International Journal of Agricultural
Science and Research (IJASR)
ISSN(P): 2250-0057; ISSN(E): 2321-0087
Vol. 4, Issue 2, Apr 2014, 125-136

EFFECT OF SOME ENVIRONMENTAL AND AGRICULTURAL FACTORS ON BIODEGRADABLE-DRIP IRRIGATION TUBES

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ABSTRACT

The efficient use of irrigation systems has grown over the years due to water shortage and the need to optimize food production using minimum amount of water. Since removing the irrigation laterals at the end of the crop season (especially for vegetables) is expected to require extensive and challenging efforts from farmers and agricultural engineers, It would be desirable to use biodegradable irrigation drip lines that would allow ploughing of these materials after the end of the cultivation season without the need to remove the tubes or any environmental impacts. In this study, the engineering properties of two different types of biodegradable drip tubes were manufactured and evaluated under different soil treatments with using the organic and biofertilizers to study the material stability and life expectancy.

Bi-OPL drip tubes appeared to possess a high resistance to all treatments. Tubes materials showed very little degradation indicated by minimal changes in tensile strength and weight. The maximum loss in tensile strength and weight did not exceed 2% for five months. On the other hand, the degradation rates for Ecovio tubes are greater after three months where weight loss was more than 3% than before (0.7 to 1%). Ecovio tubes retained good resistance for the first three months, but were less resistant on the 6^{th} month (more than 57 % loss of its tensile strength) for all treatments. The previous results show that Bi-OPL drip tubes holds for more than five months and Ecovio drip tube hold for three months as their best working life expectancy. There are no significant differences between sterilized and non-sterilized soil in terms of degradation rates of Bi-OPL drip tubes, which means that the degradations are directly related to environmental factors such as UV-sunlight, moisture and temperature. Biodegradable drip tubes remain safe to the application of organic and bio-fertilizer.

KEYWORDS: Drip Irrigation, Biodegradability, Biofertilizers, Compost, Soil

INTRODUCTION

The efficient use of irrigation systems has grown over the years driven by water shortage and the need to optimize food production. The use of traditional drip irrigation tubes or pipes is one of major challenges to the farmers and agricultural engineers. A lack of degradability, closing landfill sites, and growing water and land pollution problems have led to concerns about plastics. With the excessive use of plastics and much pressure being placed on capacities available for plastic waste disposal, the need for biodegradable plastics and biodegradation of plastic wastes has assumed significant importance in the last few years. Awareness of the waste and disposal issues and their impacts on the environment has awakened new interest of degradable polymers. Therefore, the new environmental laws driven by growing environmental awareness throughout the world have triggered the demand for new products and processes that are compatible with the environment.

The main drive for developing biodegradable materials for agricultural applications comes from the challenge to cope with the highly complicated, in technical, legal and financial terms, problem of agricultural plastic waste management. One of the main agricultural applications however, concerns the biodegradable mulching films (Briassoulis, 2007). The use of biodegradable films eliminates the need for mechanical removal, thus eliminates the plastic waste management cost, and the relevant environmental problems because of the current practices of uncontrolled burning or burying of this waste in soil (Mazollier and Taullet 2003). After their use, biodegradable films that may be confirmed beyond any doubt to be biodegradable in soil can be plowed in soil with the plant remains.

Biodegradable polymers existed from renewable resources have attracted much attention in recent years. This new interest results from global environmental impact awareness and the fossil depletion problem. Biopolymers research and development as well as their production have been the fastest for several years (Vroman and Tighzert, 2009).

Biodegradable materials would ease disputes on environment pollution and reduce reliance on fossil resources. Polylactic acid (PLA) is biocompatible and biodegradable semi-crystalline polyester and is commercially available (Wu, 1995). PLA is completely degraded under compost conditions. It is not soluble in water; nevertheless microorganisms in marine environments can degrade it. PLA is a hard material and its hardness similar to acrylic plastic (Wee et al. 2006). Microorganisms in the environment continue the degradation by converting these lower-molecular-weight components to carbon dioxide, water (in the presence of oxygen), or methane (oxygen absent) (Drumright et al. 2000; Von-Burkersroda et al. 2002). PLA degradation is enzyme sensitive, a pure PLA can degrade by 20% of its total weight after 48 h of enzymatic exposure (Varma et al. 2005), and the weight loss under the control degradation conditions is 1.6%.

