam	1,7653	1,142	0,987
	Lomy	1,5995	1,2156	0,997

2. Biodegradation at subsurface soil

The biodegradation data of bioplastic films buried in the subsurface of different soil types were presented in Table (6) as average of percent of weight, tensile strength, and elongation losses. It can be observed that the biodegradation percentage in the sub-soil surface is similar to that on the soil surface and shows the same trend. The results revealed that the biodegradation of bioplastic materials was faster in the subsurface than on soil surface.

The change of losses of Bi-OPL film was slow with maximum average 9, 10, and 11 % under sandy, sandy loam, and loamy soils respectively but the change of losses was faster and higher for the Chitosan film than for the others. Chitosan lost more than 75% of its weight, tensile strength, and elongation during the second month in all soil types. An extensive degradation was observed for Mater-Bi, Ecoflex, and Bioflex. At the end of the period of soil burial, Mater-Bi was degraded most, followed by Bioflex and Ecoflex.

Table (6): The biodegradation data of bioplastic films buried in the subsurface of different soil types.

Material	Soil type	Time (month)					Average
		1	2	3	4	5	
Bioflex	Sandy	15	27	51	78	99	54
	Sandy-Loam	14	44	72	85	100	63
	Lomy	21	51	78	91	100	68
Mater-Bi	Sandy	16	31	86	97	100	66
	Sandy-Loam	20	48	79	98	100	69
	Lomy	24	60	91	100	-	69
Ecoflex	Sandy	13	19	29	44	94	40
	Sandy-Loam	16	25	34	58	97	46
	Lomy	18	28	37	74	98	51
Chitosan	Sandy	33	74	94	100	-	75
	Sandy-Loam	39	78	94	100	-	78
	Lomy	48	85	100	-	-	78
Bi-OPL	Sandy	3	6	9	13	14	9
	Sandy-Loam	3	7	11	13	16	10
	Lomy	3	8	11	14	18	11

4. DISCUSSION

Microorganisms such as bacteria and fungi are involved in the degradation of both natural and synthetic plastics (Gu et al., 2000a). The biodegradation of bioplastics proceeds actively under different soil conditions according to their properties, because the microorganisms responsible for the degradation differ from each other and have their own optimal growth conditions in the soil. Polymers, especially bioplastics, are potential substrates for heterotrophic microorganisms (Glass and Swift, 1989). So it is clear that the biodegradation rate is very fast in the case of subsurface burial for all films

The previous results revealed that Bi-OPL has a much slower soil degradation rate compared to other films. It could be that the hydrophobicity of PLA (Bi-OPL film) is the main reason for its resistance to microbial enzymatic systems (Orhan et. al, 2004) in the different soil types. For the same reason it be observed that the Bioflex film had some resistance but less than Bi-OPL because of some biodegradable copolyester additives. In Mater Bi, starch granules and an autoxidizable fatty acid ester generate peroxides which chemically attack the bonds in the polymer molecules reducing the molecular chains to a level where they can be consumed by microorganisms. At the same time, the starch granules are biodegraded by the microorganisms present in soil.

It is well known that chitosan is mainly enzymatically depolymerized by lysozyme. The enzyme biodegrades the polysaccharide by hydrolyzing the glycosidic bonds in the chitosan chemical structure. Lysozyme contains a hexameric binding site (Freier, et al., 2005), and hexasaccharide sequences containing 3–4 or more acetylated units contribute mainly to the initial degradation rate of chitosan. The pattern of degradation of chitosan found in our studies can, in part, be explained by this mechanism of soil enzymatic degradation. Ecoflex® had some resistance, especially in the first three months, because the terephthalic acid content tends to decrease the degradation rate. The terephthalic acid content modified some properties such as the melting temperature (Witt et al., 2001), and there is no indication of an environmental risk (eco-toxicity) when aliphatic–aromatic copolyesters of the Ecoflex are introduced into degradation processes.

Other mechanisms which play significant role are physical damage due to the microorganisms, biochemical effects from the extracellular materials produced by the micro-organic activity. Moreover the rate of degradation is affected by environmental factors such as moisture, temperature and biological activity. For these reasons, it can be observed that the biodegradation rate was faster in the loamy soil than in sandy soil and also it was faster in case of subsurface burial than on soil surface.

5. SUMMARY

According to the loss in physical properties, the films can be ranged in order of decreasing susceptibility: Chitosan >>>> Mater-Bi > Ecoflex and Bioflex > Bi-OPL.

