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HYDRAULIC ANALYSIS FOR BIODEGRADABLE DRIP IRRIGATION LATERALS

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ABSTRACT

Since the irrigation laterals are usually removed at the end of the crop season, it would be desirable, especially for the vegetables, to use biodegradable irrigation drip lines that would allow roto-tilling of these materials after the end of the cultivation season, without the need to remove the laterals. This study was conducted to find out and evaluate the effect of using biodegradable tubes (Biotube, made from Bi-OPL bioplastic) on water distribution uniformity comparable with polyethylene tubes (Polytube) at various working heads. Results showed the coefficient of uniformity (UC), the emission uniformity (EU) and increased head losses whereas, coefficient of variation (CV) decreased with increasing heads when considered for both types of drip tubes. UC was achieved to almost 98.1% with Biotube and 98.2% for Polytube at 7 m. CV was 2.19 % for Biotube and 2.1% for Polytube with the head increasing to 7 m. The head losses ranged from 0.004 to 0.011 m for both drip tubes. All evaluation parameters changed insignificantly at the same head for both Bio and Polytubes. Results provided by empirical evidence the Biotubes could improve the water distribution uniformity of drip irrigation system the same as Polytubes. Thus, the technological improvement offers the potential for environment protection and introduces alternative materials employed in irrigation technology.

KEYWORDS: Bioplastic, Irrigation Uniformity, Hydraulic, Driptubes

INTRODUCTION

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. Drip irrigation laterals are produced from petroleum which is limited and takesseveral years to degrade. It led to interest in alternatives made from biodegradable plastics. This biodegradable tube can be used with no retrieval required at the end of the season and it can be biodegraded in the soil while functioning as a soil conditioner, leaving biomass.

Many studies were done to introduce more details toward the biodegradable materials and its characteristics, also some of these studies discussed the complete duration of biodegradation (Briassoulis, 2006 and 2007; British plastic federation, 2009; Gupta and Kumar, 2007; Mostafa et al. 2010; Shah et al. 2008). The early experimental biodegradable irrigation tapes were produced using ‘Mater Bi’ and tested by Briassoulis et al. (2008). The processing conditions, mechanical properties, irrigation performance and degradation behavior of the taps produced were evaluated under laboratory and greenhouse conditions. A series of studies on developing and managing microirrigation were done by Mostafa (2010) and Mostafa and Sourell (2011) to identify the properties of some bioplastic materials and the possibility to use them as biodegradable drip tubes under open field conditions. Some bioplastic materials showed good results such as Bi-OPL. The next study was done by Mostafa (2014unpublished data), to evaluate the impact of environmental and some agricultural transactions **(**organic and biofertilizers) on the material stability and life expectancy. Those will not need to be collected and disposed of after use but will decompose in the soil without any adverse environmental effect. This will erase the disposal cost, will be environmentally friendly and possibly, at least partially, the materials used may be based on renewable raw materials like agricultural wastes.

Since drip irrigation efficiency depends on application uniformity, and a successful system depends on the physical and hydraulic characteristics of the emitters (Al-Amoud, 1995), some of these constraints are related to fungal damage and non-uniform mixing of raw materials during the production process. Elastomeric materials are used to achieve flushing action and pressure compensation in the manufacture of pressure-compensating emitters. These plastic parts are difficult to manufacture with consistent dimensions. Also, the resilient material may creep overtime and gradually change the flow rate even though the pressure is constant (Solomon, 1979). Carpa and Scicolone (1998) pointed out that the major source of emitter flow rate variation is the material used to manufacture the drip tubing and its precision. There have been many studies on the hydraulics of drip irrigation. These studies have commented on the methods and parameters used for microirrigation system design. Provenzano et al. (2005) provided a procedure for evaluating total hydraulic head losses, including an extended local loss evaluation procedure, and a simplified procedure based on assuming constant outlet discharge. The results showed a 2.4% error when compared with total head loss measurements on 15 commercially available drip irrigation laterals. Gyasi-Agyei (2007) outlined the misgivings in drip irrigation lateral parameters and showed that supplied manufacturing values may be different from the effective field values because of manufacturing variations and for other reasons. Many disadvantages can be noted during drip line retrieval. For example, the labor and maintenance is more intensive; there is risk of mechanical damage to lateral especially if it's reused; increased management skills and experience are needed; and increased retrieval costs arise season after season.

