INNOVATIVE CLAY-BASED MICRO-IRRIGATION SYSTEM "SLECI" (SELF -REGULATING, LOW ENERGY, CLAY-BASED IRRIGATION) PRELIMINARY RESULTS FROM CHERRY ORCHARD TRIALS

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ABSTRACT

The "SLECI" technology (Self-regulating, Low Energy, Clay based Irrigation) is an innovative clay-based micro-irrigation system showing significant potential in providing plant roots with efficient water supply that increases crop production while saving on water and energy. It was developed by Prof. Dr. Harald Hansmann at the Institute for Polymer- and Produktionstechnologies (IPT) and patented by the Wismar University of Applied Sciences (HSW) in Germany (patent number: DE 102019005311.7). It is a self-regulating subsurface irrigation technique, that uses the actual suction force of the surrounding soil for regulation of the water release of the system. It is very simple in concept, production and installation and therefore fulfils all demands of irrigation systems in rural environments. A pilot installation at the Fruit Growing Institute – Plovdiv (FGI), Bulgaria had been created and tests are running since vegetation seasons 2019 and 2020, and continuing as part of EU Horizon 2020 project Grant agreement ID: 101000348 – DIVAGRI since 2021.

Key words: SLECI, clay-based irrigation, cherry.

INTRODUCTION

Water is the most limiting factor for agricultural production (Sauer et al., 2010). Irrigation is usually used in areas where rainfall is irregular or dry periods or drought is expected. It is applied to sustain adequate plant growth in agricultural and horticultural practices (Blanco et al., 2020). Irrigation also includes water that is used for pre-irrigation, frost protection, chemical application, weed control, field preparation, crop cooling, harvesting, dust suppression, and leaching salts from the root zone (Ogg Jr, 1986; Rieger, 1993; Heisey et al., 1994; Works, 1996; Rankova et al., 2007; Kanimozhi et al., 2019; Tiwari et al., 2020;). Depending on the cultivated crops, their demand for water and water source availability, farmers rely on several types of irrigation such as surface irrigation, spate irrigation, drip irrigation, sprinkler irrigation, center pivot irrigation, lateral move irrigation, sub-irrigation or manual irrigation (Bravdo & Proebsting, 1993; Burt et al., 2000; Kranz et al., 2012; Martínez & Reca, 2014; Megersa & Abdulahi, 2015; Haile et al., 2015; Lamm et al., 2019; *Types of Agricultural Water Use | Other Uses of Water | Healthy Water | CDC*, n.d.) . Irrigation systems can be grouped into 2 categories: gravity-fed systems and pressurized systems (Megersa & Abdulahi, 2015). Each method has its advantages and disadvantages that should be considered when choosing the best suited to the local circumstances (Burt et al., 2000).

The “SLECI” technology (Self-regulating, Low Energy, Clay based Irrigation) is an innovative clay-based micro-irrigation system showing significant potential in providing plant roots with efficient water supply that increase crop production while saving on water and energy. It was developed by Prof. Dr. Harald Hansmann at the Institute for Polymer- and Produktionstechnologies (IPT) and patented by the Wismar University of Applied Sciences (HSW) in Germany (patent number: DE 102019005311.7). It is very simple in concept, production and installation and therefore fulfils all demands of irrigation systems in rural environments. It is a self-regulating subsurface irrigation technique, that uses the actual suction force of the surrounding soil for regulation of the water release of the system. The water demand of the crops will be satisfied by the system under all conditions without the need for external water management systems, irrigation plans or measurement of the actual soil humidity. It is water saving, a low-energy system, requires no maintenance, operates sustainably (no clogging or blocking), and is environmentally advantageous (no risk of over-irrigation and groundwater pollution, precise fertilisation dosage through the water etc.). It is sustainable in production: plastic parts of the SLECI system have a share of < 50 % w/w (conventional irrigation systems: > 90 %), which will be further improved under EU Horizon 2020 project 101000348 – DIVAGRI (www.divagri.org).

