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Studies on Bioplastic for Developing and Evaluating of Drip Irrigation

DISSERTATION
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by

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Preface

The requirements in agricultural production, the environmental protection and the water resources optimization have made farmers modernize irrigation systems. One aspect of these modernizations is the installation of drip irrigation systems. However, the new environmental regulations and growing environmental awareness throughout the world have triggered the search for new products and processes that are compatible with the environment. This study presents the results of a research project using the low pressure drip system (LPS) for small areas and investigating the possibilities and limitations in developing biodegradable materials for using as drip tapes. Since the irrigation tapes /laterals are usually removed at the end of the crop season, especially for the vegetables, it would be desirable to use biodegradable irrigation drip lines that would allow roto-tilling or ploughing of these materials after the end of the cultivation season, without the need to remove the tapes/ laterals.

For developing and managing micro irrigation systems, series of studies were done to identify the properties of some bioplastic materials and the possibility to use them as biodegradable drip tubes. Some bioplastic materials indicated good results where they has the possibility to use for producing the biodegradable drip tubes instead of PE or PVC that will not need to be collected and disposed of after use but will decompose in the soil without any adverse environmental effect. This will eliminate the disposal cost; will be environmentally friendly and possibly, at least partially, the materials used may be based on renewable raw resources.

The author, who had a scholarship as a doctoral student at Federal Research Institute for Rural Areas, Forestry and Fisheries (vTI), Institute of Agricultural Technology and Biosystems Engineering, Braunschweig, Germany [the old name: Federal Agricultural Research Center (FAL), Institute of Production Engineering and Building Research], made a contribution towards a more objective discussion about the use of biodegradable drip tube and described future-oriented solution approaches.

Braunschweig, October 2010

Prof. Dr. agr. habil. Franz-Josef Bockisch   Dr. rer. hort. Heinz Sourell

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List of Abbreviations

AFM	Atomic force microscopy
BD	Biodegradation
BPF	British Plastics Federation
Ca (H_2PO_4)	Calcium Dihydrogen Phosphate
CVq	Flow Variation Coefficient
DI	drip irrigation
DSC	Differential scanning colorimetry
dw	Dry weight
E	Elongation
EMC	Equilibrium moisture content
EU	Emission uniformity
EUa	Absolute Emission Uniformity
FAO	Food and Agriculture Organization
FNR	Fachagentur Nachwachsende Rohstoffe e.V.
FTIR	Fourier transforms infrared spectroscopy
ha	hectare
H_3PO_4	Phosphoric acid
HNO_3	Nitric acid
HPLC	high performance liquid chromatography
IDE	International Development Enterprises
IE	Irrigation efficiency
K_2SO_4	Potassium Sulfate
kPa	Kilo Pascal
l/h	litre/hour
LPS	Low pressure drip system
MC	Moisture content
mw	Moist weight
N:P:K	Nitrogen:potassium:phosphorus
NaCl	Sodium chloride
NH_4NO_3	Ammonium Nitrate
PE	Polyethylene
PHA	poly-hydroxyalcanoate
PLA	Polylactide acid
PVC	Polyvinylchloride
$\overline{q}_{12.5\%}$	Average of the 12.5 % lowest values of flow rate
$\overline{q}_a$	Average flow rate
$\overline{q}_{25\%}$	Average of the 25% lowest values of flow rate
RRM	Renewable raw materials
SD	Standard deviation of flow
SDI	Subsurface drip irrigation
T	Time
TS	tensile strength
W_1 and W_2	the films weight before and after treatment

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1. INTRODUCTION

Approximately 20 % of the world's population lacks access to safe water and about a third lives in countries with moderate to high water stress, i.e., in areas where the withdrawal of freshwater exceeds 10 % of the renewable storage. If the same consumption patterns continue, two out of three people on earth will live under water-stressed conditions by the year 2025. The main factors causing increasing water demand over the last century are population growth, industrial development and expansion of irrigated agriculture. Agriculture accounts for 70 % of the total freshwater used globally, mainly for agricultural crops (UNEP, 2002a). Germany is rich in water bodies. Only 20.9 % of the annually renewable water resources are actually utilised by all users and about 1 % for agriculture irrigation. In view of such a comfortable situation, a long-term provision of water supply in Germany is ensured given a sustainable use of the water resources (Federal Statistical Office, 2005).

In Egypt, due to the existence of dry climatic conditions in most parts of the country and limited available water resources, optimization and saving of water consumption have vital importance. The average annual precipitation in Egypt is only 20 mm which is quite less than the world average with about 600 mm. At the moment, in the country the total amount of applied water from surface and underground water resources is about 67.6 billion m^3 per year, of which about 82 % or 55.2 billion m^3 is used in the agriculture sector (FAO, 2005). Unfortunately, this huge amount of water is mainly used with low efficient conventional surface irrigation methods. As a result a lot of water is lost during irrigation practices. It has been reported that in Egypt the overall irrigation efficiency is about 40 % (Osman et al., 2005).

With a secure water supply, supplementary irrigation can be used to decrease the high risk imposed by erratic rainfall, thereby increasing the incentives for the farmers to invest in higher-yielding seeds, higher-value crops, and fertilization and also to grow an additional crop (Karlberg and Penning, 2004).

The requirements in agricultural production, environmental protection and water resources optimization have made farmers modernize irrigation systems. One

aspect of these modernizations is the installation of drip irrigation systems (Miguel et al., 2009). Micro-irrigation overcomes most of the shortcomings of the conventional irrigation methods, but the gain in terms of the yield is not consistent. Drip irrigation systems are used to uniformly distribute water in agricultural fields. If water can be applied efficiently in an irrigation field, water is saved and both crop quantity and quality are increased. Drip irrigation has advantages over conventional furrow irrigation as an efficient means of applying water, especially where water is limited. Vegetables with shallow root systems and some crops, like cotton, respond well to drip irrigation with increased yield and substantially higher fruit or fiber quality with smaller water application, thus justifying the use of drip over furrow irrigation.

Technological developments within the irrigation industry have advanced significantly over the last few decades. Many of these developments have resulted in on-going improvements to water use efficiency, increased production, higher quality commodities and a decreased labour requirement for irrigation. However, the ultimate success of the application of this advancing technology still remains with the water management skill level of the irrigation water user. Therefore, as technology creates greater opportunities and computerization becomes a larger part of farm business management, the opportunity exists for the application of computer software to assist farm irrigation managers in the timing and amounts of their water applications.

Today's consumers are informed about environmental problems in which waste management has not yet reached a corporate consensus. The public wants to see eco-friendly, recyclable or degradable materials, and the abundance of plastic waste seems to be a major problem area.

With the development of degradable plastics, for the first time a group of materials was created with regard to disposal. For economic reasons, the use of degradable plastics is still negligible, but has huge potential, as these plastics are suitable for waste management to close circular flow, save oil reserves, stabilize CO_2 emissions and offer consumers an environmentally friendly option. 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. At the present, biodegradable plastics can be used in various agricultural applications, such as flowerpots, which completely biodegrade in the soil while functioning as a soil conditioner, leaving biomass. One of the main agricultural applications however, concerns biodegradable mulching films (Briassoulis, 2004). Several biodegradable mulch and low-tunnel films have been developed for protected cultivation (Scarascia-Mugnozza et al., 2006). The use of biodegradable films eliminates the need for mechanical removal and thus eliminates the plastic waste management cost and the relevant environmental problems due to the current practices of uncontrolled burning or burying of this waste in soil. After their use, biodegradable films that may be confirmed beyond any doubt to be biodegradable in soil can be ploughed in soil along with the plant remains (Briassoulis et al., 2008).

1.1 PROBLEMS

Vegetables and some crops respond well to drip irrigation with increased yield and substantially higher quality with smaller water application, thus justifying the use of drip over furrow irrigation. Arid countries, which have limited water resources (e.g., Egypt), have to use the modern irrigation system, especially the drip irrigation. The expansion of the drip irrigation is faced by some problems. These problems are summarized as followed:

1. Smallholdings: e.g., Egypt, about 50 % of holdings have an area of less than 0.4 ha (1 feddan) in the original land and 2 ha in the reclaimed land and this is a big problem for the expansion of modern irrigation systems like drip irrigation.

2. The environmental problem is the direct impact of plastic wastes on the environment. Laterals, produced from PVC or PE, are produced from petroleum which has limited resources. The PVC and PE take more than 50 years to degrade, and when burned release the carbon dioxide into the atmosphere, leading to global warming.

3. The high costs for reusing the petroleum drip lines several times, which requires removal before harvesting by hand or machines each season. The high

costs come because 1) labour and maintenance are more intensive, 2) the risks of mechanical damage to laterals used and especially if they are reused, 3) increased management skills and experience are needed and 4) increased retrieval costs season after season.

Environmental problems caused by petroleum-based plastics have led to interest in alternatives made from biodegradable polymers (bioplastics).

1.2 OBJECTIVES

The main objective of this study is testing the use of drip irrigation using bioplastic tubes. These objectives include the following:

a) Evaluating the performance of a low pressure drip system (LPS) developed by Netafim for three years of service as a good and suitable system for small fields. This investigation is necessary for a better understanding of the problems with drip irrigation systems and for a comparison with the bioplastic usage. The following specific objectives were established:

1. to measure and calculate irrigation uniformity of the LPS and determine how the discharge characteristics of reusable tubes change with time;

2. to measure and calculate the consumptive working time and costs for maintenance and laterals retrieving before harvesting;

3. to determine benefits and problems with drip irrigation and provide recommendations for improved system management.

b) Testing the possibility of using the biodegradable drip tubes that will not need to be collected and disposed of after use but will decompose in the soil without any adverse environmental effect. This will eliminate the disposal costs, will be environmentally friendly and possibly, at least partially, the materials used may be based on renewable raw resources. A series of studies were done to identify the properties of some bioplastic materials and the possibility to use them as biodegradable drip tubes for developing and managing micro irrigation systems.

This objective was as follows:

1. Study of the effects of the environmental conditions on some bioplastic materials (temperature, moisture content, soil types, and fertigation).

2. Definition of specifications for the bioplastic materials to be developed based on requirements imposed by conditions and environmental impact aspects.

3. Development and testing of some biological and chemical methods (trigger) to use with the last irrigation time as degradable factors which add to pre-degradation because the drip lines can hinder the machine during harvesting.

The previous objectives are set to achieve the idea of this work, which aims to make a combination between drip irrigation and bioplastic for using biodegradable drip tubes in the future to solve the previous problems.

1.3 OVERVIEW OF THE THESIS

The thesis consolidates the research findings on two broad fronts: I. evaluating a new low-pressure drip irrigation system as a one of the important systems suitable for small medium areas: II. identifying the properties of some bioplastic materials and the possibility to use them as biodegradable drip tubes for developing and managing micro irrigation systems. The various studies that address these themes are presented in Chapters 2-5.

The following chapter (Chapter 2 Micro-irrigation) presents a comprehensive literature review which focuses on the evaluation of surface drip distribution systems for the application of water to the soil. Drip emitters, operation of drip fields and techniques to maintain and recover emitter flow rates were reviewed.

The focus of the experimental research in this chapter was to evaluate the uniformity of the low pressure drip system (LPS) as a suitable system for the small area and study the consumptive working time for repair, maintenance and laterals retrieving. This section describes methods used to measure the flow rate in the field site, and as well as the calculation the working time costs.

Chapter 3 (Biodegradable plastic) presents a comprehensive literature review which focused on bioplastic materials and their advantages, the biodegradability of bioplastics, methods of degradation and the field of bioplastic applications.

A series of studies were done in this chapter to identify the properties of some bioplastic materials and the possibility to use them as biodegradable drip tubes for developing and managing micro irrigation systems.

Chapter 4 is the discussion and conclusion of the previous chapters and presents the main points of this study.

Chapter 5 (the same as Chapter 6 in German language) presents a general summary and conclusion for the results which are discussed in Chapter 2 and 3 and flow into recommendations to improve the usage of bioplastic materials as degradable tubes for drip irrigation.

2. DRIP IRRIGATION

2.1 INTRODUCTION

The contribution of irrigation to agricultural production is very significant to the world's food supply. However, current irrigation practices such as furrows are inefficient, causing environmental hazards such as salinity, run-off and contamination of water bodies. Micro-irrigation overcomes most of the shortcomings of the conventional irrigation methods, but the gain in terms of the yield is not consistent. Drip irrigation systems are used to uniformly distribute water in agricultural fields. If water can be applied efficiently in an irrigation field, water is saved and both crop quantity and quality are increased. Drip irrigation has advantages over conventional furrow irrigation as an efficient means of applying water, especially where water is limited. Vegetables with shallow root systems and some crops, like cotton, respond well to drip irrigation with increased yield and substantially higher fruit or fiber quality with smaller water application, thus justifying the use of drip over furrow irrigation. This chapter provides the problems and objectives of the study and also includes the background information on the issues pertinent to micro-irrigation, and finally, the results and a discussion of the field experiments are presented in this chapter.

2.1.1 Problems

Arid countries, which have limited water resources, have to use modern irrigation systems especially drip irrigation. The expansion of the drip irrigation was faced by some problems. Egypt (as a case study) is an arid country which depends on the River Nile for its water supply with an annual allocated flow of 56 billion m^3/year. Evapotranspiration is very high (from 60 mm/month in winter to 220 mm/month in summer). The total cultivated area is 3.4 million ha and 99.8 % of this area was irrigated. Surface irrigation is practiced on 3,028,853 ha (88.5 % of total cultivated area).

Smallholdings characterize Egyptian agriculture: About 50 percent of holdings have an area less than 0.4 ha (1 feddan) in the original land and 2 ha in the reclaimed land, and this is a big problem for the expansion of modern irrigation. So the aim of this chapter is to evaluate a new low-pressure drip irrigation system as one of the important systems suitable for small and medium areas.

2.1.2 Objectives

Netafim Co. developed and manufactured a low pressure drip system (LPS) which was used by Dowgert et al. (2007). According to the good potential benefits reported by them during the initial trials using LPS; the aim of this study was to evaluate the performance of LPS for three years of service in a small area. The specific objectives were established as explained before (page 4).

2.2 LITERATURE REVIEW

This literature review focuses on the evaluation of surface drip distribution systems for the application of water to the soil. Drip emitters, operation of drip fields and techniques to maintain and recover emitter flow rates will be reviewed.

2.2.1 Overview of Irrigation Methods

Irrigated agriculture has played a vital role in supporting a dramatic increase in global food production over recent decades. While only 20 % of the world's agricultural land is irrigated, it produces 40 % of world's food supply (Howell, 2001). Irrigation also improves the efficiency of other production inputs such as fertilizers, improved seeds and agrichemicals. Hence, often the low-input irrigated farming is more productive than high-input rain-fed farming (Rosegrant et al., 2002). Therefore, irrigated agriculture will be a dominating feature of future farming in order to be able to produce sufficient food for an ever-growing world population.

The term irrigation refers to technology that serves the purpose of distributing water to a crop on a field. In general irrigation methods can be divided into three categories: surface, sprinkler and micro (drip/trickle) irrigation systems (Kruse et al., 1990) as shown in Figure 2.1. Crucial advances have been made in the development of irrigation technologies since the 1970s. The drive for rigorous research on irrigation arose due to growers' demand for irrigation technologies that reduce water and labour inputs. The transition from surface to pipe irrigation, followed by a transition from the use of sprinklers to drip irrigation in intensive cropping took place after intensive research in the field of plant husbandry and engineering aspects of irrigation technologies (Mayer, 2001). A third generation of irrigation technologies (precision irrigation and computer control) is now entering for commercial use.

Surface irrigation includes flood and contour ditches, border dikes, graded furrows, corrugation and level basin. In surface irrigation, the irrigation water supply is introduced at one edge of a field and flows across the soil surface by gravity, infiltrating into soil while the stream advances across, or is ponded within the field.

Generally irrigation efficiency (IE) for surface irrigation is poor and loss of water occurs due to runoff, drainage and evaporation.
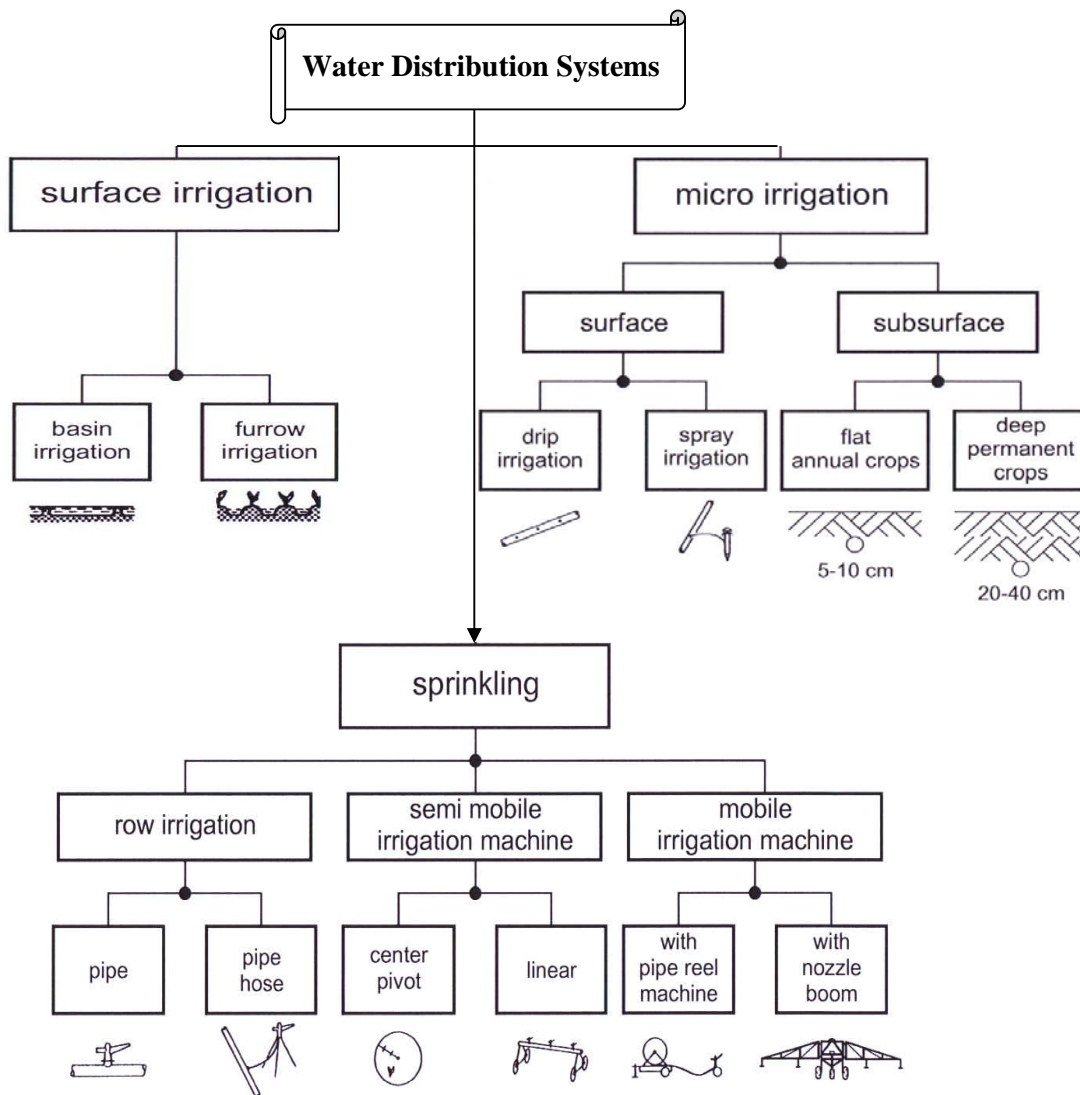
Figure 2.1: Irrigation systems classification (Sourell, 1998)

Sprinklers can involve set systems or mobile systems (linear move, travelling big gun, centre pivot, skid tow, solid set sprinkler, side roll and boom types). The mobile sprinkler irrigation systems are those where water is supplied in a pressurized network and emitted from sprinkler heads mounted on emitters fixed on moving supports. IE of sprinkler irrigation is moderate and loss of water occurs due to evaporation. Micro-irrigation (drip/trickle, subsurface, bubbler and spray) water is often distributed in

plastic conduits and emitted through drippers, trickles, bubblers, small misters or sprayers. IE of micro, especially subsurface drippers, is high and loss due to evaporation, drainage and runoff can be controlled effectively in this system. The surface, sprinkler and micro-irrigation are commercially important irrigation methods. Sub-irrigation is an uncommon technology which provides water to crops by controlling the water table level. Crop roots can then reach the capillary fringe above the water table and extract their water needs from it (Kruse et al., 1990). Lastly, hybrid methods exist that combine low energy precision application systems with a closed conduit gravity systems. Hybrid irrigation methods are those systems that do not easily fall within the categories of the former methods. Irrigation for agriculture consumes the major share of the global fresh water supply. With the increasing global concern for water use in irrigation over the last few decades, there is a crucial need to optimize efficiency of irrigated agriculture (Schultz and Wrachien, 2002). In response, substantial research work is being carried out and many earlier studies have been published about water saving irrigation, drainage, and runoff associated with irrigation systems (Framji et al., 1982; Bucks et al., 1982; Higgins et al., 1987; Jensen et al., 1990).

Sprinkler irrigation systems involves spraying water into air through nozzles and allowing it to fall on the land surface in almost a uniform pattern, at a rate less than the infiltration rate of the soil (Varshney, 1995).

Center pivot is a self-propelled sprinkler system rotates around the pivot point and has the lowest labour requirements of the systems considered. It is constructed using a span of pipe connected to moveable towers. It will irrigate approximately 50 hectares out of a square quarter section. Center pivot systems are either electric, water, or oil-drive and can handle slopes up to 15 %. Sprinkler packages are available for low to high operating pressures (200 to 500 kPa at the pivot point). Sprinklers can be mounted on top of the spans or on drop-tubes which put them closer to the crop (Broner, 2002).

Recently, it is an idea for combining between center pivot or linear move machines and stationary drip irrigation (mobile drip irrigation). The mobile drip irrigation is suitable for center pivot and linear move machines, nearly all crops and

area from 40 ha. The idea of the mobile drip irrigation consists of both, the advantages of stationary drip irrigation and the advantages of center pivot or linear irrigation machines. The mobile drip irrigation with center pivot or linear machines meaning that, the sprinklers will replaced by drip tubes to water supply to the soil and plants. The length of drip tubes will depend on water requirements and the infiltration rate of the soil. This length is different from 3 to 14m for 9 towers center pivot machine as shown in Figure 2.1. The distance between two tubes should be 0.75m. The operating pressure at the inlet of drip tubes is about 50 kPa or 100 kPa. The advantages for mobile drip irrigation versus sprinkler irrigation systems are water saving from 20 %, energy saving about 60 %, high water application distribution, no water loss by wind drift and possibility of chemigation. The disadvantages for mobile drip irrigation versus sprinkler irrigation systems are water filtration very important, high capital requirements (if it used for one season per year) and high irrigation intensity (Sourell and Derbala, 2005).

Figure 2.2: A mobile drip irrigation idea (Sourell and Derbala, 2005).

Linear move systems are similar in construction to center pivot systems except that, rather than rotating on a fixed end point, the entire system moves laterally across the field. They are designed primarily for use on rectangular shaped fields. In general,

for a linear move system to be feasible, the ratio of length to width should be at least 2.2; that is, the irrigation system is no more than one-half as long as the laterals travel distance. The system is best suited to fields with a minimum amount of slope (0 to 4 %) (Smajstrla et al., 2002).

2.2.2 Drip Irrigation

With the development of the plastic industry after the Second World War, inexpensive, water-resistant plastic was available also for the agricultural industry. Perforated tubes were used to irrigate individual plants under low pressure with water almost directly emitted to the root zone. The technology was further refined during the 1970s. In the 1990s the technology was being introduced to smallholder farmers as an efficient and easy-to-operate method (Or, 2000). Drip irrigation (DI) is one of the most efficient methods of watering crops. Its field application efficiency can be as high as 90 % compared to 60 – 80 % for sprinkler and 50 – 60 % for surface irrigation (Dasberg and Or, 1999).

Drip systems have often been associated with capital-intensive commercial farms. The largest barriers to its expansion to small-scale farmers have been high capital costs, typically starting from US $1500 per hectare and the lack of system sizes suitable for small plots. The high cost of most commercially available drip systems is due to components that are optimized for fields of four hectares or larger and designed to minimize labour and management costs. By contrast, early drip systems were simple, but these designs were abandoned because they did not fit the needs of large-scale farmers in developed countries. They are, however, well suited for drip irrigating small plots (Andersson, 2005).

2.2.2.1 Advantages and disadvantages of micro-irrigation

Micro-irrigation has advantages as well as disadvantages to be considered and understood before adopting the technology. Hoffman et al. (2007) reported that the advantages include water conservation and reduced deleterious water quality impacts due to high application efficiencies, automation capabilities, improved or increased yields, ease of chemical applications, and potential sustainability. Disadvantages

include a high potential for emitter plugging, high system costs and required high levels of management.

2.2.2.1.1 Advantages

Micro-irrigation is commonly used in areas with limited water and high water costs, but it has great value in other areas as well. Properly designed, installed, and managed micro-irrigation systems can eliminate surface runoff and associated soil erosion, efficiently and uniformly apply water-soluble fertilizers, and achieve high uniformity and efficiency of water application. They generally tend to have smaller wetted areas, reduced deep percolation and lower evaporation losses than other irrigation methods. There can be water and chemical savings because of increased efficiency, reduced weed control costs because a limited surface area is wetted, and better productivity can be achieved due to improved control of water and nutrients in the root environment. Micro-irrigation generally has high production efficiencies, whether expressed as yield per unit water, yield per unit nutrient input, or yield per unit land area. Advanced cultural practices, such as the use of plastic or sheet paper mulches to reduce weed growth, heat soils, and decrease soil evaporation, are also facilitated by drip irrigation. Due to relatively small pipe and valve sizes, micro-irrigation systems are easily and inexpensively automated, which reduces labor costs and improves general management flexibility.

Fertilizers and other water soluble chemicals such as pesticides (e.g., nematicides, systemic insecticides, herbicides) and soil amendments (e.g., acids, polymers, powdered gypsum) can be efficiently and effectively applied through micro-irrigation systems. Plastic films (biodegradable and non-biodegradable), large sheet paper, and other mulches often work very well in drip irrigated crop culture to control weeds (and eliminate herbicide use) and reduce soil evaporation losses. In addition, micro-irrigation methods are low-pressure systems that typically use less total energy compared to sprinklers.

2.2.2.1.2 Disadvantages

Because of their relatively small orifice sizes, micro-irrigation emitters can be easily plugged due to physical, chemical, and biological factors. Clogging adversely affects uniformity, and can negate the benefits and effectiveness of micro-irrigation.

Micro-irrigation systems are generally expensive to install and maintain but are similar in costs to most other advanced irrigation methods. Operational costs will be high due to the need for chemical treatment, filtration, and labor for routine flushing of lines, although lower energy costs and water savings may offset some of this increase. There can also be significant costs associated with the retrieval and disposal of tape/tube and non-biodegradable plastic mulches. A high level of management is required to operate and maintain a micro-irrigation system. Managers require a greater level of training and proficiency than for surface or sprinkler systems.

As a general rule, micro-irrigation systems are less forgiving of mismanagement or poor design than methods that irrigate a much larger portion of the root zone. These problems range from over-irrigation and excessive leaching of chemicals to severe drought, salinity, or nutrient stresses.

Polyethylene micro-irrigation tubing can be physically damaged by a number of mechanical and natural causes. Damage by farm equipment commonly occurs.

2.2.3 Affordable Drip Systems for Smallholder Farmers

In recent years there have been efforts to promote irrigation technologies that have so far been perceived as exclusively for commercial farmers, but which are now available in forms that meet the above-mentioned criteria such as increased affordability, divisibility, rapid payback and improved water efficiency. Chapin Watermatics, International Development Enterprises (lDE), Netafim, and some other actors have made pioneering efforts. All of these have developed and launched versions of drip systems, which are now showing promise for raising the water efficiency, land productivity, and incomes of smallholders (Shah and Keller, 2002). For example, IDE-India promotes drip kits costing almost 80 % less than conventional drip systems and is thus bringing about a shift from subsistence farming to higher value production. This could translate into a doubling of the income of poor farmers,

and in addition to enhancing household food security and improving the nutritional status of farm families (IDE, 2004).

The drip irrigation technology frees the farmer from the limitations of rain-fed farming, enabling him/her to cultivate all year round, grow a wider variety of crops, have higher cropping intensity and do priority farming. Good irrigation technologies and agricultural practices coupled with enhanced participation of the poor in the markets is the key to income generation (IDE, 2004). The drip irrigation systems described below are examples of the most common among the variety of low-cost systems (Postel et al., 2001).

2.2.4 Low Pressure Drip Irrigation

The low pressure system (LPS) is a systematic development of a low cost drip irrigation system. The system is designed to operate at low pressures (30-50 kPa) by taking advantage of the slopes graded into furrow-irrigated fields. Thus, LPS provides an effective low energy and economical upgrade for furrow irrigation. Furthermore, LPS mitigates environmental issues arising from difficult-to-control surface irrigation, nonpoint source pollution, deep percolation of soluble salts and pesticides, erosion and sedimentation of watersheds. The introduction of LPS provides an alternative initial low cost, low energy systems with a multiyear life expectancy, displaying a number of advantages associated with permanent DI and SDI systems.

The major objective of LPS is to provide a one to five year life span irrigation system with water and fertilizer application advantages of DI and SDI (Subsurface Drip Irrigation) systems, but at a lower initial cost. The initial LPS cost is dependent on the sophistication level of the system. Conceptually, LPS is designed to (Phene et al., 2007):

- help growers use existing infrastructures such as leveled fields, water sources and pumps,
- minimize front end investment,
- provide fast return on investment,
- reduce energy cost for pumping and pressurizing,
- move and reuse equipment easily and

- provide low system maintenance and management.

Two additional advantages of LPS could be: 1) low pressure/low flow design suggests that LPS could operate similarly to furrow irrigation by applying water uniformly over 1/4 mile- (400 m)-long rows and thus could potentially replace large Western furrow irrigated acreage and 2) water discharge rates being lower than most soil infiltration rates would not require the use of rigorous high frequency irrigation scheduling (LPS can stay on for longer periods of time without creating runoff and/or deep percolation). It is the purpose of this paper to present and discuss evidence for the applicability of LPS for use in 400 meter long rows and the agronomic benefits of low pressure/low flow irrigation. In addition, the economic benefits of low pressure drip irrigation will be discussed.

