Comparison of an innovative porous pipe irrigation system to drip irrigation under controlled conditions

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Abstract. With increasing water scarcity and irrigated agriculture being the biggest water consumer worldwide, water saving irrigation is important. So far, drip irrigation is the most water efficient way of irrigation, avoiding virtually all application losses, including drift, interception, evaporation and deep percolation. However, drip irrigation depends on the pressurized point source emission of water which produces a typical structure of different levels of water supply depending on the distance to the point source emission, creating gradients in spatial and temporal distribution of water and oxygen supply in the root zone. Porous pipes, in contrast, supply water all along the pipe with a very low pressure, resulting in the matric potential of the soil to be the main driving force for distribution of water in the soil. In the present study the suitability of an innovative porous pipe for subsurface irrigation of "Lollo Bionda" lettuce was tested and compared to a state-of-the-art drip irrigation system. Results show that with the porous pipe system 35% less water was used, while a 9% increase in total fresh biomass was measured, as compared to drip irrigation. This resulted in a significantly higher water use efficiency of 58 kg/m^3 as compared to 34.4 kg/m^3 under drip irrigation. The presented results were obtained under controlled conditions in a greenhouse during one cropping period only and must therefore considered as preliminary. More experiments both under protected cultivation and in open field conditions need to be carried out to confirm the massive water saving potential of porous pipes.

Keywords: Ecotubes, micro irrigation, lettuce, water saving, water use efficiency

1. Introduction

Water scarcity is increasing due to changing rainfall pattern as a result of climate change and due to more water being used by a growing population and increased industrial production. However, agriculture is by far the biggest water user worldwide with irrigated agriculture being responsible for 69% of freshwater use [1]. At the same time, with only 20% of agricultural land under irrigation, the contribution of irrigated agriculture to global food production is estimated to be 40% [2]. Thus, the present level of food supply can only be maintained with irrigated agriculture. Therefore, to strengthen food production and reduce water scarcity, the use of water saving irrigation is mandatory.

Drip irrigation is considered to be the most water efficient way of irrigation as water is directly applied to the root zone. Compared to traditional surface irrigation methods which depend on temporary flooding of the field the evaporation losses are massively reduced and losses by drift and interception as produced in sprinkler irrigation do not occur. Technically, above 90% application efficiency (AE) can be achieved by drip irrigation and with sub-surface drip irrigation (SDI) virtually all losses can be avoided. In the agricultural practice, however, the actual AE depends on a series of management factors, too. Besides losses due to suboptimal set-up or defective pipes, which are a common source of water loss in drip irrigation, the positioning of the emitters and the application rate affect the efficiency of the system to supply water to the root-zone in way that it can be taken up by the plant roots effectively. As drip irrigation depends on the point source water application through emitters (drippers) the water movement in the soil depends not only on the difference in matric potential, but also on a temporal increase of water content above field capacity (FC) which creates the so-called “wetting front” [3] and makes water moving down into the soil. The water distribution under a point source emitter has the shape of an onion with different levels of water content and at the points above the wetting front conditions are created that are similar to water logging, producing a temporal reduction of oxygen supply in the rootzone. Other areas more distant to the emitter have a lower water content [4].

Porous pipes depend on an ancient method of water application through clay pots first used in the Middle East. The functioning principle is that water is applied to the soil through a porous material which is in contacts with the surrounding soil material. If water is used by plants the matric potential of the drying soil increases and the potential gradient makes the water move. Based on the method of clay pot irrigation, clay pipes were developed, which made water delivery to the field more efficient [5]. However, clay materials are bridle and prone to damage and decay in the soil. Due to the high diameters used, the material is heavy, and installation is labor intensive. Therefore, nowadays synthetic materials are used to produce porous pipes. Among them is the porous pipe system produced by “EcoTube Germany GmbH”, which is made from recycled tyres [6]. A porous pipe system is operated at a very low pressure in order to promote the water movement from the pipe to the surrounding soil material. As the water moves along the gradient, water-logging like conditions are avoided and as the whole pipes functions as an emitter, differences in water content are produced only along the line [7]. Thus, if the porous pipe is well place underneath the crop row, it can be assumed that water and oxygen supply are at optimum throughout the irrigation cycle. So far, porous pipes are not widely used in irrigated agriculture. Lack of suitable materials made porous pipe systems deteriorate quickly and reduced the uniformity of water application. Furthermore, the requirement of high-quality water and the necessity of permanent subterranean installation which interfere with other on-farm management procedures, i.e. soil tillage, may have been reasons for the lack in adoption of porous pipes.