SLECI has already provided convincing results with moringa trees and cucumbers in Namibia and Ghana. For the purpose of gathering additional scientific proven data and field verification of the SLECI’s positive effect on crops and environment, a cherry orchard trial was established and carried out at the Fruit Growing Institute – Plovdiv (FGI), part of Agricultural Academy, Bulgaria.

MATERIALS AND METHODS

The SLECI technology

The figures below show the operating principle (Figure 1A) and installation/set-up (Figure 1B) of the tube with clay elements.

Figure 1a shows the core element of the system: A clay tube (emitter), with length 8 cm and outer diameter 18 mm, is pushed onto a perforated plastic supply line inside the clay tube and sealed against the supply line at both ends. Thus, irrigation water can be delivered to the outer surface of the clay shell by permeation through the clay body. The driving force for the permeation and thus for the release of water is the so-called suction tension of the soil. For sufficient water release, the geometry of the clay body (surface and wall thickness) and the specific hydraulic conductivity of the clay material must be coordinated. The hydraulic conductivity of the clay body is created by a capillary pore structure. This pore structure is determined by the composition of the clay (mineral and elemental composition as well as the grain size distribution of the clay powder) and the firing conditions. The capillarity of the clay bodies leads to the development of a suction tension that depends on the pore size distribution.This suction tension opposes the suction tension of the surrounding soil during operation. The supply line can be pressurized directly from a water tank, as shown in Figure 1B. The hydraulic conductivity c_h of the clay body enables the surrounding soil to extract water from the pipe system through the clay body as a result of its suction tension.

The amount of water V released in this process depends on the suction tension □p acting at the interface to the clay body, the surface area of the clay body O, the specific hydraulic conductivity of the clay material c_h and the thickness d of the clay layer between the inner and outer surface of the clay body and the time t:

$$V = \square p * O * c_h * t / d$$

Ideally, exactly the same amount of water is permeated through the clay body that the plant evaporates via the leaf surface. However, losses due to deep percolation and evaporation at the soil surface must also be compensated. The soil serves as a buffer storage for water with a time shift that is determined by the permeation velocity of the water between the clay body and the plant roots. In this respect, the soil condition (soil texture, mineral composition, etc) plays a further role in irrigation, as well as soil moisture content.

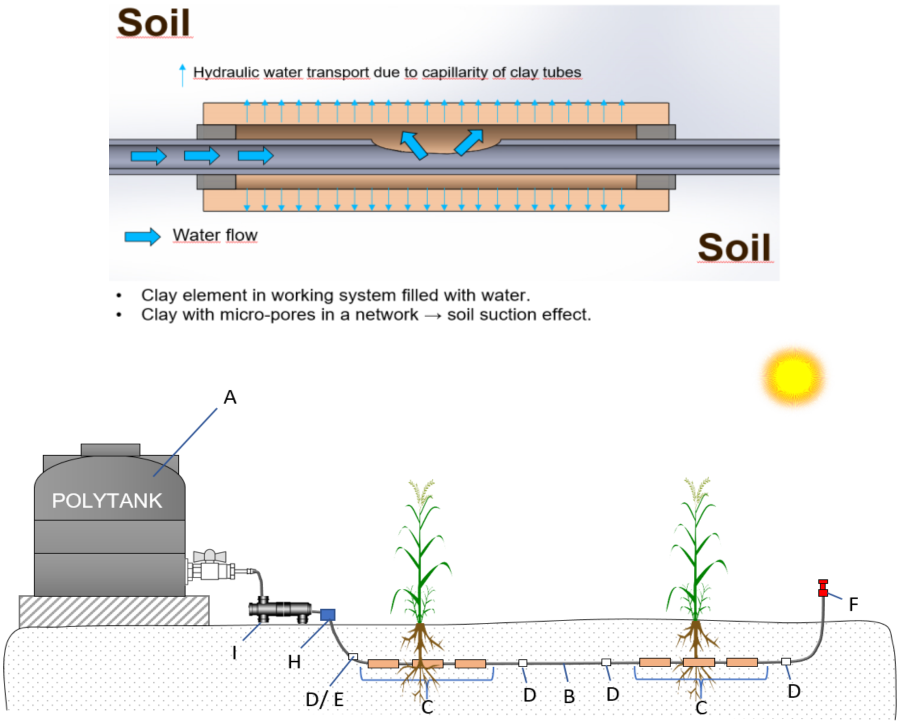

Figure 1. SLECI-irrigation concept and mechanism (A) and installation/set-up (B)