Degradable plastics are define as those which undergo a significant change in chemical structure under specific environmental conditions. These changes result in a loss of physical and mechanical properties, as measured by standard methods. In most applications envisaged for films or fibres in contact with the soil, loss in tensile properties is the most relevant practical criterion to characterize its degradation (Mostafa et al. 2010 and Orhan et al. 2004). Biodegradable plastics undergo degradation from acting naturally occurring microorganisms such as bacteria, fungi, and algae (Kumar et al. 2011).

Technological developments within the irrigation industry have advanced significantly over the last few decades. Many of these developments have resulted in advancing improvements to water use efficiency, increased production, higher quality commodities and a decreased labor need for irrigation. However, the supreme success of applying this advancing technology remains with the water management skill level of the irrigation water user.

Laterals are produced from petroleum, a limited and take more years to degrade. It led to interest in alternatives made from biodegradable plastics. This biodegradable tube can be used and it can be biodegraded at the end of the season without retrieval needed or any bad effects on the environment.

For developing and managing microirrigation, a series of studies were done by Briassoulis et al. (2008), Mostafa (2010) and Mostafa and Sourell (2011) to identify the properties of some bioplastic materials and the possibility to use them as biodegradable drip tubes. Some bioplastic materials showed good results. A later study was done by Mostafa (2014, unpublished data), to study the hydraulic performance of the Bio drip prototype (Biotube) and compared with polyethylene prototype (Polytube). This step was to verify the Biotube validity for using as drip tubes in drip irrigation network.

The objective of the present study was to enhance the product quality. A study involving two different types of bioplastic tubes were conducted to evaluate the impact of environmental factors and some agricultural transactions **(**Organic and biofertilizers) on the biomaterial stability and life expectancy. Those bioplastic tubes will not be collected and disposed after use, instead they will decompose in the soil without any adverse environmental effects. Their usage will erase the disposal cost; they are environment friendly products and possibly, at least partially, their materials may be based on renewable raw materials like agricultural wastes.

MATERIALS AND METHODS

A field experiment was carried out at the Research Farm of Agriculture Faculty, Benha University – Kalyobia Governorate, Egypt, during March to September 2012 to study the engineering properties and microbiological effects for the biodegradable drip tubes (produced from commercial bioplastics available on the market (Ecovio and Bi-OPL) was assessed per DIN EN 13432:2000 and ASTM D5988:2003) under different soil treatments (non-sterilized and sterilized soil) with using the biofertilizers and compost to study the material stability and life expectancy for producing the biodegradable drip tubes. Sterilized soil was used to measure the effects of microbial activity from compost and biofertilizers on the biotubs.

Studied Polymers

- Ecovio®, a biodegradable polymer consists of 45% polylactic acid and 55% Ecoflex (aliphatic-aromatic copolyester based on the monomers 1, 4-butanediol, adipic acid and terephthalic acid) for film extrusion (BASF, 2010).
- Bi-OPL® is produced from polylactic acid (PLA is made of degradable materials and compostable in accordance with DIN EN 13432 (Oerlemansplastics, 2008).

These materials have been developed for conversion to flexible films using a blown film or cast film process. Typical applications are agricultural films and compost bags.

Used Microorganisms

The biofertilizer cultures (*Azotobacterchroococcum, Bacillus circulans*and *Bacillus megaterium*) were prepared by strains reserved in the Agricultural Botany Department (Microbiology Branch), Faculty of Agriculture, Benha University, Egypt.

