ACTA TECHNICA CORVINIENSIS
– Bulletin of Engineering
Tome X [2017]
Fascicule 4 [October – December]
ISSN: 2067 – 3809

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STUDY ON IRRIGATION SYSTEMS IN AREAS THREATENED BY DESERTIFICATION – REVIEW

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Abstract: Global climate change increases the areas subject to desertification, the greatest scourge that threatens Earth. One third of the globe is subject of aridity, affecting more than one billion people in 110 countries, including five countries in the European Union, including Romania. In this paper there are presented some modern methods of irrigation, applicable effective in areas threatened by desertification, namely: drip irrigation, with variants wetting the surface and water underground, irrigation by condensation of water vapor existing in the pores of the soil or the atmosphere and the complementary systems for irrigation by condensation, such as systems to optimize the temperature in the root zone of the plants.
Keywords: irrigation systems, desertification, condensation

INTRODUCTION

According to the United Nations Convention to Combat Desertification (http://www2.unccd.int), desertification is the degradation of land in arid, semi–arid and sub–humid areas, resulting from various causes, including climate and human activities.

The Fifth Report of the Intergovernmental Panel on Climate Change (IPCC, 2013) mentions that global average air temperature has increased by about 0,85ºC in the last 100 years (1850–2012), the period 2001–2013 is one of the warmest in the data stream recorded after 1850. Also, the number of hot days increased frequency of heat waves registering a growth trend evident in most of Europe, Asia and Australia. Over 90% of extreme events produced in Europe in the last 30 years are the dangerous hydro–meteorological phenomena (floods, storms) and climate (heat waves, droughts, forest fires) (EEA, 2010).

In this context, climate change is a major challenge for agriculture, water resources and ensuring stability crops being key priorities in policy of prevention and mitigation of extreme events.

Globalization demographic, economic and climatic factors exert great pressure in the agricultural sector to increase food production and reduce water consumption. Part of this pressure linked to the global need for water due to the livestock sector. Statistically, it is known that meat production requires 8–10 times more water than grain production. 70% of global water consumption goes on agriculture for irrigation. Irrigated agriculture accounts for 20% of total cultivated land (global average), but bring 40% of food (WWDR, 2016).

MATERIAL AND METHOD

In Romania, a change in the climate falls in the global context, but with specific geographic region in which our country is situated. Agricultural areas of Romania are affected by drought frequency (approx. 7 million ha), temporary excess of water (approx. 4 mil ha), water erosion and landslides (approx. 6.4 million ha), compaction (approx. 2.8 million ha), etc. It noted that drought is the limiting factor that manifests the largest agricultural area. In this context, the data indicate that most agricultural areas vulnerable to water scarcity in the soil are the Dobrogea, southern Romanian Plain, south–eastern and eastern Moldova and western Tisa Plain. These areas are mainly used in agriculture (approx. 80% of the total, of which approx. 60% is arable land) and forestry (approx. 8%), especially the Danube Meadow (National Strategy on reducing the effects of drought prevention and combating land degradation and desertification, short, medium and long – MARD, 2008).

Farmers apply two methods: dryfarming and agriculture through irrigation. Technology "dryfarming" is profitable for crop production without irrigation in areas receiving less than 500 mm rainfall annually or less. In areas with heavy rain, strong winds, uneven distribution of rainfall, the term "dryfarming" it is also recommended under irrigated crop in terms of annual rainfall between 601–700 l/sqm. The basic problems of the system "dryfarming" are so accumulation in soil of a small amount of annual rainfall, keeping moisture in the soil until it is used by plants, preventing evapotranspiration direct soil moisture during the growing season, adjust the quantity the plant extracts water from the soil, choice of crops suitable for arid, applying appropriate treatments to crops and evaluate products based on superior composition of plants that require small amounts of water (ANM, 2014).