The reason for this study was to compare a porous pipe system to a state-of-the-art drip irrigation system in terms of water use and crop performance in a horticultural crop, namely lettuce. The research hypotheses were formulated as follows: (1) The water use of porous pipe irrigation is lower than under drip irrigation; (2) Crop development under porous pipe irrigation is improved as compared to drip irrigation.

2. Materials and Methods

2.1 Experimental site

The experiment described in this study was carried out at the University of Applied Science Weihenstephan-Triesdorf, Freising experimental station in a greenhouse built in east-west orientation (48°24'11.6"N, 11°43'50.2"E). The greenhouse segment used has a potential planting area of 200 m^2. It features a double-layer glass cover and a full-climate control system KliWaDu of Hochschule Weihenstephan-Triesdorf (HSWT) and Positronik (Germany). A minimum temperature was set to 10° C and 8° C during day and night, respectively, to avoid low temperatures affecting crop growth. During the duration of the experiment the average temperature was 19° C, and the average relative humidity of the air was 62.5%. The actual temperature during the experiment is represented in Figure 1.

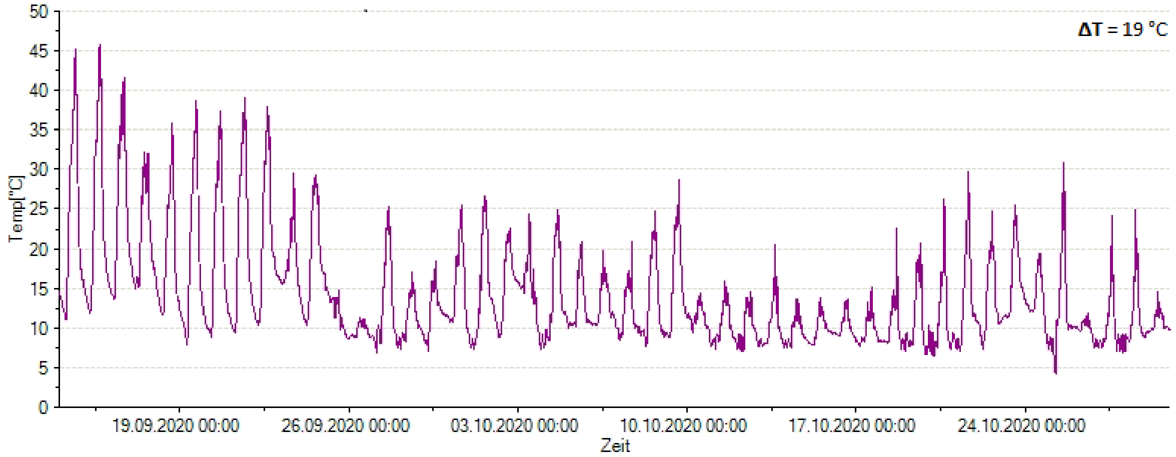

Figure 1 Temperature in the experimental greenhouse during the experiment

2.2 Plant material

The plant material used was "Lolla Bionda" lettuce (*Lactuca sativa* var. capitata - Lollo Bionda). 14-days-old seedlings were purchased at a nearby commercial nursery and planted on 14 September 2020, which was the start of the experiment. The experiment ended after 45 days on 29 October 2020 with the complete destructive sampling of all plants.