Environmental Condition

During March to September, 2012, this region is characterized by arid, no rainfall, an average high temperature, medium humidity and medium to high evaporation. Measured data are presented in Figure 1 for experiments' location. The soil is clayey textured as shown in Table 1.

Compost is primarily used as a soil conditioner. The physical and chemical properties of the used (cattle manure and herbal plants residues (50: 50)) are: pH 7.6, Electrical conductivity (EC) 3.1 dS m^{-1}, total organic matter values 32.7 %, bulk density 0.625 g cm^{-3}. The moisture content 23.50 %, water holding capacity value 3.7 g water/g dry and the porosity 62.67% (Khater, 2012).

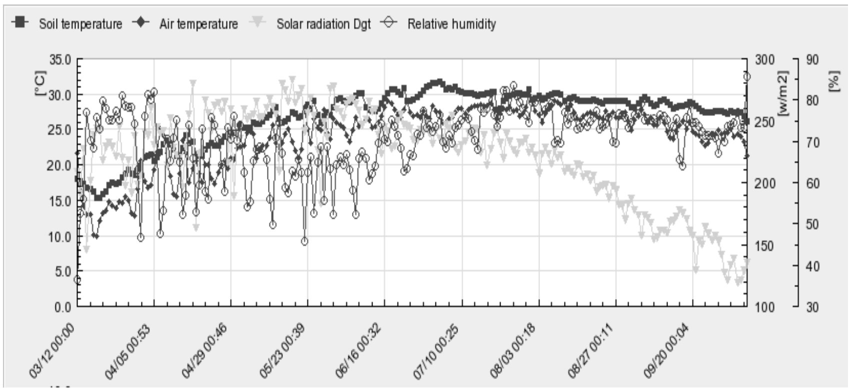

Figure 1: Weather Station Data for Location of Experiments

Table 1: Mechanical and Physical Characteristics of the Soil

Sand (%)	Silt (%)	Clay (%)	Texture Class	Organic Matter (%)	Bulk Density (g/cm^3)	Field Capacity (%)	Wilting Point (%)
22.5	31	46.5	clay	3.1	1.36	51.1	17.05

Experimental Procedures

Bioplastic tubes (10 cm in length and 22 mm in diameter) made up of polylactic acid and ecoflex (Ecovio) and only poly lactic acid separately (Bi-OPL) were used for the study. It was then weighed and disinfected by washing in 70% ethanol for 1 h, rinsed twice with sterile distilled water before being placed in the soil.

The experimental soil was divided into two groups, one of them was sterilized by using formaldehyde according to (Trevors, 1996) and the other one was left without sterilization. Polypropylene bags (10 liter in volume) were filled with soil (9 bags filled with non-sterilized soil and other 9 filled with sterilized soil treatments). Compost added to three bags of each soil group with rate of $20m^3$/Acre, other three bags of each soil group were inoculated with biofertilizers (*Azotobacterchroococcum;* 8.8×10^{11}cfu ml^{-1}, *Bacillus megaterium;* 9.3×10^{11}cfu ml^{-1} and *Pseudomonas fluorescens*9.5×10^{11}cfu ml^{-1} as mixed solution with rate 100 ml of each culture for bag) and was repeated monthly for three times. The last three bags of each soil group were left without treatment (control). Four bioplastic tubes for each type were placed in each bag. All the bags were kept in the open field and each of them was irrigated every week to adjust the humidity to 60% of soil holding capacity controled by tensiometer.

Engineering Measurements

The bioplastic tubes were tested at the beginning of March as standard and were retrieved at 15^{th} Apr., 30^{th} May, 15^{th} Jul. and 1^{st} Sep. of incubation, and were gently rinsed with sterilized water to remove the soil particles and retrieved under aseptic condition to determine total microbial biofilm. After that they were air-dried for 24 h, photographed and weighed. The tensile strength (TS) and weight losses were measured. Each tube was cut into tensile pieces 6x1 cm in size and TS was measured with a tensile testing machine (Daiei Kagaku – ArimotoKigyo Co., Ltd. Japan). Weight losses for the materials were measured according to Khan et al. (2006) by the following equation:

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

Where: W_1 and W_2 are the films weight before and after treatment respectively.