The main target of this study is to continue the work in this field by using a bioplastic material that was tested in our previous studies to manufacture a Bio drip tube prototype. The hydraulic performance of the Bio drip prototype (Biotube) was measured, analyzed and compared with polyethylene prototype (Polytube). This step is to verify the Biotube validity for using as drip tubes in a drip irrigation network.

MATERIALS AND METHODS

According to the previous studies, Bi-OPL bioplastic material was chosen to use as Biotube. Bi-OPL is a biodegradable material produced from polylactic acid in accordance with DIN EN13432 (Oerlemansplastics, 2011). The used material biodegradability and its characteristics were studied in our previous works (Mostafa et al., 2010; Mostafa and Sourell, 2011), also some of these studies discussed the complete biodegradation process. Bi-OPL wasrecommended as: (a) being biodegradable; (b) having the characteristics to perform as an irrigation system (i.e., exposed to field conditions, water contact and have enough useful life “six months”); (c) be processed with conventional polyethylene processing machinery. The tubes are extruded and the drippers are inserted after manufacturing. A common process for manufacturing irrigation pipes from polyethylene was used for manufacture. About 45 meters of each biodegradable and polyethylene irrigation tubes were produced to be tested in the laboratory.

Tubes were set up and the overall performance and the hydraulic behavior of the experimental irrigation tubes were evaluated in the laboratory at the Institute of Agricultural Technology, Thünen Institute (TI), Braunschweig, Germany.Poly Ethylene and Bioplastic laterals of 16 mm inner diameter with a thickness of 0.2 mm, 15 m length, and 1 m emitter spacing were alternately laid on a zero - slope as shown in Figure 1. The emitters were turbo conical on-line, integrated and non compensating with a nominal flow of 3.53 l/h at 101.2 kPa and the manufacturing coefficient of variation (CV) was 3.75%. Tubes were testedto compare different types of laterals, three drip tubes of every type and every tube including 16 emitters were tested under 3, 5, and 7 m inlet pressure heads. The ASAE test standard procedure (1996 a, b) was followed. A sliding tray containing graduated cylinders was placed directly below the tubes with each cylinder positioned to receive water from one emitter. One end of each tube was connected to a water source and the other end was sealed. Pressure head was noted using gauges at each end of the tubes to check if there was a noticeable pressure drop across the line and was controlled and adjusted by two valves and a pressure regulator. This ensured that the pressure remained constant during each set of measurements. Emitter discharge was measured over three pressures of 3, 5, and 7 m. The discharge of the emitters was measured volumetrically and repeated three times. A stopwatch was used to measure the flow times. Measuring time is usually 30 min, so the experimental errors committed are reduced. Pressure was measured with gauges at the beginning and the end of each lateral. The water volumes were collected in the graduated cylinders and manually read and recorded.

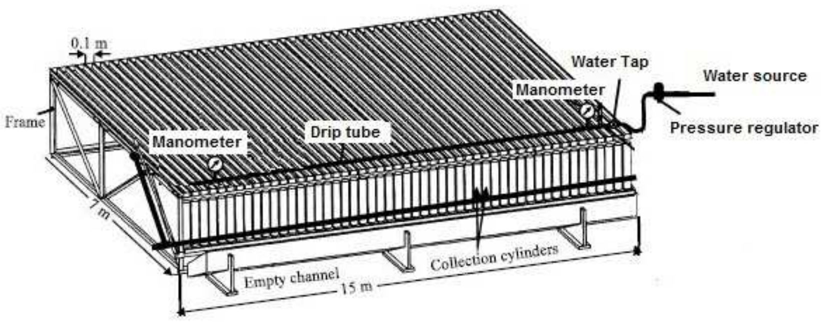

Figure 1: Measurement of the Emitter Discharge Rate in the Laboratory Test Unit

Evaluation Parameters

Water uniformity can be expressed in drip irrigation by uniformity coefficient, and emission uniformity which all are a function of coefficient of variation of flow rates. Coefficient of variation is considered as a design which can be expressed all uniformity expressions by Wu and Barragan (2000) and Amer and Gomaa (2003).

- **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 (ASAE, 1996a):

$$EU = \frac{\overline{q}_{25\%}}{\overline{q}_a} \times 100 \quad [1]$$

Where, EU is emission uniformity (%), $\overline{q}_{25\%}$ is average of the 25 % lowest values of flow rate (l/h), and $\overline{q}_a$ is average flow rate (l/h).