2.2.4.1 Components of a typical LPS system

A typical LPS consists of several specific components. Depending on the size of the system, the topography of the site, the soil characteristics, the crop, the water/fertility requirements, the water source, availability and/or quality or the application considered, LPS may vary considerably in physical layout but generally will basically consist of some of the components shown in Figure 2.3, although LPS will often be as simple as the system shown in Figure 2.3. The various components of the system can be added as desired and are divided into: connection to water source, control head works including a fertigation system, field distribution system, dripper line laterals, accessories and installation tools and optional automation and instrumentation (Dowgert et al., 2007).

The headwork of a basic LPS consists of specific components, as shown in Figure 2.3. Field systems may vary considerably in physical layout but generally will consist of the following or some variations of the following components (Dowgert et al., 2007):

a. Air vents: Air vents are a critical component of any hydraulic network. If air is not released, air pockets are formed in the distribution lines, reducing the effective diameter of the pipe. The use of air relief valves at all high points of the LPS is the most efficient way to control air. There are three major types of air vents: (1)

Air/Vacuum Relief Vents, also known as kinetic air valves. These air vents discharge large volumes of air before a pipeline is pressurized, especially at pipe filling. They admit large quantities of air when the pipe drains and at the appearance of water column separation; (2) Air Release Vents are also known as automatic air valves. These vents continue to discharge air, usually in smaller quantities, after the air vacuum valves close, as the line is pressurized and (3) Combination Air Vents, also known as double orifice air valves, fill the functions of the two types of air vents described above.
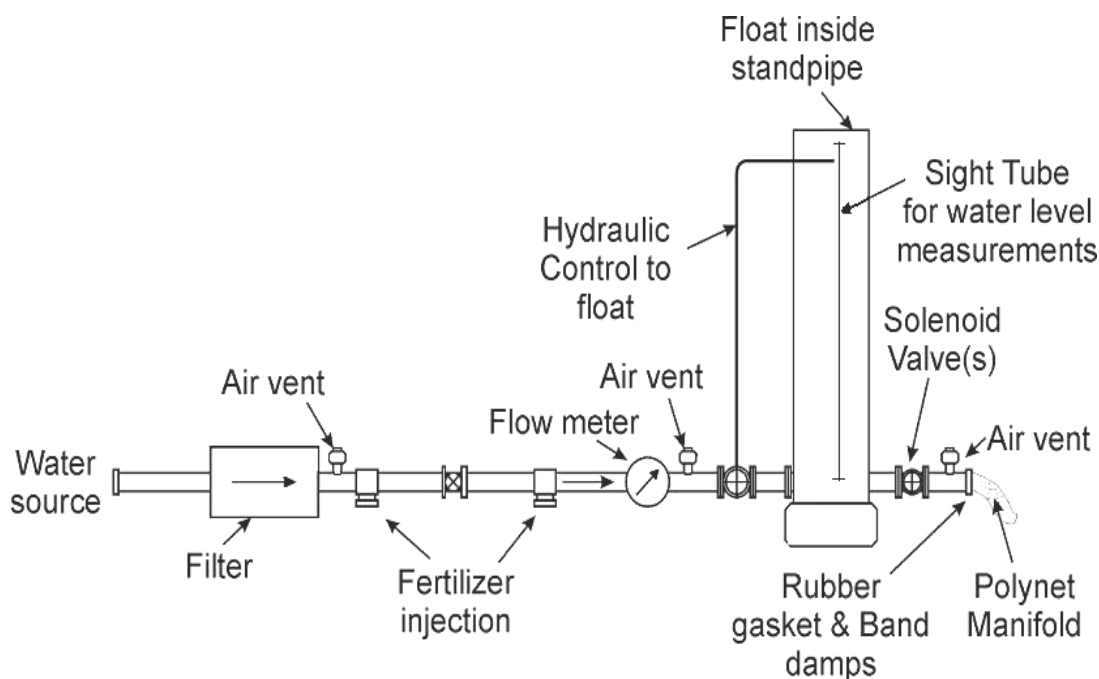
Figure 2.3: Components of a typical LPS system (Dowgert et al., 2007)

b. Filtration: The main purpose of filtration is to keep mainlines, submains, laterals and emitters clean and working properly. Many factors affect the selection of a filtration system. Designers should use the correct equipment for a specific farm water source. With LPS, the choice of a filtration system is further limited by the availability of electrical power and hydraulic pressure. Screen filters and gravity filters (low pressure) have been used successfully with LPS.

c. Flow-meter: Knowing how much water and when it is supplied are critical measurements for correctly operating LPS irrigation. Inline flow meters should record total flow and flow rate.

d. Float Control Valve: The main control valve is regulated by a float, located in the pipe at the present maximum water level. The valve is hydraulically controlled by the float and opens or closes to maintain a constant water level and head pressure on the downstream LPS system.

e. Standpipe: The main purpose for the standpipe is to accurately control the pressure applied to the LPS dripper lines. Typical standpipes are 3.26 m high and 0.3 to 0.76 m in diameter with inlet and outlet flanges. Water level and downstream pressure control are achieved by using a float which activates the float control valve shown upstream of the standpipe as in Figure 2.3. A clear, external water level tube allows the operator to visually determine the water level in the standpipe. Inlet and outlet pipes are connected to the standpipe by bolted flanges. In areas where wind gusts are occurring, the standpipe can be anchored to the ground by three or more steel cable ties.

f. Fertilizer Injector: Fertilizer injection methods range from dripping fertilizers at calculated rates into the standpipe (no available electrical power or necessary pressure) to using fully computerized monitoring and control systems. When electrical power is available, injecting with metering pumps is the most versatile method for injecting chemicals into LPS systems. Automatic time and programmable controllers are usually the best way to control fertilizer injection. When full automation is used, the metering of the fertilizer is programmed for injection during the middle of the irrigation cycle to avoid the line filling time of the irrigation cycle. Injection of chemicals can also be stopped during filter flushing operations. Continuous measurements of pH and EC are also recommended to ensure adequate system performance and to control the pump on or off and/or in the case of accidents and malfunctions.

The field distribution system consists of automatic or manual valves, flexible poly submains/manifolds with lateral connectors, air vents and manual clamps. Figure 2.4 shows a photograph of a typical manifold and lateral setup (the manual valve for

system operation is not visible). Depending on the type of LPS applications, there are several types of thin-wall dripper lines with emitters integrated within the pipe wall that are available for LPS. The available types of LPS dripper lines are based on life expectancy (1-5 years) and types of tillage application. Emitters with different flow path configurations, discharge rates and operating pressure range are presently being used in LPS applications.

Figure 2.4: A photograph of a typical manifold and lateral setup (Dowgert et al., 2007)

Full automation of LPS is available, although strictly optional. Because LPS applies water at a rate usually lower than the soil infiltration rate, high frequency irrigation management is not necessary to prevent runoff and/or deep percolation.

2.2.5 Evaluation Methods

Performance evaluation is the most practical tool to assess the success of any changes in irrigation management. That is why performance evaluation studies have gained significance since the early 2000s. Compared to developed countries, performance evaluation studies are not sufficient in many of developing countries both in the aspects of their number and content. Especially, environmental performance indicators cannot be calculated due to a lack of reliable data. Reasons for low performances can only be determined by performance evaluation. Then, related measures can be taken and overall system performance be improved.

The most significant purpose of performance evaluation is to provide effective project performance through continuous information flow to project management at each stage. Continuous performance evaluation helps project management assess whether or not performance is sufficient. If not, it allows management to determine the required measures to reach desired performance levels. Performance evaluation providing a periodical information flow about the key indicators of an irrigation project is an effective management tool in monitoring irrigation schemes (Bos, 1997; Cakmak et al. 2009). It also facilitates the determination of possible problems and thus improves the performance of irrigation schemes.

The method of evaluation proposed by Merriam and Keller (1978), adopted by FAO (1986), is based on the discharge measurements of a sample of emitters. This sample is selected from four laterals located at the inlet, at a third and two-thirds of the length of the submain and at its downstream end. Four pairs of emitters are selected along each lateral, located at the inlet, at a third and two-thirds of the length of the lateral and at its downstream end. Aspects of this procedure, which can be improved, deserve some comments. On the one hand, the selected locations represent, from the viewpoint of mathematical probability, neither the mean flow of all the unit emitters nor, above all, their variance. On the other hand, no reason is given for the recommendation on averaging out each pair's discharge. This can be justified from a statistical viewpoint if more uniform results are desired, such as in the case of units with two emitters per plant or other special circumstances.

Additionally, the extreme locations in the lateral and submain suggested by Merriam and Keller (1978) provide useful information on head losses in laterals and submain, and it seems unreasonable to disregard their potential contribution to the hydraulic analysis of the unit. A recent approach by Burt (2004) includes a practical methodology for field evaluation. Hydraulic-statistical analysis of drip irrigation units is based on the works of Wu and Gitlin (1975), Karmeli and Keller (1975), Bralts et al. (1987), Kang and Nishiyama (1996) and Valiantzas (1998). Hydraulic analysis of Juana et al. (2002a, b; 2004; 2005) can be considered as a more specific application.

Smajstrla et al. (1997) demonstrates a field technique for evaluating the application uniformity of a drip distribution system. This method used the top 1/6 and bottom 1/6 emitter flow volumes, flow rate, or time to fill a container. The sum of the top and bottom 1/6 of the emitters are plotted on Figure 2.5 to calculate the application uniformity.
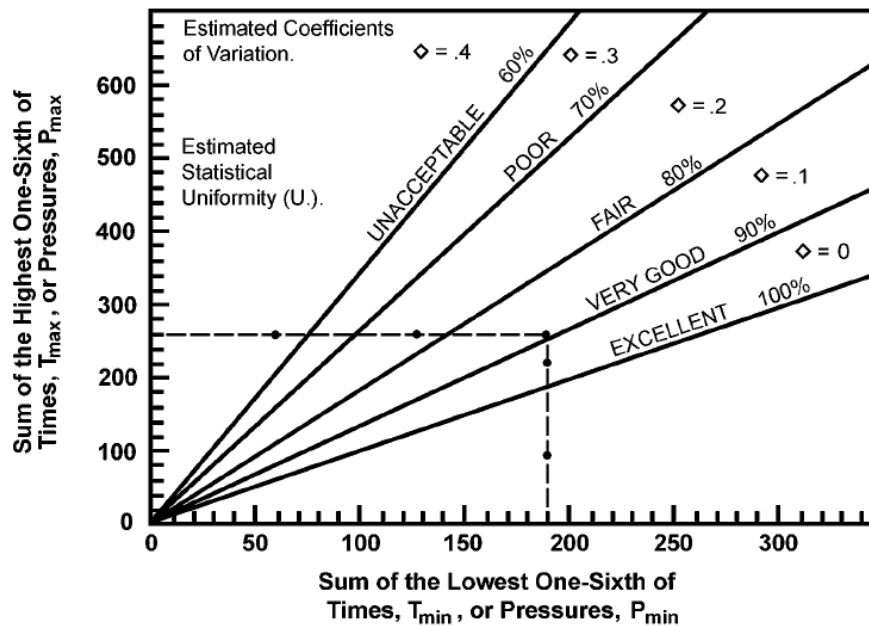
Figure 2.5: Statistical uniformity nomograph (Smajstrla et al., 1997)

An additional method of evaluating the application uniformity of a system is described in Burt (2004). This method uses a distribution uniformity using the average depth of application of the lower quartile over the average depth of application. This method has been used by USDA and NRCS since the 1940s.

Lamm et al. (2002) utilizes this method in calculating the distribution uniformity of drip laterals applying wastewater. Distribution uniformities ranged from 54.3 % to 97.9 % for the tubing evaluated.

2.2.6 Economic Analysis of Drip Irrigation

The most economical irrigation system is that in which water is applied to the fields with the least possible losses and costs. In addition to avoidance of problems resulting from extravagance in using irrigation water, the selection of the most suitable

irrigation system depends on many factors such as: industrial, technological progress, water and equipment costs, irrigation efficiency for each system and availability of labour costs which have a great importance to judge the suitable irrigation system for the site and time according to which costs change, also the costs vary with the design of the system, intensity of use (as dictated by weather), degree of mechanization, water source, mechanical damage and age of the installation. To get an economic evaluation of the irrigation system, the operating costs as well as the additional revenues generated must be estimated accurately.

The irrigation manager should be able to choose the proper irrigation system to keep costs to a minimum. The selection of an irrigation system cannot be made without considering the costs. The designer or manager will try to select the least costly system. The choice of irrigation system should involve both capital or fixed and operating or variable costs. Capital costs are easily identified sums of money which must be paid when installing a system. Operating costs are far less clear and spread over many years. The total costs are classified as fix and variable costs as illustrated in FAO (1992b).

Drip irrigation system comprises main pipe, sub-main pipe, laterals, micro tube, screen valve and control valve. The cost of installing a drip system varies from 780 to 1100 € ha^{-1} depending the quality of the material (Chengappa et al., 2007). The cost of drip installation is lower for widely spaced crops like orchards as compared to vegetables, which are close spaced, since there are fewer lateral pipelines. The number of laterals depends upon the spacing of the crop for which drip irrigation is given. Hence, the wider the spacing between rows, the lower the cost on laterals will be and vice versa. The cost of drip worked on per hectare basis of vegetable crops is to the tune of 800 € ha^{-1}, while for mulberry the investment on drip was 703 € ha^{-1}. The average lifespan of drip irrigation equipment is assumed as 5 to 10 years.

2.3 EXPERIMENTAL PROCEDURE

The focus of this research was to evaluate the uniformity of the low pressure drip system (LPS) and study the consumptive working time for repair, maintenance and laterals retrieving. This section describes methods used to measure the flow rate in the field site, and as well as the calculation the working time costs.

Netafim Germany (the developer and manufacturer of LPS) sponsored this study by installing a low pressure system on a field with five hectares at Federal Research Institute for Rural Areas, Forestry and Fisheries (vTI), Institute of Agricultural Technology and Biosystems Engineering, Braunschweig, Germany [the old name: Federal Agricultural Research Center (FAL), Institute of Production Engineering and Building Research].

2.3.1 Evaluation of the irrigation system

The LPS was installed and commissioned in the summer 2008 and 2009. The technical components include the head unit, the distributor hose and the drip tubes as shown in Figure 2.6.

Head control up to 70 m^3/h. include : double screen filter 3" , water meter 4" , PVC 4" LP valve, float device, glued stand pipe, PVC connection pipes , PVC flanges, screw sand gaskets.

Float control valve (to assure that the system is operated at the recommended pressure and to prevent over flushing): The main control valve is regulated by a float, located in the pipe at the present maximum water level (4 m). The valve is hydraulically controlled by the float and opens or closes to maintain a constant water level and head pressure on the downstream LPS system.

Standpipe (to accurately sustain the required pressure within the system): The main purpose for the standpipe is to accurately control the pressure applied to the LPS dripper lines. Standpipes are 5 m high and 0.3 m diameter with 4" flange inlet connection with 6" outlet.

Water level and downstream pressure control are achieved by using a float which activates the float control valve shown upstream of the standpipe as in Figure

2.6. A clear, external water level tube allows the operator to visually determine the water level in the standpipe. Inlet and outlet pipes are connected to the standpipe by bolted flanges. In areas where wind gusts are occurring, the standpipe can be anchored to the ground by three or more steel cable ties.
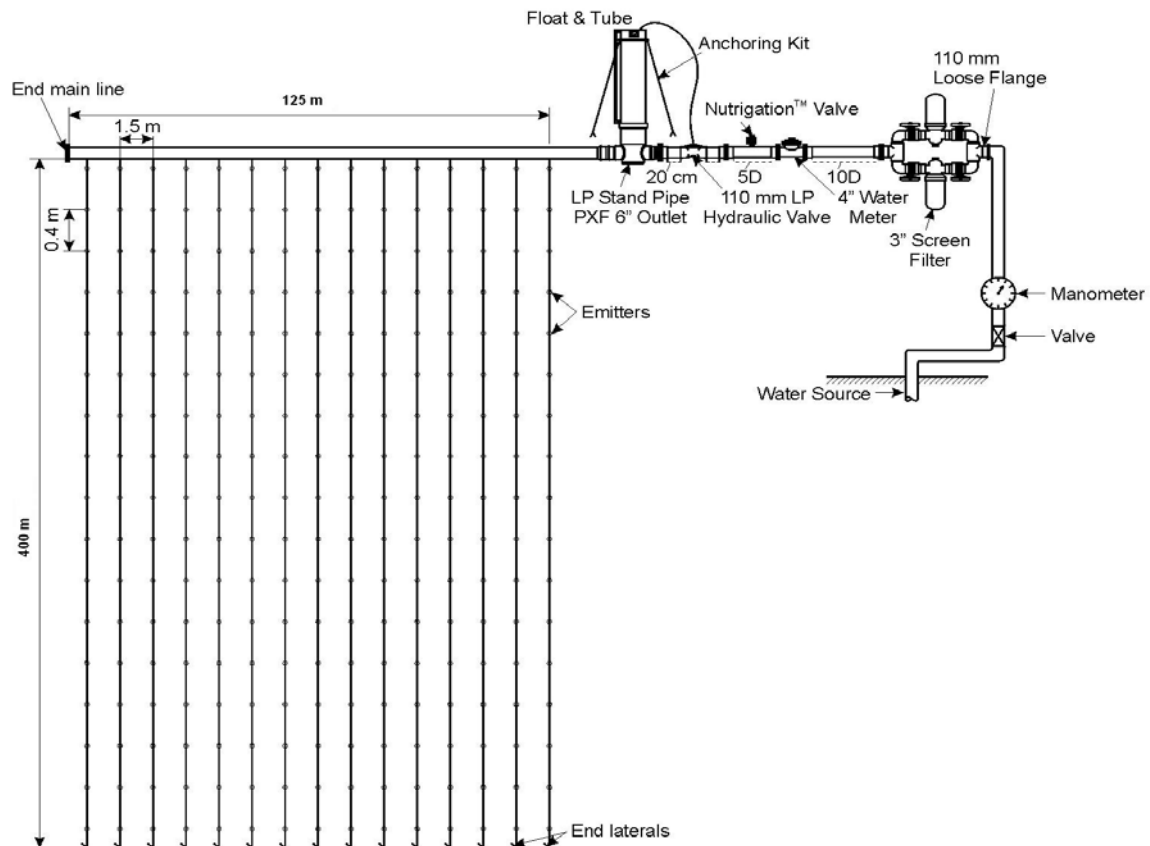
Figure 2.6: Diagram of the LPS components

The field distribution system consists of:

1. Polynet XF™ Water supply and distribution hose with diameter 163 mm and 125 m long consist of lateral connectors,

2. Air vents and manual clamps (the most efficient way to control air).

3. Drip lines with 22 mm and 400 m long are connected to the distributor hose at a distance of 1.5 m. these lines are conventional drip tubes include Dripnet PC™ with a flow rate of 0.6 lh^{-1} per emitter and an emitter distance on the tube of 0.4 m. the terrain inclination in the flow direction of the water is 1 m.

2.3.1.1 The evaluation method

The evaluations have been carried out according to Merrian and Keller (1978) recommendations, which have been followed in later works of other authors (Keller and Bliesner, 1990; Ortega et al., 2002).

In order to carry out the evaluation, the first step is to choose the standard representative subunit from the studied operational irrigation unit, then determine the flow discharged by the emitters.

Three laterals are taken into account in the study. In each lateral, three emitters are selected as a control point and repeated every 50 m along the lateral as shown in Figure 2.7. The emitters are evaluated in each of the control points.
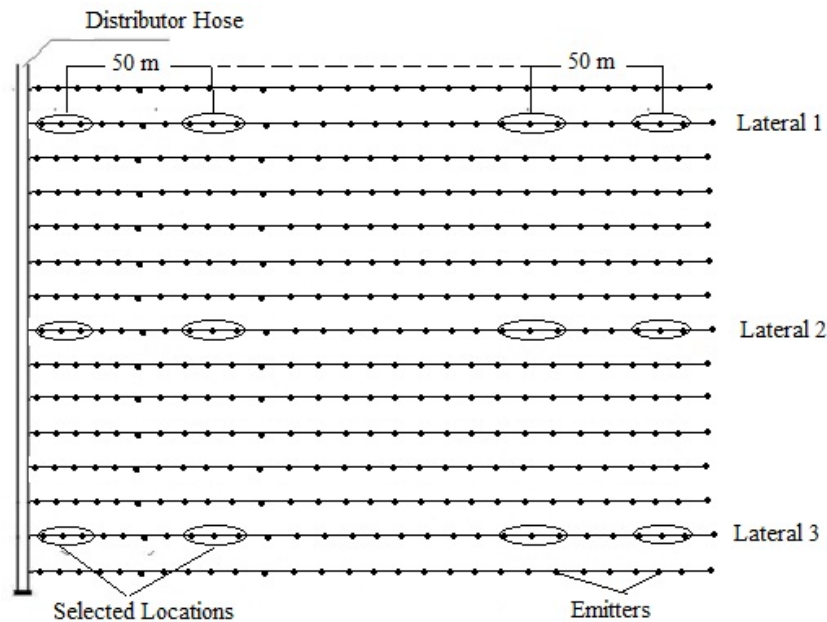
Figure 2.7: Diagram of the localization of control points in the test unit

The discharged flow in every control point is determined by measuring the volume of water discharged by every emitter during a definite time. Measuring time is usually 30 min, so that the experimental errors committed are minimised. Pressure was measured with gauges at the beginning and the end of each lateral. One-litre measuring cylinders were used to collect the water from the emitters. The measurements were repeated tree times for each season.

2.3.1.2 Evaluation parameters

2.3.1.2.1 Emission Uniformity (EU)

This is determined as a function of the relation between average flow emitted by the 25 % of the emitters with lowest flow and the mean flow emitted by all the control emitters, such as equation [1] shows:

$$EU = \frac{\overline{q}_{25\%}}{\overline{q}_a} \times 100 \qquad (ASAE, 1996a) \qquad [1]$$

Where,

EU: emission uniformity (%),

$\overline{q}_{25\%}$: average of the 25 % lowest values of flow rate (l/h),

$\overline{q}_a$: average flow rate (l/h).

The evaluated system is classified according to the EU values obtained, following Merrian and Keller (1978) and ASAE, 1996a; 1996b criterion and that by the IRYDA (1983), which is more demanding, as Table 1 shows.

Table 2.1: System classifications according to Emission Uniformity values (EU)

EU (%)	Classification Merriam and Keller (1978) and ASAE, 1996a; 1996b	Classification IRYDA (1983)
< 70	Poor	Unacceptable
70 – 80	Acceptable	Poor
80 – 86	Good	Acceptable
86 – 90	Good	Good
90 – 94	Excellent	Good
> 94	Excellent	Excellent

2.3.1.2.2 Absolute Emission Uniformity (EUa)

This is defined by Keller and Karmeli (1974) and it considers not only the possible effects derived from the lack of water in certain points of the plant zones, but also the excess produced as a consequence of the application heterogeneity of the system. Its expression is exposed in equation [2].

$$EU_a = 0,5 \times \left[\frac{\overline{q}_{25\%}}{\overline{q}_a} + \frac{\overline{q}_a}{\overline{q}_{12.5\%}} \right] \text{(Keller and Karmeli, 1974)} \quad [2]$$

Being: $\overline{q}_{12.5\%}$ average flow perceived by the 12.5 % of plants which perceive the highest flow in the test subunit.

2.3.1.2.3 Flow Variation Coefficient (CV$_q$)

Flow Variation Coefficient is determined as related to the typical deviation of flow data and mean flow, such as is described in equation [3]. It is used in order to characterize water uniformity application, following the classification criterion shown in Table 2.2.

$$CV_q = SD / \overline{q}_a \qquad \text{(ASAE, 1996 b)} \qquad [3]$$

Being: SD: standard deviation of flow (l/h)

Table 2.2: Localized irrigation subunits classification according to CV$_q$ (ASAE, 1996 b)

CV range (%)	Classification
Below 5	Excellent
5 to7	Average
7 to 11	Marginal
11 to 15	Poor
Above 15,	Unacceptable

2.3.2 Measurement of the Consumptive Working Time

The study was concentrated on the consumptive time for repair and maintenance required to the laterals during the growing season. In addition, the consumptive time for the laterals retrieving before the harvesting to calculate the costs and to find the problems may occur during this operation.

After the drip system was installed, two persons were needed to maintain and repair the lateral bores and cracks by cutting these parts and using flare connectors

(coupling or fittings) to connect the two lateral parts. Each worker used a stopwatch to calculate the consumptive time.

At the end of the season for corn, the installed laterals must be retrieved before the harvesting because the harvesting procedure will destroy the tube. The machine manufactured by Netafim (Figure 2.8) was used to collect or retrieve all laterals from the field. This machine requires a tractor and two workers.

A hydraulically driven reel is mounted to the rear of a trailer and an operator must manually overlook the operation.

The procedures for retrieving drip lateral from the field vary from grower to grower. But before retrieving the lateral, it must be make certain that there is no crop interference, and that the laterals have no water in them.

Figure 2.8: Retrieval machine powered by a tractor

Before the retrieving, the team must first disconnect the laterals from the PolyNet distributor hose manually (connectors (fitting) between distributor hose and laterals (Figure 2.9)).

Figure 2.9: Connectors between PolyNet distributor hose to laterals

The drip lateral retriever remains at the field edge during operation. To operate the retriever properly, the following steps are suggested (Barreras, 2000):

1. Install one empty plastic roll on the retrieval

2. Stretch the lateral to the spring-loaded flap, insert the end of the lateral into a hole by the roll side, and coil the end of lateral on the roll.

3. Start tractor engine and adjust the retrieval hydraulic motor speed to wind drip lateral. Since the other end of drip lateral is open, water in the drip tapes is squeezed by the flap and extracted from the tape.

4. After drip lateral is retrieved, secure the exposed lateral end on the roll and then move the retriever to the next and repeat the steps.

All operating time were measured according to Sourell et al. (2010) and the labour costs were calculated according to KTBL (2009).

2.4 RESULTS AND DISCUSSION

2.4.1 Uniformity of Drip System

2.4.1.1 Performance uniformity of the unused laterals (New)

Uniformity evaluation parameters for the new LPS lateral according to ASAE EP458 method made by Netafim working team (Dowgert et al., 2007). The experiment was made with the same laterals which described in our study with 80 m laterals length and 30 kPa for pressure. The mean value for emitter discharge in unused irrigation laterals were 0.625 l.h-1 with standard deviation ± 0.015 l/h (Figure 2.10).
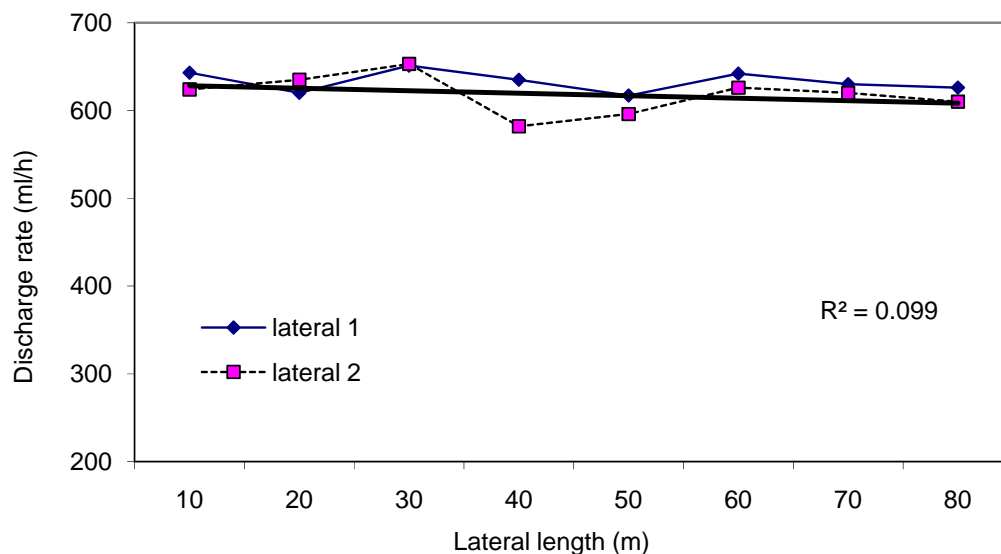
Figure 2.10: Discharge rate of selected emitters for the first season (new system, Dowgert et al., 2007)

Uniformity parameter values in 2 new irrigation laterals were similar. The highest mean values, EU = 99, and EUa = 98.5 % and the lowest were 98 % for each other. Emitter performance for each of the 2 new irrigation laterals was < 0.2, implying that there was no uniformity problem originating from hydraulics (Dowgert et al., 2007). The coefficients of variation of flow rates were 0.02 and 0.04, it was classified as excellent during the entire experiment in the irrigation system that in the first season.

2.4.1.2 Performance uniformity of the used laterals

The performance parameters of the installed drip system are shown in Table 2.3 and Figures 2.11 and 2.12. The operating pressure of system was 40 kPa during the 2nd and 3rd growing seasons.