2.3 Experimental design

The experimental design was a completely randomized block design (CRBD) with two treatments and five replications. Given the conditions in the greenhouse with heating pipes following the side walls, a temperature gradient in north-south direction was detected. To account for the differences in temperature the five plots of each treatment were randomly arranged along the temperature gradient. Each plot was 3.6 m x 1.2 m in size and planted with three rows with 12 plants each, whereby the outer rows and the first and last plants of the center row were considered border and the 10 plants in the center of the plot were used for plant growth monitoring.

2.4 Irrigation systems

The irrigation system tested is produced and marketed by the company "ecotube Germany GmbH", who financially supported this study. Prior to the experiments the ecotube porous pipes were tested for discharge on a length of 10 meters with five repetitions for a pressure range between 0.5 and 1.5 bar. For the experiment, an operation pressure of 0.6 bar was used following the recommendations of the producer. As a reference to evaluate the functioning of the porous pipe, a state-of-the-art drip irrigation system was used, which was set-up using Aries^{TM} drip pipes of Netafim. A comparison between the two irrigation systems is represented in Table 1.

Table 1. Comparison of ecotube and drip irrigation with respect to technical dimensions

		ecotube	Drip irrigation
Distance between emitters	[m]	---	0.3
Operation pressure	[bar]	0.6	1
Flow	[L/m*h]	1.3	5.3
Pressure compensation	[-]	no	no

Except for the lateral lines, which supply the water to the plants and were the subject of the comparison the irrigation systems were built in the same way. At the inlet of the irrigation system a 120-mesh disc filter was installed to ensure good water quality. The differences in pressure were obtained by a pressure reducer at the inlet of each plot (Figure 2).

Water application was controlled automatically through the KliWaDu System of HSWT. For that end four tensiometers were installed at 10, 15, 20 and 30 cm depth, respectively, for monitoring of the matric potential of the soil. The system recorded values for matric potential in a 1-hour interval. Irrigation was initiated automatically when soil matric potential reached the pre-determined threshold of -200 mbar. The depth for the activation was selected differently for drip irrigation and ecotube as 15 cm and 20 cm, respectively. The reason for that difference was that the highest root density was expected to be lower in ecotube as compared to drip irrigation for the lower point of water application. The amount of water applied for a single application was controlled by a time-switch.