The evaluated system is classified according to the EU values got, following Merriam and Keller (1978) and ASAE, 1996 a, b.

- **Flow Variation Coefficient (CVq)**

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 to characterize water uniformity application, following the classification reported by ASAE (1996b).

$$CV_q = SD / \bar{q}_a \quad [2]$$

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

- **Uniformity Coefficient (UC)**

The Christiansen's coefficient of uniformity (Christiansen, 1942; Zoldoske and Solomon, 1988) can be expressed as:

$$UC = 100 \left[\frac{\frac{1}{n}\sum_{i=1}^{n} |q_i - \bar{q}_a|}{\bar{q}_a} \right] \quad [3]$$

Where q_i is emitter discharge and n is the number of emitters.

- **Head Friction Losses**

One difficulty in drip irrigation lateral hydraulics is in finding out a correct estimation of the friction factor, *f*, as used in the Darcy-Weisbach equation to find out hydraulic head loss in the lateral. This difficulty arises because of varying *f* along the lateral because of changes in discharge with location. Watters and Keller (1978) used the Darcy-Weisbach equation for smooth pipes with turbulent flow in trickle irrigation and combined that with the Blasius equation to predict friction loss of lateral with multiple outlets. The equation was modified by Amir (2012) as follows:

$$h_f = \frac{0.486\, l\, q^{1.75}}{d^{4.75}} \quad [4]$$

Where, h_f = frictional head loss (m), q= discharge (l/h), d = diameter of the pipe (mm), l = the pipe length (m).

RESULTS AND DISCUSSIONS

Uniformity of Discharge Rate

Different performance parameters were calculated in the laboratory to explain the relationship between the working head and discharge rate, the emitter discharge exponent, the coefficient of variation, the coefficient of uniformity and emission uniformity. Results showed that measured discharge flow rates of all emitters Figure 2 were similar and uniformly distributed at the same working head. Most emitters operated close to the mean discharge rate with standard deviation ranged from ± 0.057 to ± 0.079 Lh^{-1}. However, the two laterals showed almost even discharge rates with high correlation (0.996) at the same working head Figure 3. Average differences between the measured flow rate of Bio and Polytubes were 2.6, - 2.1 and 1.4 % at 3, 5 and 7 m working head respectively. At the same time the discharge increased linearly by increasing head. By increasing head from 3 to 7 m, discharge was increased from 1.55 to 2.84 Lh^{-1} and from 1.51 to 2.79 Lh^{-1} for Bio and Polytubes respectively Figure 3.