2.4.1.2.1 Uniformity of discharge rate

Mean discharge rate of all emitters was 0.616 and 0.578 l/h for the 2nd and the 3rd season, respectively. Figure 2.11 shows that most emitters operate close to the mean discharge rate with standard deviation ranged from ± 0.05 to ± 0.08 l/h. However, the three laterals showed almost even discharge rates. On the other hand, Figure 2.12 shows that some partial plugging of emitters more than 1st and 2nd seasons led to high variation between the emitters' flow with high standard deviation (from 0.086 to 0.115 l/h).
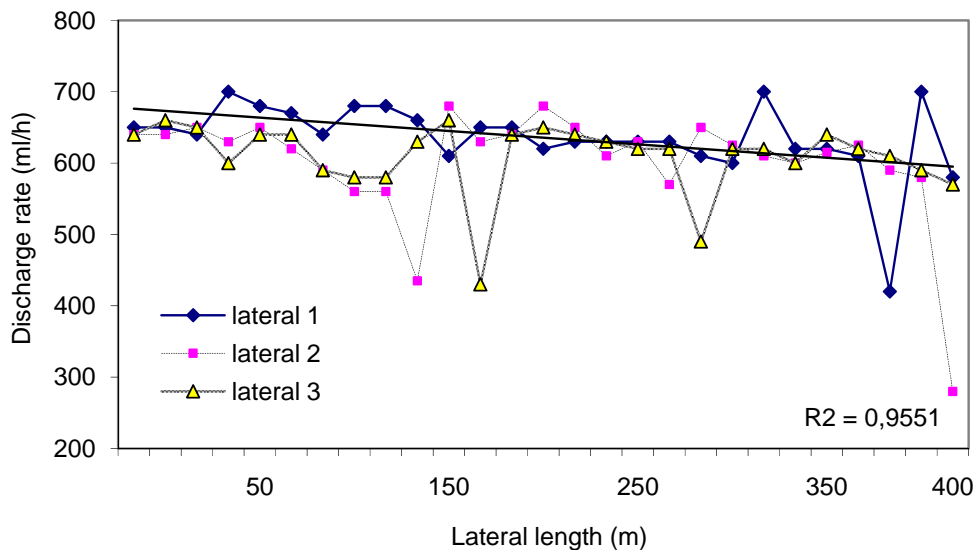
Figure 2.11: Discharge rate of selected emitters for the second season

According to the data plotted in Figures 2.10, 2.11, and 2.12 the mean flow rate of the used laterals was lower than those of the new one. The used laterals, probably the internal spiral layer of the laterals, stretched during the lateral installation or the retrieving operation at the end of last the season, which led to decreased discharge. In addition, some emitters the partially clogged (Safi et al., 2007).
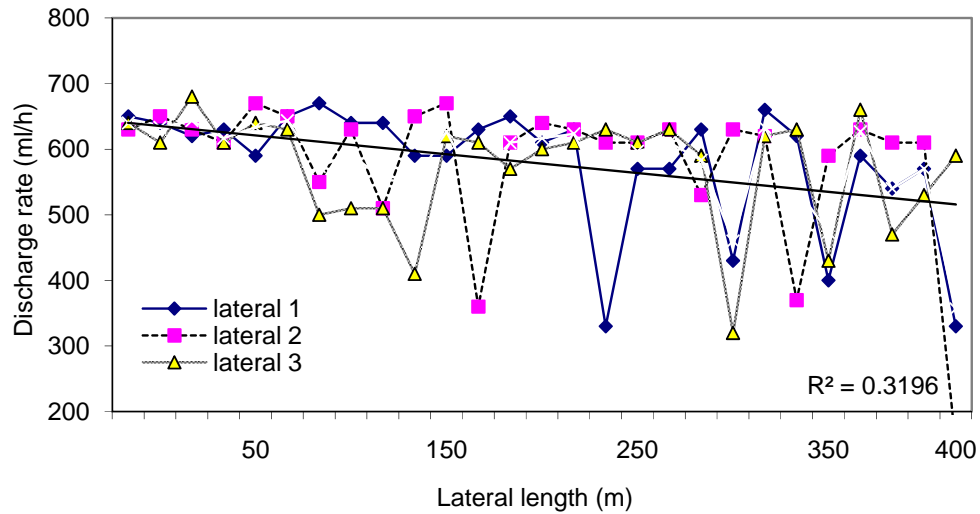
Figure 2.12: Discharge rate of selected emitters for the third season

2.4.1.2.2 Distribution uniformity

Uniformity evaluation parameters and the variation observed in EU and EUa for the 2nd and the 3rd seasons are indicated in Table 2.3. The emission uniformities for all three laterals during the 2nd season ranged from 84.9 to 89.7 %, meaning they were completely good according to Marriam and Keller (1978) and ASAE 1996, and ranged between acceptable and good according to IRYDA (1983) for both EU and EUa.

In contrast, the emission uniformities were determined for the 3rd season (Table 2.3) where, the EU and EUa values were 77.3 and 82.5 % respectively. These values classified the system's uniformity between poor and acceptable for EU and between acceptable to good for EUa (ASAE, 1996 and IRYDA, 1983). In addition, by the partial clogging of some emitters, these results probably influenced some defects occurring during the retrieving operation at the end of last the season.

Table 2.3: Distribution uniformity parameters for three laterals during the two growing seasons

| Distance from inlet (m) | Mean emitter discharge rate (means, l/h) | | | | | |
| | Second season | | | Third season | | |
	Lateral 1	Lateral 2	Lateral 3	Lateral 1	Lateral 2	Lateral 3
20	0,647	0,643	0,650	0,636	0,637	0,643
50	0,683	0,633	0,627	0,624	0,643	0,627
100	0,666	0,570	0,583	0,650	0,563	0,507
150	0,640	0,582	0,573	0,603	0,587	0,545
200	0,633	0,656	0,643	0,630	0,627	0,593
250	0,630	0,603	0,623	0,490	0,617	0,623
300	0,637	0,628	0,577	0,573	0,593	0,510
350	0,617	0,613	0,620	0,537	0,553	0,573
400	0,567	0,483	0,590	0,480	0,543	0,530
Average	**0,636**	**0,602**	**0,609**	**0,580**	**0,581**	**0,573**
SD[*] (l/h)	**0,054**	**0,080**	**0,051**	**0,095**	**0,115**	**0,086**
CV_q	**0,08**	**0,13**	**0,08**	**0,16**	**0,20**	**0,15**
EU (%)	**89,8**	**84,9**	**89,7**	**78**	**75,2**	**78,6**
EUa (%)	**89**	**87,6**	**89,3**	**83**	**81,6**	**83**

* SD. Standard deviation.

2.4.1.3 Flow Variation Coefficient (CV_q)

The value for CV_q used in these calculations was taken from field estimated variability. The low CV_q indicated good performance of the system throughout the cropping season. The coefficients of variation of flow rates were 0.08 to 0.13 during the second season and ranged from 0.15 to 0.20 during the third season (Table 2.3). Taking into account ASAE (1996 b) classification, CV_q was marginal during the entire experiment in the irrigation system that in the second season. In the third season, the CV_q value was unacceptable for most of the experiment. Similar results were estimated by Patel and Rajput (2007) for the in-line labyrinth type dripper was

reported to between 0.046 and 0.066, indicating a good performance of the drip system. The problem must have been due to the clogging of some emitters. These results agree with those of the emission uniformities.

2.4.2 Consumptive Working Time

The installation working time of the drip system per hectare was calculated and plotted in Figure 2.13. There is no difference between the installation time spent for the new and the reused system (reused means the average data for both second and third season), where the installation time for the head station and distribution hose was 1.04 and 1.05 h ha^{-1} respectively. On the other hand there is a small increase in the reuse laterals' installation time (from 6.9 to 7.56 %). The reason for this increase was some splices or fittings which hindered the installing machine and took some time to repair.
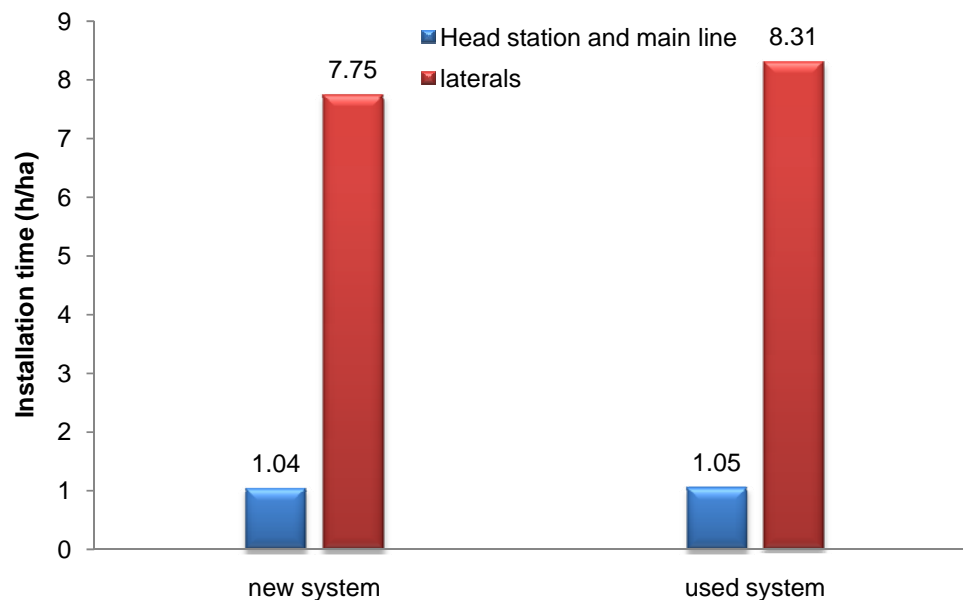
Figure 2.13: The installation working time of the drip system per hectare

Figure 2.14 shows the repairing time and number of problems for the three seasons (repairing time means the summation of all repairs time during the season). There is a big difference between the new and the reused systems in the time spent on repairs and their number, where the number of repairs for the reuse systems was more

than 8 to 12 times than the number of repairs for the new one. The time spent on repairs was 0.52, 1.04 and 3.12 hha^{-1} for the three seasons respectively. It was observed that the repairing time was increased each season because of bores and laterals creaks which occur during the retrieval operation at the end of each season.
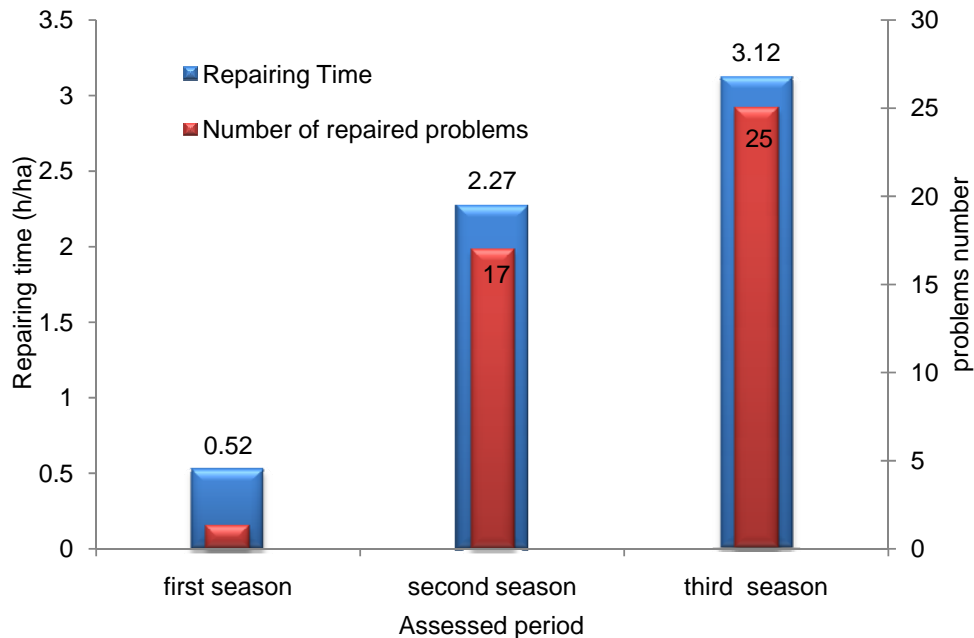
Figure 2.14: Spent time and the number of repairing problems for LPS laterals during three cultivation seasons

At the end of each season especially for the annual crops, the drip system had to be removed from the field before the harvesting. The system either had to be laid out on another field (in this case all drip system must be removed) or stored until needed again (in this case only the laterals must be retrieved). The data plotted in Figure 2.15 shows that there is no difference between the time spent in removing the head station and main line in both new and reused system (reused means the average data for both second and third season). However, there is a small increase in the spent time for the reused laterals (7.25 %) vs. the new one.
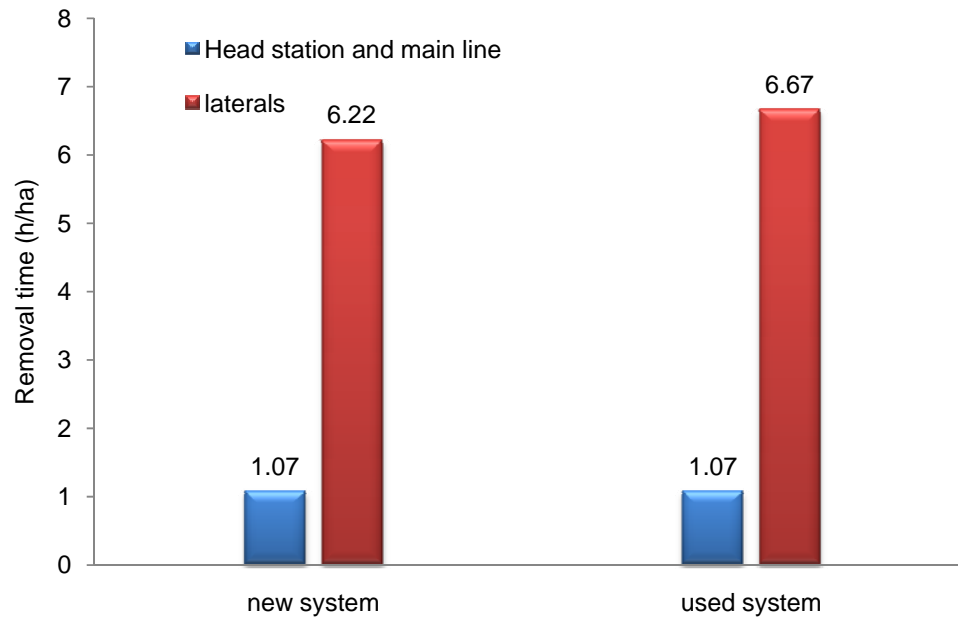
Figure 2.15: Spent time in removing the system during 1st season (new system), 2nd and 3rd seasons (used system)

This increase is caused by the fittings' problems, where: 1) leading to stop the retrieving machine for some time (made rewinding the laterals difficult), 2) the fitting could fail in dividing the lateral into two pieces, so had to be repaired and put back to work, and 3) sometimes the fitting stopped between two plants and can prevent the lateral retrieving. All of these reasons lead to an increase the time needed for removing laterals.

2.4.3 Cost Estimation of Drip Lines Repairing and Removing

The total costs of laterals repairing and retrieving are shown in Figure 2.16. The repairing of laterals including the fitting price, the labour costs and the retrieving costs include the cost of tractor, retrieving machine, and labour. The fittings price and rent of tractor and the retrieving machine according to Netafim list price 2009 and the work-hour value according to KTBL (2009).

A comparison between repairing the laterals and retrieving of both the new and reused systems (Figure 2.16) showed that the repairing cost for the reused laterals was 6.55 and 5.12 times higher than the new one. At the same time there is a small

difference in retrieving costs between the three seasons. The results caused by the difference in working time was explained before (Figure 2.14 and 2.15)
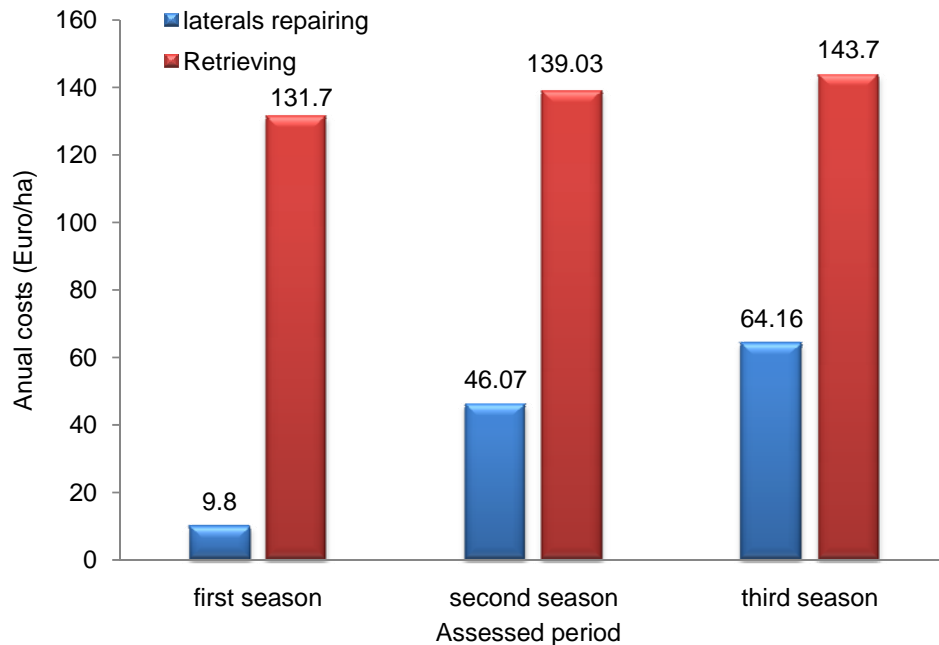
Figure 2.16: The total costs of repairing and retrieving the laterals (€ ha^{-1})

2.5 CONCLUSION

LPS is a well researched system for drip irrigation, typically available for flood irrigated crops. There are significant agronomic advantages to using a low pressure, low flow drip system specifically related to greater lateral water movement in the soil and a better air-water ratio. These advantages translate into measurably improved water use efficiency when compared to flood irrigated crops and energy savings compared to flood and sprinkler irrigated crops.

Poor system distribution uniformity is caused by manufacturing variability, emitter blockage and wear and tear. Emitter clogging can be addressed by cleaning the emitters. Also the repairs will immediately improve the field distribution uniformity.

Over time, wear and tear will then become the main problem (e.g., damage which occurs during the lateral retrieving at the end of the last season) adds to performance variability. Field defect variation estimates the effect of blockages and wear and tear on distribution uniformity by comparing emitter emission uniformity to manufacturing variation. The coefficient of variation due to blockages, wear and tear is

Cv_{defect} = 0.34 (Barber, 2006). This is at least 5 times, and probably more like 8 to 10 times, the variation that would be expected compared to new emitters.

Repeated reuse of the drip-line leads to a decrease the distribution uniformity and increase in costs, where the distribution uniformity decreased by 10.5 and 21.6 % for reusing the laterals in the second and third year respectively. Moreover, the cost of repairing laterals was more than 5 and 6.5 times for both the 2nd and 3rd season. It was observed that the lateral removal needed to be executed with care, otherwise there is a risk of stretching, especially if it is retrieved in the mid-afternoon. Stretching the laterals will cause non-uniformity because it increases the emitter spacing, causing the flow rate to decrease. Also, if stretching occurs, the lateral's wall becomes thinner, meaning it could burst under field conditions. The laterals' removal requires intensive labour because the work team must first undo the tail-ends of the drip lines that are going to be retrieved in order to flush the water out.

From the previous results many potential problems or disadvantages to drip lines retrieval can be observed:

1- labour and maintenance is more intensive,
2- risk of mechanical damage to lateral especially if it is reused,
3- increased management skills and experience are needed,
4- increased retrieval costs season after season.

All of the last disadvantages agree with Barreras (2000) and Burt and Styles (1999).

In addition there is another serious problem known: the direct impact of plastic wastes on the environment. Laterals are produced from PVC or PE which are produced from petroleum, a limited resource. The PVC and PE take more than 50 years to degrade, and when burned, release the carbon dioxide into the atmosphere leading to global warming.

Environmental problems caused by petroleum-based plastics have led to interest in alternatives made from biodegradable polymers (bioplastics). So we think about using the bioplastic materials to produce the drip tube. This biodegradable tube can be used for one season and it can be biodegraded at the end of the season without retrieval required or any bad effects on the environment.

A series of studies will be done in the next chapters to identify the properties of some bioplastic materials and the possibility to use them as biodegradable drip tubes for developing and managing micro irrigation systems.

3. BIODEGRADABLE PLASTIC

3.1 INTRODUCTION

In the second part of the last century, plastics experienced a huge surge in demand which by far surpassed the total production volume of steel. Plastic turned into the material of industrial progress and modern consumption and displaced, to some extent, traditional materials like steel, aluminum, paper and glass.

Today's consumers are informed about environmental problems in which waste management did not yet reach a corporate consensus in public. The public wants to see eco-friendly, recyclable or degradable materials, and the abundance of plastic waste seems to be a major problem area.

Research has been working for a few years to produce plastics from renewable materials, and the development of new methods and materials costs a lot of time and money. Furthermore, even bio-plastics are now produced in small quantities, which makes their production relatively expensive (materials from renewable raw materials cost about two to three times as much as standard plastics) (FNR, 2010). Of the total world plastics market, the bio plastic's share of around 860,000 tonnes per year is still negligible, but has huge potential, as these plastics are suitable for waste management to close circular flows, save oil reserves, stabilize CO_2 emissions and offer consumers an environmentally friendly option.

Research and development regarding biodegradable plastics are continuously advanced and some materials such as starch, cellulose, and lactic acid found abundantly in agricultural/animal resources are at the stage where they can be manufactured in fairly large amounts and processed into marketable products. Biodegradable plastics are best used in the making of products where biodegradability is of intrinsic value.

One key target market for biodegradable plastics has been agriculture. Not only are biodegradable products being used by agriculture, but certain types of biodegradable materials are being manufactured from agricultural commodities such as corn starch and dairy products (Demirbas, 2007). 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. At the present, biodegradable plastics can be used in various agricultural applications, such as flowerpots, which completely biodegrade in the soil while functioning as a soil conditioner, leaving biomass. One of the main agricultural applications however, concerns biodegradable mulching films (Briassoulis, 2004). Several biodegradable mulch and low-tunnel films have been developed for protected cultivation (Scarascia-Mugnozza et al., 2006). The use of biodegradable films eliminates the need for mechanical removal and thus eliminates the plastic waste management cost and the relevant environmental problems due to the current practices of uncontrolled burning or burying of this waste in soil. After their use, biodegradable films that may be confirmed beyond any doubt to be biodegradable in soil can be ploughed in soil along with the plant remains (Briassoulis et al., 2008).

3.1.1 Problems

As concluded in the previous chapter, two big potential problems can be observed:

1. The environmental problem which is known as direct impact of plastic wastes on the environment. Laterals, produced from PVC or PE, are produced from petroleum which has limited resources. The PVC and PE take more than 50 years to degrade, and when burned release the carbon dioxide into the atmosphere, leading to global warming.

2. The high costs for reusing the petroleum drip lines several times, which requires removal before harvesting by hand or machines each season. The high costs come because 1) labour and maintenance are more intensive, 2) risk of mechanical damage to lateral especially if reused, 3) increased management skills and experience are needed and 4) increased retrieval costs season after season.

Environmental problems caused by petroleum-based plastics have led to interest in alternatives made from biodegradable polymers (bioplastics).

3.1.2 Objectives

Since the irrigation tapes/laterals are usually removed at the end of the crop season, especially for the vegetables, it would be desirable to use biodegradable irrigation drip lines that will allow roto-tilling or ploughing of all biodegradable materials together after the end of the cultivation season, without the need to remove the tapes/pipes.

So, the objective was to test biodegradable materials to produce drip tubes that will not need to be collected and disposed of after use but will decompose in the soil without any adverse environmental effect. This will eliminate the disposal costs, will be environmentally friendly and possibly, at least partially, the materials used may be based on renewable raw resources.

A series of studies were done in this chapter to identify the properties of some bioplastic materials and the possibility to use them as biodegradable drip tubes for developing and managing micro irrigation systems.

This objective was as follows:

1. Study the effects of the environmental conditions on some bioplastic materials (temperature, moisture content, soil types, and fertigation).
2. Definition of specifications for the bioplastic materials to be developed based on requirements imposed by conditions and environmental impact aspects.
3. Development and testing some biological and chemical methods to use with the last irrigation time as degradable factors which add to pre-degradation because the drip lines can hinder the machine during harvesting.

3.2 LITERATURE REVIEW

This literature review focuses on bioplastic materials and their advantages, the biodegradability of bioplastics, methods of degradation and the field of bioplastic applications.

3.2.1 Background Information on Petroplastics and Biodegradable Plastics

Petroplastics can be divided into three categories: Thermoplasts, duroplasts and high performance plastics. Mouldable thermoplasts are responsible for 70 % of the worldwide plastic consumption represented by polyvinylchloride (PVC), polystyrene (PS) and polyethylene (PE). These thermoplasts demonstrate the highest substitution potential for bioplastics (British plastic federation (BPF), 2009). Duroplasts are irreversible, non-moldable plastics, which are represented by polyurethane and epoxyresins. High-performance plastics like polyamide or polyethylene terephthalate are made of a combination of different polymers. A pre-requisite for modern retailing is the hydrophobic and inert character of thermoplasts. During manufacture and post-consumer disposal, petroplastics seem to be more ecologically friendly materials than biologically based polymers as they can be incinerated with heat recovery or mechanically recycled to utilize the energy content of the plastics. Petroplastics used in agricultural products have long been bioassimililated by combined peroxidation and biodegradation. Most contain transition metal prooxidants with the peroxidation products being biodegradable (Feuilloley et al., 2005).

Polylactide acid (PLA), starch and poly-hydroxyalcanoate (PHA) are the most used representatives for biodegradable plastics. They are non-toxic and produced from renewable resources (Gupta and Kumar, 2007). They feature a high degree of polymerisation and high crystallinity. These properties make them highly competitive with non-biodegradable petroplastics. Nowadays, production is either based directly (in plants) or indirectly (in bacteria) on photosynthetically produced precursors, at prices which are becoming competitive with those of petroplastics.

3.2.2 Bioplastics

Plastics are very rugged, can be processed in many ways and are also lighter and cheaper than most other materials. They are therefore the first choice in many industrial and commercial applications.

Of the 53.2 million tonnes of plastics produced in Europe, about one third comes from Germany. They are required not only for packaging (27 percent) and building materials (27 percent), but also for automotive and furniture manufacturing and in the electrical industry and household goods manufacturing. Correspondingly, consumption is increasing continuously, from 60 million tonnes world-wide in 1980 to an estimated 260 million tonnes in the year 2010 (FNR, 2010; Khan et al., 2006). However, not all plastics are alike. Whereas duroplastics remain solid forever after hardening, thermoplastics can be formed by heating. These thermoplastics are the most widespread, with a market share of 80 percent.

Bioplastics is the designation for innovative plastics manufactured from regenerative raw materials. They can replace the previously used fossil plastics and plastic materials in many applications. Creative scientists and technicians are currently not only engaged in adapting them to conventional machines, but are also discovering new uses. For example, packaging materials, disposable cutlery and flower pots made of bioplastics are already available.

Depending on the requirements, some bioplastics guarantee a long period in use, whilst others are biodegradable and degrade to form their naturally present, non-toxic initial components (Briassoulis, 2006). Microorganisms such as fungi, bacteria and enzymes ensure that only water, carbon dioxide and biomass remain, which are utilised naturally. Regardless of whether bioplastics go to biogas plants, are used to produce heat or are composted after use, materials gained from plants only release as much CO_2 as they withdrew from the atmosphere during their growth phase.

However, bioplastics do not only have ecological advantages. They also help to conserve fossil raw materials and reduce our dependency on mineral oil, an opportunity which we should not disregard in times of constantly rising prices for fossil raw materials for economic reasons (Alvarez et al., 2006).

In the interest of renewable economic cycles, the development of bioplastics is currently in full progress. This wasn't always so, even though they played an important part at the beginning of the history of plastics. The first mass-produced plastic was gained by the chemical transformation of natural substances.

Around 1923, the mass production of cellophane began, another plastic made of renewable resources. However, the production of the clear and crackling cellulose film is expensive and therefore strongly receding. Another property of this cellulose product is a disadvantage: Due to its sensitivity to water and permeability to water vapour, is must be coated with polyvinyl chloride and thereby loses its biodegradability (Singh and Sharma, 2008).

Finally, large-scale production of today's standard plastics polyethylene (PE) and polypropylene (PP) was successful from 1956. With the industrial manufacture of plastics, many methods were developed through the years to process those (Lorcks, 2006).

Research and development into bio-plastics was only resumed from 1980. Renewable resources, closed cycles of matter and suitability for composting then became decisive arguments (Kyrikou and Briassoulis, 2007). A leap in patenting activities is an indicator of the massive research and market perspectives in the plastics industry in the field of modern bioplastics.

3.2.2.1 Advantages of Bioplastics

Bioplastic has many advantages can be concluded (Siracusa et al., 2008):

- are produced from renewable raw materials
- have a relatively long stability depending on their composition
- can be degraded biologically
- can be decomposed into non-toxic source materials
- are CO_2-neutral
- Economic use can be made of overcapacities in agriculture, which also makes ecological sense.

- Forestry and agriculture acquire alternative possibilities for production and income through renewable raw materials. (Siracusa et al., 2008; www.european-bioplastics.org).

Advantages over petroleum based plastics (Siracusa et al., 2008):

- Renewable annual raw material source
- Products produced are compostable within 45 – 120 days vs. thousands of years for petroleum based products. The degradation process of the item is temperature, humidity and thickness dependent
- Converting corn to the plastic resin requires 20 % to 30 % less energy
- PLAs' good rigidity allows them to be a possible replacement for polystyrene
- Are not price sensitive
- PLA resins are exempted on the list of synthesized resins (PP, PS, etc) which are subject to environment tax
- Has lower water absorbance (0.13 %)
- High heat resistance
- Low taste transfer
- Oil resistant.

3.2.3 Biodegradable Polymers Classification

A vast number of biodegradable polymers are chemically synthesized or biosynthesized during the growth cycles of all organisms. Some micro-organisms and enzymes capable of degrading them have been identified (Bordes et al., 2009). Figure 3.1 proposes a classification with four different categories, depending on the synthesis:

- Polymers from biomass such as the agro-polymers from agro-resources, e.g., starch, cellulose,
- Polymers obtained by microbial production, e.g., the polyhydroxyalkanoates,
- Polymers chemically synthesized using monomers obtained from agro-resources, e.g., poly (lactic acid),
- Polymers whose monomers and polymers are both obtained by chemical synthesis from fossil resources.

Of these, only categories (a)–(c) are obtained from renewable resources. We can sort these different biodegradable polymers into two main families, the agropolymers (category a) and the biodegradable polyesters (categories b–d), also called biopolyesters.
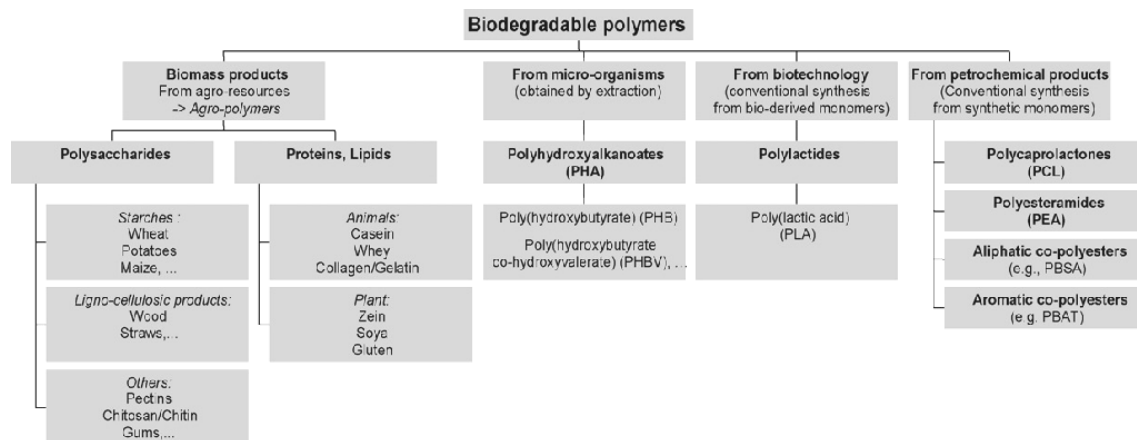
Figure 3.1: Classification of the biodegradable polymers (Bordes et al., 2009)

3.2.4 Bioplastic Raw Materials

Although bioplastics can be manufactured from many vegetable raw materials and starch is gaining a key position, cellulose and sugar also have certain significance.