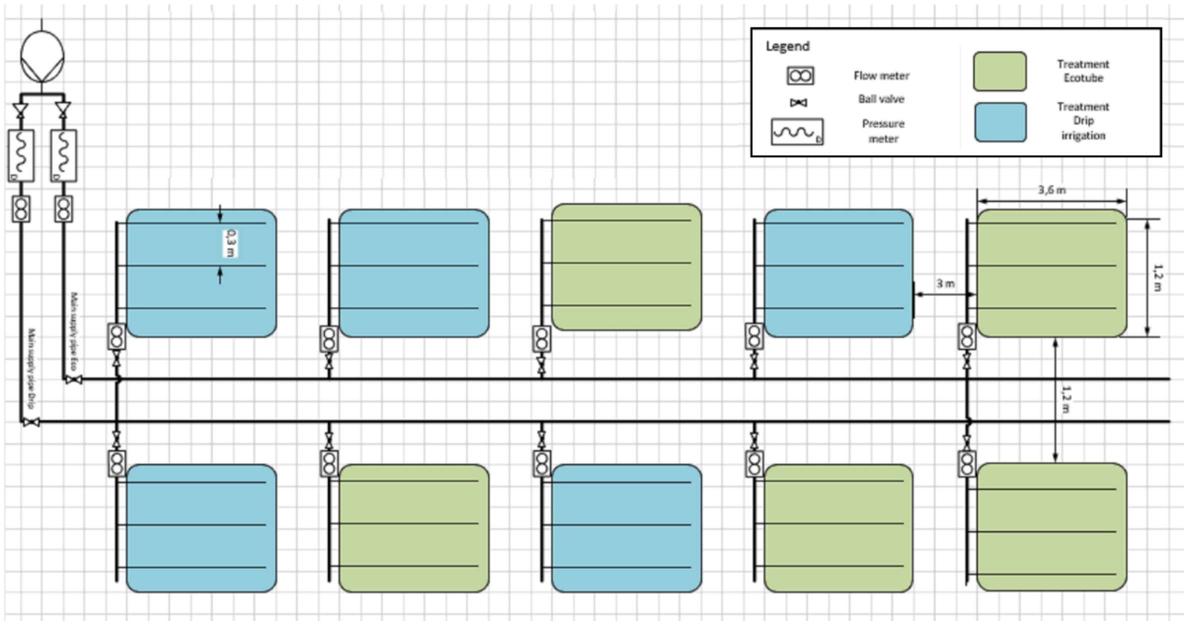

Figure 2. Sketch of the experimental set-up to compare drip irrigation and porous pipe irrigation

2.5 Cropping

Before planting of the seedlings, the whole experimental field was uniformly tilled by use of a rotary hoe twice. Subsequently, irrigation systems were installed as described in section 2.4. After installation of the irrigation systems no more tilling was done. Pest and disease monitoring was done daily in form of visual assessment. As a response to pest infestation “Neudosan” neem-oil (Neudorff, Germany) was applied three times in a three-day interval. Slug pellets were applied as a preventive measure. The pest and disease management was uniformly applied throughout all experimental plots. Once per week weeds were mechanically removed from all plots.

2.6 Plant growth monitoring

Plant growth parameters comprised: number of leaves, plant height and head diameter and were monitored once per week on 10 plants per plot. The number of leaves was assessed visually, plant height and head diameter were measure by use of a ruler. For the plant height the compressed nursery substrate in which the seedlings were grown at the time of planting served as the reference surface. The head diameter was defined as the largest distance between the outmost leaves of one plant. At the end of the experiment, all plants were harvested, and the individual fresh biomass of the monitoring plants was determined by use of a digital balance.

2.7 *Statistical evaluation*

Data were recorded by use of Microsoft Excel®. For statistical evaluation raw data were transferred to R-Studio®. Prior to analysis all plots were tested for normal distribution and homogeneity of variance. If normal distribution and homogeneity of variance were confirmed, significant differences were analyzed by ANOVA as well as post-hoc test. When data distribution was not normal significances were analyzed using the parameter free Kruskal-Wallis test.

3. Results

3.1 *Irrigation systems performance and water use*

As expected, the water discharge of the ecotube porous pipe showed an exponential increase over a pressure range from 0.5 to 1.5 bars. At levels below 0.5 bars the water discharge was obviously uniform (*data not shown*) while at a pressure above 1.0 bar a considerable variation between the replication was observed, while as in the range between 0.5 and 0.8 bars the water discharge is uniform with 1.3 L/h*m (Figure 3), which is in agreement with the recommendation of the producer to use 0.6 bars as operation pressure for the system.

In Figure 4 the development of the matric potential in the experimental plots during the time of experiment is displayed. During that time ecotube irrigation was activated 14 times; 4 times were preliminary test runs with an early activation and lower duration. Drip irrigation was activated 9 times. Even with a lower number of applications the overall water use was higher in drip irrigation due to the higher discharge rate. The total water use in the experiment was 1053.5 L in drip irrigation and 611.5 L in ecotube (Table 2).