Microbiological Measurements

Total microbial biofilmwas determined and the enzyme activity of dehydrogenase (DH) and lipasewas measured using method of Schinner et al. (1997) in soil placed under bioplastic tubes for each treatment.

RESULTS

BI-OPL Tubes

The change of weight of Bi-OPL tubes was not observed for most of the experiment's time Figure 2. The tubes weight losses in non-sterilized soil as well as sterilized soil started without a clear lag phase and reached less than 1% for control, compost and biofertilizers treatments. At the end of the experiment the weight losses were increased to less than 2% for all treatments.

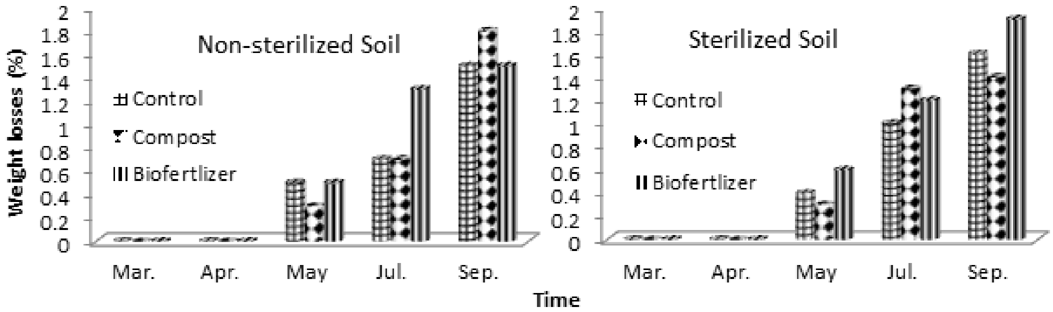

Figure 2: Weight Loss (%) of Bi-OPL Tubes at Non-Sterilized and Sterilized Soil Treatments

Amendment of compost recorded the highest weight loss percentage in non-sterilized soil, while inoculation of biofertilizers recorded the highest weight loss percentage in sterilized soil.

Tensile strengths for bioplastic samples are illustrated in Figure 3. Bi-OPL tubes were remarkably resistant after four months where the loss of tensile strength was only 2% for all treatments. On the other hand, tubes remained slightly resistant until the end of the experiment (15 % loss of tensile strength) with some cracks were observed from the photographical observation as shown in Figure 4. The Bi-OPL materials at control, compost and biofertilizers treated soil had the same trend in losses with a very few differences.

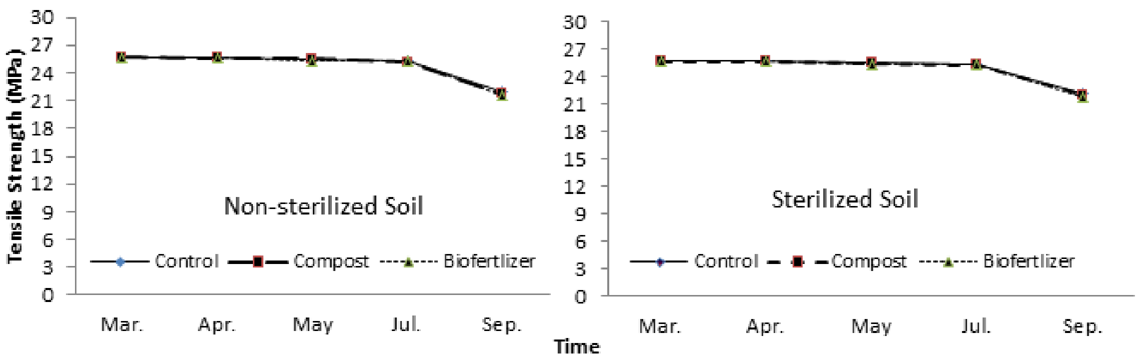

Figure 3: Tensile Strength (MPa) of Bi-OPL Tubes at Non-Sterilized and Sterilized Soil Treatments