In this paper there are presented some modern procedures of introducing water into the soil, applicable effective in areas threatened by desertification, namely: drip irrigation, consisting of watering through tubes or strips, the water being dispensed drop by drop, into the root zone, with variations in surface and water underground watering; irrigation by condensation of the water vapor existing in the soil pores (underground) or the atmosphere (air); complementary systems for irrigation by condensation (temperature optimization systems in the plant roots).

RESULTS

◫ Drip irrigation systems

A drip irrigation system is based on distribution of water slowly and evenly, drop by drop, in an amount and with a frequency tailored to the needs of the plant, with offsetting strict evapotranspiration, with close supervision rules watering (Payero et al, 2008). Drip irrigation involves the distribution of water directly to plant roots, reducing water consumption by 70%, while achieving higher yields by up to 90%. Drip irrigation method introduced the concept of fertigation, irrigation, fertilization while using irrigation water as support (Phuntsho et al, 2012). They are using nutrients and stimulating total water soluble. They are managed in strict rules, without being scattered in the areas between the rows that does not require fertilization.

The surface drip irrigation presents a number of advantages over conventional systems (eg. sprinkler irrigation), namely: the ability to irrigate land irregularly shaped; soil moisture is maintained at field capacity, strictly in the root zone; it is reduced weeds, between rows of plants because the soil is dry; between rows is facilitated access to culture for mechanized or manual work; reduces soil erosion; plant leaves stay dry and thus reduce the risk of diseases and burns; pressures are much lower than in conventional systems, reducing pumping costs (energy saving).

A schematic diagram of a surface drip irrigation system is presented in Figure 1 (Bloomer et al., 2013).

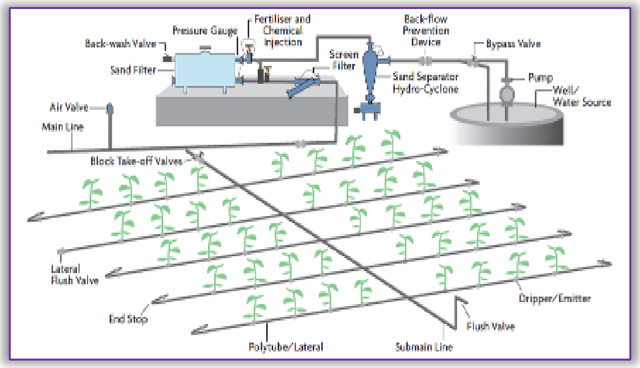

Figure1 – Components and layout of a drip irrigation system (Bloomer et al., 2013)

◫ Subsurface drip irrigation

Compared to surface drip irrigation, the subsurface enables the execution of all agricultural mechanized (Gil et al, 2008). This system is especially advantageous as the soil surface remains dry, which leads to the decrease in the degree of weed. Also, the volume of wet soil in the root zone is larger compared with surface drip irrigation (Figure 2). The subsurface drip irrigation can be operated continuously or intermittently at a pressure of about 1 (one) atmosphere, at a dispensing flow rate between 0.4 and 10 l/h (http://www.eurodripusa.com).

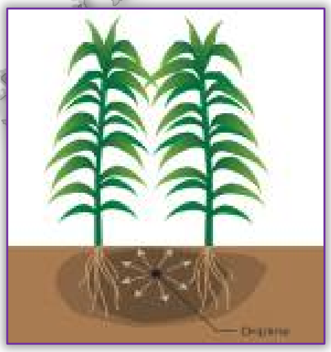

Figure 2 – The distribution of water in the roots area (http://www.eurodripusa.com)

IRRIGATION BY CONDENSATION SYSTEMS

◫ Concept description

Condensation is the process by which water is transformed from gaseous into liquid. Condensation is important for water cycle because it forms clouds. They produce precipitation, which is the main way to return water to Earth (https://ro.wikipedia.org).