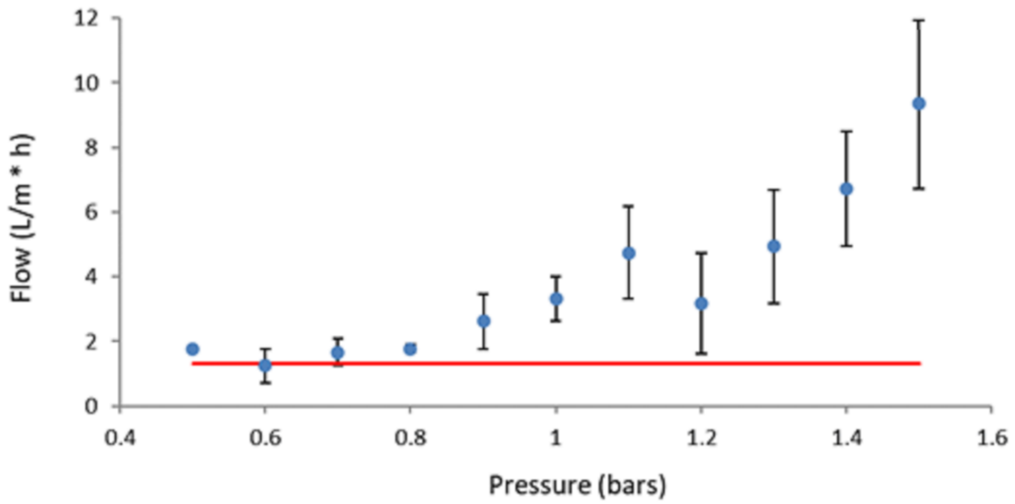

Figure 3. Water discharge of ecotube porous pipe at different levels of pressure. Points represent the average of five flow measurements and error bars the mean standard deviation. 1.3 L/m*h is the nominal discharge rate at the recommended operation pressure of 0.6 bars

Table 2. Total water use for irrigation in the treatments drip irrigation and ecotube

	drip irrigation [L]	ecotube [L]
1	192.5	137.0
2	220.5	126.5
3	216.5	109.5
4	216.5	100.0
5	207.5	138.5
sum	1053.5	611.5
std	10.0	15.2