Figure 4: Photographical Comparison between the Different Treatments at the End of Experiment Showing the Cracks of Bi-OPL Tubes (Inside Circles)

Total microbial biofilm on Bi-OPL tubes in sterilized and non-sterilized soil tabulated in Table 2. The number of microorganisms that colonized bioplastic film recorded high level beginning of May (the third month) until it reached its highest record in July, except that the total fungal biofilm had reached its highest values in May. From the data in Table 2, the disappearance of fungi and actinobacteria was noticed during the first three month in sterilized soil while they appeared during the second month in non-sterilized soil.

Table 2: Total Microbial Biofilm on Bi-OPL tubes in Sterilized and Non-Sterilized Soil Treated with Compost or Biofertilizers

Treatments	Total Fungal Biofilm (10^5×cfu/cm^2)					Total Bacterial Biofilm (10^5×cfu/cm^2)					Total Actinobacterial Biofilm (10^5×cfu/cm^2)				
	Mar	Apr	May	Jul	Sep	Mar	Apr	May	Jul	Sep	Mar	Apr	May	Jul	Sep
	Sterilized Soil														
Control	ND*	ND	ND	ND	ND	20	24.5	30	38	36	ND	ND	ND	ND	ND
Compost	ND	ND	ND	1.0	2.0	45	72.3	100	196	108	ND	ND	2.3	42.5	36
Biofertilizers	ND	ND	ND	ND	ND	32	43.5	66	150	100	ND	ND	ND	20.0	12
Non-Sterilized Soil															
Control	ND	0.23	0.30	0.25	0.1	40	41.1	45	148	78	ND	ND	ND	ND	10
Compost	ND	2.20	2.85	0.87	0.4	52	64.3	123	288	180	ND	ND	26	80	47
Biofertilizers	ND	1.42	1.96	0.64	0.2	50	84.8	113	356	162	ND	ND	15.6	50	28

***ND**: not detected

The soil treated with compost or biofertilizers showed high records of total microbial biofilm compared to control. Total bacterial biofilm were represented in high numbers followed by total actinobacteria and total fungi number in all periods. It is clear that soil treated with compost showed highly records of total bacterial, fungal and actinobacterial biofilm than soil inoculated with biofertilizers.

Data in Table 3 showedsoil microbial activity that is a term used to indicate the vast range of activities carried out by microorganisms in soil that located under bioplastic tubes. Dehydrogenase activity reflects the total oxidative activity of the microbial biomass andlipases are effective enzymes for hydrolysis of ester bond of polyesters (such as polylactic acid). In sterilized and non-sterilized soil, amendment of soil with compost lead to higher values of dehydrogenase activity than soil inoculated with biofertilizers or untreated soil (control). The highest values of dehydrogenase activity showed at second month.

Table 3: Periodically Change in Dehydrogenase and Lipase Activity in Soil under Bi-OPL Tubes

Treatments	Dehydrogenase(μg TPF g^{-1}dw h^{-1})					Lipase (Lipase Units,= ml 0.05M of NaOH)				
	Mar	Apr	May	Jul	Sep	Mar	Apr	May	Jul	Sep
	Sterilized Soil									
Control	3.1	7.9	6.5	4.5	4.4	3.2	4.0	5.6	9.5	7.5
Compost	34.2	37.0	32.5	30.9	25.6	20.3	32.7	39. 0	39. 6	18.7
Biofertilizers	20.4	23.1	22.1	13.7	20.3	15.9	21.7	27.4	35.8	28.2

Table 3: Contd.,

Non-Sterilized Soil										
Control	21.3	28.1	20.1	16.0	13.8	16.1	20.1	26.4	29.9	21.3
Compost	40.6	47.8	44.5	45.8	38.9	25.1	36.0	50.6	52.4	32.4
Biofertilizers	31.8	38.4	32.7	24.0	22.3	21.7	34.3	54.2	59.2	29.1

Until July, sterilized soil that amended with compost gave higher values of lipase activity than soil inoculated with biofertilizers. The Contrary showedinnon-Sterilized Soil. In last month lipase activity in sterilized soil that inoculated with biofertilizers increased than Soil amended with compost While the contrary showedinnon-sterilized soil. These results agreed with data of weight loss percentage of Bi-OPL tubes at sterilized and non- sterilized soil in Figure 2.