3.2.5.1 Starch

Starch is the most interesting raw material for the development and production of bioplastics. It is not only available everywhere, but also offers a particularly good cost-performance ratio. It is stored in numerous plants in the form of microscopic grains. Whereas maize, wheat and potatoes are the most important supplies of starch in Europe, America and South Africa, tapioca is the main source in Asia. Industrial processes separate by-products such as proteins, oils and vegetable fibre so that only highly purified starch remains. Starch-bearing flours are also well suited for the production of bioplastics and biodegradable products (Zhan et al., 2009; Serrentino et al., 2007).

Chemically, starch, as well as cellulose, belongs to the carbohydrates. It consists of two components. The branched, polymerised amylopectin, the main

component of starch, surrounds the non branched amylose. Over 45 million tonnes of starch are produced industrially world-wide, of which almost 10 million tonnes in Europe and almost 2 million tonnes in Germany (Lorcks, 2006). Almost half of this now flows into technical applications and a high proportion of the produced starch is directly converted in continuous biotechnical processes into glucose (Briassoulis, 2007).

For the production of bioplastics, not only the starch polymer is important, but also its monomer, glucose is used. In biotechnical and/or chemical processes, this is converted into thermoplastic polyester and polyurethane. The milled products flour and semolina, as well as pellets or powder made from grain, potatoes or maize, are also particularly economical raw materials for certain applications. The by-products of the starch industry can also be used as raw materials for fermentation processes (Martin et al., 2008).

3.2.5.2 Cellulose

Cellulose is contained in large quantities in most plants. In cotton the proportion is about 95 %, 40-75 in hardwood and 30-50 % in softwoods. Apart from wood, cellulose is the most significant renewable resource in terms of quantities - around 1.3 billion tonnes are annually harvested for technical applications world-wide. However, chemical processes are necessary to separate the cellulose fibres from undesired by-products such as lignine and pentoses. The cellulose end product is used mainly to manufacture paper and cardboard, but also textiles such as viscose fibres (Mohee et al., 2008).

Cellulose also has potential in the production of plastics. For example, cellulose esters are amorphous thermoplastics which contain special plasticisers or are modified with other polymers. They are characterised by high toughness and are often used as polymer components in compounds with other bioplastics (Briassoulis, 2007).

The transparent cellophane film used for packaging is also a cellulose product. However, it lost its formerly high market share to the substantially cheaper polypropylene films.

3.2.5.3 Sugar

Sugar (or saccharose) from sugar beets or cane is a disaccharide and is comparable with starch as a raw material in many ways. About 130 million tonnes of sugar were produced world-wide in 2000 (of which three quarters were cane sugar). 17 million tonnes were produced in the European Union. Because sugar can be used in many technical ways, its use as a regenerative raw material offers interesting perspectives (Nathalie et al., 2008).

3.2.5 Biodegradability of Bioplastics

The ASTM (American Society for Testing and Materials) standard D-5488-94d defines biodegradability as "Capable of undergoing decomposition into CO_2, methane, water, inorganic compounds, or biomass in which the predominant mechanism is the enzymatic action of microorganisms that can be measured by standard tests, in a specific period of time reflecting available disposal conditions."

Biodegradable and degradable polymers (which have distinctly different characteristics) offer an alternative to traditional synthetic polymers (which generally exhibit long life properties and remain intact until managed within specific waste management treatment technologies such as thermal or mechanical treatment).

Biodegradable polymers cover a broad range of polymer materials that exhibit the ability to naturally degrade by biological activity under specific environmental conditions to a defined extent and within a given time. As previously discussed, plastics can be synthetically manufactured from fossil material feedstocks such as petroleum, they can be produced from biological sources (also referred to as renewable raw materials such as maize, potato, wheat and other carbohydrate sources as feedstock), or through a combination or blend of both feedstock sources and various additives (Murphy and Bartle, 2004). Both conventional synthetic polymers and biopolymers can be constructed in such a way so as to provide the plastics material with these properties. Traditionally synthetic petrochemical-derived plastics are enhanced with additives to prevent environmental degradation taking place thereby prolonging the usable life of the materials (Albertsson and Huang, 1995). Research carried out in the 70's centred on capturing the degradable qualities existing in these

materials to enable degradation after a certain period of time primarily in response to declining void space in landfill. However the research was thwarted by difficulties in producing a plastic that would not degrade too early (i.e., whilst still in use) as well as materials that only partially degraded and those that left toxic substances after degradation took place. The development of biodegradable polymers has also been hindered by high development costs, competition with the material properties and lower cost of conventional plastics and a lack of acceptance by producers and consumers alike (Omnexus, 2005).

Interest in renewable raw materials (RRM) based polymers in the 70's was primarily a result of the 1973 oil crisis and the realisation that supply of fossil oil feedstock was not secure, however, after oil prices fell, it was no longer such an issue (Mecking, 2004). Lately this interest has been renewed and attention drawn to the disadvantages of overdependence on finite fossil resources, a transition induced by unstable geopolitical influences on oil supply and the growing awareness of anthropogenic climate forcing. This has prompted demand for more sustainable production and consumption practices through European Union legislation; consumer awareness of environmental issues and advances in technology, such pressure to create biodegradable polymers has caused world production capacity to increase substantially over the past decade (Figure 3.2). 650 thousand tonnes of bioplastics were consumed worldwide in 2009, more than twice as much as five years earlier. For 2010, experts forecast a demand of 860 thousand tonnes (European bioplastics, 2010).

RRM based biopolymers represent the highest proportion of truly biodegradable production capacity as illustrated in Figure 3.2 which is anticipated to continually grow over the coming years as technology develops and larger production facilities take advantage of economies of scale resulting in lower production costs. Within Western Europe consumption of bio-plastics in 2004 has been estimated to be in the region of 40 thousand tonnes having grown from 8 thousand tonnes in 2000 with the world market for bio-plastics (RRM based) by 2020 being estimated to reach 30 Million tonnes although this shall still only represent an estimated 2 % of the total plastics production (Mecking, 2004; Murphy and Bartle, 2004; Narayan, 2004; Brian, 2005; Omnexus, 2005).
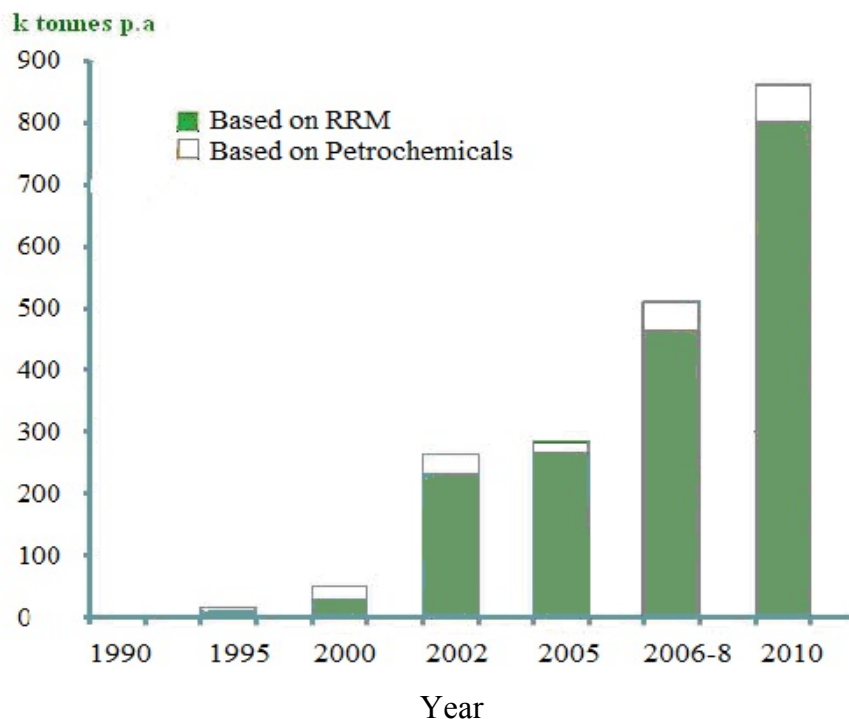
Figure 3.2: Annual worldwide bioplastics production capacity (European bioplastics, 2010)

3.2.6 Methods of Biodegradation

Just as important as the way in which a material is formed, is the way in which it is degraded. A general statement regarding the breakdown of polymer materials is that it may occur by microbial action, photodegradation, or chemical degradation. All three methods are classified under biodegradation, as the end products are stable and found in nature.

Many biopolymers are designed to be discarded in landfills, composts, or soil. The materials will be broken down, provided that the required micro-organisms are present. Normal soil bacteria and water are generally all that is required, adding to the appeal of microbially reduced plastics (Sain, 2002). Polymers which are based on naturally grown materials (such as starch or flax fiber) are susceptible to degradation by micro-organisms. The material may or may not decompose more rapidly under aerobic conditions, depending on the formulation used and the micro-organisms required.

In the case of materials where starch is used as an additive to a conventional plastic matrix, the polymer in contact with the soil and/or water is attacked by the microbes. The microbes digest the starch, leaving behind a porous, sponge-like structure with a high interfacial area, and low structural strength (Zhang et al., 2009). When the starch component has been depleted, the polymer matrix begins to be degraded by an enzymatic attack. Each reaction results in the scission of a molecule, slowly reducing the weight of the matrix until the entire material has been digested.

Another approach to microbial degradation of biopolymers involves growing micro-organisms for the specific purpose of digesting polymer materials. This is a more intensive process that ultimately costs more, and circumvents the use of renewable resources as biopolymer feedstocks. The micro-organisms under consideration are designed to target and breakdown petroleum based plastics (Kolybaba et al., 2003). Although this method reduces the volume of waste, it does not aid in the preservation of non-renewable resources.

Photodegradable polymers undergo degradation from the action of sunlight (ASTM D883:1996). In many cases, polymers are attacked photochemically and broken down to small pieces. Further microbial degradation must then occur for true biodegradation to be achieved. Polyolefins (a type of petroleum-based conventional plastic) are the polymers found to be most susceptible to photodegradation. Proposed approaches for further developing photodegradable biopolymers includes incorporating additives that accelerate photochemical reactions (e.g., benzophenone), modifying the composition of the polymers to include more UV absorbing groups (e.g., carbonyl) and synthesizing new polymers with light sensitive groups (Andreopoulos et al., 1994). An application for biopolymers which experience both microbial and photodegradation is in the use of disposable mulches and crop frost covers.

Some biodegradable polymer materials experience a rapid dissolution when exposed to particular (chemically based) aqueous solutions. The remaining solution consists of polyvinyl alcohol and glycerol. Similar to many photodegradable plastics, full biodegradation of the aqueous solution occurs later, through microbial digestion. The appropriate microorganisms are conveniently found in wastewater treatment

plants (Blanco, 2002). Procter & Gamble has developed a product similar to Depart, named Nodax PBHB. Nodax is alkaline digestible, meaning that exposure to a solution with a high pH causes a rapid structural breakdown of the material (Leaversuch, 2002). Biopolymer materials which disintegrate upon exposure to aqueous solutions are desirable for the disposal and transport of biohazards and medical wastes. Industrial "washing machines" are designed to dissolve and wash away the aqueous solutions for further microbial digestion.

3.2.7 Standard Testing Methods

3.2.7.1 Visual observations

The evaluation of visible changes in plastics can be performed in almost all tests (e.g., mass loss, clear-zone test, changes in mechanical properties…..etc). Effects used to describe degradation include roughening of the surface, formation of holes or cracks, de-fragmentation, changes in colour, or formation of bio-films on the surface. These changes do not prove the presence of a biodegradation process in terms of metabolism, but the parameter of visual changes can be used as a first indication of any microbial attack. To obtain information about the degradation mechanism, more sophisticated observations can be made using either scanning electron microscopy (SEM) or atomic force microscopy (AFM) (Ikada, 1999). After an initial degradation, crystalline spherolites appear on the surface; that can be explained by a preferential degradation of the amorphous polymer fraction, etching the slower-degrading crystalline parts out of the material. In another investigation, (Kikkawa et al., 2002) used AFM micrographs of enzymatic ally degraded PHB films to investigate the mechanism of surface erosion. A number of other techniques can also be used to assess the biodegradability of polymeric material. These include; Fourier transform infrared spectroscopy (FTIR), differential scanning colorimetry (DSC), nuclear magnetic resonance spectroscopy (NMR), X-ray photoelectron spectroscopy (XPS), X-ray Diffraction (XRD), contact angle measurements and water uptake. Use of these techniques is generally beyond the scope of this review, although some are mentioned in the text.

3.2.7.2 Weight loss measurements: Determination of residual polymer

The mass loss of test specimens such as films or test bars is widely applied in degradation tests (especially in field- and simulation tests), although again no direct proof of biodegradation is obtained. Problems can arise with correct cleaning of the specimen, or if the material disintegrates excessively. In the latter case, the samples can be placed into small nets to facilitate recovery; this method is used in the full-scale composting procedure of DIN EN 13432:2007. A sieving analysis of the matrix surrounding the plastic samples allows a better quantitative determination of the disintegration characteristics. For finely distributed polymer samples (e.g., powders), the decrease in residual polymer can be determined by an adequate separation or extraction technique (polymer separated from biomass, or polymer extracted from soil or compost). By combining a structural analysis of the residual material and the low molecular weight intermediates, detailed information regarding the degradation process can be obtained, especially if a defined synthetic test medium is used (Witt et al., 2001).

3.2.7.3 Changes in mechanical properties and molar mass

As with visual observations, changes in material properties cannot be proved directly due to metabolism of the polymer material. However, changes in mechanical properties are often used when only minor changes in the mass of the test specimen are observed. Properties such as tensile strength are very sensitive to changes in the molar mass of polymers, which is also often taken directly as an indicator of degradation (Erlandsson et al., 1997). Whilst, for an enzyme-induced depolymerization the material properties only change if a significant loss of mass is observed (the specimen become thinner because of the surface erosion process; the inner part of the material is not affected by the degradation process), for abiotic degradation processes (which often take place in the entire material, and include the hydrolysis of polyesters or oxidation of polyethylenes) the mechanical properties may change significantly, though almost no loss of mass due to solubilization of degradation intermediates occur at this stage. As a consequence, this type of measurement is often used for materials

where abiotic processes are responsible for the first degradation step (Tsuji and Suzuyoshi, 2002; Mostafa et al., 2010).

3.2.7.4 CO_2 evolution/O_2 consumption

Under aerobic conditions, microbes use oxygen to oxidize carbon and form carbon dioxide as one of the major metabolic end products. Consequently, the consumption of oxygen (respirometric test) (Hoffmann et al., 1997) or the formation of carbon dioxide are good indicators for polymer degradation, and are the most often used methods to measure biodegradation in laboratory tests. Due to the normally low amount of other carbon sources present in addition to the polymer itself when using synthetic mineral media, only a relatively low background respiration must be identified, and the accuracy of the tests is usually good. In particular, the type of analytical methods, especially for the determination of CO_2 has been modified. Although used originally in aqueous test systems for polymer degradation, CO_2 analysis was also adapted for tests in solid matrices such as compost (Pagga, 1998), and this method has now been standardized under the name, controlled composting test (ASTM 3826:1998; ISO 14855:1999; JIS 6953:2000). For polymer degradation in soil, CO_2 detection proved to be more complicated than in compost because of slower degradation rates that led not only to long test durations (up to 2 years) but also low CO_2 evolution as compared to that from the carbon present in soil. One means of overcoming problems with background CO_2 evolution from the natural matrices compost or soil is to use an inert, carbon-free and porous matrix, wetted with a synthetic medium and inoculated with a mixed microbial population. This method proved practicable for simulating compost conditions (degradation at ~60 °C) (Bellina et al., 2000), but has not yet been optimized for soil conditions.

3.2.7.5 Clear-zone formation

A very simple semi-quantitative method is the so-called clear-zone test. This is an agar plate test in which the polymer is dispersed as very fine particles within the synthetic medium agar; this results in the agar having an opaque appearance. After inoculation with microorganisms, the formation of a clear halo around the colony

indicates that the organisms are at least able to depolymerize the polymer, which is the first step of biodegradation. This method is usually applied to screen organisms that can degrade a certain polymer (Nishida and Tokiwa, 1993; Abou-Zeid, 2001), but it can also be used to obtain semi-quantitative results by analyzing the growth of clear zones (Augusta et al., 1993).

3.2.7.6 Enzymatic degradation

The enzymatic degradation of polymers by hydrolysis is a two step process: first, the enzyme binds to the polymer substrate, and then subsequently catalyzes a hydrolytic cleavage. PHB can be degraded either by the action of intracellular and extracellular depolymerases in PHB-degrading bacteria and fungi. Intracellular degradation is the hydrolysis of an endogenous carbon reservoir by the accumulating bacteria themselves while extracellular degradation is the utilization of an exogenous carbon source not necessarily by the accumulating microorganisms (Tokiwa and Calabia, 2004). During degradation, extracellular enzymes from microorganisms break down complex polymers yielding short chains or smaller molecules, e.g., oligomers, dimers, and monomers, which are smaller enough to pass the semi-permeable outer bacterial membranes. The process is called depolymerization. These short chain length molecules are then mineralized into end products, e.g., CO_2, H_2O, or CH_4, the degradation is called mineralization, which are utilized as carbon and energy source (Gu, 2003).

3.2.7.7 Controlled composting test

The treatment of solid waste in controlled composting facilities or anaerobic digesters is a valuable method for treating and recycling organic waste material (Shah et al., 2008). Composting of biodegradable packaging and biodegradable plastics is a form of recovery of waste which can cut the increasing need of new landfill sites. Only compostable materials can be recycled through biological treatment, since materials not compatible with composting could decrease the compost quality and impair its commercial value. The environmental conditions of the composting test are the following: high temperature (58 °C); aerobic conditions; proper water content (about

50 %). Mature compost is used as a solid matrix, as a source of thermophilic microorganisms (inoculum), and as a source of nutrients. The test method is based on the determination of the net CO_2 evolution, i.e., the CO_2 evolved from the mixture of polymercompost minus the CO_2 evolved from the unamended compost (blank) tested in a different reactor (Bellina et al., 1999). A very important requisite is that the packaging material under study must not release, during degradation, toxic compounds into the compost which could hinder plants, animals, and human beings by entering the food chain (Tosin et al., 1998).

3.2.8 Fields of Application for Bioplastics

3.2.8.1 Packaging materials

Apart from simple, foamed duroplastic packaging chips made on the basis of starch, there are now numerous packaging materials made of bioplastics. Almost anything is technically possible. Bioplastics can be blown as films or multi-layered films, extruded as flat films, they can be thermally formed or deep drawn, printed, fused, sprayed or glued and can be used with common plastic processing techniques to manufacture packaging materials. In short, the manufacturers of packaging materials and packers can process bioplastics without difficulty with almost all conventional machines (Kirwan and Strawbridge, 2003).

Established packaging applications for bioplastics are carrier bags which have a dual purpose as bags for compostable kitchen and garden wastes, trays for chocolates, fruit, vegetables, meat and eggs, beakers for dairy products, bottles, nets or bags for fruit and vegetables. Blister packs in which the film closely encases the product are also possible. There are jars and tubes for cosmetic articles. Packaging materials made of bioplastics with barrier effects, aroma-tight with good machine handling capabilities are available and are being constantly further developed (Martin et al., 2008).

Coatings of paper and cardboard composites with bioplastics are leading to new packaging materials with good properties in use. In the USA, a mineral water bottle made of the bioplastic PLA has already been introduced on the market. Whereas the

larger part of biopackages on the market still fill a niche, compostable sacks and bags to collect biological wastes already have a leading market share.

It is no wonder that it is the packaging sector which is considered to offer the greatest potential for bioplastics. Users, packers and branded article manufacturers profit from the consumer-friendly packages. The disposal of used packages made of bioplastics can be conducted in several ways. The preferred disposal option is utilisation to gain energy in waste incinerators. Bioplastics, which are also biodegradable and compostable, can also be utilised in composting and biogas plants (Nathalie et al., 2008).

3.2.8.2 Catering products - no dishwashing

Catering products are also often as similarly short-lived as packaging materials. Once used, beakers, plates and cutlery disappear with the adhering food residues into the bin, which overflows after celebrations or other large events. In this, compostable bioplastics not only offer genuine ecological alternatives, by composting, disposal problems can also be substantially reduced. Manufacturers have understood: Whether crockery, beakers, cutlery, trays, drinking straws or the wrapping films for burgers, the entire range of catering requisites is now also manufactured from bioplastics. The freedom of design for the user is unrestricted. Any colour or shape is possible.

According to British Plastics Federation (BPF), 2009, fast food companies are also well advised to use catering products made of bioplastics. If commercial gastronomy would use exclusively compostable packages, only one waste container would be necessary for compostable or fermentable wastes.

3.2.8.3 Products for the garden and landscaping

In horticulture, the adaptable service life of bioplastics plays a special role. Appropriately utilised, this can save the gardener a lot of work. Mulch films made of biodegradable bioplastics must not be collected laboriously after use; they can be simply ploughed in. Planting and raising pots decay in the soil and do not become waste. Bowls for flowers and vegetable plants made of bioplastics can be composted

together with kitchen and garden wastes on the compost heap (FNR "Fachagentur Nachwachsende Rohstoffe e.V.", 2010; www.european-bioplastics.org).

Bioplastic string, tape and clips used to fasten high-growing plants such as tomatoes also save costs. Whereas the products previously used in vegetable cultivation required laborious collection by labourers after the harvest, the bioplastic variants can be put with the plants on the compost heap (Kirwan and Strawbridge, 2003).

Compostable seed tapes and agent capsules made of bioplastics are also common. Degradable films and nets are used in mushroom cultivation and to wrap tree and shrub roots for sale. Films, tapes and nets made of bioplastics reinforce freshly dug embankments and prevent soil erosion until the plants have firmly rooted. Graveyard products such as planters, pots and everlasting candles with biodegradable sheaths and decorative materials can be composted on the spot after their useful life. For golf course operators, biodegradable tees are an interesting alternative: They must no longer be collected and the problem simply rots away (Sorrentino et al., 2007; Lorcks, 2006).

3.2.8.4 Pharmaceutical and medical applications

In the medical sector, bioplastics are used for completely different reasons than in packaging materials or the catering branch. This pertains to reabsorbable threads or implants which degrade in the body and require no further operations to remove them. As special quality is required here, the raw materials are particularly expensive: Over 1000 Euros/kg in some cases (Lorcks, 2006).

Reabsorbable bioplastics can be used for many purposes. For example, thermoplastic starch is an alternative to gelatine as a material for capsules or tablets. Polylactides and its copolymers are used as surgical stitching materials, as medicine depots or as reabsorbable implants such as screws, pins and plates (Kyrikou and Briassoulis, 2007).

The surgeon has a choice between different polymer compositions with defined times in which the implant is reabsorbed by the body. The implant with the optimum polymer composition is chosen for the required duration of mechanical support, e.g., for a bone fracture. Whatever the case, a second operation as necessary for metal

implants is unnecessary as implants made of suitable bioplastics degrade in the body within a calculable period (Gupta and Kumar, 2007).

3.2.9 Conclusion

It has to be kept in mind that bioplastics have only a small share of the current 50 Mton total plastics market (about 2 % by year 2009). They represent a new material group which can make use of all the established recovery and recycling technologies for conventional plastics and moreover offer the new option of organic recycling.

Technical solutions to use mainly non-food crops are under investigation or already in use. All parties involved should focus their activities to enable the growth of bioplastics and to support sustainable development which takes into account that no raw material has unlimited availability and therefore the most efficient use of resources must be achieved. Bioplastics should be regarded as a solution to promote sustainable development and not as a threat to it.

From the previous review, it was found that there are some categories from bioplastic used as commercial products. It will be use some of them in the study to test its suitability to produce biodegradable drip tubes. These categories are:

1. Polysaccharides: starches (Mater Bi), cellulose (FR 39), and pectin (Chitosan),
2. Polylactides: polylactic acid (Bi-OPL and Bioflex),
3. Petrochemical products: aliphatic-aromatic co-polyesters (Ecoflex).

3.3 BIOPLASTIC MATERIALS UNDER THE STUDY

It was used some of bioplastics to test its suitability to produce biodegradable drip tubes. The materials under study were:

1. Ecoflex® F BX 7011, 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 polylactic acid (PLA) and 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; 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 is made of degradable materials (corn) and compostable in accordance with DIN EN 13432 (Oerlemansplastics, 2008).

6. Fibrous Casing (FR 39®) is a renewable raw material produced from cellulose. It is used as casing for some foods (CaseTech, 2008).

3.4 TEMPERATURE AND RELATIVE HUMIDITY

This part focused on the determination of the equilibrium moisture content (EMC) of some bioplastic materials that could be used for agricultural foil mulch and as a source to produce biodegradable drip tubes. Equilibrium moisture content (EMC) is very important to determine the desirable conditions for the growth of microorganisms which cause deterioration and degradation of the material. Thus, this section aims to determine the EMC of some commercial bioplastics.

3.4.1 Experimental Procedures

According to DIN EN ISO 12571:1996, equilibrium moisture content was determined for five commercially available bioplastic samples which were used as agricultural mulch film (Bioflex, Ecoflex, Mater Bi, Chitosan and Bi-OPL foil), and cellulose fiber (FR 39), which is used as food casing, to study the material stability and find out which is better for producing the biodegradable drip tubes.

Samples with 10 x 10 cm and 0.1 mm thickness were taken and put on a wire mesh, then above a plastic dish containing a saturated salt solution. The samples, wire mesh and dishes were placed inside a basket. The basket was put in a plastic bag with an air-tight seal. These bags were put inside a climate chamber at different temperatures (10, 20, 30, 40 and 50 °C) and in order to obtain different relative humidity values (43, 53, 65, 75, 85 and 95 %) in the surrounding materials in the bags, the chemical substances listed in Table 3.1 were used. The development was controlled with combined T/RH-sensors. After 2 or 3 weeks, until a constant relative humidity inside the bags was reached, samples were weighed and the moisture contents were calculated.

A climate chamber measuring 3.5 x 2.75 x 3.0 m was used to control the temperature conditions. Capacitive humidity sensors (Aluminum 12 mm $\phi \pm 2$ % for RH and 1 K for temperature accuracy, AHLBORN GmbH, Germany) contained a glass substrate with a humidity-sensitive polymer layer between two metal electrodes. With absorption of water, corresponding to the relative humidity, the dielectric

constant, and as a result, the capacity of the thin-film capacitor, changed. The measuring signal is directly proportional to the relative humidity and is not dependent on the atmospheric pressure.

Moisture content for the materials was measured according to ASHRAE (1997). The materials were put in the drier until a constant weight was obtained. The following equation [4] was used to calculate the MC:

$$MC = \frac{(mw - dw)}{dw} \times 100 \qquad \text{(ASHRAE, 1997)} \qquad [4]$$

Where:

MC: Moisture content (%, dw)

mw: Moist weight   (kg)

dw: Dry weight (kg)

Table 3.1: Chemicals substances used for adjusting different relative humidity values

Name	Materials	Relative humidity (%)
Sodium sulfate	$Na_2SO_4.10\ H_2O$	95
Potassium chloride	KCl	85
Sodium chloride	NaCl	75
Sodium nitrite	$NaNO_2$	65
Magnesium nitrate	$(Mg\ NO_3).6\ H_2O$	53
Potassium carbonate	$K_2CO_3.2\ H_2O$	43

3.4.2 Results

3.4.2.1 Mater-Bi

Figure 3.3 shows the equilibrium moisture content (EMC, % dw) of Mater-Bi at different predetermined relative humidity values and temperatures. The samples were placed under conditions of relative humidity ranging from 43–95 % and temperatures of 10–50 °C.

The results revealed that the equilibrium moisture content of Mater-Bi increased with increasing the relative humidity, but it decreased with increasing the temperature. It seems that the relative humidity has a greater effect on the equilibrium

moisture content than the temperature, where, changing the relative humidity from 43 to 95 % leads to an increase of 12.17 % in the moisture content of the material at 10 °C temperatures. On the other hand, increasing the temperature from 10-50 °C caused a decrease of 4.3 % in the equilibrium moisture content of the material at 43 % relative humidity, while at the higher temperatures and relative humidity (50 °C and 95 %), increasing the relative humidity from 43 to 95 % at 50 °C caused an increase of 9.41 %, whereas it was 7.06 % when the temperature increased from 10-50 °C at 95 % relative humidity.

The average of EMC from 43 to 95% relative humidity ranged from 2.37 to 12.24 %, on the other hand it ranged from 8.10 to 4.78 % for 10 to 50 °C. At low relative humidity (43 %) the maximum equilibrium moisture content was 4.30 % at 10 °C, while it was a low of 0 % at 50 °C. As relative humidity rises, the equilibrium moisture content (EMC) reached a high of 16.47 % at 10 °C and a low of 9.41 % at 50 °C.
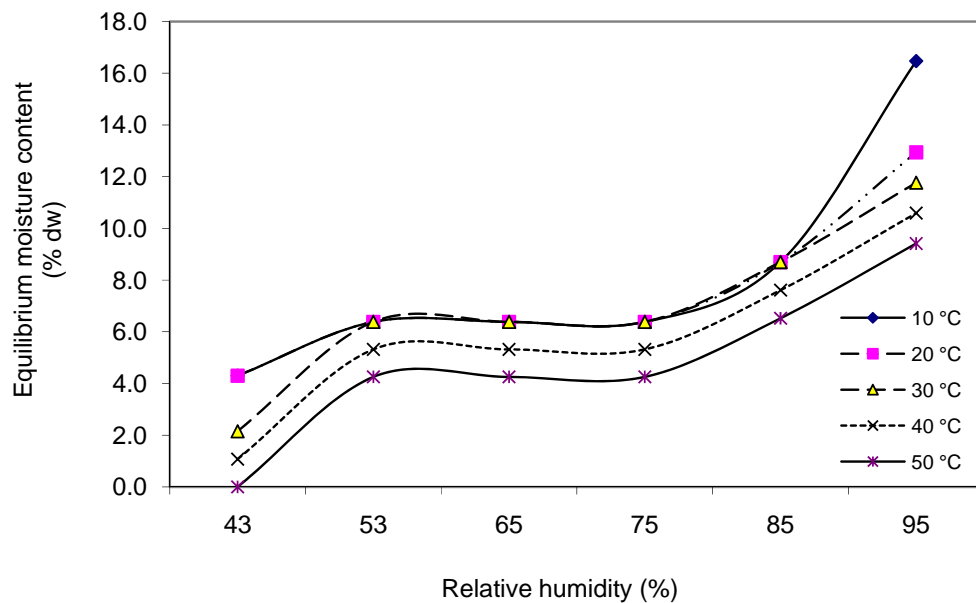
Figure 3.3: Equilibrium moisture content of Mater Bi at different temperatures and different relative humidity

3.4.2.2 Ecoflex

At low relative humidity (43 %) the maximum equilibrium moisture content was 5.88 % at 10 °C while it was a low of 3.53 % at 50 °C as shown in Figure 3.4. As relative humidity rose, the equilibrium moisture content (EMC) reached a high of 8.24 % at 10 °C and a low of 7.06 % at 50 °C. It was also noticed that changing the relative humidity from 43 to 95 % lead to an increase of 2.36 % in the moisture content of the material at 10 °C temperature. On the other hand, increasing the temperature from 10-50 °C caused a decrease of 2.35 % in the equilibrium moisture content of Ecoflex material, while at the higher temperatures and relative humidity (50 °C and 95 %), increasing the relative humidity from 43 to 95 % at 50 °C caused an increase of 3.53 %, whereas it was 1.18 % when the temperature increased from 10-50 °C at 95 % relative humidity.