Water entering the first ground hygroscopic and capillary saturates all its particles and the pores of the capillary of a particular layer. The water which is under the force of gravity gradually penetrates in depth, continuously wetting the soil to a depth that ensures its saturation water absorbent, film and capillary. Soil water movement occurs in three forms: vapor movement, capillary movement, the gravity movement. The movement of the vapor occurs as a result of differences in vapor pressure of water in the different layers of the soil. The movement takes place from the higher layers by the vapor pressure of the lower pressure layers (Kleps, 2002). Lebedeff (Lebedeff, 1927), studying the movement of water vapor in the soil, determined that, in a year, about 72 mm of water condensed from the vapor in the atmosphere in a soil type mold. Water condensation in the atmosphere increases as the difference between absolute humidity and water vapor pressure is higher. In Romania, Botzan (Botzan 1966) found the process in research on water balance in soils irrigated Dobrogea on the Black Sea coast and on the terrace of the Danube at Braila. Studies in this area are of practical importance, both in terms of the water balance in the soil and in the study of crop resistance to drought conditions unfavorable intervals during the growing season.

State of the art

Irrigation by condensation is an inexhaustible resource of water for irrigation, the combination of high relative humidity, the air temperature and the low temperature of water circulating through a closed loop system. Irrigation by condensation is designed primarily to arid and semi–arid areas, where groundwater is deep and fresh water sources are rare.

Worldwide, studies on irrigation by condensation were made over time by several researchers (Widegren, 1986; Nordel, 1987; Ruess and Federer, 1990; Gustafsson and Lindblom, 2001).

Absorption of water by plants is very effective in moderating the distribution of daily water, as demonstrated in the plant irrigation condensation built in 1993 by Swiss Company Ingenieurbüro (Hausherr, 1993), the condensation stream of moist air in underground pipes of halved consumption of water at tomato crop. The temperature into the soil has been decreased by increasing the distance between the pipes or decreasing the burial depth, although in both cases the condensation rate increased.

Other theoretical and experimental studies of the irrigation by condensation system were carried out in Adana, Turkey (Gustafsson et al., 1999), resulting in the possibility of irrigation 4.6 mm/day with an energy consumption of 1.6 kWh/m^3.

In 1987, Nordell built a small–scale plant in a greenhouse cucumbers in Övertorneå, Northern Sweden. The air conditioning system was intended to reduce the temperature difference between night and day. During the day, moist air was circulated through underground pipes for heating and cooling ambient soil. When designing an irrigation by condensation system, underground piping configuration such that the critical temperature is reached by the pipe walls and not in the soil between two parallel pipelines. In this way, the roots will grow freely in the space between the pipes. Pipes diameter, depth of burial and pipe spacing is chosen depending on water availability and temperature distribution in the soil (Figure 3) (Lindblom, 2006).

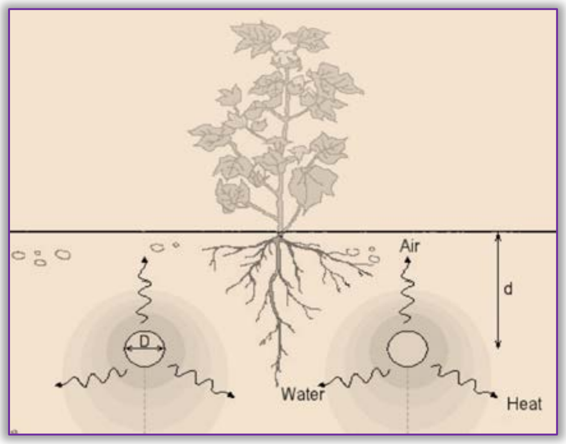

Figure 3 – Section through pipes buried into the soil (Lindblom, 2006)

The length of the pipes affects the efficiency of the dehumidification of air, since the rate of condensation decreases along the pipe. Small depths of burial of the pipeline can increase the rate of condensation resulting in a superficial layer of the water distribution in the soil, water that accumulates on top of the pipe. If one takes into account sunlight, shallow burial depth leads to a lower production of water at a rate of greater evaporation surface due to additional heating of the soil surface. The power consumption of the fan necessary to drive the flow of air through a perforated pipe was 0.4 kWh per 1 m^3 of the condensed water (Lindblom & Nordell, 2006).