A *water tank*
B *water line*
C *clay tubes*
D/E *Connectors*
F *venting end cap*
H *Valve*
I *UV-C filter (optional)*

Design of the experimental plot

Experimental field of 30 cherry trees of cultivar 'Bigarreau Burlat' was planted in the spring of 2019 at the Fruit Growing Institute – Plovdiv (FGI). The inter row and in row (between trees) spacing was 5 m and 3 m respectively. During the vegetation seasons 2019-2022, standard agricultural practices and soil cultivation at 20-25 cm depth were applied (Figure 2).

Figure 2. General look of the experiment in Plovdiv (BG) - 2019

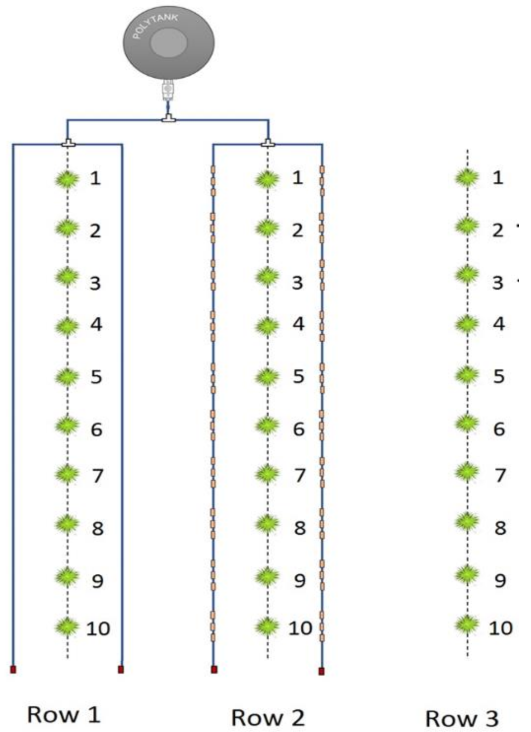

Figure 3. Design of the experiment: Row 1 – Drip irrigation (60 cm); Row 2 – SLECI clay-tube micro-irrigation; Row 3 – Non-irrigation control

Figure 4. Manual installation of the lines and clay tubes in 2019

The irrigation system was established with clay emitters produced at IPT, Germany. It was set with three variants – the new micro-irrigation with clay tubes SLECI and two reference (control) variants with drip irrigation (60 cm between drippers) and non-irrigation. Each variant (row) had 10 replicates (trees) (Figure 3).

Upon installation the lines with clay tubes were placed underground at depth 40-50 cm as this is where the roots of the newly planted trees are situated. Along the row 2 lines were placed surrounding each tree with 6 clay tube elements (3 on each side) forming a circle (Figure 4). As the tree grows new elements will be added at different depths and distance from the tree.

Assessing the vegetative traits of the experimental trees

The dynamics of thickening of the tree trunk diameter was recorded at 30 cm from the ground. Length of annual (terminal) shoot growth is determined at the end of the vegetation period by measuring the length of all branches produced in the same year on each replicate of the three variants. Average leaf area was calculated by measuring the area of 10 leaves from different parts of the canopy of each replicate from the three variants. The total number of leaves on each tree was counted.

Climate and soil conditions

Climate characteristics (rainfall, air and soil temperature, air humidity and soil moisture) were constantly monitored and recorded (Figure 5) via a climate station located at the experimentation field.