Within the time scale of our experiments, Bi-OPL appeared to possess a high resistance to soil types. Bi-OPL materials recovered from the soil demonstrated very little degradation, indicated by lower changes in tensile strength, weight losses and with maximum 26% decrease in elongation at break. An extensive degradation was observed for Chitosan films. At the end of experiments, Chitosan films were completely degraded at all of soil types and both of surface and subsurface positions. The starch contained in Mater Bi samples was degraded after 60 days with 4% weight losses and lead to 3% observed losses in tensile strength.

Weight losses of Ecoflex and Bioflex were greater after three months (more than 30%) than before (5 to 10%). The tensile strength of both Ecoflex and Bioflex films decreased by about 4% and 3% by Week 12 in loamy soil and loamy sand soil, respectively. More than 40% of the elongation capacity of the films was lost by month 3 in both soil types. The decrease of %E in both films was slightly faster in loamy and loamy sand soil than in sandy soil.

In general, it can concluded that the biodegradation of all bioplastic films under the study was faster in subsurface than surface positions. According to the biodegradation rate of films, the soils can be ranged as: Loamy soil >>>Sandy loam >> sandy soil.

The previous results and summary revealed that each of following:

1. Bi-OPL holds for more than five months in all soil types.
2. Ecoflex, Bioflex and Mater Bi may hold for three months as best working life expectancy.
3. Chitosan can be used as a mulch film but can not be used as biodegradable drip tubes.
4. Sandy soil performs better than loamy and sandy loam soils in term of biodegradation long life.

5. The biodegradable materials may perform well in sandy soil, where the biodegradation rate in sandy soil was slow because of microorganisms' activity reduction.
6. After producing in the future, the biodegradable drip tubes can be used in surface, not in subsurface, drip irrigation because of microorganisms' activity.

6. ACKNOWLEDGEMENTS

The author would like to acknowledge, present deep gratefulness and appreciation to his home country Egypt, for giving him the opportunity to come to the Germany to obtain his Ph. D. through a governmental scholarship.

7. REFERENCES

BASF Company, 2007. Production information, Ecoflex® Brochure (www.basf-ag/ecoflex)

Bonhomme, S., Cuer, A., Delort, A.M., Lemaire, J., Sancelme, M., Scott, C., 2003. Environmental biodegradation of polyethylene. Polym Degrad Stab. 81,441–52.

Cuilbert, S., and Contard, N., 2005. Innovations in Food Packaging: Agro-polymers for edible and biodegradable films: review of agricultural polymeric materials, physical and mechanical characteristics. Elsevier Ltd

Demirbas, A., 2007. Biodegradable plastics from renewable resources. Energy sources part-A-recovery utilization and environmental effects 29(5), 419-424.

De Prisco, N., Immirzi, B., Malinconico, M., Mormile, P., Petti, L., and Gatta, G., 2002. Preparation, physico-chemical characterization and optical analysis of polyvinyl alcohol-based films suitable for protected cultivation. J. of Applied Poly. Sci. 86, 622–632.

Dintcheva, T. and Mantia, F.P.La., 2007. Durability of a starch-based biodegradable polymer. Polym Degrad Stab. 92, 630-634

Espi, E., Salmero`n, A., Fontecha, A., Garcı`a, Y., and Real, A., 2006. Plastic films for agricultural applications. J. Plastic Film & Sheeting, 22(2), 85–102.

Fernando, WC., Suyama, K., Itoh, K., Tanaka, H., and Yamamoto, H., 2002. Degradation of an Acylated Starch-Plastic Mulch Film in Soil and Impact on Soil Microflora. Japanese society of soil science and plant nutrition, 48 (5), 701-709.

FKUR company, 2008. Production description (http://www.fkur.de/?page=95).

Freier, T., Koh, H., Kazazian, K., and Shoichet, M. S., 2005. Controlling cell adhesion and degradation of chitosan films by N-acetylation. Biomaterials 26, 5872–5878

Glass, J.E., Swift, G., 1989. Agricultural and Synthetic Polymers, Biodegradation and Utilization, ACS Symposium Series, 433. Washington DC: American Chemical Society. p. 9–64.

Grifin, GJL., 1994. Editor. Chemistry and technology of biodegradable polymers. London: Blackie Academic & Professional.

Gu, JD., Ford, TE., Mitton, DB., Mitchell, R., 2000a. Microbial corrosion of metals. In: Revie W, editor. The Uhlig Corrosion Handbook. 2nd Edition. New York: Wiley.915–927.

Imam, H., Cinelli, P., Gordon, H., and Chiellini, E., 2005. Characterization of biodegradable composite films prepared from blends of poly (vinyl alcohol), cornstarch and lignocellulosic fiber. J. of Poly and the Envir. 13(1), 47–55.