Figure 3.4: Equilibrium moisture content of Ecoflex at different temperatures and different relative humidity

3.4.2.3 Chitosan

The maximum equilibrium moisture content for Chitosan materials at low relative humidity (43 %) was 7.64 % at 10 °C while it was a low of 3.47 % at 50 °C.

As relative humidity rises, the EMC reached a high of 19.44 % at 10 °C and a low of 13.19 % at 50 °C (Figure 3.5). It was also noticed that changing the relative humidity from 43 to 95 % leads to an increase of 11.80 % in the moisture content of the material at 10 °C temperatures. On the other hand, increasing the temperature from 10-50 °C caused a decrease of 4.17 % in the equilibrium moisture content of Chitosan material, while at the higher temperatures and relative humidity (50 °C and 95 %), increasing the relative humidity from 43 to 95 % at 50 °C caused an increase of 9.72 %, whereas it was 6.25 % when the temperature increased from 10-50 °C at 95 % relative humidity.

Figure 3.5: Equilibrium moisture content of Chitosan at different temperatures and different relative humidity

3.4.2.4 Bioflex

Bioflex had the same trend as Ecoflex and Mater Bi, where the EMC increases with increasing relative humidity, but decreases slightly in the case of increasing the temperature (Figure 3.6). The results revealed that 10, 20, 30 and 40 °C had the same effect on the moisture content of Bioflex. When the relative humidity was changed from 43 to 95 %, it leads to an increase of 2.37 % in the moisture content. On the other hand, increasing the temperature to 50 °C caused a small decrease in the EMC, and

lead to a decrease of about 0.20, 0.21, 0.14, 0.31, 0.30 and 0.08 % when changing the relative humidity from 43 to 95 %, respectively.
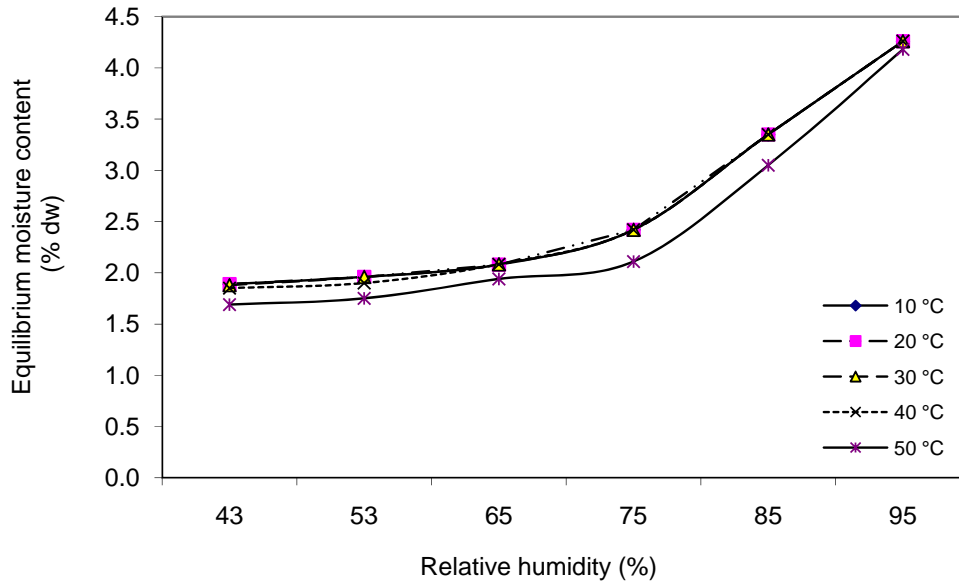
Figure 3.6: Equilibrium moisture content of Bioflex at different temperatures and different relative humidity

3.4.2.5 Bi-OPL

From the data plotted in Figure 3.7, it can be observed that Bi-OPL looks like Bioflex. In the case of changing relative humidity from 43 to 75 %, and the temperature from 10 to 50 °C, we can find that the EMC was stable (1.03 %). On the other hand, the mean of EMC increased to 0.12 and 0.5 % when the relative humidity increasing to 85 and 95 %. So we can find that neither temperature (10 to 50 °C) nor relative humidity (43 to 95 %) had an effect on the EMC of Bi-OPL.

3.4.2.6 Cellulose (FR 39)

Figure 3.8 shows that the maximum equilibrium moisture content for FR 39 materials at low relative humidity (43 %) was 11.21 % at 10 °C, while it was a low of 10.27 % at 50 °C. As relative humidity rises, the EMC reached a high of 29.99 % at 10 °C and a low of 25.58 % at 50 °C. It is also noticed that changing the relative humidity from 43 to 95 % leads to an increase of 18.78 % in the moisture content of the material

at 10 °C temperatures. On the other hand, increasing the temperature from 10-50 °C caused a decrease of 0.97 % in the equilibrium moisture content of Cellulose material, while at the higher temperatures and relative humidity (50 °C and 95 %), increasing the relative humidity from 43 to 95 % at 50 °C caused an increase of 15.34 %, whereas it was 4.41 % when the temperature increased from 10-50 °C at 95 % relative humidity.
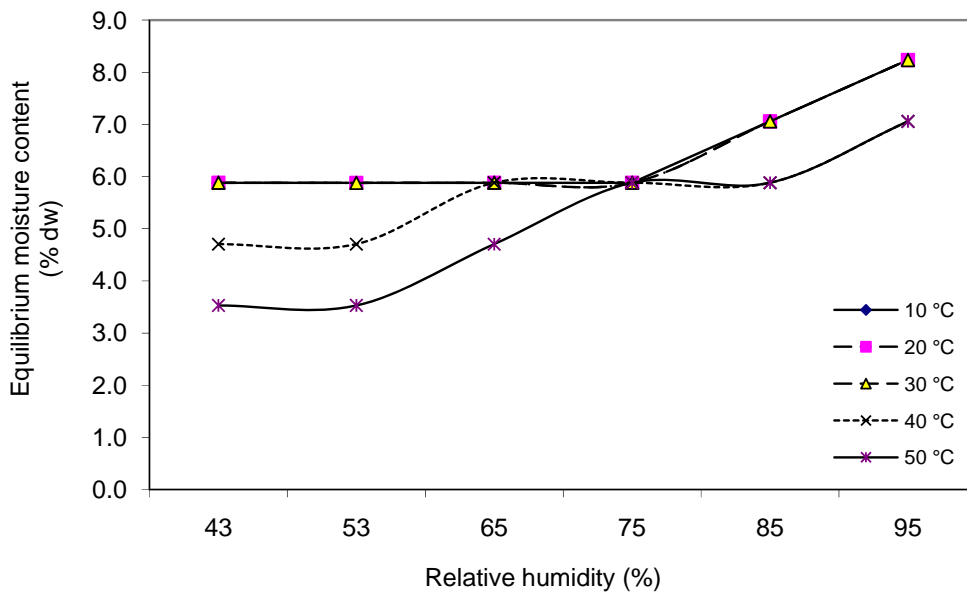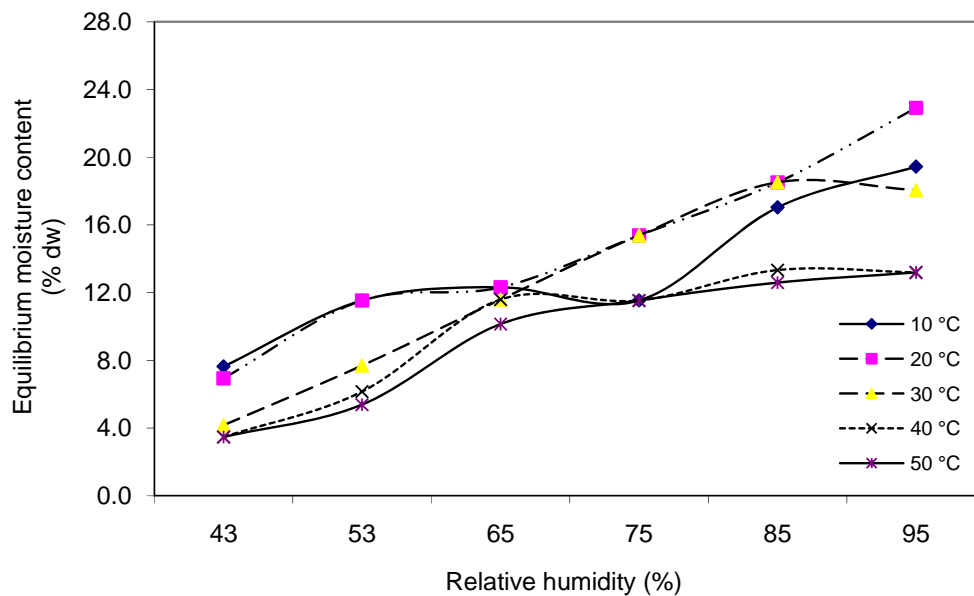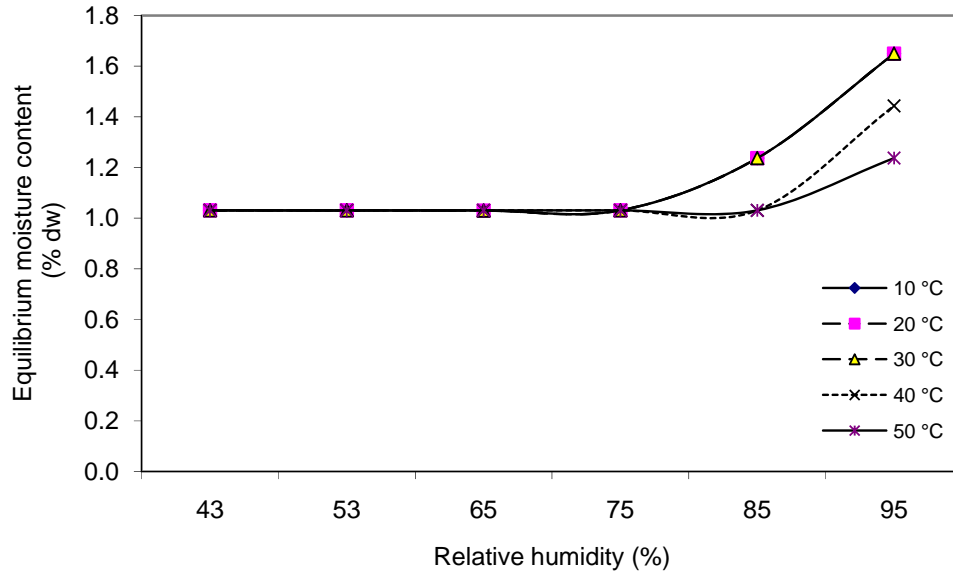

Figure 3.7: Equilibrium moisture content of Bi-OPL at different temperatures and different relative humidity

3.4.3 Discussion

The results revealed that cellulose has a great effect by changing the relative humidity from 43 to 95 %, followed by both Mater-Bi and Chitosan, which the EMC increased by 17.90 , 9.87 and 12.22 %, respectively. On the other hand, there is a small effect on the EMC by changing the relative humidity on each of materials: Ecoflex (2.58 %), Bioflex (2.40 %) and Bi-OPL (0.50 %). This may be due to the fact that the moisture content is identical to the sorption isotherms, where water is adsorbed from the vapor of the ambient air, and the moisture content is in equilibrium with the ambient relative humidity.
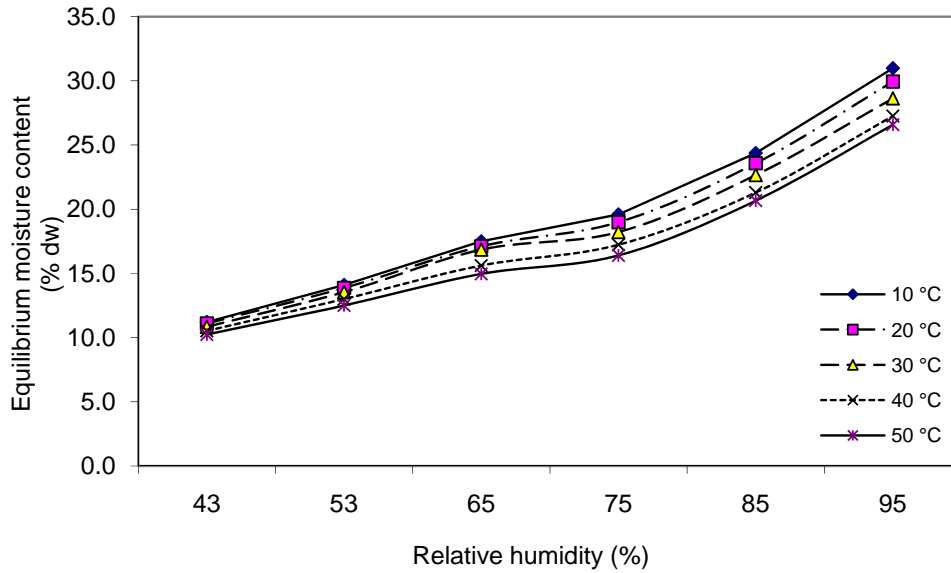
Figure 3.8: Equilibrium moisture content of Cellulose at different temperatures and different relative humidity

Two mechanisms are responsible for this sorption phenomenon. At low relative humidity values, water molecules are attached to the pore film wall forming a thin water film. As relative humidity rises, this film becomes thicker and capillary condensation starts taking place in the narrow pores. The two mechanisms overlap each other, but at high relative humidity, the capillary condensation becomes dominant (Künzel, 1991).

The equilibrium moisture content of bioplastic materials increases with the rise of relative humidity at the same temperature. This is due to the vapor pressure deficit that decreases with increasing relative humidity and creates an atmosphere close to saturation and also increases the ability of sheet thickness to absorb more moisture from the surrounding atmosphere. On the other hand, according to Künzel (1994) and Krus (1995), with increasing temperature from 10 to 50 °C, equilibrium moisture content decreases.

3.4.4 Conclusion

The results revealed that the equilibrium moisture content of all materials under study increased with increasing relative humidity but it decreased with increasing the

temperature. The equilibrium moisture content of Cellulose was the highest, Chitosan and Mater-Bi was higher than Ecoflex and Bioflex and it was the lowest for Bi-OPL (Figure 3.9).

The temperature and relative humidity play an important role in the biomaterial degradation, where it can lead to microorganism activity which can attack and degrade the biomaterials (Watts et al., 1995; Ashour, 2003; Tzankova and La Mantia, 2007; and Shah et al., 2008). According to the previous results, Ecoflex, Bioflex and Bi-OPL may all hold for a longer period of time than Cellulose (FR 39), Chitosan and Mater-Bi. Finally, it can be observed that the material FR 39, which is made of cellulose, could be difficult to be use as a drip tube because of the high moisture content. It causes good environmental conditions for microorganisms to attach the biomaterials leading to a short life. For these reasons, FR39 "cellulose" will be excluded from the next experiments.
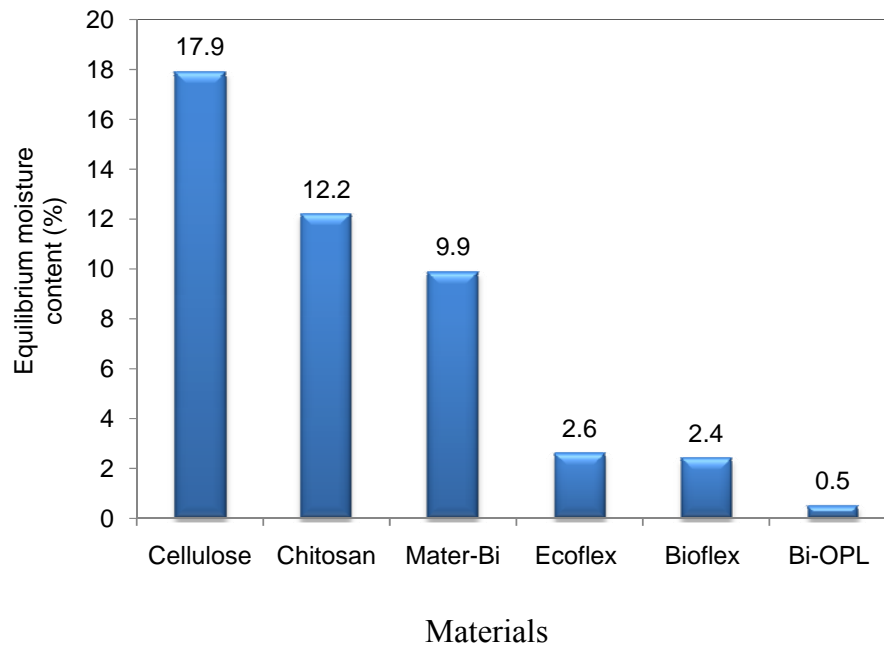
Figure 3.9: Average of equilibrium moisture content at different temperatures and different relative humidity

3.5 BIODEGRADATION IN DIFFERENT SOIL TYPES

In this section, the mechanical properties of five different types of commercial bioplastics available on the market as agricultural mulch film were evaluated under different soils 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.

3.5.1 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 producing the biodegradable drip tubes.

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 3.2.

Table 3.2: The physical and chemical analysis of the different soil types

Texture	Sand %	Silt %	Clay %	PH	CaCO$_3$ 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, AHLBORN GmbH, 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 and % 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 [5]:

$$\text{Weight losses } (\%) = \frac{(W_2 - W_1)}{W_1} \times 100 \quad \text{(Khan et al., 2006) [5]}$$

Where:

W$_1$ and W$_2$ are the films weight before and after treatment.

3.5.2 Results

3.5.2.1 Biodegradation on soil surface

3.5.2.1.1 Sandy soil

The weight loss of plastic films during degradation in sandy soil is shown in Figure 3.10. 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.

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).
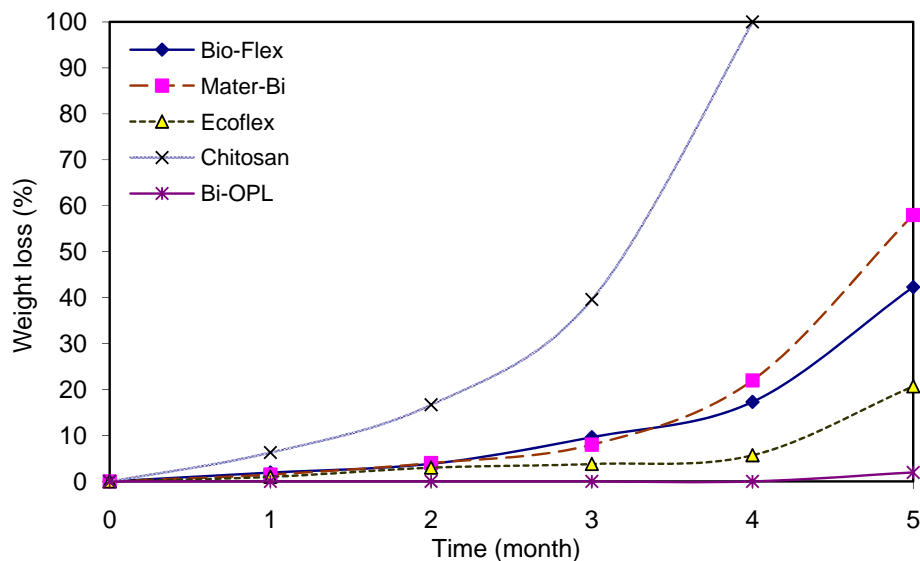
Figure 3.10: Weight loss (%) of the different biodegradable plastics in sandy soil

Tensile strengths for bioplastic samples are shown in Figure 3.11 and the elongation losses were showed in Table 3.3. 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.
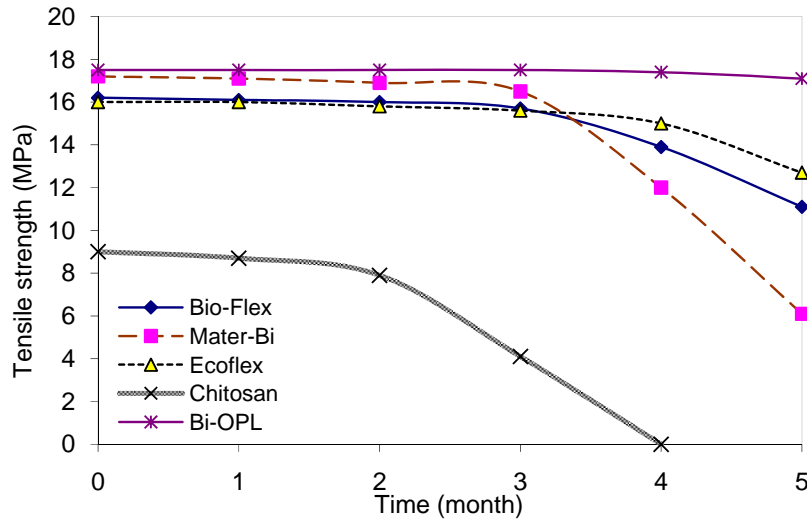
Figure 3.11: Tensile strength (MPa) of the different biodegradable plastics in sandy soil

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 as shown in Figure 3.12. It could be that the hydrophobicity of PLA (Bi-OPL) is the main reason for 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 micro-organisms or from the soil chemistry.

Table 3.3: Elongation loss (%) of the different biodegradable plastics in sandy soil

Time (month)	Elongation (%)				
	BioFlex	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
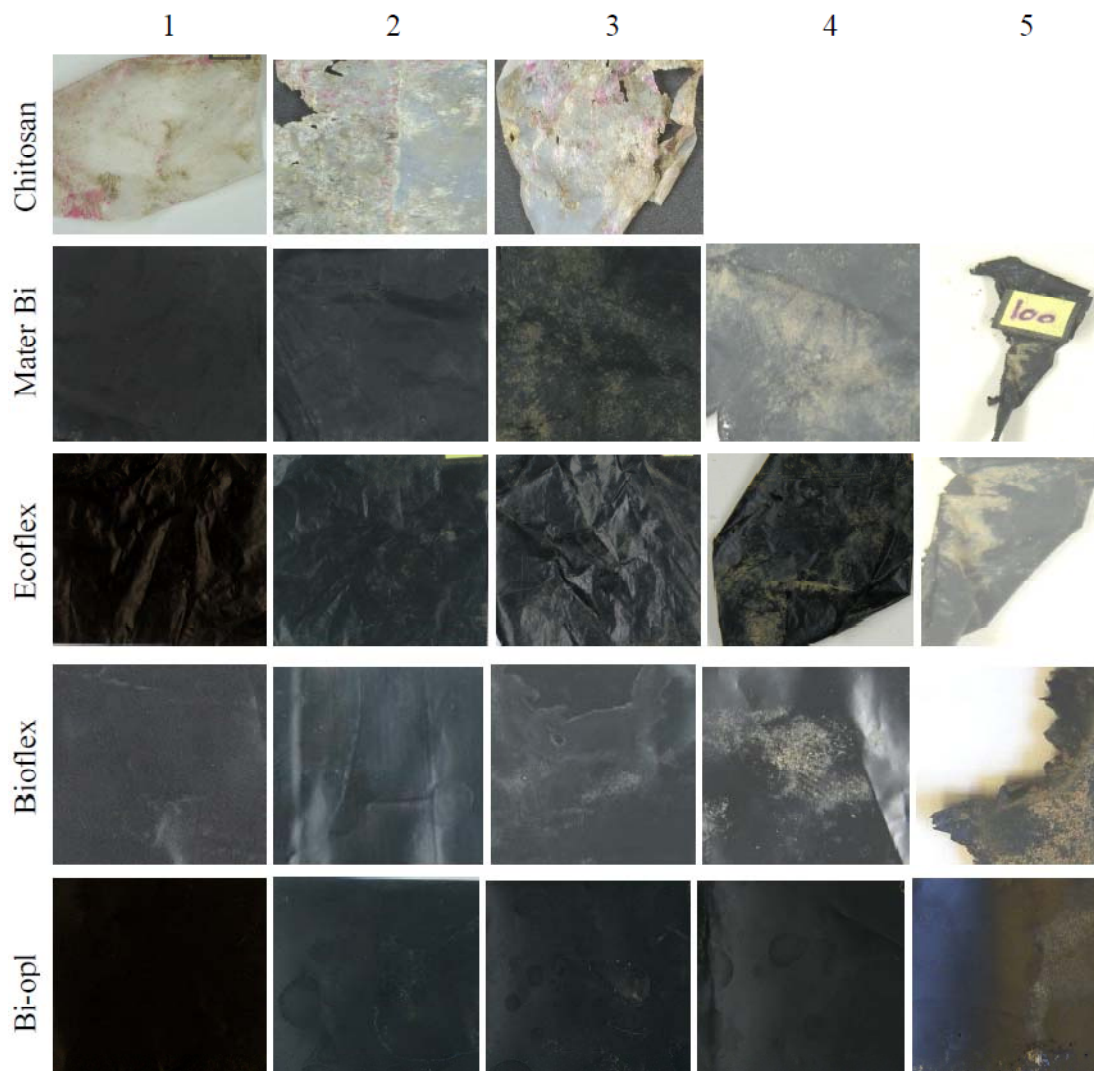
Figure 3.12: Photographical comparison between the different bioplastic materials under sandy soil for five months

3.5.2.1.2 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 3.13 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 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 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.
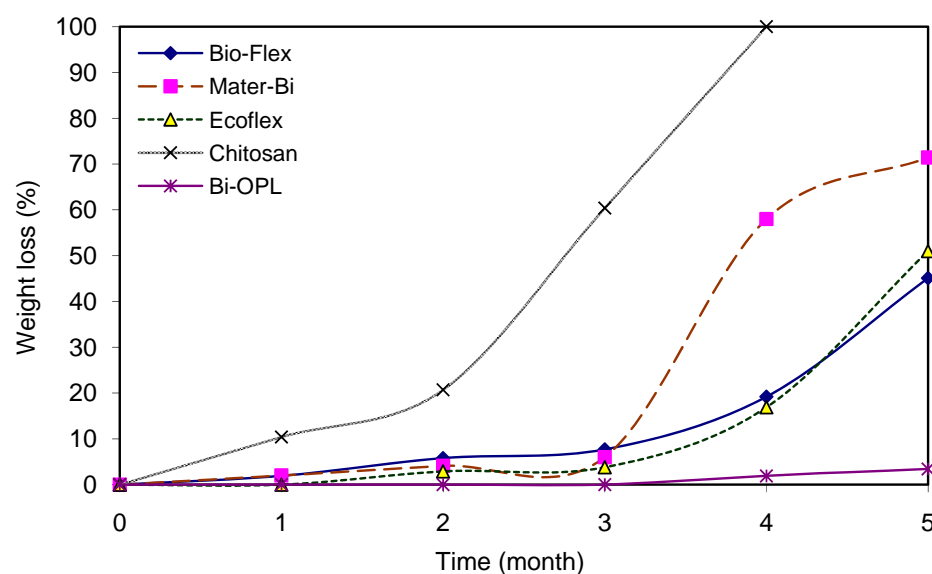
Figure 3.13: Weight loss (%) of the different biodegradable plastics in sandy-loam soil

The tensile strengths of the films were plotted in Figure 3.14 and the elongation losses were shown in Table 3.4, also the photographical observation was shown in Figure 3.15. 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 of treatment (41 % and 39 % respectively) and more than 63 % and 78 % losses in elongation capacity respectively.
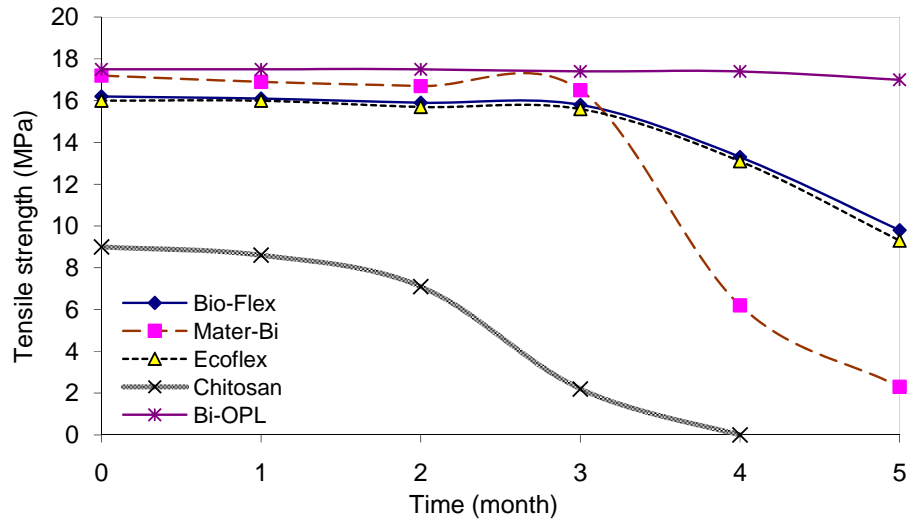
Figure 3.14: Tensile strength (MPa) of the different biodegradable plastics in sandy-loam soil