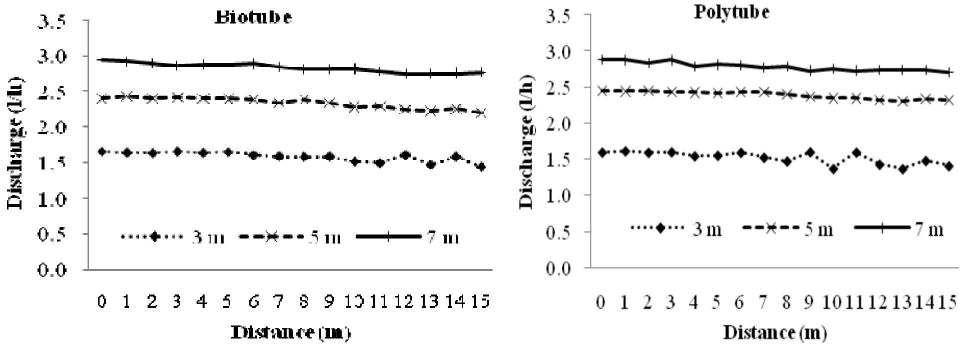

Figure 2: Discharge Rat at Different Heads

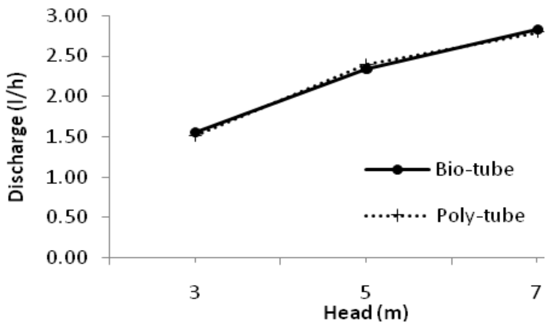

Figure 3: The Relationship between Pressure Head and Discharge

Effect of Hydraulic Head on Water Distribution Uniformity

Uniformity evaluation parameters and the variation observed in EU, CV and UC for Bio and Polytubes are pointed in Figure 4. Obviously higher heads lead to higher uniformity of water distribution. Based on the results, notable that UC and EU increase linearly with head. However, results are limited only to a maximum head of 7.0 m. For CV, results show that increasing head leads to decreasing CV values. It is obvious the coefficient of uniformity did not differ substantially (max. 2.2%), whereas the distribution uniformity differed slightly (max. 5.5%) for a 0.2 m change in head for both Bio and Polytubes.

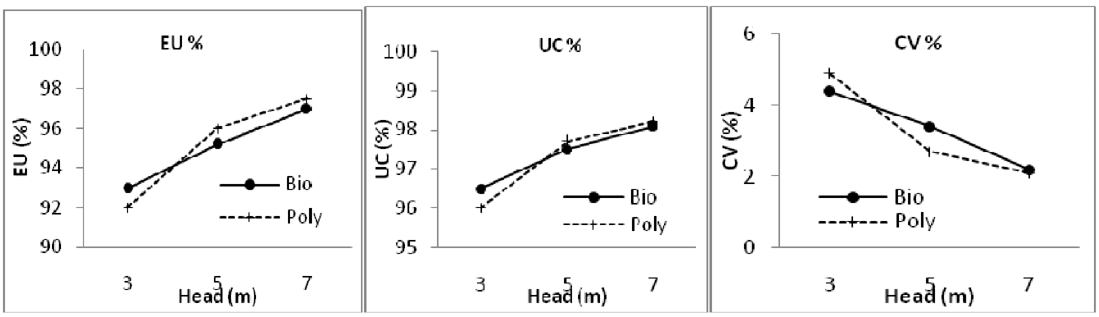

Figure 4: Uniformity Evaluation Parameters for Bio and Polytubes

In fact, a two-tail t-test at the 5% significance showed there is no significant difference in the mean values of UC between Bio and Polytubes at the same head. The same is true for the emission uniformity EU and coefficients of variation CV. It is also clear from Figure 4 the maximum EU of 97 and 97.5 % and maximum UC of 98.1 and 98.2% occur at a head of 7.0 m for both Bio and Polytubes. Therefore, from both hydraulic and practical standpoints, an operating head of 7.0 m reckoned from the junction of the most upstream laterals may be considered as ideal when the drip system is laid on a level surface. The EU and UC uniformities for all laterals ranged from 92 to 98.2 %, meaning they were excellent according to Marriam and Keller (1978) and ASAE (1996 b). The same is true for CV, where the low CV pointed out good performance of the system throughout the cropping season. The coefficients of variation were less than 5%. Considering ASAE (1996 b) classification, CV was excellent during the entire experiment.

Relationships between Water Distribution Uniformity and Head

Simple linear regression analysis was employed to form some predictive models for water distribution uniformity as a function of head, capitalizing on the linear trend noted between these parameters as previously discussed. However, the focus was on the Christiansen's coefficient of uniformity instead of Merriam and Keller's emission uniformity owing to a better linear trend in the results of UC compared to EU. As obvious in Figure 4, UC is more linear and related to heat compared to the more sensitive EU.

The results of the linear regression analysis between UC and head gave the best fit of data for Biotube and Polytube as depicted graphically in Figure 5. All linear regression models presented variance ranging from 0.91 to 0.979. They may prove useful for predicting the coefficient of uniformity of the both Bio and Polytubes when the operating head with the junction of the most upstream lateral is set between 3.0 and 7.0 m.

The choice of water distribution parameter is not too critical (Ella et al., 2009). In fact, any of the measures of water distribution uniformity may be used for design purposes as suggested by Barragan et al. (2006). In their study, it was proved that EU, UC and other measures of water distribution uniformity are correlated with each other, making any of them eligible as a design criterion. Therefore, for purposes of developing mathematical relationships or models, the use of UC over EU should not pose any problem as far as drip irrigation planning and design is concerned.