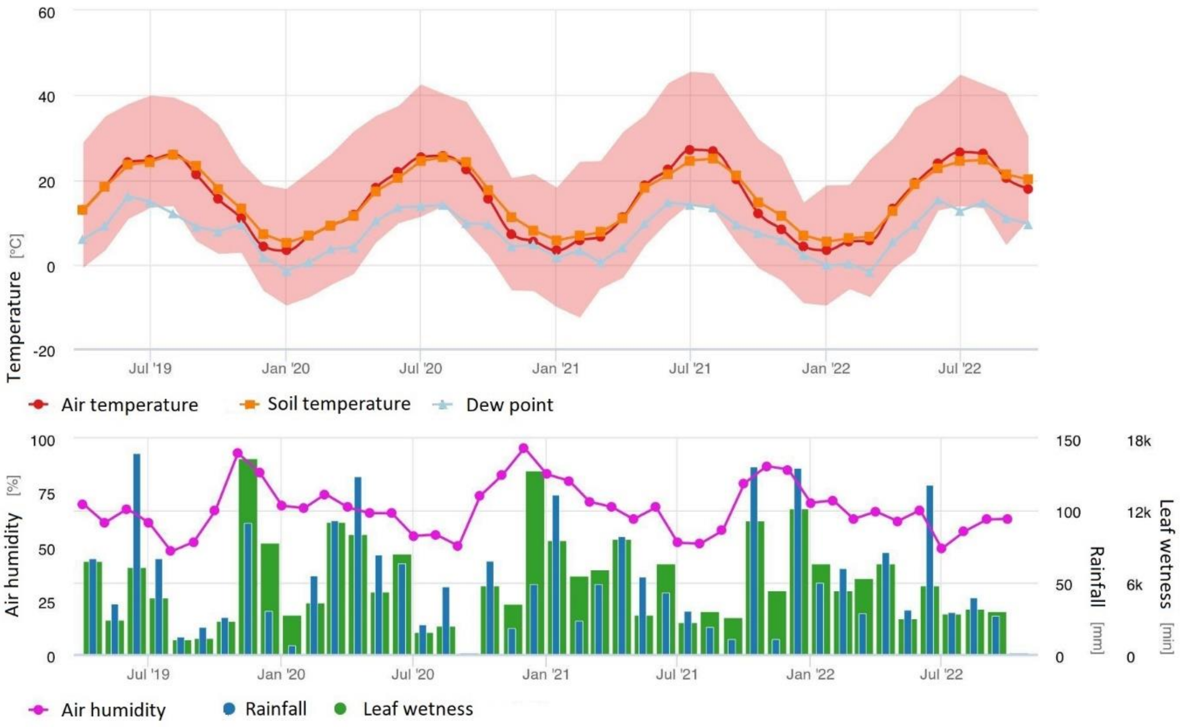

Figure 5. Climate at FGI’ pilot site, 2019-2022

Soil water properties (Figure 6) were analysed in Laboratory for Irrigation and Fertigation, at the Faculty of Agricultural Sciences and Food of Ss. Cyril and Methodius University in Skopje, North Macedonia. The results showed that soil retention at 0.33 bar is very low, about 8.05%. Similarly, the soil retention at 15 bars (wilting point) and in the other 4 analyzed points have same trend. Many authors indicated direct connections of the soil retention with soil texture, mineral composition of the soil, organic matter content, etc. (Tanaskovikj., 2009; Markoski et al., 2020). Generally, the results in our investigation showed that the soil is very sandy, with low soil retention influencing the effectiveness of the SLECI clay-tube micro-irrigation.