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 3.4: Elongation loss (%) of the different bioplastics in sandy-loam soil

| Time (month)	Elongation (%)				
	Bioflex	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
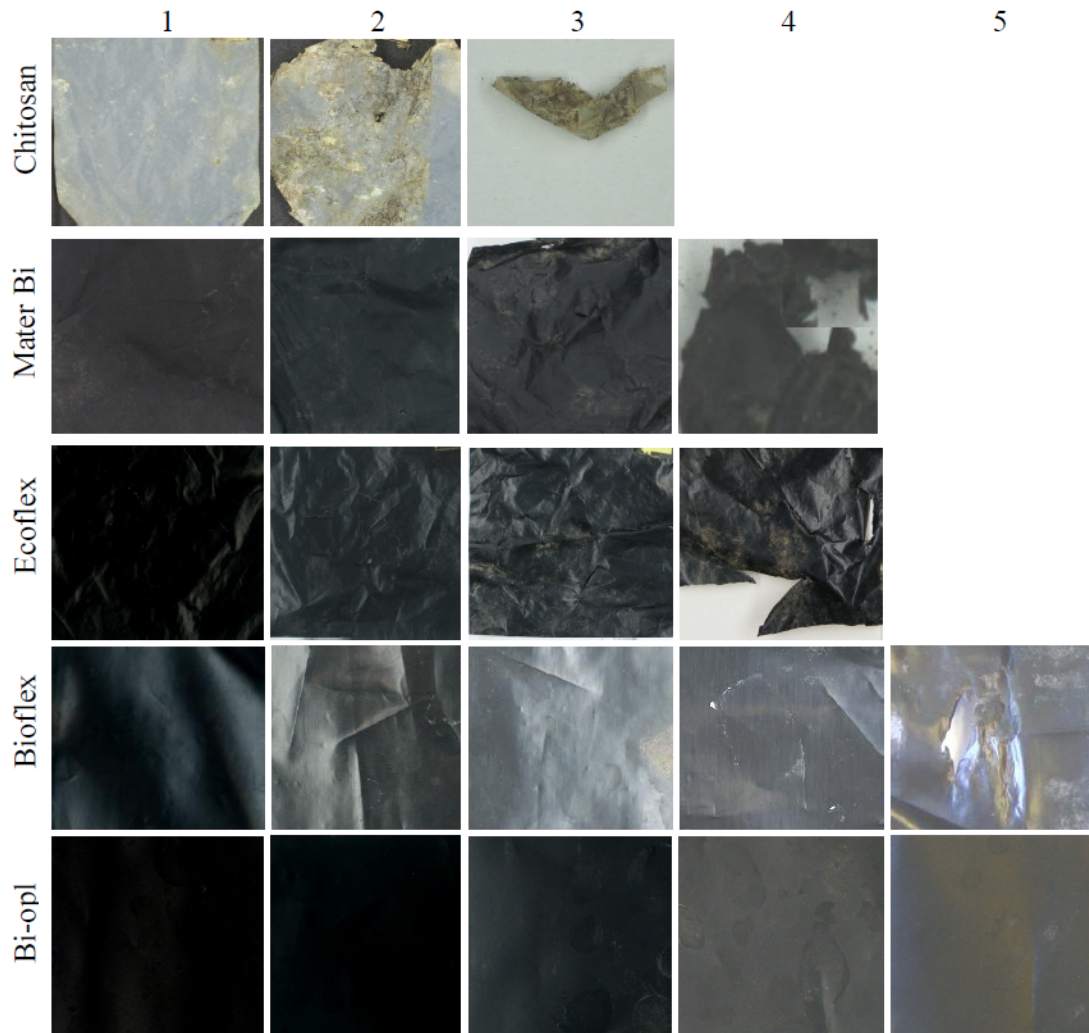
Figure 3.15: Photographical comparison between the bioplastic materials under sandy-loam soil for five months

3.5.2.1.3 Loamy soils

Average weight loss in Bi-OPL and Bioflex at the second month was approx. 0 % compared with 56.3 % for Chitosan (Fig. 3.16 and 3.18), 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 %).
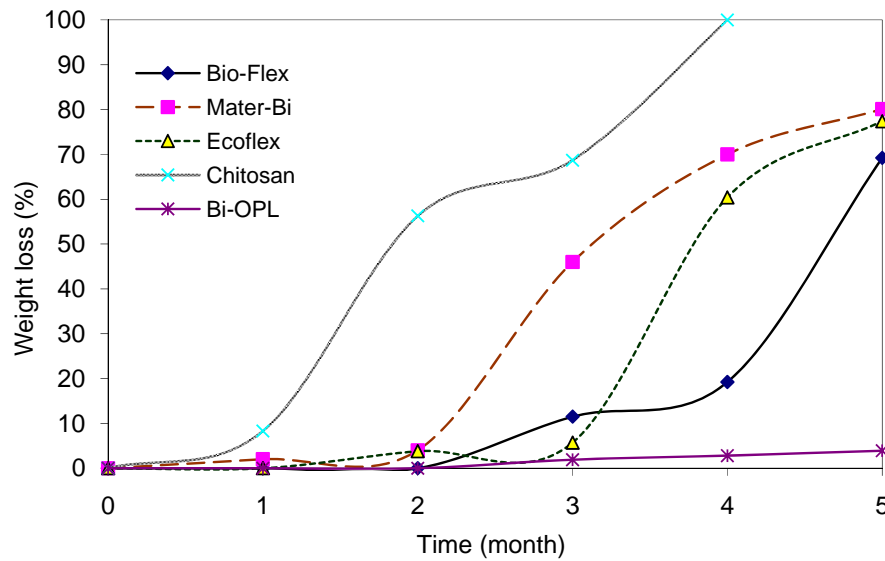
Figure 3.16: Weight loss (%) of the different biodegradable plastics in loamy soil

The tensile strength losses and the elongation capacity showed nearly the same trend for both Bioflex and Ecoflex (Fig. 3.17 and Table 3.5), 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.
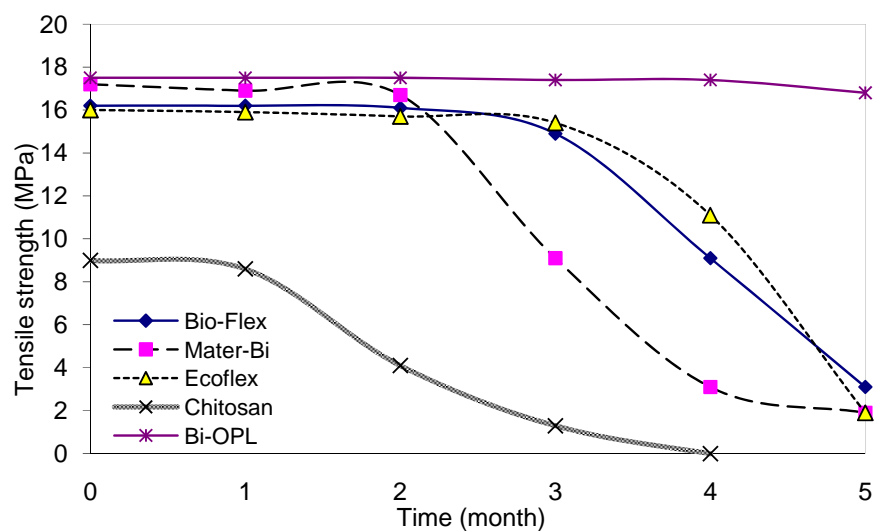
Figure 3.17: Tensile strength (MPa) of the different bioplastics in loamy soil

Mater Bi retained good resistance at two months (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 3.5: Elongation loss (%) of the different bioplastics in loamy soil

| Time (month)	Elongation (%)				
	Bioflex	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
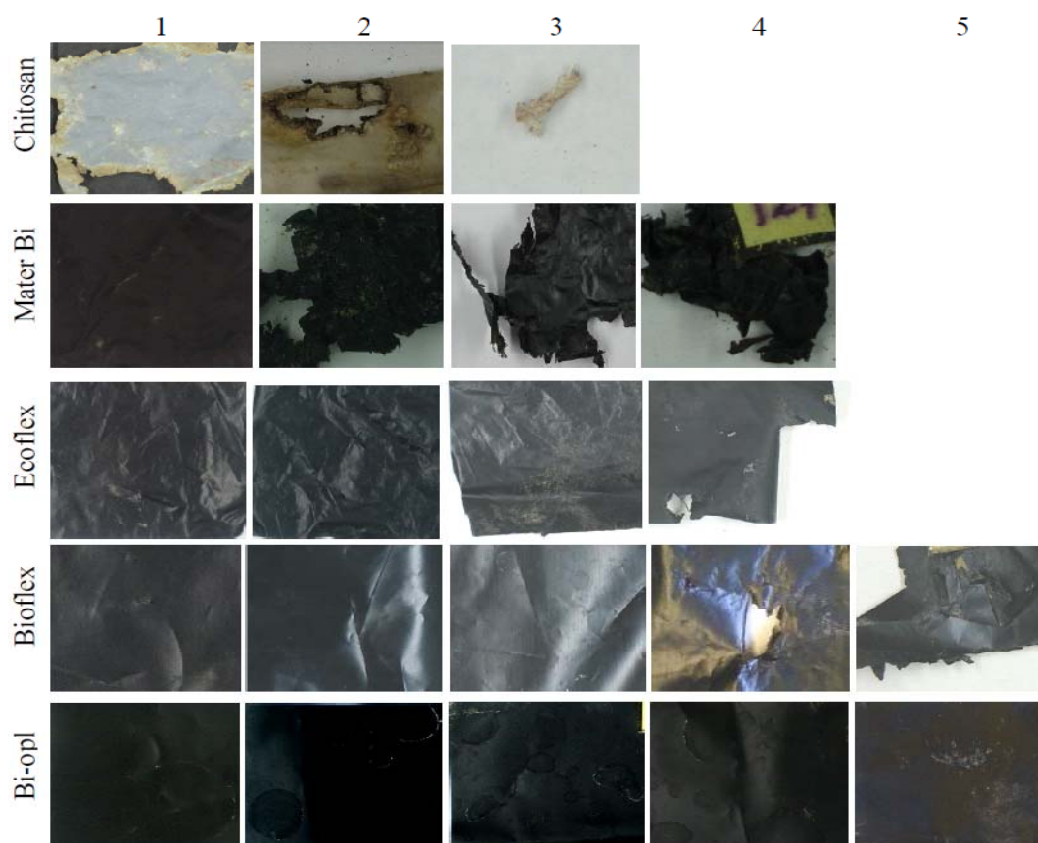
Figure 3.18: Photographical comparison between the bioplastic materials under loamy soil for five months

3.5.2.1.4 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 (Figure 3.6). The best fit of the data was obtained as the following equation [6] (agreed with Mostafa and Sourell, 2009):

$$BD = a\, T^b \qquad\qquad [6]$$

Where,

BD: Biodegradation, (%)

T : Time, (month)

a,b : Constants are listed in Table 3.6

Table 3.6: Multiple regression analysis for biodegradation data for the different materials at different soil types

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

3.5.2.2 Biodegradation at subsurface soil

The biodegradation data of bioplastic films buried in the subsurface of different soil types were presented in Table (3.7) 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 a maximum average of 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 3.7: The biodegradation data (%) of bioplastic films buried in the subsurface of different soil types

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

3.5.3 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 the subsurface burial of 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 could 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 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 enzymatic ally 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 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 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.

3.5.4 Conclusion

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 in all 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 and Mater Bi may hold for three months and Bioflex for four 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 bioplastic long life.

Finally, it can be recommended that Chitosan can not be used as a drip tube because of the high degradation rate in the soil leading to short life. For this reason, Chitosan will be excluded from the next experiments.

3.6 EFFECT OF FERTIGATION

This part focused on the determination of fertilizers effects on the four bioplastic materials that succeeded during the previous experiments. Fertigation is the application of fertilizers, soil amendments, or other water soluble products through an irrigation system. This technique, already used in the last century for the application of manure, liquid or suspended materials, is now growing rapidly for the application of readily soluble mineral fertilizer and chemicals because of efficiency and convenience (Nassar, 2000).

Thus, this section aims to determine the effect of fertilizers on the mechanical properties of the bioplastic materials.

3.6.1 Experimental Procedures

The mechanical properties of four different types of commercial bioplastics (Bioflex, Ecoflex, Mater Bi and Bi-OPL) were assessed under fertigation conditions to study the material stability.

A small drum kit was designed as a drip system (Figure 3.19). The system consists of a 100 liter drum raised one meter from the ground, a 1.5 m PVC submain and four bioplastic laterals made from Mater Bi, Bi-PL, Ecoflex and Bioflex.

A heat paste machine "Polystar 100 G" (Figure 3.20) was used to produce the laterals from the biomaterials with 0.5 m long and 22 mm diameter. The 0.5 m lateral pieces were connected together with in-between dripper to make 4 m long lateral for each type.

The main nutrients used as a fertilizer for the plants are nitrogen (N), potassium (K) and phosphorus (P). Nitrogen and potassium are easily applied through the drip system, but phosphorus is not usually recommended for application, particularly in its inorganic form.
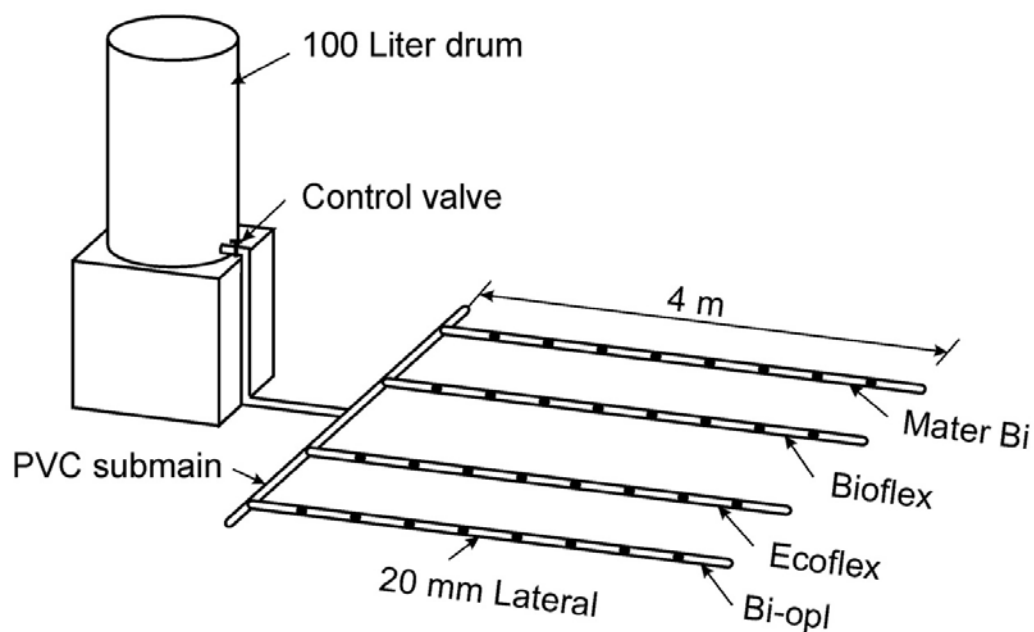
Figure 3.19: Schematic of a small drip system

Figure 3.20: A heat paste machine "Polystar 100 G" used for producing biodegradable laterals

According to Evans and Waller 2007, the maximum recommended concentration of nutrients for fertigation is 1 kg for each m^3 of irrigation water, also fertilizer equation (N:P:K = 2:1:1) can be used as the general equation for fertilizer rate. So in this experiment, Ammonium Nitrate (NH_4NO_3, 28 % N), Potassium Sulfate (K_2SO_4, 48 % K_2O) and Calcium Dihydrogen Phosphate (Ca (H_2PO_4)$_2$, 46 % P_2O_5)

were used to make the previous fertilizer equation (N:P:K = 2:1:1). Nitrogen and potassium were applied through the drip system but phosphorus was added directly to the soil. The irrigation system was operated for four hours with fertigation (Nassar, 2000). Three treatments were used, without fertilizer (control), 1 kg/m^3 and 2 kg/m^3 concentration. Tensile strength TS and elongation E were measured after 1 and 15 days with a tensile testing machine (Daiei Kagaku – Arimoto Kigyo Co., Ltd. Japan). Each strip was cut into tensile pieces 6 x 2 cm in size.

3.6.2 Results

In most applications envisaged for biomaterials 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 Bioflex samples are shown in Figure 3.21, it was remarkably susceptible (44.7 and 46 % loss of tensile strength after 1 day under 1 and 2 kg/m^3 respectively), while it remained relatively resistant without fertigation. After 15 days, the change of TS for Bioflex was not observed without fertigation but it was reduced significantly - as much as 44.7 and 51.5 %, under 1 and 2 kg/m^3 treatment respectively. Also small decreases were observed for the elongation during the treatments.
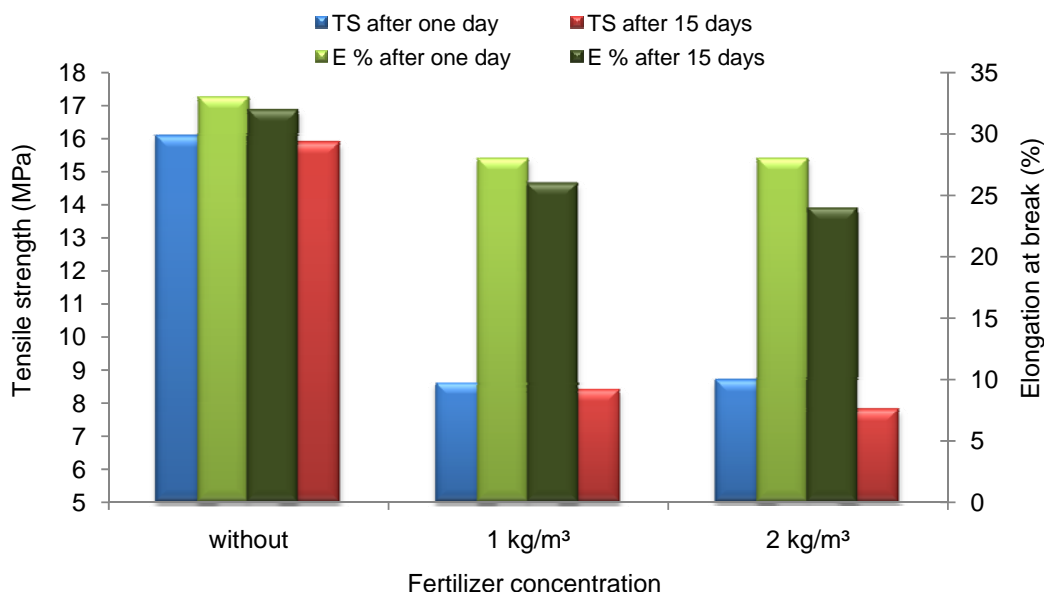
Figure 3.21: Effect of fertigation on the mechanical properties of Bioflex

The TS loss of Ecoflex under fertigation conditions started without an apparent lag phase and reached approx. 1.7 % after two weeks under 1 kg/m^3 (Figure 3.22) but with 2 kg/m^3 treatment, the TS loss was increased (4.3 and 5.2 % for 1 and 15 days respectively). However, elongation loss of 3, 34 and 39 % achieved after 15 days for control, 1 and 2 kg/m^3 concentration respectively.
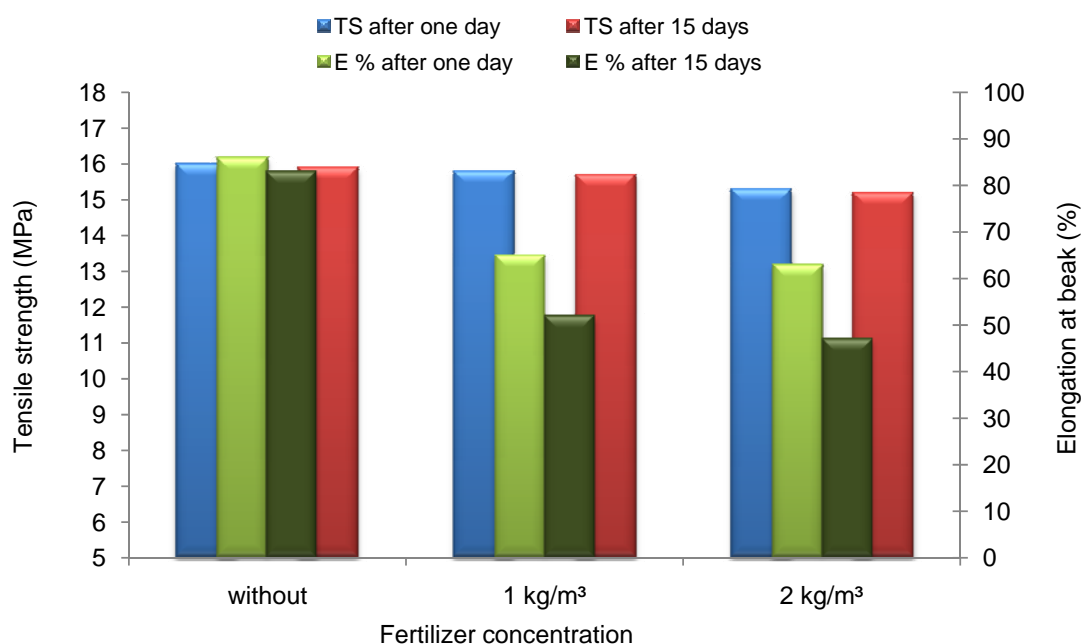
Figure 3.22: Effect of fertigation on the mechanical properties of Ecoflex

Bi-OPL remained relatively resistant during the treatment (only 0.5 % loss of tensile strength and 6 % loss of elongation capacity (Figure 3.23)), while Mater Bi remained slightly resistant at the time. The TS loss of Mater Bi started without an apparent lag phase and reached approx. 1.8 % after two weeks under 2 kg/m^3 (Figure 3.24). However, elongation loss of 12, 21 and 29 % achieved after 15 days for control, 1 and 2 kg/m^3 concentration respectively.
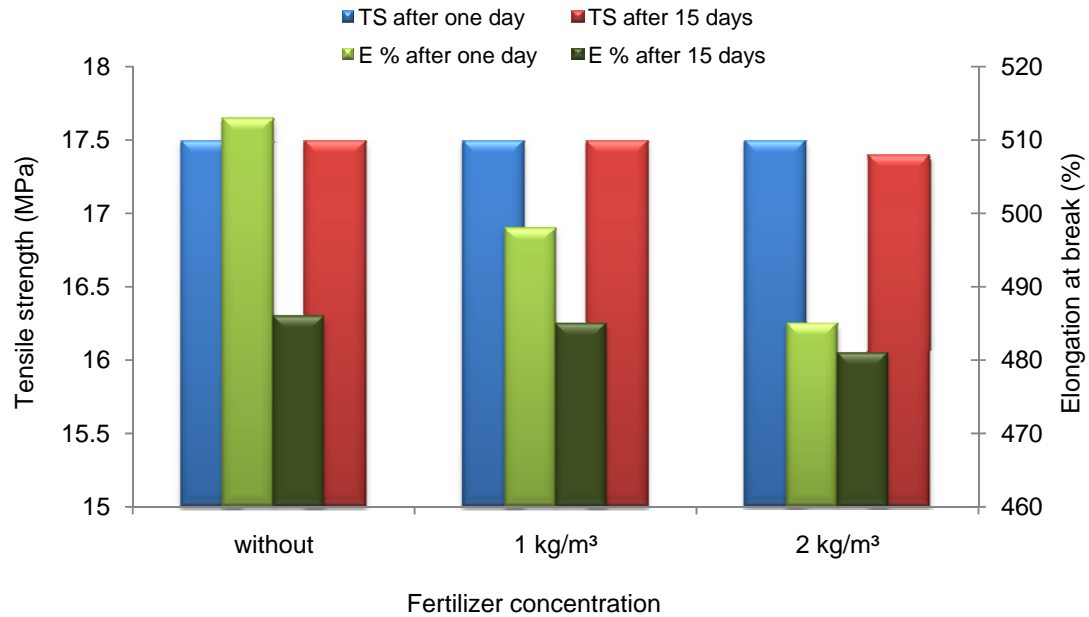
Figure 3.23: Effect of fertigation on the mechanical properties of Bi-OPL
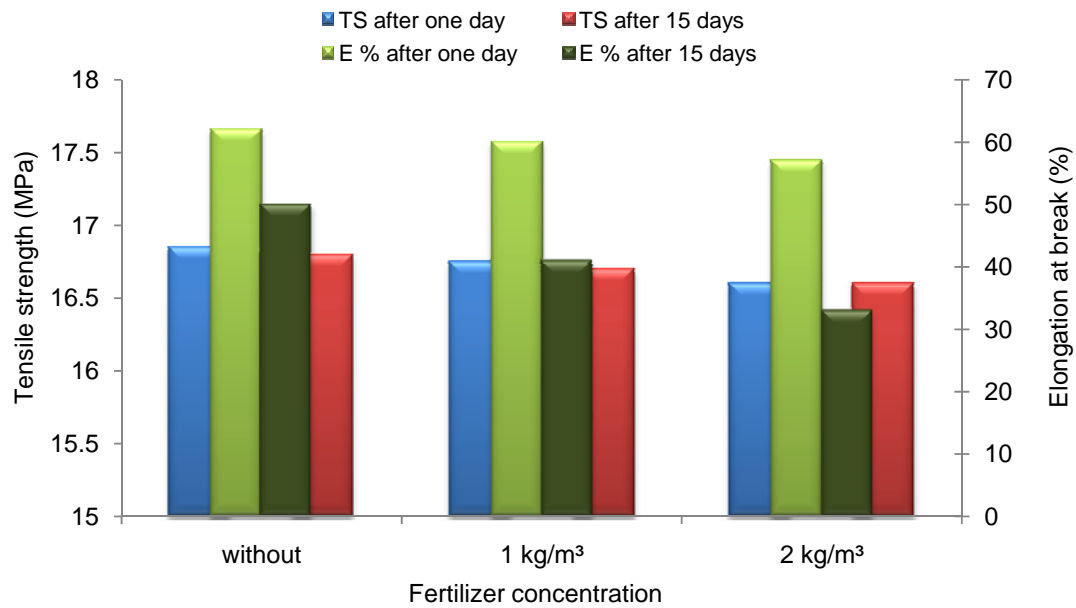
Figure 3.24: Effect of fertigation on the mechanical properties of Mater Bi

3.6.3 Discussion

Within the time scale of our experiments, Bi-OPL appears to possess a high resistance to fertilizer conditions. The Ecoflex and Mater Bi materials demonstrated

very little degradation, indicated by lower changes in tensile strength especially with the high fertilizer concentration (2 kg/m^3). An extensive degradation was observed for Bioflex plastic (50 % TS losses). In Bioflex, there are some additives like autoxidizable fatty acid ester may generate peroxides which chemically attack the bonds in the polymer molecules reducing the molecular chains to a level where they can be affected by fertigation (Orhan et al., 2004). Moreover the rate of degradation is affected by environmental factors such as moisture, temperature and biological activity.

3.6.4 Conclusion

From the previous results, Bi-OPL, Ecoflex and Mater Bi materials appear to possess a high resistance to the fertilizer under the experimental conditions as shown in Figure (3.25). They can be used as a lateral without any problems and with fertigation under the recommended fertilizer rate (1 kg/m^3). It is difficult to use Bioflex material with fertigation because of the degradation probability, but it can be used as a lateral without fertigation.

Figure 3.25: Losses of the mechanical properties of different biomaterials

3.7 DEGRADATION METHODS

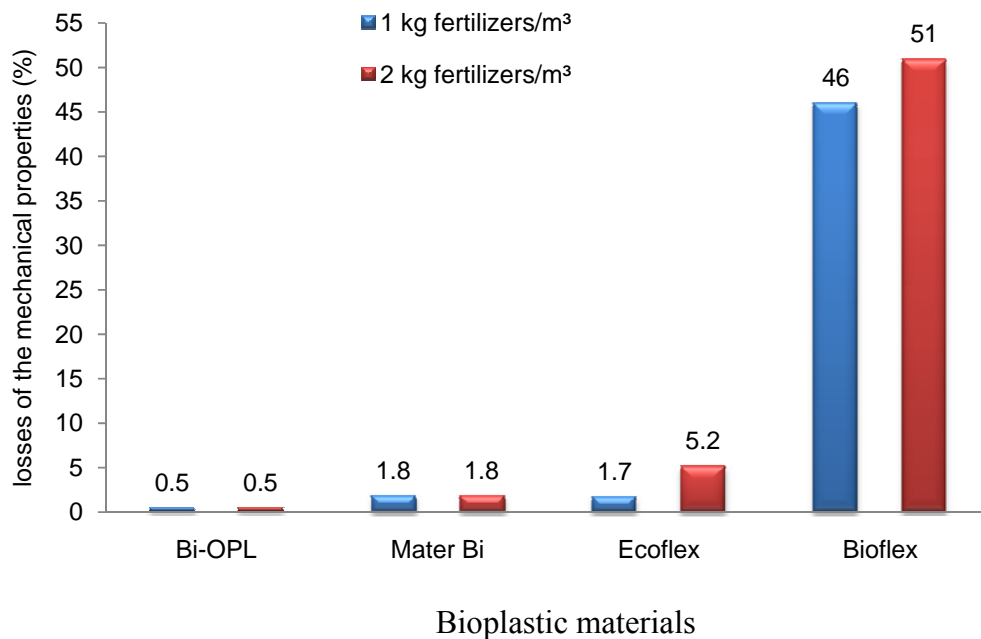Since the underlying purpose of this study is to use the laterals access for one season only and since these laterals may hinder the machine during harvesting or during the soil preparation for the next season, it is better to find a suitable method to use as a preliminary degradation method between the last irrigation time and before the harvesting at "2-3 weeks."

From the previous experiments and results, it was observed that some bioplastic materials can be use as degradable drip laterals for drip irrigation systems.

The aim of this experiment was to evaluate the suitability of the biological (enzymatic) and chemical methods for assaying the degradability of bioplastic materials. The idea is to use a degradation method at the end of the last irrigation by pumping a degrading substance into the lateral network allowing enough time for them to deteriorate.

3.7.1 Biological Degradation

Much literature was searched on the topic of biological degradation with micro-organisms like bacteria and fungi, or with enzymes. It was found that using bacteria or fungi to degrade bioplastic takes much longer than using enzymes. So in this experiment the degradation by enzymes was studied.

3.7.1.1 Experimental Procedures

A commercially available lipase from Pseudomonas sp. (PsL) (L9518-500UN, Sigma, Germany) was used for Ecoflex degradation in the experiments. The enzyme formulation (50 % protein content, one unit will produce 1.0 μmole of glycerol from a triglyceride per min at pH 7.0 at 37 °C) was dissolved in 0.9 % NaCl solution to a concentration of 5mg/ml and stored at 20 ^{o}C (Marten et al., 2005; Frederick et al., 2008; Nakajima et al., 2009).

For Mater Bi degradation, α-amylase (EC 3.2.1.1) from Bacillus licheniformis (A4551, Sigma Germany) was used with activity of 1000 units/mg protein. One unit will liberate 1.0 mg of maltose from starch in 3 min (pH 6.9, 20 ^{o}C). A working

solution was prepared by diluting a suspension of twice crystallized α-amylase in 0.9 % NaCl solution to a concentration of 0.1 mg/ml (Alberta et al., 2009, Li et al., 2004).