Immirzi, B., Santagata, G., Vox, G., and Schettini, E., 2009. Preparation, characteristics and field testing of a biodegradable sodium alginate-based spray mulch. Biosy engine. 102, 461 – 472

Immirzi, B., Malinconico, M., Romano, G., Russo, R., and Santagata, G., 2003. Biodegradable films of natural polysaccharides blends. J. of Materials Science Letters. 22(20), 1389–1392.

Kaewta, K., and Tanrattanakul, V., 2008. Preparation of cassava starch grafted with polystyrene by suspension polymerization. Carbohydrate Poly. in press.

Kapanen, A., Schettini, E., Vox, G., and Ita¨vaara, M., 2008. Performance and environmental impact of biodegradable films in agriculture: a field study on protected cultivation. J. of Poly and the Envir. 16(2), 109–122.

Khan, A., Bhattacharia, K., Kader, A., and Bahari, K., 2006. Preparation and characterization of ultra violet (UV) radiation cured bio-degradable films of sago starch/PVA blend. Carbohydrate polymers, 63, 500-506.

Kijchavengkul, T., Auras, R., Rubino, M., Ngouajio, M., and Fernandez, T., 2008a. Assessment of aliphatic-aromatic copolyester biodegradable mulch films. Part I: field study. Chemosphere, 71, 942–953.

Kijchavengkul, T., Auras, R., Rubino, M., Ngouajio, M., and Fernandez, T., 2008b. Assessment of aliphatic-aromatic copolyester biodegradable mulch films. Part II: laboratory simulated conditions. Chemosphere, 71, 1607–1616.

Kyrikou, I., and Briassoulis, D., 2007. Biodegradation of agricultural plastic films: a critical review. J. of Poly. and the Envir. 15(2), 125–150.

Malinconico, M., Immirzi, B., Santagata, G., Schettini, E., Vox, G., and Scarascia G., 2008. Chapter 3: an overview on innovative biodegradable materials for agricultural applications. In: Progress in Polymer Degradation and Stability Research (Moeller H Wed), pp. 69–114. Nova Science Publishers, Inc, NY, USA.

Malinconico, M., Immirzi, B., Massenti, S., La Mantia, P., Mormile, P., and Petti, L., 2002. Blends of polyvinylalcohol and functionalized polycaprolactone. A study of the melt extrusion and post-cure of films suitable for protected cultivation. J. of Material Science. 37, 4973– 4978.

Mostafa, H., and Sourell, H., 2009. Equilibrium moisture content of some bioplastic materials for agricultural use (drip tubes). Agric Eng Inter: the CIGR Ejournal. Manuscript LW 1180. XI. May.

Novamont company, 2008. http://www.materbi.com/ing/html/PDF/EPD_PE_ 180202.pdf

Oerlemansplastics company, 2008. www.oerlemansplastics.nl and www.azenos.com_nav-info_biopl_php

Orhan Y., Hrenović, J., and Büyükgüngör, H., 2004. Biodegradation of plastic compost bags under controlled soil conditions. Acta Chim. Slov. 51, 579−588.

Orhan, Y., and Büyükgüngör, H., 2000. Enhancement of biodegradability of disposable polyethylene in controlled biological soil. Inte Biodeter & Biodeg 45, 49-55

Radhakumary, C., Prabha, D., Suresh, M., and Reghunadhan, C.P., 2005. Biopolymer Composite of Chitosan and Methyl Methacrylate for Medical Applications. Trends Biomater. Artif. Organs. 18 (2).

Shah, A., Hasan, F., Hameed, A., Ahmed, S., 2008. Biological degradation of plastics: A comprehensive review. Biotechnology Advances 26, 246–265

Swift, G., 1993. Directions for environmentally biodegradable polymer research. American Chemical Society, Acc of Chem Res. 26, 105-110.

Tien, C. Le., Letendre, M., Ispas-Szabo, P., Mateescu, A., Delmas-Patterson, G., Yu, L., and Lacroix, M. 2000. Development of Biodegradable Films from Whey Proteins by Cross-Linking and Entrapment in Cellulose. J. Agric. Food Chem. 48, 5566-5575

Witt, U., Einig, T., Yamamoto, M., Kleeberg, I., Deckwer, W., and Müller R., 2001. Biodegradation of aliphatic-aromatic copolyesters: evaluation of the final biodegradability and ecotoxicological impact of degradation intermediates. Chemosphere, 44(2), 289-299.

Yadav, V., and Bhise, B., 2004. Chitosan: A potential biomaterial effective against typhoid. Current Science. 87.