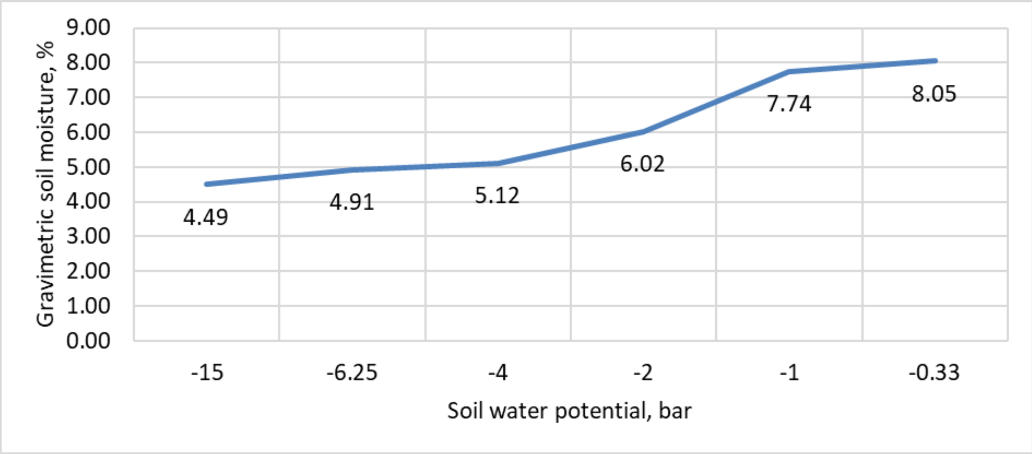

Figure 6. Soil water retention curve

RESULTS AND DISCUSSION

The preliminary results from the soil moisture show that the clay-tube micro-irrigation gradually increase and maintain optimal moisture through time while reducing water loss. The water is located mainly in the root area (40-50 cm) and evaporation and percolation losses are minimal. In previous research of patterns of soil wetting, Koumanov et al., (1998) investigate and confirm that the application efficiency of irrigation water is closely related to the hydraulic conductivity of the soil and varies essentially between soil types. Investigation results suggest the need for changing of scheduling and management of micro-irrigation taking in account both the specific climatic conditions and the soil hydraulic characteristics. For the fruit trees, irrigation water is not equally available throughout the wetted soil volume, even under drip-irrigation. Zones of rapidly decreasing soil moisture values are being formed along the skeletal roots and the root water uptake is most intensive in the vicinity of the tree trunk. The local depletion of soil water storage necessitates a shortening of the periods between applications - a daily or even permanent supply of irrigation water would be the most favourable for the trees.

The wetting patters around the SLECI emitters was estimated in a one-meter-deep soil profile left to dry on the sun. After 24h, wet spots were visible in the soil forming spheres with 30 cm in diameter around every clay emitter laid in a circle of six around every tree (Figure 7).

Figure 7. Soil profile with the wetting pattern in variant with horizontal SLECI – Jul-2020.

Water consumption under the specific conditions of Fruit Growing Institute - Plovdiv was constantly monitored using smart ultrasonic water meters.

The data for the daily water consumption using the SLECI irrigation system in 2019 and 2020 is summarised on table 1. It varies from 1.50 litres per tree in hot summer days to 0.83 litres per tree near the end of the vegetation period when the days are still warm, but the nights are cooler, the soil temperature drops and the demand of the trees for water is smaller as they prepare to enter dormancy period.

During typical hot days with rain (16 mm of rainfall) the water consumption drops to 1.10 litres per tree per day and down to 0.77 litres per tree per day in the days following the rainfall. In comparison, the drip irrigation was constant 10 litres per day per tree and the non-irrigation control relied only on rainfall which was unevenly distributed (July - 66.6 mm, August - 12.6 mm, September - 19.6 mm and October - 26.2 mm).

Table 1. Summary of the water consumption and meteorological conditions during vegetation seasons 2019 and 2020 in SLECI treatment

Date	Clay-tube micro-irrigation	Rainfall [mm]	Soil temperature [°C]			Air temperature [°C]			Air humidity [%]
	l/tree /day	Sum	Average	Min	Max	Average	Min	Max	Average
* Hot days without rainfall									
3-Aug	1.50	0	26.2	24.9	27.6	26.38	19.33	35.21	53.11
26-Aug	1.46	0	27.5	25.8	29.2	26.9	18.6	38.2	47.3
* Hot days with rainfall									
20-Sep	1.10	16	21.2	19.7	23.5	16.5	10.8	24.5	62.6
* Hot days following rainfall									
21-Sep	1.10	0	19.7	18.3	21.2	14.7	5.8	25.2	59.1
27-Sep	0.77	0	20.4	19.3	21.5	20.6	14.8	27.8	51.3
* Hot days with cool night and without rainfall near the end of the vegetation period									
10-Oct	0.83	0	16.8	15.4	18.5	16.4	5.6	30.5	68.8

After 1 year of operation in the test field (including winter underground storage), clay bodies with adhering earth in the "original state" were sent to IPT-Wismar directly from the FGI to be tested for hydraulic conductivity. The decrease in hydraulic conductivity compared to the new condition is approximately 17%. The difference is statistically significant. Measures to minimize the deterioration of the clay elements were tested throughout EU Horizon 2020 project Grant agreement ID: 101000348 – DIVAGRI, resulting in the use of better water filters, change of the winter storage and operation methods and change of the design.