3.7.1.1.1 Laboratory methods

The bioplastic films were cut to approximately 3 cm × 2 cm. The film was then placed in test tubes containing 10 ml of enzyme solution and incubated at 25 $^{\circ}$C. After 3 days of incubation, the films were gently washed with diluted water, dried and their tensile strength was measured. Biodegradability was evaluated as the ratio of the loss of tensile strength of the film after 3 days reaction to the initial tensile strength of Ecoflex and Mater Bi films. In addition, the soluble products of hydrolysis (maltose) after one, two and three days of Mater Bi immersion were analyzed by high performance liquid chromatography (HPLC) (Duisburg, Dtl. Germany; SIL 10ADAutosampler, LC10AT pump, DGU-3A degasser, RID-RID-10A detector, SPD10AUV detector (210 nm), CTO-10A- oven, SCL-10AVP controller, Aminex HPX-87H 300 x 7.8 mm column (Bio-Rad Laboratories GmbH, Germany)), according to the method of Vasanthan et al. (2001) and Li et al. (2004). A standard solution of maltose was used for calibration. Experiments were performed in triplicate. A quantitative analysis of the metabolites produced (adipic acid and terephthalic acid) from Ecoflex was also performed by HPLC following the method of Marten et al. (2005) and Frederick et al. (2008).

3.7.1.1.2 Field methods

Degradation tests with the biomaterials in the field were performed according to Marten et al. (2005) and Briassoulis (2004) and showed positive results at the end of laboratory experiments.

Four 0.5 m long laterals with a diameter of 22 mm made from the biomaterials a (manually produced as explained in effects of fertigation section) were filled with enzyme solution and left in the soil surface on the open field, the other four laterals were filled with water (without an enzyme) as a control. The enzyme solution and water were discharged from the laterals through a dripper (0.6 l/h) fixed in each lateral.

After 20 days, the films were gently washed with diluted water, dried and their tensile strength was measured.

3.7.1.2 Results and Discussion

3.7.1.2.1 Laboratory Experiments

The first experiments were set up to assess the biodegradation potential of Ecoflex. This screening stage was conducted by exposing Ecoflex films to lipase in order to measure its ability to degrade the co-polyester under a laboratory temperature 25 $^{\circ}$C.

Several by-products were expected to arise from biodegradation of the co-polyesters such as adipic acid and terephtahlic acid, which are consistent with an enzymatic hydrolysis of the ester bonds as the mechanism for biodegradation.

A quantitative analysis of the metabolites produced from Ecoflex was performed by HPLC. Adipic acid was detected in only very small amounts (Figure 3.26). The supernatant was also hydrolyzed and re-injected to the HPLC, but no additional peak was observed on the chromatogram and no change in the amounts of adipic acid, or terephthalic acid was observed for either enzymatic and water hydrolysis.
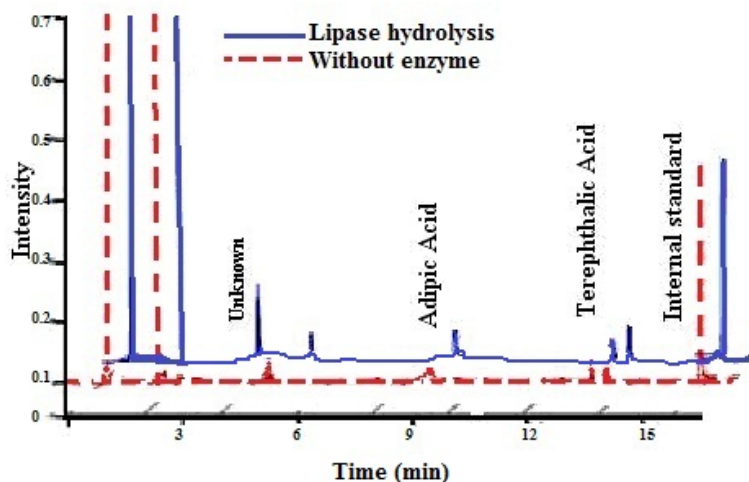

Figure 3.26: Illustration of adipic acid concentration in solution as it is released in the media with the breakdown of the copolymer by lipase

The TS loss of Ecoflex started without an apparent lag phase and reached approx. 1.8 % after the incubation time with lipase treatments than the beginning (Figure 3.27) but without enzyme treatment, the TS loss was 1.2 %. However, elongation loss of 25 and 21 % was achieved with and without enzymes than the beginning respectively. That means there is no significant effect from lipase enzymes.
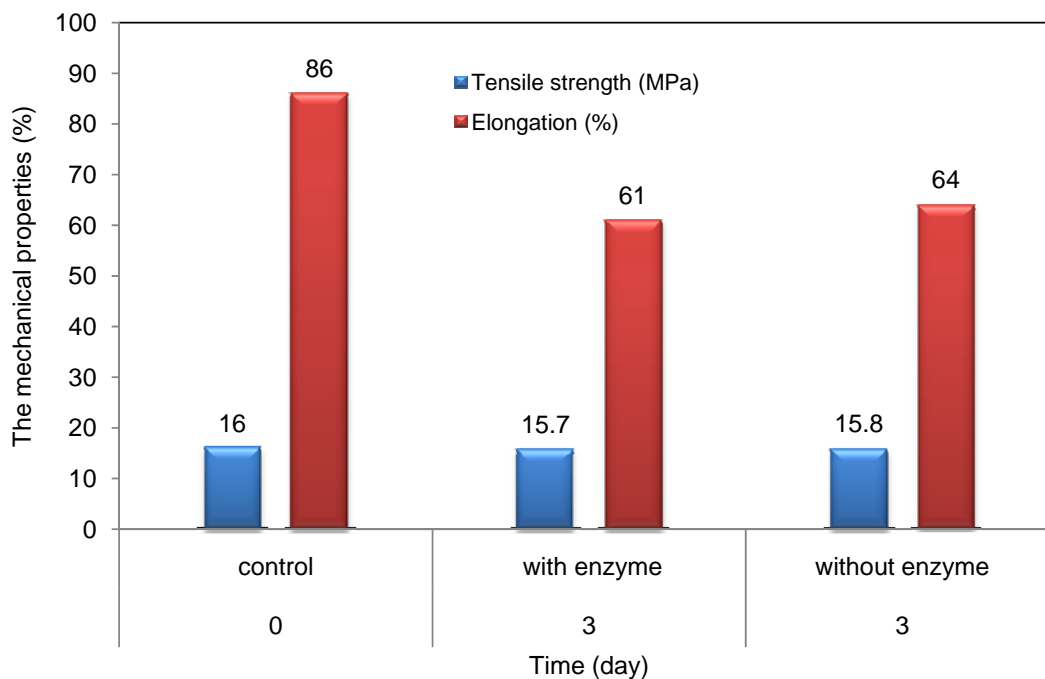
Figure 3.27: Effect of lipase enzyme on the mechanical properties of Ecoflex

Results of experiments indicate that all replicates show minimal to no degradation at the time of incubation. Furthermore, no significant increase in degradation is obtained by increasing the exposure time to 6 days. This was probably due to the pH shift in the absence of any buffer in the solution, low temperature; where the optimum activity of lipase between 40-50 $^{\circ}$C (Marten et al., 2005), or the samples need to be in a small pieces to increase the exposure surface area.

The second experiments were set up to assess the biodegradation potential of Mater Bi. This screening stage was done by exposing Mater Bi films to α-amylase in order to measure its ability to degrade films under laboratory temperature 25 $^{\circ}$C.

The content of maltose in the hydrolysates of Mater Bi was determined by HPLC at different time periods of hydrolysis (Figure 3.28). The concentration of

soluble products during hydrolysis differed with the duration of hydrolysis. At the onset of hydrolysis, no sugars were detected by HPLC. When α-amylase hydrolysis of the materials progressed, maltose was produced, whereas enzyme hydrolysis (24 h) produced at least 0.2 g/g Mater Bi and hydrolysis (48 h) produced more maltose (0.35 g/g Mater Bi). After 72 h of hydrolysis, the maltose content was decreased (0.3 g/g Mater Bi). On the other hand, no sugars were detected for the control experiment (without enzyme).
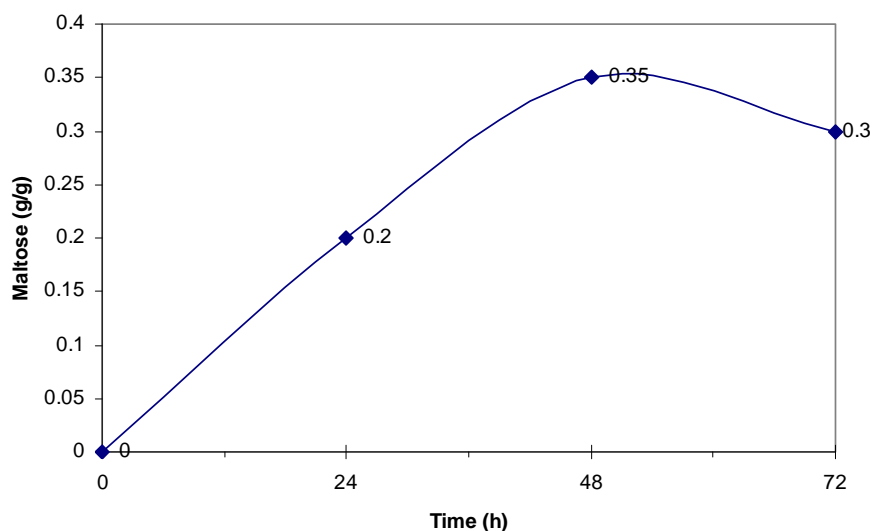
Figure 3.28: Maltose concentration in the solution as it is released in the media with the breakdown of Mater Bi by α-amylase.

The tensile strength losses and the elongation capacity are shown in Figure 3.29. The tensile strength losses were 12.2 % at the end of incubation with the enzyme, whereas they were only 0.5 % without the enzyme. The elongation capacity loss was higher with enzyme treatment (34 %) than without enzyme (17 %). That means α-amylase has a good effect on the biodegradability under laboratory conditions.

From the laboratory experiments it was observed that the positive enzymatic degradability results for Mater Bi and the negative one in the case of Ecoflex. So it can be continue measuring the enzymatic degradability for Mater Bi under field conditions.
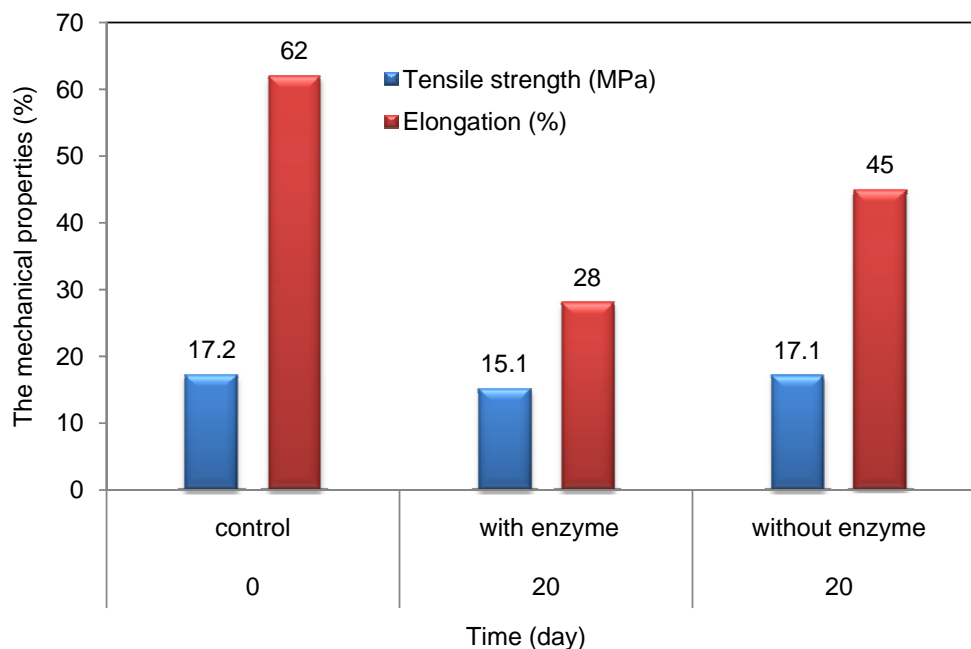
Figure 3.29: Effect of by α-amylase enzyme on the mechanical properties of Mater Bi

3.7.1.2.2 Field Experiments

The results of the mechanical testing of the laterals made of Mater Bi during their exposure in the field with and without enzyme are presented in Figure 3.30. The tensile strength losses were 1.70 % at the end of the experiment with the enzyme, whereas they were 1.16 % without enzyme. The tensile strength was not affected significantly by the enzyme or the water flow during 20 days exposure in the field for. At the same time, the elongation at break property of the exposed samples more clearly deciphers their ageing evolution in terms of their mechanical behavior: As shown in Figure 3.30, the elongation at break values fall much lower than the 36 % and 42 % of the initial values within the 20 days, both with and without enzyme respectively, a well known behavior of Mater Bi analyzed already extensively with films in (Briassoulis, 2007 and Briassoulis et al., 2008).

The evolution of the tensile strength does not follow the evolution of the corresponding elongation at break values. This allows the laterals samples to function satisfactorily mechanically for a much longer period than the elongation at break would suggest (Briassoulis, 2007).
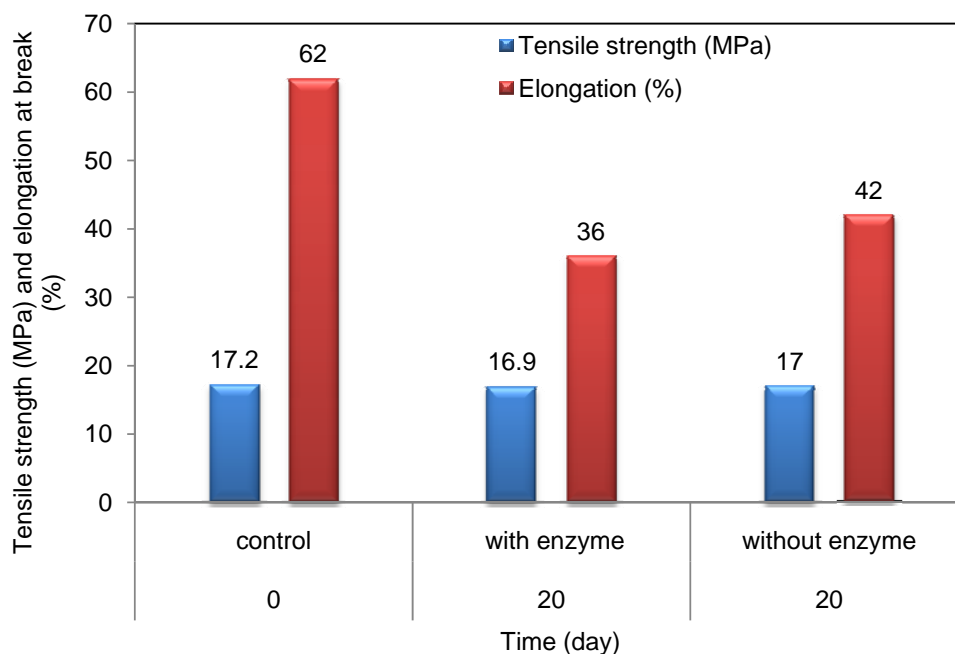
Figure 3.30: Tensile strength (MPa) and elongation at break (%) of the biodegradable laterals during their open exposure in the field

3.7.1.3 Conclusion

There are no differences between the results of the present work and those of literature with Ecoflex which emphasize the need for careful consideration of test conditions in conducting assessments of the potential for biodegradation and fate of aliphatic–aromatic co-polyesters in the environment. The biodegradation process is significantly slower at ambient temperatures (25 ^{o}C) than in a higher one (Marten et al., 2005; Briassoulis, 2007 and 2008) but it does seem likely that these polymers would eventually degrade given a sufficiently long period of exposure to enzyme at these temperatures.

In general, the biodegradation of Ecoflex caused by exposure to lipase enzyme can be characterized by a slower degradation rate compared to earlier studies.

In the case of Mater Bi, the mechanical behavior of the biodegradable samples was tested in the laboratory and in the field. It was found that 35 % of the material biodegrade in laboratory conditions within the experimental time, while it was

enzymatically biodegraded with a maximum 0.54 % more than without enzymes under the field conditions. These results indicate that, under field conditions, it is difficult to obtain a satisfactory rate of degradation with the enzyme in the desired time (20 days), for several reasons including the large differences in temperature between day and night (more than 25 $^{\circ}$C), which may cause the death of the enzyme, or at least decrease its activity. Also, most of the solution leaked from the laterals samples during three days, reducing the enzyme concentration.

From previous results we can conclude that the use of enzymes is not appropriate for analysis under field conditions and the limited time for each of Mater Bi and Ecoflex. Therefore, it is suggested the use of other means such as chemical means to reach the aim of the study as described in the following section.

3.7.2 Chemical Degradation

From biological degradation results, it was found that the use of enzymes is not appropriate as a degradation way under field conditions with the limited time for each of the Mater Bi and Ecoflex. Therefore, the suggestion is to use some chemical methods like acids to achieve the objective of the study, which is to find a quick way as a preliminary degradation method under field conditions.

Treatments with acids are mainly needed to dissolve precipitates of calcium carbonate and calcium residue from fertilizer applied in the drip irrigation system. It might be used to clean the drippers' water passages from other mineral deposits like ferric oxides. Acids can be applied through the drip-irrigation system by a fertilizer pump.

In many cases, bioplastic materials are attacked chemically by acids that can attack the long chain hydrocarbon molecules, and broken down to small pieces. Further microbial degradation must then occur for true biodegradation to be achieved in the soil (Shah et al., 2007 and Auras et al., 2005). Acids can be injected into the system within ten to fifteen minutes only after the system has reached maximum operation pressure (usually at the end of the last irrigation time).

3.7.2.1 Experimental Procedures

The mechanical properties of three different types of commercial bioplastics (Ecoflex, Mater Bi and Bi-OPL) were assessed under acid conditions to study the material brake down.

A small drum kit was designed as shown in section 3.5.1 (Figure 3.19). The system consists of three bioplastic laterals made from Mater Bi, Bi-OPL and Ecoflex with 4 m long.

According to Netafim (2008) the suitable acids to be injected throw the irrigation system without any hazard or bad affects are nitric acid (HNO_3, 60 %) and phosphoric acid (H_3PO_4, 85 %) with 0.6 % concentration.

Three treatments were used for both nitric and phosphoric acid which injected into lateral samples for 10 minutes with concentration 0.1, 0.5 and 1 %. After periods

of 0, 5, 10 and 20 days, a sample with 0.5 m was taken from each lateral and each sample was cut into tensile pieces 6 x 2 cm in size. Three pieces were used for each treatment for tensile strength (TS) and elongation measuring. TS were measured with a tensile testing machine (Daiei Kagaku – Arimoto Kigyo Co., Ltd. Japan).

3.7.2.2 Results and Discussion

The interaction of chemical compounds with a bioplastic material is a unique characteristic between them. The absorption of these chemical compounds may affect the final mechanical properties of a biomaterial. Therefore, the mechanical properties of bioplastic pumped with two acids as a function of time was studied to assess the suitability of the bioplastics as shown in Figures 3.31, 3.32 and 3.33.

For samples pumped with phosphoric acid (Figure 3.31), Bi-OPL shows tensile strength losses of around 2, 4, and 9 % under 0.1 % acid at 5, 10 and 20 days respectively. With increasing the acid concentration to 0.5 and 1 %, tensile strength losses were increased, where they were 3, 6.3, 16 % and 7.4, 10.3, 18.8 % for the same time, respectively. On the other hand, the tensile strength of Mater Bi and Ecoflex decreased more quickly than Bi-OPL. The tensile losses percent for both Mater Bi and Ecoflex take the same trend with 0.1 and 0.5 % concentrations but Ecoflex indicated more losses and quickly than Mater Bi with 1 % concentration. The tensile strength reached to 0 MPa (100 % losses) at the end of Mater Bi treatment with 0.5 and 1 % concentrations [during samples taking by day 20 from the field, it was very difficult because the samples broken down as shown in Figure 3.32]. In the case of Ecoflex, the break down was earlier than Mater Bi (day 10) with 1 % concentration.
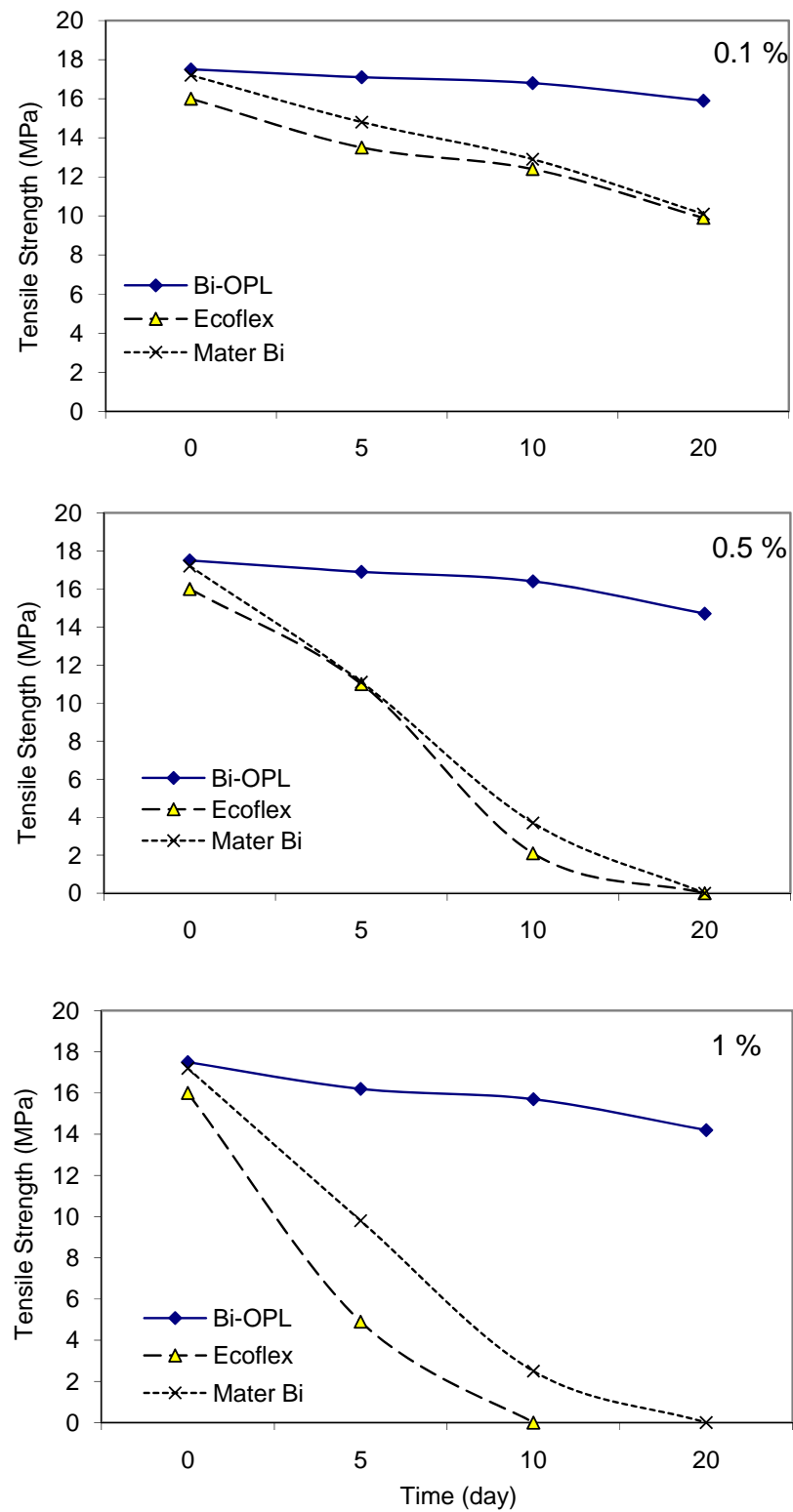
Figure 3.31: Tensile strength (MPa) of the biodegradable laterals during their open exposure in the field under different concentrations of phosphoric acid

Figure 3.32: Completely break down of Mater Bi and Ecoflex under phosphoric acid conditions

The chemical degradation data of bioplastic samples with different nitric acid concentrations were presented in Figures (3.33 and 3.34) as percentage average of tensile strength losses. It can be observed that the degradation percentage was similar to that on the phosphoric acid and showed the same trend.

The results revealed that the chemical degradation of bioplastic materials was faster in case of nitric acid.

The change of losses of Bi-OPL was slow with a maximum average of 14, 16, and 19 % under 0.1, 0.5 and 1 % acid concentrations by the day 20, respectively. An extensive degradation was observed for Mater Bi and Ecoflex. During the treatments, Ecoflex was degraded most, followed by Mater Bi. The tensile strength reached to 0 MPa (100 % losses) at the end of Mater Bi treatment (day 20) with both 0.5 and 1 % concentrations. However, in the case of Ecoflex, the completely break down was earlier (day 10th) in both 0.5 and 1 % concentrations.

As discussed above, all bioplastics in this study show hydrolytic degradability, depending on the acidic conditions. Overall, the three bioplastics studied exhibit slow to moderate degradability in low acidic conditions (0.1 %). However, Mater Bi and Ecoflex reveal higher degradability in the high acidic conditions rather than Bi-OPL.

In comparison, Bi-OPL is less susceptible to degradation in acidic conditions than Mater Bi and Ecoflex, the order of increasing susceptibility being Bi-OPL << Mater Bi ≤ Ecoflex.
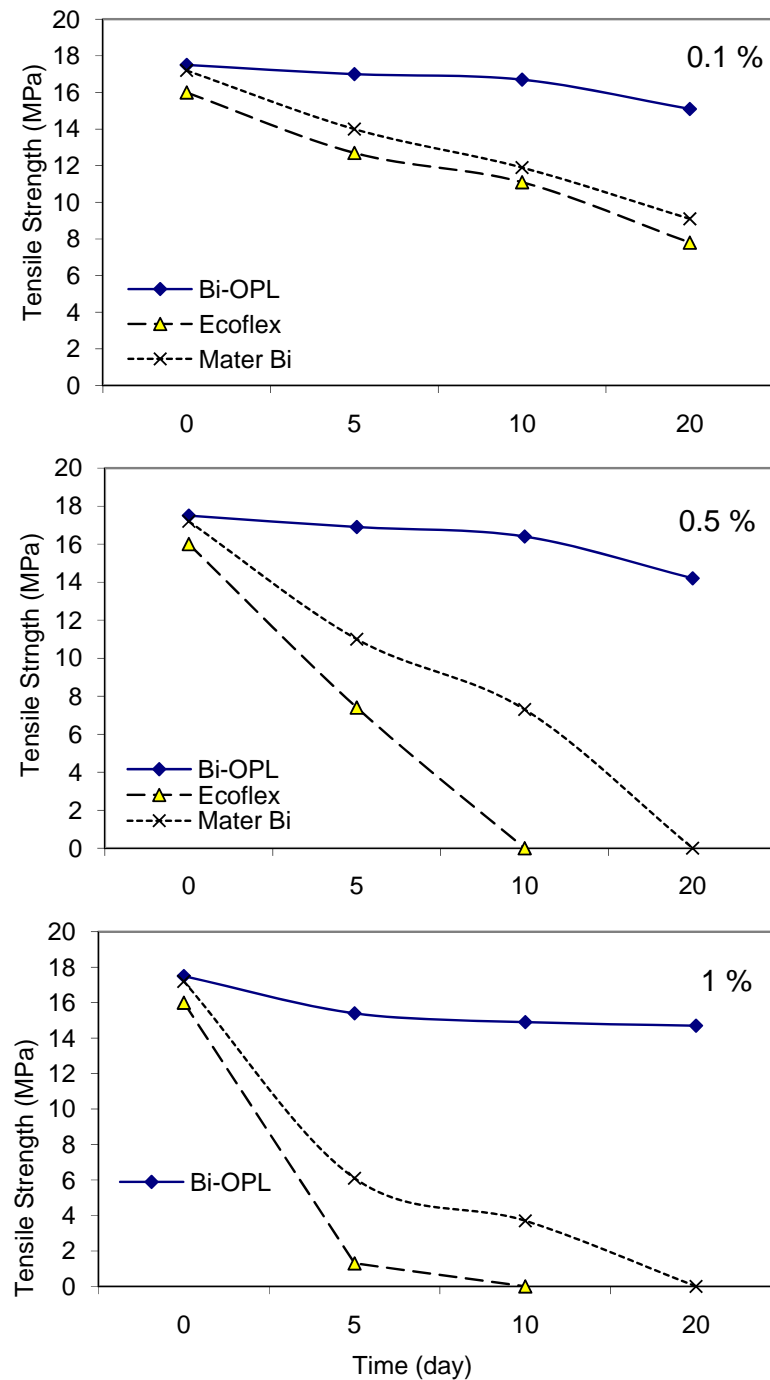

Figure 3.33: Tensile strength (MPa) of the biodegradable laterals during their open exposure in the field under different concentrations of nitric acid
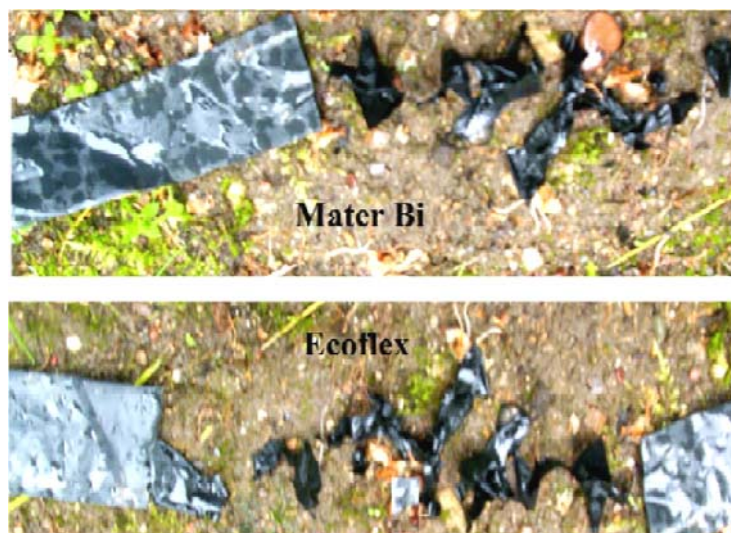
Figure 3.34: Completely break down of Mater Bi and Ecoflex under nitric acid conditions

All samples showed a decrease of the tensile strength. Also, Table 3.8 shows a reduction of the elongation at break in the same trend. In all cases, the three bioplastics became more brittle with a decrease in the elongation at break. The elongation in every sample is an indication of the brittleness of the sample as a function of time which is an indication for degradation.