Ecovio Tubes

Within the time frame of the experiments, Ecovio tubes had a different resistance which was indicated by changes in weight. The data plotted in Figure 5 show the weight losses of Ecovio tubes over time. For both non-sterilized and sterilized soil, a lag phase of three months, after which slight weight losses in the 4th month were observed, but after that more weight loss values were observed. The losses were faster in the 6th month (3.3, 3.5 and 3.6% for non-sterilized: control, compost and biofertilizer respectively) and (3, 3 and 3.2% for sterilized: control, compost and biofertilizer respectively).

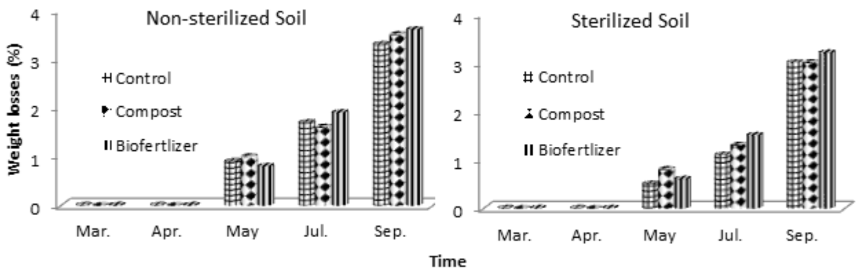

Figure 5: Weight Loss (%) of Ecovio Tubes at Non-Sterilized and Sterilized Soil Treatments

The tensile strengths of Ecovio tubes were plotted in Figure 6. The tensile strength of all non-sterilized soil treatments showed the same trend with a notable decrease until the 5th month (22.7, 27.9 and 23.6% for control, compost and biofertilizer respectively). At the end of the experiment, more reduction was noticed (59, 61 and 64% for control, compost and biofertilizer respectively).

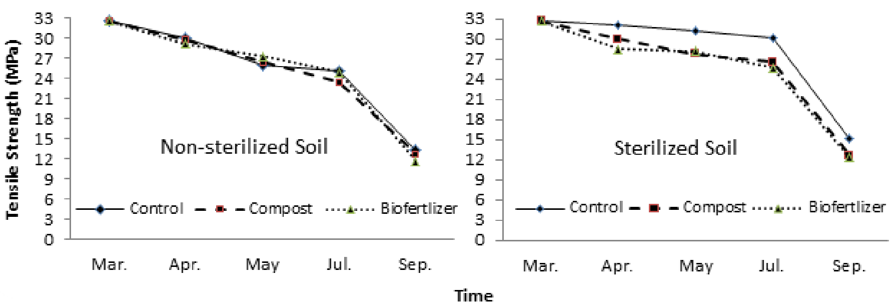

Figure 6: Tensile Strength (MPa) of Ecovio Tubes at Non-Sterilized Soil Treatments

Tubes in sterilized control soil Figure 6 retained good resistance at three months (7 % loss of tensile strength), but was only slightly resistant at the end of the treatment (57.7 % loss of tensile strength). On the other hand, compost and biofertilizer treatments showed more losses than the control, where the losses of tensile strength were 18.7 % and 21.2 % at four months and 61.3% and 62.3% at the end of the treatment, respectively. According to the photographic observation Figure 7, all tubes' material was become more brittle than before, in addition, some cracks appeared at the end of the treatment. By following the number of microorganisms in biofilm formed on Ecovio tubes, which tabulated in Table 4, we can observe the superiority of bacteria in colonizing bioplastic film whether in sterilized or non-sterilized soil. In sterilized soil fungi and actinobacteria have small role for Ecovio tubes colonization.