The data for the daily water consumption in 2020 revealed that even with the slight clogging (17% reduced hydraulic conductivity) the clay-tube micro-irrigation (SLECI) still performs adequate and providing up to 1.50 l/tree/day in very hot days (around 38°C air temperature) with insignificant rainfalls (4 mm). The assumption made in 2019 that 1.46 litres/tree/day is the limit of the system under the current conditions was wrong, and the self-regulating properties of the system are working as expected.

The collection of data continued in 2021 and 2022 and followed the same patterns. All gathered data will be used in collaboration with the project partners in EU Horizon 2020 project Grant agreement ID: 101000348 – DIVAGRI to prepare a prediction model of the water consumption for the similar conditions. In the next investigation period, more detailed soil moisture monitoring analysis will be included with aim to compare water consumption and soil moisture dynamic in all treatments during all season.

Trunk diameter is measured at 30 cm from the ground. The dynamics of thickening of the tree trunk diameter in the first vegetation (2019) revealed a steady growth of the trees with SLECI clay-tube micro-irrigation and drip micro-irrigation while the growth of the non-irrigation control trees was slightly suppressed during the hot period and resumed normal rates as the temperatures dropped. As a result, the final average trunk diameter of the non-irrigation control variant is significantly lower that the trunk diameter of the trees watered with the SLECI clay-tube irrigation system and drip irrigation. During the second vegetation in 2020 the trend of the trunk diameter growth is retained similar to the previous year (Figure 8).

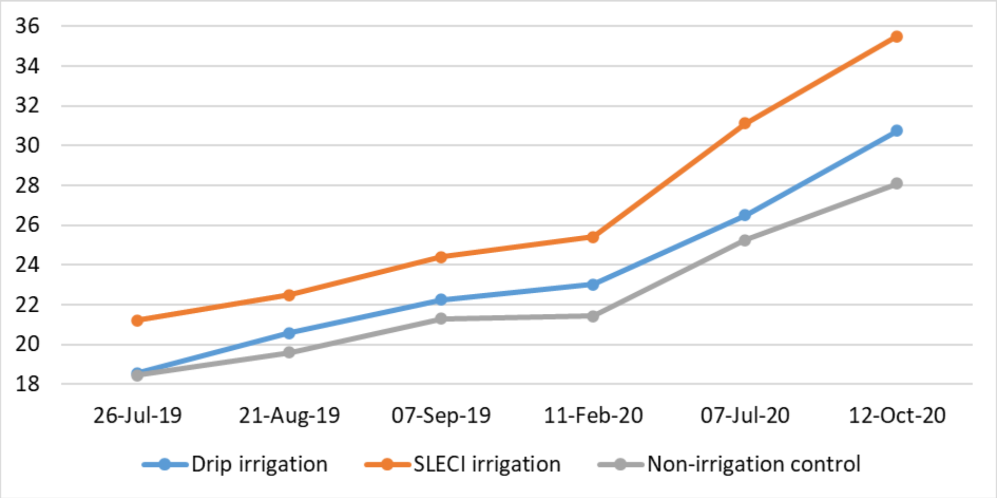

Figure 8. Dynamics of the trunk diameter growth of young cherry trees cv. 'Bigarreau Burlat' in the three analysed variants during the first and second vegetation period

Length of annual (terminal) shoot growth is determined at the end of the vegetation period by measuring the length of all branches produced in the same year by each replicate of the three treatments. Although in the first year after planting, there is no proven statistical difference between the three variants, the drip irrigation produced highest number of shoots, but shorter in length. The clay-tube micro-irrigation induced more balanced growth in terms of number of shoots and their length, resulting in the highest total length of the terminal shoot growth – 175.90 cm average (Table 2). In 2020, as the trees grow and their root system expand and reach deeper, the SLECI substantially exceeds the growth in comparison of the other two treatments (Table 3). The data for minimal length of the annual shoot growth confirms the data from the trunk diameter, suggesting slight decrease of the growth during hot and dry days in the drip irrigation treatment and even more in non-irrigation treatment.