Samples testing at time show a bigger variation of the elongation at break compared with the samples tested in 0 time. Where, Bi-OPL was more ductile at 0.1 % acid concentration than the others. Also all bioplastic samples were more brittle in case of nitric acid than phosphoric acid.

It could be observed from these treatments that there were onsets for tensile strength and elongation losses. However, under acidic condition, bioplastics degradation behaviours were quite different from that in neutral environment. As the chain scission went on, more carboxylic end groups were produced. Hydrogen ions attacked the ester bond and triggered the autocatalysis effect, which has so far been identified to be responsible for the degradation mechanism.

Table 3.8: The elongation at break of the bioplastics in phosphoric and nitric acids

| Time (day) | Elongation % under effect of phosphoric acid | | | | | | | | |
| | Bi-OPL | | | Mater-Bi | | | Ecoflex | | |
	0.1%	0.5%	1%	0.1%	0.5%	1%	0.1%	0.5%	1%
5	317	291	261	29	22	12	31	24	5
10	265	203	144	19	7	3	16	9	-
20	230	177	112	10	-	-	8	-	-
Elongation % under effect of nitric acid									
5	293	271	223	23	11	9	21	6	3
10	236	169	128	15	4	2	11	-	-
20	202	142	99	4	-	-	3	-	-

- could not be measured because samples completely broken down.

The pH affects reaction rates through catalysis. After shifts in acid concentration, reaction rates of esters, for example, may change some orders of magnitude due to catalysis. Ester hydrolysis can, thereby, be either acid or base catalysed (Müller et al., 1998; Tsuji and Ikada, 2000; Yi et al., 2004; Yew et al., 2006). The effect of pH on degradation has been investigated carefully for most biodegradable polymers. The breaking strength was found to depend markedly on the pH of the degradation and was found to be highest and fastest degradation at low and high pH (Jung et al., 2006; Li et al., 2008).

3.7.2.3 Conclusion

It could be concluded from the experimental data that the acid has a great effect on degradation behavior. Hydrogen ions could still penetrate into the matrix and induced random chain cleavage. It was hypothesized that the fastest decrease of TS was due to incubation and enhanced Hydrogen catalysis effect provided by the acidic media. An abundance of Hydrogen replaced carboxylic end groups to accelerate the ester hydrolysis. Since the autocatalysis effect played no crucial role in Bi-OPL degradation under low pH condition, the composition of the polymer then had less impact on the degradation behavior, so the degradation result was similar with other polymers according Li et al. (2008). The results obtained in this study have indicated that both Ecoflex and Mater Bi samples have the same degradation rate at various acids levels and times. They degrade significantly faster in a high acidic than in low

concentration. Bi-OPL at the acids levels, however, retained the largest amount of tensile strength of the three concentrations studied and in general, showed better hydrolytic resistance than Mater Bi and Ecoflex within the studied acids range.

Finally, it can be recommended that the use of 0.5 % concentration of nitric or phosphoric acid can achieve the objective of the study under field conditions with the limited time.

4. DISCUSSION AND CONCLUSION

The idea of this study is to solve some problems that hinder the expansion of the use of drip irrigation and its advantages in the provision of water and energy. These problems include high annual costs especially for the retrieval and maintenance of drip laterals. Also smallholdings are a big problem for the expansion of modern irrigation systems like drip irrigation.

Another goal is to protect the environment from some of the problems resulting from the use of drip laterals made from petroleum products. Some, such as limited fossil resources (crude oil), take more than 50 years to degrade and when burned release the carbon dioxide into the atmosphere, leading to global warming. According to the new environmental regulations and a growing environmental awareness throughout the world, which have triggered the search for new products and processes that are compatible with the environment, laboratory and field experiments were done to study the suitability of some bioplastic materials already used in agriculture for use as biodegradable drip tubes.

4.1 Low Pressure Drip System

Drip irrigation provides the opportunity to save water and the potential to increase net income by applying water in the right quantity and at the right time. Small fields (< 10 hectares) would benefit from LPS irrigation system which has the ability to distribute the amount of water applied. LPS is a well researched system for drip irrigation, typically those available for flood irrigated crops. There are significant agronomic advantages to using a low pressure, low flow drip system. These advantages translate into measured improved distribution uniformity when compared to flood irrigated crops and energy savings compared to flood and sprinkler irrigated crops.

Repeated reuse of the drip-line leads to a decrease the distribution uniformity and increase in costs, where the distribution uniformity decreased by 10.5 and 21.6 % for reusing the laterals in the second and third year respectively. Moreover, the cost of repairing laterals was more than 5 and 6.5 times for both 2nd and 3rd season. It was

observed that the lateral removal needed to be executed with care, otherwise there is a risk of stretching, especially if it is retrieved in the mid-afternoon. Stretching the laterals will cause non-uniformity because it increases the emitter spacing, causing the flow rate to decrease. Also, if stretching occurs, the lateral's wall becomes thinner, meaning it could burst under field conditions. The laterals' removal requires intensive labour because the work team must first undo the tail-ends of the drip lines that are going to be retrieved in order to flush the water out. Over time, wear and tear will then become the main problem (e.g., damage which occurs during the lateral retrieving at the end of the last season) adds to performance variability. Field defect variation estimates the effect of blockages and wear and tear on distribution uniformity by comparing emitter emission uniformity to manufacturing variation.

Many potential problems or disadvantages to drip lines retrieval can be observed: labour and maintenance is more intensive, risk of mechanical damage to lateral especially if it reuse, increased management skills and experience are needed and increased retrieval costs season after season. All of these disadvantages are agreed with Barreras (2000) and Burt and Styles (1999).

In addition there is another serious problem known, the direct impact of plastic wastes on the environment. Laterals are produced from PVC or PE which are produced from petroleum, a limited resource. The PVC and PE take more than 50 years to degrade, and when burned, release the carbon dioxide into the atmosphere leading to global warming.

Environmental problems caused by petroleum-based plastics have led to interest in alternatives made from biodegradable polymers (bioplastics).

A series of studies will be done in the next chapters to identify the properties of some bioplastic materials and the possibility to use them as biodegradable drip tubes for developing and managing micro irrigation systems.

4.2 Bioplastic Materials

Some environmental factors affecting the bioplastic degradation were studied, such as temperature, moisture content, soil types, and fertigation. Also some degradable methods were studied in the laboratory and field to find a suitable method

for the preliminary degradation between the last irrigation and harvesting, approximately 2-3 weeks.

From the literature review, it was found that there are some categories of bioplastics used as commercial products and used in our study, such as Polysaccharides (starches (Mater Bi), cellulose (FR 39) and pectin (Chitosan)), Polylactides (polylactic acid (Bi-OPL and Bioflex)) and Petrochemical products (aliphatic-aromatic co-polyesters (Ecoflex)).

The general results of bioplastic samples under the studied conditions were concluded in Figure (4.1).

4.2.1 Temperature and Relative Humidity

The equilibrium moisture content of all materials under study increased with increasing relative humidity from 43 % to 95 %, but it decreased when increasing the temperature from 10 to 50 ^{o}C. The results revealed that cellulose has a great effect by changing the relative humidity from 43 to 95 %, followed by both Mater-Bi and Chitosan, which the EMC increased by 17.90 , 9.87 and 12.22 %, respectively. On the other hand, there is a small effect on the EMC by changing the relative humidity on each of materials: Ecoflex (2.58 %), Bioflex (2.40 %) and Bi-OPL (0.50 %). This may be due to the fact that the moisture content is identical to the sorption isotherms, where water is adsorbed from the vapor of the ambient air and the moisture content is in equilibrium with the ambient relative humidity. The FR39 material, which is made of cellulose, could be difficult to be use as a drip tube because of the high moisture content. It creates good environmental conditions for microorganisms to attack the biomaterials, leading to a short life and it was excluded from the next experiments.

4.2.2 Effect of Different Soil Types

The biodegradation results of bioplastics in different soil types indicated that the biodegradation of all bioplastic materials under study was faster in subsurface than surface positions. The results and summary revealed that Bi-OPL holds for more than
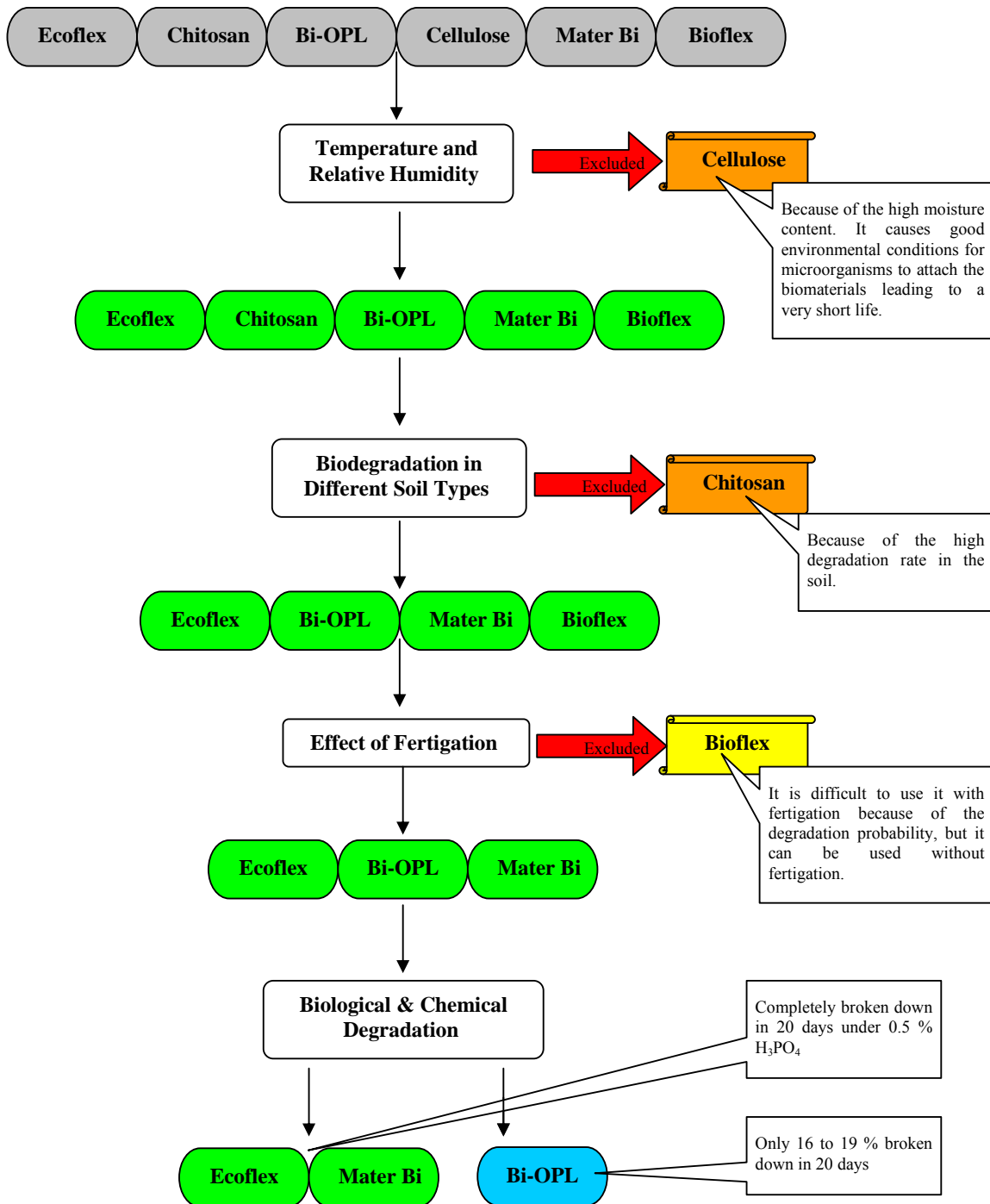
Figure 4.1: The Degradation experiments and results structure for the biomaterials under the study

five months in all soil types, Ecoflex and Mater Bi may hold for three months and Bioflex for four months as best working life expectancy, Chitosan can be used as a mulch film but can not be used as biodegradable drip tubes and finally, sandy soil performs better than loamy and sandy loam soils in term of bioplastic long life. 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 could 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 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.

Other mechanisms which play significant role are physical damage due to 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 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.

4.2.3 Effect of Fertigation

Bi-OPL, Ecoflex and Mater Bi materials appear to possess a high resistance to the fertilizer under the experimental conditions. Ecoflex and Mater Bi materials demonstrated very little degradation, indicated by lower changes in tensile strength especially with the high fertilizer concentration (2 kg/m^3). They can be used as a lateral without any problems and with fertigation under the recommended fertilizer rate (1 kg/m^3). An extensive degradation was observed for Bioflex plastic (50 % TS losses). In Bioflex, there are some additives like autoxidizable fatty acid ester may generate peroxides which chemically attack the bonds in the polymer molecules reducing the molecular chains to a level where they can be affected by fertigation (Orhan et al., 2004). It is difficult to use Bioflex material with fertigation because of

the degradation probability (so it was excluded), but it can be used as a lateral without fertigation.

4.2.4 Degradation Methods

The biodegradation of Ecoflex caused by exposure to lipase enzyme can be characterized by a slower degradation rate compared to earlier studies. This was probably due to the pH shift in the absence of any buffer in the solution, low temperature; where the optimum activity of lipase between 40 - 50 ^{o}C (Marten et al., 2005), or the samples need to be in a small pieces to increase the exposure surface area. Also in the case of Mater Bi, it was found that the materials biodegraded in laboratory conditions within the experimental time by 35 %, while it was enzymatically biodegraded with a maximum 0.54 % more than without enzyme under the field conditions. It is difficult to obtain a satisfactory rate of degradation with the enzyme in the desired time (20 days), for several reasons including the large differences in temperature between day and night (more than 25 ^{o}C), which may cause the death of the enzyme, or at least decrease its activity. It can be concluded that the use of enzymes is not appropriate as a method for degradation under field conditions and the limited time for each of the Mater Bi and Ecoflex.

The chemical degradation indicated that both Ecoflex and Mater Bi samples have the same degradation rate at various acids levels (phosphoric and nitric acids) and times. They degrade significantly faster in highly acidic solutions than in low concentrations. However, at the acid level, Bi-OP, retained the largest amount of tensile strength of the three concentrations studied and in general, showed better hydrolytic resistance than Mater Bi and Ecoflex within the studied acid ranges.

Finally, it can be recommended that the use of 0.5 % concentration of nitric or phosphoric acid can achieve the objective of the study under field conditions with the limited time. To save money, concentrated and inexpensive technical acids should be used, such as concentrated technical nitric or phosphoric acid, which applied as fertilizer through the drip system. It will be fine as a future work if the biological scientists and companies can find suitable and cheap enzymes with the ability to degrade the bioplastic materials under field conditions and in a short time.

4.3 Resume

LPS can operate and perform efficiently and conserve water in the smallholdings (less than 10 hectares).

For developing and managing micro irrigation systems, series of studies were done to identify the properties of some bioplastic materials and the possibility to use them as biodegradable drip tubes. Some bioplastic materials like Mater Bi, Ecoflex and Bi-OPL indicated good results where they have the possibility for use for producing the biodegradable drip tubes, instead of PE or PVC, that will not need to be collected and disposed of after use but will decompose in the soil without any adverse environmental effect. This will eliminate the disposal cost; will be environmentally friendly and possibly, at least partially, the materials used may be based on renewable raw resources.

So, further study can be conducted in the field with a rail bioplastic tubes at larger scale in order to validate the methodology and to have field data in order to better design the system.

4.4 Overview on Environmental and Economical Advantages of Bioplastics

There are many good reasons to support the bioplastics innovation. Environmental aspects are top of the list. It is not however possible to make blanket assumptions such as "bioplastics are the more environmentally friendly solution". It is furthermore important to consider the following: Sustainability covers not only environmental aspects but also economic and social components. If jobs, growth markets or global export opportunities develop from innovative technologies such as bioplastics, this is positive both for the economy and the individual. Bioplastics can be produced throughout Europe and will therefore reduce dependence on imports while offering export opportunities (European Bioplastics, 2008).

The situation for bioplastics is typical for innovations: High research and development costs, high production costs caused by small scale production, Optimisation potential of production facilities not exploited to the full and considerable price differential to conventional commodity products.

The price of bioplastics has continued to fall over the past ten years (Figure 4.2). Their competitiveness over conventional plastics should also continue to improve into the future through more effective processes, possible economies of scale and simultaneous increasing competition from new market players (European Bioplastics, 2008).
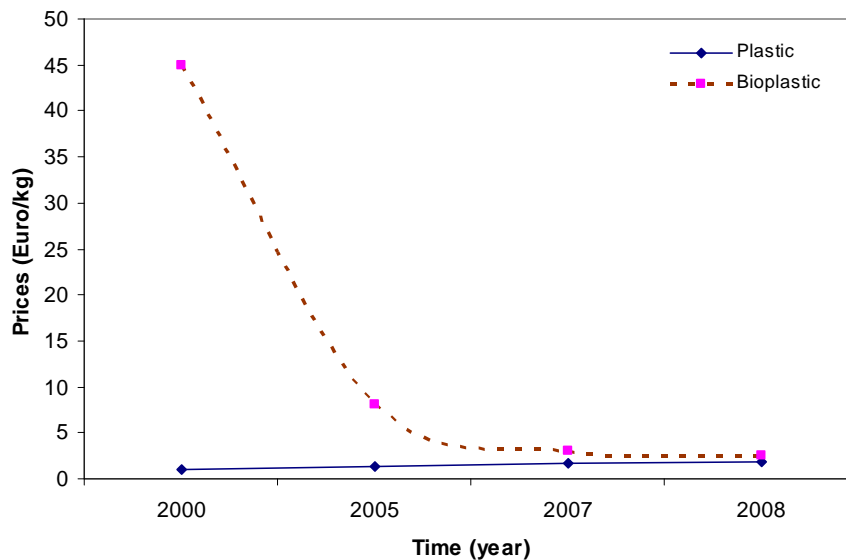

Figure 4.2: Plastic and bioplastic pricing trends (Bohlmann, 2007; European Bioplastics, 2008).

Whilst conventional plastics have experienced strong price increases of 30 - 80% in recent times as a result of high crude oil prices, bioplastics prices in some cases sank considerably. For the most part, the new materials largely remain more expensive than their crude oil based counterparts, however the relative price differential has clearly diminished (price range for all types: 1.50 – 3 .00 €/kg) (Bohlmann, 2007).

Agricultural products such as starch are comparatively price stable and affordable raw materials (Prices per tonne): Starch: 300 – 400 € in comparison with crude oil: 400 € (Based on 70 US$/barrel, 1 € = 1.20 US$). The economic competitiveness of bioplastics is restricted by generally very high development costs and lack of the economies of scale which come with mass production. Based on forecasts for the development of crude oil prices, use of renewable resources will become increasingly economical into the future. It is essential for further development

that products are marketed profitably even at this early stage. The market and production must grow, investment must be made into larger production facilities, and the necessary product optimisation must be able to be financed (European Bioplastics, 2010).

Noteworthy: The world market for bioplastics is estimated to be between 3 to 4.5 % by 2010 of the total plastic market. According to the Food and Agriculture Organization of the United Nations, 4.2 billion hectares are available for agricultural production worldwide, but only 1.5 billion hectares are actually used, of which 900 million hectares are in less developed countries. As such, there is still scope for increasing the production of agricultural crops for both food and bioplastics.

5. SUMMARY

However, the new environmental regulations and growing environmental awareness throughout the world have triggered the search for new products and processes that are compatible with the environment. This study presents the results of a research project using the low pressure drip system (LPS) for small areas and investigating the possibilities and limitations in developing degradable materials for using as drip tapes. Since the irrigation tapes /laterals are usually removed at the end of the crop season, especially for the vegetables, it would be desirable to use biodegradable irrigation drip lines that would allow roto-tilling or ploughing of these materials after the end of the cultivation season, without the need to remove the tapes/ laterals.

► Low pressure drip system (LPS)

The aim of this part was to evaluate the performance of LPS developed by Netafim for three years of service, calculate the consumptive working time and costs for maintenance and laterals retrieving before harvesting and determine benefits and problems with drip irrigation and provide recommendations for improved system management. Small fields (<10 ha) benefit from LPS irrigation systems that have the ability to distribute the amount of water to meet demand.

The old drip-line (reused) leads to decrease the distribution uniformity and increase in costs, where the distribution uniformity decreased by 10.5 and 21.6 % for reusing the laterals in the second and third year respectively. Moreover, the cost of repairing laterals was more than 5 and 6.5 times for both 2nd and 3rd season. Many disadvantages to drip lines retrieval can be observed, including that labour and maintenance is more intensive, risk of mechanical damage to lateral especially if it reused, increased management skills, experience is needed and increased retrieval costs arise season after season.

Laterals are produced from petroleum, a limited resource and take more years to degrade. It led to interest in alternatives made from biodegradable plastics. This

biodegradable tube can be used for one season and it can be biodegraded at the end of the season without retrieval required or any bad effects on the environment.

▶ Biodegradable plastic

The main aim was to test some biodegradable materials for use as drip tubes that will not need to be collected and disposed after use but will decompose in the soil without any adverse environmental effect. This will eliminate the disposal cost, will be environmentally friendly and possibly, and at least partially, the materials used may be based on renewable raw resources.

Some environmental factors affecting the bioplastic degradation were studied such as temperature, moisture content, soil types and fertigation. Also some degradable methods were studied in laboratory and field to find a suitable method to use as a preliminary degradation method between the last irrigation time and before the harvesting (2-3 weeks). The most important results could be summarized as follows:

- The results revealed that the equilibrium moisture content of all materials under study increased with increasing relative humidity from 43 % to 95 % but it decreased with increasing the temperature from 10 to 50 °C. The equilibrium moisture content of Cellulose was the highest and for Bi-OPL it was the lowest. Ecoflex, Bioflex and Bi-OPL may all hold for a longer period of time than Cellulose, Chitosan and Mater-Bi. The high moisture content causes good environmental conditions for microorganisms to attach the biomaterials leading to a short life.

- The biodegradation results of bioplastics in different soil types indicated that the biodegradation of all bioplastic materials under the study was faster in subsurface than surface positions. Bi-OPL holds for more than five months in all soil types, while Ecoflex, Mater Bi and Bioflex may hold between three to four months as best working life expectancy. Chitosan can be used as a mulch film but can not be used as biodegradable drip tubes. Sandy soil performs better than loamy and sandy loam soils in term of bioplastic long life.

- From the Fertigation results, Bi-OPL, Ecoflex and Mater Bi materials appear to possess a high resistance to the fertilizer under the recommended fertilizer rate (1 kg/m^3). It is difficult to use Bioflex material with fertigation because of the degradation probability, but it can be used as a lateral without fertigation.

- The biodegradation of Ecoflex caused by exposure to lipase enzyme can be characterized by a slower degradation rate compared to earlier studies. Also in the case of Mater Bi, it was found that the materials biodegraded in laboratory conditions within the experimental time with 35 %, while it was enzymatically biodegraded with a maximum of 0.54 % more than without enzymes under field conditions. It can be concluded that the use of enzymes is not appropriate as a means of degradation under field conditions and the limited time for each of the Mater Bi and Ecoflex.

- The chemical degradation indicated that both Ecoflex and Mater Bi samples have the same degradation rate at various acids levels (phosphoric and nitric acids) and times. They degrade significantly faster in a highly acidic solution than at low concentrations. Bi-OPL showed better hydrolytic resistance than Mater Bi and Ecoflex within the studied acids range. Finally, it can be recommended that the use of 0.5 % concentration of nitric or phosphoric acid can achieve the objective of the study under field conditions with the limited time.

▶ **Conclusion**

Low pressure drip system (LPS) can be use as a good way to expand the drip irrigation especially for smallholdings. Ecoflex, Mater Bi and Bi-OPL polymers are recommended as biomaterials for producing the biodegradable drip tubes can be conducted in the field at larger scale as further study to validate the methodology and obtain real field data for optimal design of the irrigation system.

6. ZUSAMMENFASSUNG

Neue Umweltauflagen haben den weltweiten Anstieg des Umweltbewusstseins und die Suche nach neuen Produkten und Prozessen, die mit der Umwelt im Einklang stehen ausgelöst. Die vorliegende Studie präsentiert die Ergebnisse eines Forschungsprojektes mit dem Niedrdruck-Tropf-System (LPS) für kleine Flächen. Im zweiten teil der Arbeit werden die Ergebnisse der Untersuchung zu Möglichkeiten und Grenzen bei der Entwicklung abbaubarer Materialien für die Verwendung von Tropfrohren dargestellt. Da die Tropfrohre gewöhnlich nach der Ernte, besonders bei Gemüsepflanzen entfernt werden, wäre es wünschenswert, biologisch abbaubare Tropfrohre zu verwenden, um die Bodenbearbeitung ohne das Entfernen der Tropfrohre durchführen zu können.

Niederdruck-Tropf-System (LPS)

Das Ziel dieses Teils war es, eine Bewertung des Niederdruck-Tropf-Systems in Bezug auf Arbeitsaufwand und Kosten für die Wartung, sowie der Tropfrohr-Rückgewinnung vor der Ernte durchzuführen. Ferner sollten die Vorteile und Probleme mit den Tropfrohren aufgezeigt und Empfehlungen für ein verbessertes Systemmanagement geben werden. Kleine Felder (< 10 ha) profitieren von LPS Bewässerungssystemen, welche das Wasser bedarfsgerecht verteilen.

Die Wasserverteilung der wiederverwendeten Trofrohre führte zu einem Abfall der Streuung um 10.5 und 21.6 %, entsprechend des wiederholten Einsatzes im zweiten und dritten Jahr. Darüber hinaus waren die Kosten, für die Reparatur der Tropfrohre, um 5- und 6.5 mal höher für die 2. und 3. Saison. Viele Nachteile wurden bei der Wiederinbetriebnahme der Tropfrohre beobachtet: Gefahr der mechanischen Zerstörung besonders bei Wiederverwendung; höhere Handhabungsfähigkeiten und Erfahrung und allgemein höherer Arbeitszeitaufwand.

Tropfrohre werden üblichesweise aus PE erzeugt. Für den Abbau von PE werden mehrere Jahre benötigt und bei der Verbrennung entsteht Kohlendioxid, welches in der

Atmosphäre zur globalen Erwärmung beiträgt. Daher werden Alternativen verfolgt, wie die Herstellung aus biologisch abbaubaren Kunststoffen.

Biologisch abbaubarer Kunststoff

Das Hauptziel war es, verschiedene biologisch abbaubare Materialien für den Einsatz als Tropfrohre zu prüfen, die nicht nach dem Gebrauch von dem Feld entfernt werden müssen und bei ihrer Zersetzung keine negative Auswirkung auf die Umwelt ausüben. Hierdurch werden Entsorgungskosten gespart. Die verwendeten Materialien basieren auf der Grundlage nachwachsender Rohstoffe.

Einige Umwelteinflüsse, wie Temperatur, relative Luftfeuchtigkeit, Bodentyp und Flüssigdüngung, die den Abbau von Biokunststoff beeinflussen können, wurden untersucht. Ferner wurden auch einige Methoden zur Abbaubarkeit in Labor und Feldstudien untersucht, um eine geeignete Methode zur Vorbereitung der Zersetzung, für den Zeitraum zwischen der letzten Beregnung und der Ernte, zu entwickeln. Die wichtigsten Ergebnisse können wie folgt zusammengefasst werden:

• Die Ergebnisse zeigten, dass der Feuchtigkeitsgehalt in allen Materialien mit einem Anstieg der relativen Luftfeuchtigkeit von 43 % auf 95 % zunahm, aber bei gleichzeitigem Temperaturanstieg von 10 auf 50 °C sank. Bei Zellulose war der Feuchtigkeitsgehalt am höchsten und für Bi-OPL am niedrigsten. Ecoflex, Bioflex und Bi-OPL können alle die Feuchtigkeit für einen längeren Zeitraum halten als Zellulose, Chitosan und Mater Bi. Ein hoher Feuchtigkeitsgehalt führt zu guten Umweltbedingungen für Mikroorganismen, die die Biomaterialien nach kurzer Dauer zersetzen.

• Die biologische Abbaubarkeit von Biokunststoffen ist abhängig vom Bodentyp und erfolgt im Unterboden schneller als im Oberboden. Bi-OPL hielt für mehr als fünf Monate in allen Bodenarten während Ecoflex, Mater Bi und Bioflex zwischen drei und vier Monaten hielten. Chitosan kann als Mulchfolie verwendet werden, aber nicht für biologisch abbaubare Tropfrohre. Im Sandboden ist die Nutzungsdauer von Biokunststoff länger als in Lehmböden oder sandigen Lehmböden.

- Die Ergebnisse der Fertigation (Flüssigdüngung) zeigen, dass die Materialien Bi-OPL, Ecoflex und Mater Bi eine hohe Widerstandskraft gegenüber dem Dünger bei einer Rate von 1 kg/m^3 besitzen. Bei Bioflex zeigte sich, aufgrund seiner hohen Abbaugeschwindigkeit, als schwierig bei der Fertigation, aber es kann zur Tropfbewässerung ohne Fertigation (Flüssigdüngung) eingesetzt werden.

- Der biologische Abbau von Ecoflex zeigte eine langsamere Abbaugeschwindigkeit durch die Einwirkung des Enzyms Lipase. Auch bei dem Material Mater Bi, wurde festgestellt, dass die biologische Zersetzung unter Laborbedingungen innerhalb der experimentellen Zeit mit 35 % erfolgte. Unter Feldbedingungen wurde während des enzymatischen Abbaus mehr als 0,54 % abgebaut, im Gegensatz zur Anwendung ohne Enzyme. Daraus kann geschlossen werden, dass der Einsatz mit begrenzter Zeit von Enzymen zum Abbau der Materialien Mater Bi und Ecoflex unter Feldbedingungen wenig Erfog hat.

- Der chemische Abbau lässt darauf schließen, dass unter Verwendung von unterschiedlichen Säuren (Phosphorsäure und Salpetersäure) und Zeiten sowohl Ecoflex als auch Mater Bi die gleichen Abbaugeschwindigkeiten haben. In stark sauren Lösungen werden sie signifikant schneller abgebaut als in Lösungen mit niedrigen Konzentrationen. Bi-OPL zeigte eine höhere hydrolytische Resistenz im Vergleich zu Mater Bi und Ecoflex innerhalb der untersuchten Säure-Konzentrationen. Abschließend wird als Ergebnis dieser Studie, unter Feldbedingungen und mit begrenzter Zeit die Verwendung von 0,5 % Salpetersäure oder Phosphorsäure empfohlen. Beide Säuren tragen zur Nährstoffversorgen der Pflanzen bei.

Durch weitere Studien soll der Einsatz dieser Materialien weiter erforscht und mit realen Felddaten für die optimale Gestaltung der Bewässerungssysteme validiert werden.

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