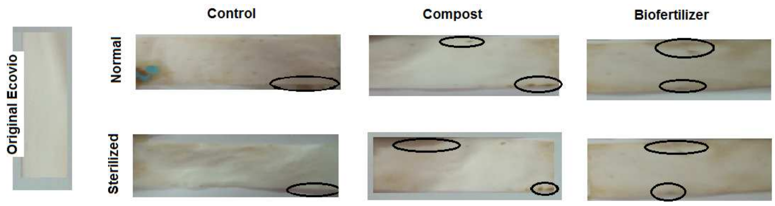

Figure 7: Photographical Comparison between the Different Treatments Showing the Cracks of Ecovio Tubes (Inside Circles)

The soil treated with compost or biofertilizers showed high records of total microbial biofilm compared to control. It is clear that soil treated with compost showed highly records of total bacterial, fungal and actinobacterial biofilm than soil inoculated with biofertilizers.

Table 4: Total Microbial Biofilm on Ecovio Tubes in Sterilized and Non-Sterilized Soil Treated with Compost or Biofertilizers

Treatments	Total Fungal Biofilm (10^5×cfu/cm^2)					Total Bacterial Biofilm (10^5×cfu/cm^2)					Total Actinobacterial Biofilm (10^5×cfu/cm^2)				
	Mar	Apr	May	Jul	Sep	Mar	Apr	May	Jul	Sep	Mar	Apr	May	Jul	Sep
	Sterilized Soil														
Control	ND*	ND	ND	ND	ND	9	19	30	36	72	ND	ND	ND	ND	ND
Compost	ND	ND	12.3	15.4	4.0	47	89	123	180	360	ND	ND	ND	37	10
Biofertilizers	ND	ND	ND	ND	ND	38	73	113	162	216	ND	ND	ND	16	10
Non-Sterilized Soil															
Control	ND	9.6	10.2	11.5	1.0	51	85	124	150	200	ND	ND	ND	16	10
Compost	ND	27.6	33.5	25.1	10.0	60	169	274	360	396	ND	32.2	67.3	72	50
Biofertilizers	ND	19.8	26.7	18.3	10.0	54	112	150	350	268	ND	ND	12.3	27	20

ND: *not detected*

Microbial activities in soil located under Ecovio tubes were recorded in Table 5. In both types of soil, amendment of soil with compost leads to higher values of dehydrogenase activity than soil inoculated with biofertilizers or untreated soil (control). The highest values of dehydrogenase activity were shown on the third month (May). It is clear that the highest values of lipase activity were observed on the second month, after that, they gradually decreased whether in sterilized or non-sterilized soil. The amendment soil with compost gave higher values of lipase activity than soil inoculated with biofertilizers.

Table 5: Periodically Change in Dehydrogenase and Lipase Activity in Soil under Ecovio Tubes

Treatments	Dehydrogenase (µg TPF g^{-1}dw h^{-1})					Lipase (Lipase Units,= ml 0.05 M of NaOH)				
	Mar	Apr	May	Jul	Sep	Mar	Apr	May	Jul	Sep
	Sterilized Soil									
Control	2.3	5.6	12.1	10.9	9.6	4.0	26.3	19.8	7.9	1.1
Compost	34.2	38.9	41.8	38.6	35.2	32.7	51.2	31.8	22.7	15.3
Biofertilizers	20.4	24.3	35.6	29.9	29.5	21.7	44.4	35.0	17.6	12.3
Non-Sterilized Soil										
Control	28.1	21.9	26.8	14.5	18.6	20.1	36.7	29.0	18.1	13.0

Table 5: Contd.,										
Compost	44.5	48.5	57.8	50.4	38.7	36.0	73.6	44.0	24.2	20.3
Biofertilizers	38.4	38.5	43.5	42.1	35.1	34.3	52.4	42.2	26.4	21.2