Constructive solutions

The document US 4459177 (O'Hare, 1984) relates to a system for the transfer of moisture in the soil horizontally (Figure 4), which can be used in the production of drinking water or irrigation in arid zones. The system uses solar energy for extracting moisture from the soil by heating soil water evaporation and subsequent condensation of water vapor.

Convection column 1 is a black box type solar collector rectangular form, vertically arranged. In its interior, the heated air flows from the entrance to the exit located at the bottom of the upper part, the lower part forming the circulation. This edition pulls warm air from the solar evaporation pipe 2 by 4 in the condensation pipe 3. The pipe 4 has small holes through which soil moisture enters through capillarity and soaking. The water is evaporated by hot air stream in line 4 and transferred to the pipe 3 is cooled by the soil around, which condenses. The water formed by condensation in the pipe 3 can be extracted using a pump or by removing the cap 5 from the outlet pipe 7. The outlet pipe in place of the porous material can be used for drainage into the soil. In this way the water is transferred from a wet to a dry area.

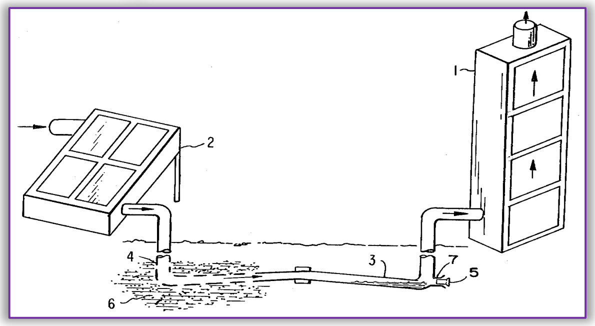

Figure 4 – System for the transfer of moisture into the soil, horizontally (O'Hare, 1984): 1 – convection column; 2 – solar collector; 3 – condensation pipe; 4 – evaporation pipe; 5 – cap; 6 – moist soil; 7 – exit pipe

National Institute for Research in Rural Engineering, Water and Forestry (INRGREF) of Tunisia built in 2004 a pilot plant for underground irrigation by condensation and air irrigation (Figure 5 and Figure 6), in a region characterized by climate variable and minimal rainfall (Lindblom and Nordell, 2006). The pilot plant includes the following main parts:

- a hot water storage tank heated by solar energy, which takes place humidifiers;
- a network of underground pipes with a length of 13 m and a diameter of 63 mm, placed at different depths (0.25 m and 0.4 m);
- an air irrigation system (dew induced irrigation) with vertical pipes;
- a monitoring system of parameters: current air and soil temperature, moisture etc.

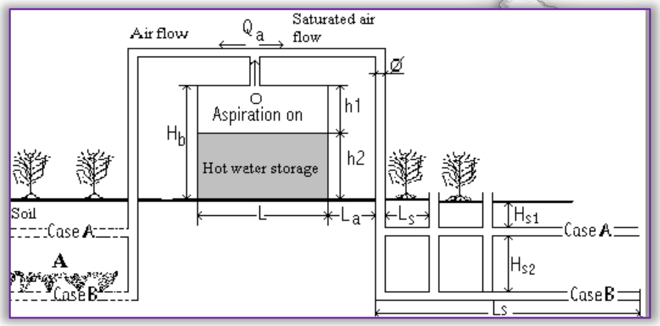

Figure 5 – Sketch of pilot plant (Lindblom and Nordell, 2006): irrigation by condensation (right side); air irrigation (left side); H_{s1}=0.25 m; H_{s2}=0.4 m

Figure 6 – The pilot plant located in the experimental field (Lindblom and Nordell, 2006)

According to experimental research carried out in the pilot plant, underground irrigation by condensation provides a quantity of water that ensures more than 50% of the water needs of vegetable crops in arid areas of Tunisia (Table 1) (Chaibi, 2013). This amount of water can be doubled by the 20% increase of the water temperature in the storage tank.