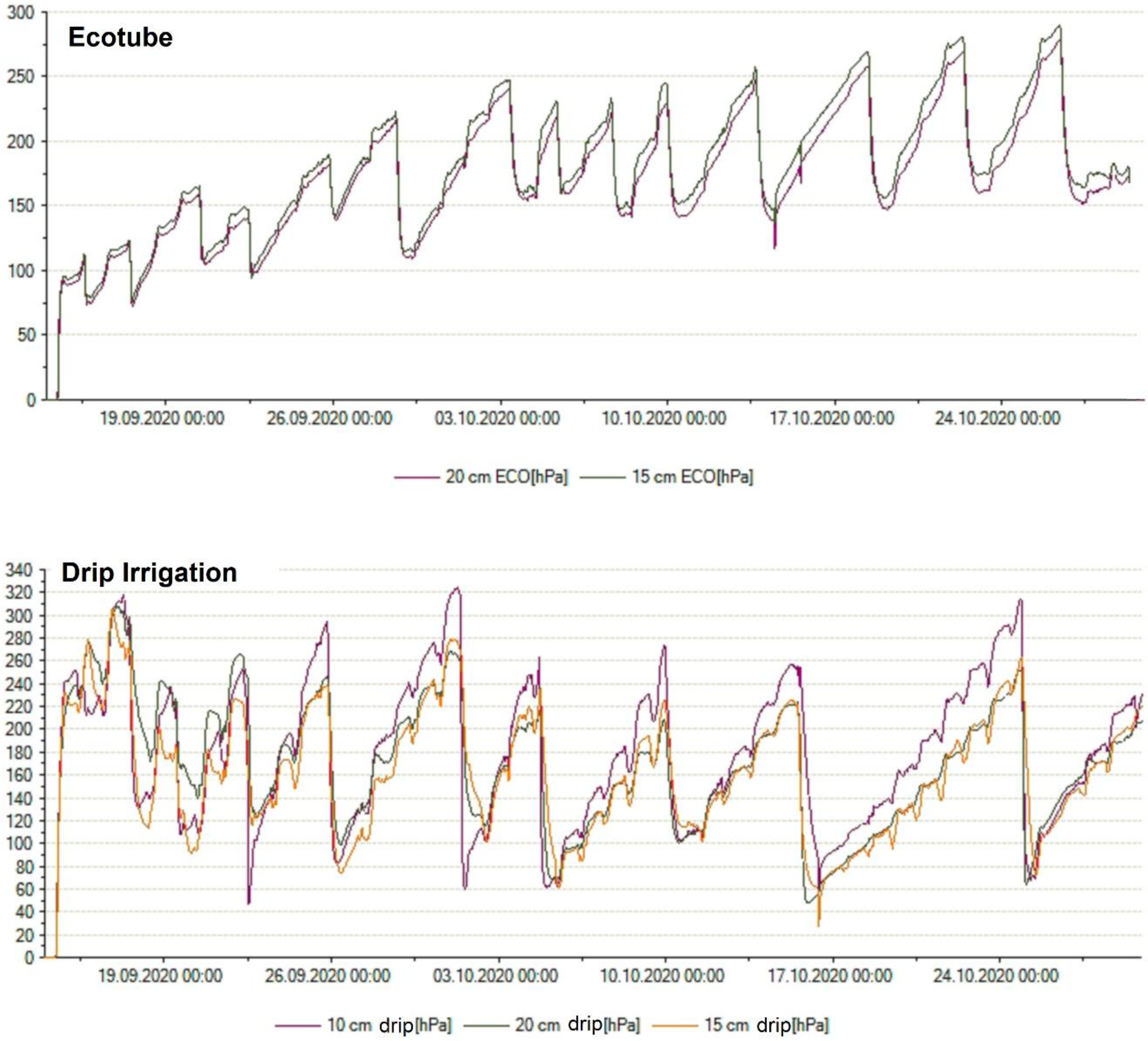

Figure 4. Matric potential during the experimental period in different depths of the plots irrigated with ecotubes (upper) and drip irrigation (lower)

3.2 Crop growth and yield

Figure 5 shows the crop development of lettuce plants during the irrigation experiment in terms of number of leaves, plant height and head diameter.

Three weeks after the start of the experiment a significantly higher number of leaves was determined in the ecotube treatment. This trend continued until harvest resulting in an average of 24 leaves in the ecotube treatment as compared to only 22 leaves in the drip irrigation treatment.

The plant height did not significantly differ during the first three measurements with ecotube irrigated plants showing a slightly higher mean height. At harvest, the plant height of 15.3 cm and 14.5 cm in ecotube and drip irrigation, respectively, was statistically significant. However, the magnitude of the difference is too low as to have a real impact on crop quality.

Head diameter was determined in length and width. In both dimensions the ecotube irrigated plants averaged higher with differences become statistically significant towards the end of the cropping cycle, especially in one direction, determined as length