DISCUSSIONS

It is well known that UV-sunlight, water, temperature, microbial and other environmental factors have a deterioration effect on many bioplastic materials. These materials, when exposed to the outdoor environment, undergo significant changes, causing loss of engineering characteristics and this depends on the sun light intensity, microorganisms' activity and other environmental factors. Therefore, the changes in engineering and microbial characteristics for Bi-OPL and Ecovio tubes were discovered. According to Song et al.'s study (2009), PLA belonged to the slow biodegradation rate plastic with mass loss of 5% after 90 days. This was also in accordance with our observation that Bi-OPL tubs (made from 100% PLA) had a biodegradation rate of 2 % in six months.

The environmental degradation of PLA occurs by a two-step process. During the initial phases, the high-molecular weight chains hydrolyze to lower-molecular-weight oligomers and this rate is slow (Guo et al. 2012). The process can be accelerated by acids or bases, and it is affected by temperature and moisture levels. This leads to a significant change in the chemical structure of the material.

Microorganisms such as bacteria and fungi are involved in degrading both natural and synthetic bioplastics (Gu et al, 2000). 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 & Swift, 1989; Tokiwa & Calabia, 2008).

Previous results revealed that Bi-OPL tubes have a much slower degradation rate compared to Ecovio tubes. It could be the hydrophobicity of PLA (Bi-OPL tubes) is the main reason for its resistance to microbial enzymatic systems (Orhan et al, 2004) in the different soil treatments. For the same reason, it could be observed that the Ecovio tubes (contain 45% PLA) had some resistance but less than Bi-OPL because of some biodegradable copolyester additives (55% Ecoflex) especially in the first four months. Ecoflex had some resistance, 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 Ecovio are introduced to the degradation processes.

Other mechanisms which play significant role are physical damages because of the micro-organisms, biochemical effects from the extra cellular materials produced by the micro-organic activity. Moreover the rate of degradation is affected by environmental factors such as UV-sunlight, 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 according to our previous study.

CONCLUSIONS

In recent years, there has been a marked increase in interest in biodegradable materials for use in agriculture and other areas. In particular, biodegradable polymer materials are of interest. Biodegradable plastics offer many advantages such as increased soil fertility, low accumulation of bulky plastic materials in the environment, and reduction in the cost of waste management. As a result, many researchers are investing time into modifying traditional materials to make them more user-friendly. This paper is intended to study two different types of bioplastic drip tubes and to evaluate the impact of organic and biofertilizers on the material stability and life expectancy. Those bioplastic drip tubes will not be collected and disposed after use. Instead, they will decompose in the soil without any adverse environmental effect.

Within the time scale of our experiments, Bi-OPL tubes appeared to possess a high resistance to all treatments. Tubes materials demonstrated very little degradation, indicated by lower changes in tensile strength and weight losses with a maximum of 2% until the 5th month. At the 6th month the losses have increased particularly for tensile strength (15%). The degradation rates for Ecovio tubes are greater after three months where weight loss was more than 3% than before (0.7 to 1%). Ecovio tubes retained good resistance at three months, but they were only slightly resistant at the 6th month (more than 57 % loss of tensile strength) for all treatments.

The results and discussion support the following conclusions:

- Bi-OPL drip tubes holds for more than five months and Ecovio drip tube hold for three months as their best working life expectancy.
- There are insignificant differences between sterilized and non-sterilized soil in Bi-OPL tubes degradation rates, which means that the microorganisms' activity has secondary effect and the primary effect is related to environmental factors such as UV-sunlight, moisture and temperature.
- Organic and biofertilizer can be safely used with biodegradable drip tube.
- In future studies, the biodegradable drip tubes will be connected with drip irrigation system to operate and evaluate in large scale.

ACKNOWLEDGEMENTS

The authors would like to present deep gratefulness and appreciation to Dept. of Agric. Eng., Fact. of Agric., Benha University, Egypt (www.bu.edu.eg) for giving them the opportunity to fulfil this study.

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