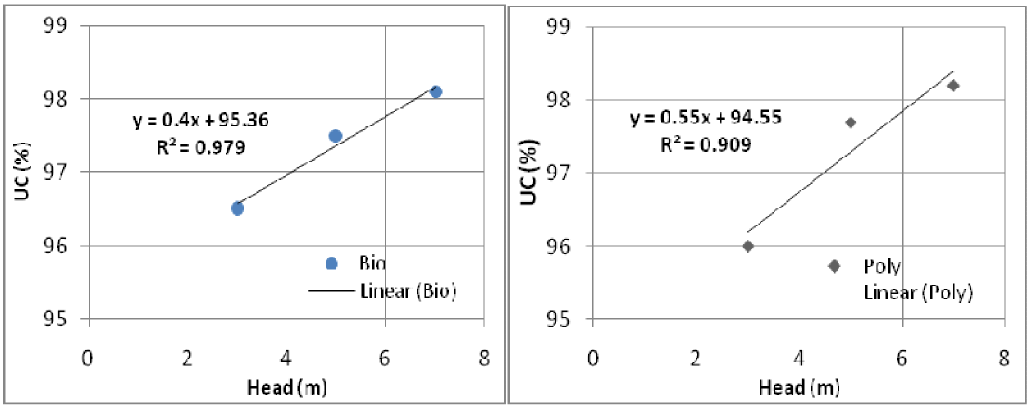

Figure 5: Observed and Predicted UC vs Head for Bio and Polytubes

Head Losses

Since obviously all the lateral inlet heads are equal, the frictional losses along the lateral are based on the respective flow rates in the reach, which are simple multiples of the matching tube downstream.

By changing pressure head from 3, 5, to 7 m along φ16-lateral, the friction head losses were increased as shown in Figure 6. The total friction head loss was recorded as 0.004, 0.008, and 0.011 m for Biotube respectively. The same trend was happening to Polytube (0.0037, 0.0082, and 0.0107 m head losses). High correlation (0.996) was found between the calculated friction losses in Bio and Polytube at the same head. Coefficient of determination, r^2, was found with no intercept equal to 0.99 and 0.97 for Bio and Polytube respectively.

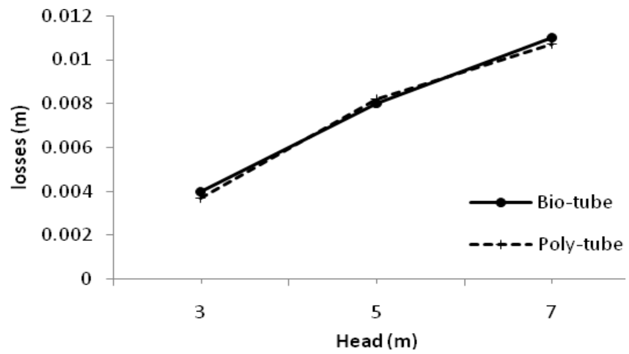

Figure 6: The Friction Head Losses for Bio and Polytube

CONCLUSIONS

This study was conducted to find out and evaluate the effect of using Biodegradable tubes on water distribution uniformity comparable with polyethylene tubes at various operating heads. Bio and Polytubes were manufactured and tested for water distribution uniformity under average operating pressure heads of 3 to 7 m.

Results showed the coefficient of uniformity (UC), the emission uniformity (EU) and head losses increased, whereas, coefficient of variation (CV) decreased with increasing heads considered for both types of drip tubes.

Emission uniformity EU was achieved almost 93, 95.2 and 97 % for Biotube and about 92, 96 and 97.5% for Polytube at 3, 5 and 7 m respectively. Coefficient of uniformity UC was achieved almost 96.5, 97.5 and 98.1% Biotube and about 96, 97.7 and 98.2% for Polytube at 3, 5 and 7 m respectively. Coefficient of variation CV was decreased from 4.4 to 2.19 % for Biotube and from 4.9 to 2.1% for Polytube with increasing the head from 3 to 7 m respectively. The head losses ranged from 0.004 to 0.011 m for both drip tubes. All evaluation parameters such as coefficient of variations, emission uniformity, coefficient of uniformity, and head losses were insignificantly changed at the same head for both Bio and Polytubes.

Results provided by empirical evidence the Biotubes could improve the water distribution uniformity of drip irrigation system similar to Polytubes. Thus, the technological improvement offers the potential for environmental protection and introduces alternative materials to be employed in irrigation technology, especially of interest due to the increasing the price of petroleum material and its scarcity in the near future.

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