Table 2. Length of annual (terminal) shoot growth at the end of 2019

Variant	Total length (cm)	Number of shoots	Average length (cm)	Max length of shoot (cm)	Min length of shoot (cm)
Drip Irrigation	145.50	6.50	22.69	58	4
SLECI irrigation	175.90	6.00	28.75	55	4
Non-irrigation control	150.22	5.89	27.23	70	4

* No significant difference between variants

Table 3. Length of annual (terminal) shoot growth at the end of 2020

Variant	Total length (cm)	Number of shoots	Average length (cm)	Max length of shoot (cm)	Min length of shoot (cm)
Drip Irrigation	524.33	18.00	27.78	56.00	6.00
SLECI irrigation	897.33	27.00	33.65	54.00	11.00
Non-irrigation control	362.67	14.33	27.16	41.00	5.00

Average leaf area was calculated by measuring the area of 10 leaves from different parts of the canopy of each replicate from the three variants. The variant with SLECI clay emitters produced an average of 136.5 leaves per tree which is almost twice than the non-irrigation control while there is little difference in the average leaf area. The increase of the total leaf area is with 93.62% (Table 4).

Table 4. Leaf area of cherry trees cv. 'Bigarreau Burlat' in the three variants – 2019

Variant	Average number of Leaves per tree	Average Leaf Area [cm2]	StdDev	Max of Area [cm2]	Min of Area [cm2]	Total Leaf Area [cm2]
Drip Irrigation	89.50	52.75	18.09	91.13	26.21	4721.13
SLECI irrigation	136.50	64.72	16.03	89.76	34.13	8834.28
Non-irrigation control	72.16	63.23	14.65	89.41	35.06	4562.68

First flowering (Apr-2020) and fruiting (Jun-2020) of the trees in the test field occurred in the second vegetation after planting. All treatments, including the control, produced flower buds in 2019 and started to bloom late in March 2020. In the first days of April, in the phenological phase "full flowering", after a series of spring frost incidents, most of the flowers were damaged and the crop was reduced to single fruits on the SLECI clay-tube micro-irrigation variant. Further investigation of the fruit and yield characteristic was impossible for the season 2020.

CONCLUSIONS

Installing the lines of the clay-tube micro-irrigation underground at depth 40-50 cm allows the application of standard agricultural practices and soil cultivation at 20-25 cm depth without damaging the components of the system. The sandy soil with low water retention reduced the effectiveness of the SLECI clay-tube micro-irrigation, nevertheless, the SLECI formed wetting pattern with spots of 30 cm in diameter around every clay emitter. This located the water mainly in the root area (30-50 cm) and evaporation and percolation losses are reduced. The SLECI system with clay tubes (emitters) placed underground at depth 40-50 cm uses only up to 1.50 l/tree per day to maintain constant soil moisture throughout the rootzone of young cherry trees and therefore providing the plants' roots with proper water supply that is one of the reasons for increasing crop.

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REFERENCES

Blanco, V., Blaya-Ros, P. J., Torres-Sánchez, R., & Domingo, R. (2020). Influence of regulated deficit irrigation and environmental conditions on reproductive response of sweet cherry trees. *Plants*, *9*(1), 94.