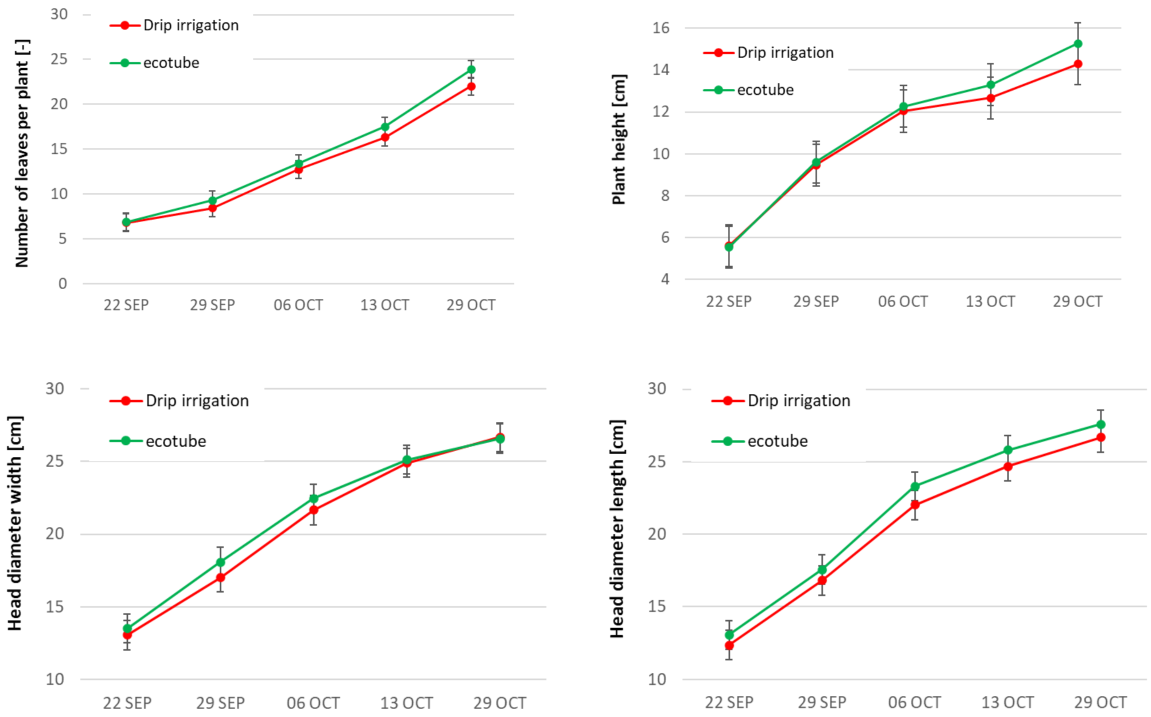

Figure 5. Crop development during the irrigation experiment: Number of leaves, plant height and head diameter of “Lollo Bionda” lettuce irrigated with drip irrigation and ecotubes. Data points represent the mean of 50 test plants, error bars represent standard deviation.

At harvest the complete fresh biomass of all individual heads was determined. No quality grading took place and marketability of the lettuce was not considered. The overall mean weight of the drip irrigated lettuce was 179.1 g/plant, while the ecotube irrigated lettuce averaged 197.2 g/plant. That represents a 9.2% higher fresh biomass yield (Figure 6).

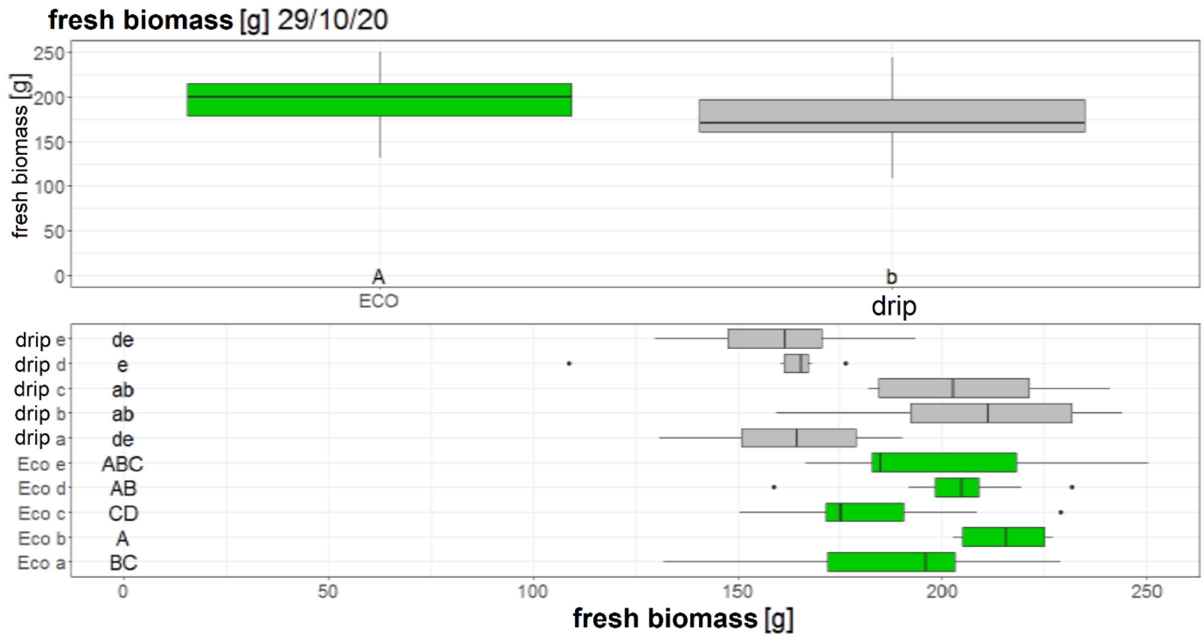

Figure 6. Statistical comparison of fresh biomass of “Lollo Bionda” lettuce irrigated with drip irrigation and ecotube at harvest in the whole experiment (upper, N=50) and according to plots (lower, N=10)