Bravdo, B., & Proebsting, E. L. (1993). Use of Drip Irrigation in Orchards. *HortTechnology Horttech*, *3*(1), 44–49. https://doi.org/10.21273/HORTTECH.3.1.44

Burt, C. M., Clemmens, A. J., Bliesner, R., Merriam, J. L., & Hardy, L. (2000). Selection of Irrigation Methods for Agriculture. In *Selection of Irrigation Methods for Agriculture*. American Society of Civil Engineers. https://doi.org/10.1061/9780784404621

Haile, G. G., Kasa, A. K., & others. (2015). Irrigation in Ethiopia: A review. *Academia Journal of Agricultural Research*, *3*(10), 264–269.

Heisey, L. W., Heinemann, P. H., Morrow, C. T., & Crassweller, R. M. (1994). Automation of an intermittent overhead irrigation frost protection system for an apple orchard. *Applied Engineering in Agriculture*, *10*(5), 669–675.

Kanimozhi, G., Sathayamoorthy, N. K., Babu, R., & Prabhakaran, J. (2019). Effect of herbigation through micro sprinkler on weeds flora, weed dry weight and weed control efficiency. *IJCS*, *7*(3), 3528–3531.

Koumanov, K., Dochev, D., & Stoilov, G. (1998). Investigations on fertigation of peach on three soil types-patterns of soil wetting. *Bulgarian Journal of Agricultural Science (Bulgaria)*.

Kranz, W. L., Evans, R. G., Lamm, F. R., O'Shaughnessy, S. A., & Peters, R. T. (2012). A review of mechanical move sprinkler irrigation control and automation technologies. *Applied Engineering in Agriculture*, *28*(3), 389–397.

Lamm, F. R., Bordovsky, J. P., & Howell Sr, T. A. (2019). A review of in-canopy and near-canopy sprinkler irrigation concepts. *Transactions of the Asabe*, *62*(5), 1355–1364.

Markoski, M., Mitkova, Tatjana, Tanaskovik, V., Nechkovski, S., Spalevic, V., (2020). The influence of soil texture and organic matter on the retention curves at soil moisture in the humic calcaric regosol of the Ovche Pole region, North Macedonia. *Agriculture & Forestry, Vol. 66* Issue 2: 33-44, 2020, Podgorica, DOI:10.17707/AgricultForest.66.2.03

Martínez, J., & Reca, J. (2014). Water Use Efficiency of Surface Drip Irrigation versus an Alternative Subsurface Drip Irrigation Method. *Journal of Irrigation and Drainage Engineering*, *140*(10), 4014030. https://doi.org/10.1061/(ASCE)IR.1943-4774.0000745

Megersa, G., & Abdulahi, J. (2015). Irrigation system in Israel: A review. *International Journal of Water Resources and Environmental Engineering*, *7*(3), 29–37.

Ogg Jr, A. G. (1986). Applying herbicides in irrigation water—a review. *Crop Protection*, *5*(1), 53–65.

Rankova, Z., Koumanov, K. S., Kolev, K., & Shilev, S. (2007). Herbigation in a cherry orchard--efficiency of pendimethalin. *I Balkan Symposium on Fruit Growing 825*, 459–464.

Rieger, M. (1993). Under-and overtree microsprinkler irrigation for frost protection of peaches. *HortTechnology*, *3*(1), 81–85.

Sauer, T., Havlík, P., Schneider, U. A., Schmid, E., Kindermann, G., & Obersteiner, M. (2010). Agriculture and resource availability in a changing world: The role of irrigation. *Water Resources Research*, *46*(6). https://doi.org/10.1029/2009WR007729

Tanaskovikj, V., (2009). “The influence of irrigation regime with micro-irrigation on yield and water use efficiency of green pepper in Skopje region” Ph.D. Thesis, Ss. Cyril and Methodius University, Faculty of Agricultural Sciences and Food, Skopje, pp.152

Tiwari, S. N., Jatav, R. K., & Singh, R. (2020). *A REVIEW ON DESIGN OF DRIP IRRIGATION SYSTEM FOR MANGO CROP*.

Types of Agricultural Water Use | Other Uses of Water | Healthy Water | CDC. (n.d.). Retrieved February 27, 2022, from https://www.cdc.gov/healthywater/other/agricultural/types.html

Works, H. I. (1996). *Irrigation for frost protection in forest nurseries: room for improvement*.