3.3 Water use efficiency

The fresh biomass yield was used to estimate the potential yield level and correlate to the water used for irrigation. The yield level of 16.4 t/ha and 14.9 t/ha for ecotubes and drip irrigation, respectively, is lower than the average yield level in Germany. This can be mainly attributed to the fact that the experiment was carried out in autumn with a lower mean temperature and less solar radiation.

Water use efficiency (WUE) [kg/m^3] was calculated as the quotient of yield per unit of water: WUE = Y / I with Y being yield [kg/ha] and I being irrigation water applied [m^3/ha] [8]. Comparing ecotube to drip irrigation, WUE was nearly doubled (Table 3).

Table 3. Yield and irrigation parameters of "Lollo Bionda" lettuce irrigated with drip irrigation and ecotubes.

Parameter		Drip irrigation	ecotube
Number of leaves	[-]	22.0	24.0
Plant height	[cm]	14.5	15.3
Head diameter	[cm]	26.7	27.6
Fresh biomass	[g/plant]	179.1	197.2
Yield level	[t/ha]	14.9	16.4
Water use	[L/m^2]	48.8	28.3
Water use efficiency	[kg/m^3]	30.6	58.0

4. Discussion and conclusion

In this study a porous pipe irrigation method was compared to drip irrigation of "Lollo Bionda" lettuce under controlled conditions.

The first hypothesis was that water use of porous pipe irrigation is lower than under drip irrigation. Using a fully automatic irrigation system the matric potential of the soil was kept within the optimum range for growing lettuce and avoid excessive irrigation. This system enabled a good comparison and it showed that the water use in the porous pipe system was substantially lower than under drip irrigation. This finding can be attributed in part to the fact that drip irrigation was applied on the surface and a certain amount of evaporation took place. This could have been avoided by using SDI. However, surface drip irrigation was selected as a reference as it is common practice in vegetable irrigation. Further, it is assumed that the comparatively high application rate of the point source emission method produced an, excessive downward movement of the wetting front, which can be seen at conditions above FC in the lower part of the rootzone after irrigation. This indicates that the drip irrigation scheduling should have been modified in a way to have lower application rates at a higher irrigation frequency. This was the case in the porous pipe irrigation, where irrigation intervals were appropriate to keep the water supply at the optimum level, showing the suitability of the porous pipe system to be coupled with an automatic irrigation system. Due to the low application rate and the large contact time with the soil, no wetting front is formed and deep percolation losses are avoided.

The second hypothesis was that crop development under porous pipe irrigation is improved as compared to drip irrigation. The limited extend of this study with only one crop cycle does not enable a definite answer, but it was clearly shown that the crop development was better in the ecotube treatment. All parameters were better and more consistent in the plants irrigated with porous pipe, while the drip irrigated plants exhibited a higher variation in their development and finally averaged at a lower yield level. This difference is attributed to the fact that the porous pipe irrigation creates optimum levels of water supply all along the crop row. As mentioned above, a wetting front and water content levels above FC are avoided which means that the plants always have a good supply of water and oxygen and no gradient is produced as when irrigated with point source emitters.

Given the combination of a low water use and a good crop development in this study the WUE of the irrigation was nearly doubled in the porous pipe system as compared to drip irrigation. This is a good indicator that using innovative materials with good discharge properties, porous pipes can be a water saving irrigation method that promotes good crop development. However, further studies about porous pipe systems need to confirm these findings and the question about irrigation water quality and the long-term application quality of the system must be addressed.

5. Acknowledgement

The financial support of EcoTube Germany GmbH is gratefully acknowledged.

6. Literature

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