Table 1. Coverage degree (production/demand) for the irrigation by humid air condensation (Chaibi, 2013)

Daily water production (mm/day)	Rate of satisfaction in water needs (%)				
	Green beans	Peas	Tomato	Potatoes	Onion
2.8	51–56	69–71	57–64	61–68	74–81

Dew induced irrigation

The dew induced irrigation system is an alternative of the irrigation by condensation and was first introduced in 2003, at the International Conference ICEE in Brack, Libya. Dew induced irrigation is obtained by placing the horizontal lines of vertical pipes buried with the top end above the soil surface, which allows the evacuation of the air flow in hot and humid atmosphere. Because of the difference in temperature between the flow of air from the underground pipe and the ambient air, the vapors form a cloud of condensed water droplets falling to the ground in the form of dew. This system can also be used to protect crops from frost, because the latent heat released by steam condensed prevent sudden drop in temperature during the night (Figure 7) (Lindblom, 2003).

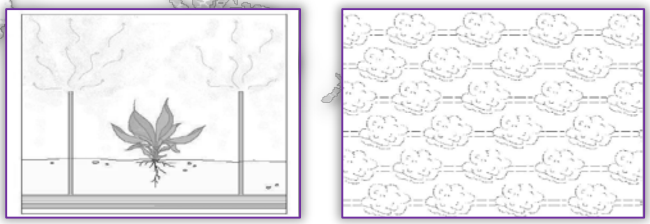

Figure 7 – The principle of the dew induced irrigation system (Lindblom, 2003)

Since the amount of water extracted from the atmosphere increases with increasing temperature difference between ambient air and the air in the pipes, the best performance can be achieved when the hot water tank is stored during the day and at night used for irrigation.

The irrigation device Airdrop (Figure 8) (Dolasia, 2011; Kaja, 2012) uses the process of condensation to collect moisture from the air. Through the air intake system of the turbine, the air is channeled into the underground through a copper coil and the temperature is brought quickly to the ground. This process creates an environment with a humidity of 100%, from which the water is then collected and stored in an underground tank to be pumped into the underground irrigation system.

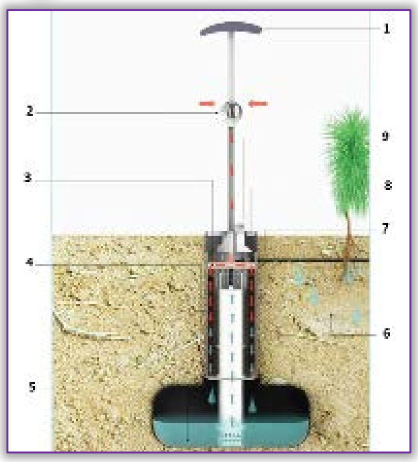

Figure 8 – The irrigation device Airdrop (Dolasia, 2011)
1 – photovoltaic panel with spherical surface; 2 – turbine; 3 – the direction of air flow; 4 – condensation process; 5 – tank; 6 – water distribution in the soil; 7 – semipermeable pipe; 8 – battery; 9 – air out

Air flow regime inside the copper coil can be laminar or turbulent (Figure 9) (http://bustler.net/news). In the case of laminar flow, air passes directly through the tube and condensate is formed only on the inner wall of the tube, which is only cold area with warm air comes into contact. Turbulent flow of air was carried out by placing a spiral coil of copper, to increase the contact surface between the air and the pipe and when the air temperature falls to the ground temperature. Copper coil acts as a resistance to the air and creates the effect of turbulent flow.

Figure 9 – Flow regimes through the copper coil (http://bustler.net/news): laminar (left); turbulent (right)

TEMPERATURE OPTIMISATION SYSTEMS IN THE ROOTS AREA – CONCEPT DESCRIPTION

The principle underlying the temperature optimizing system in the plants roots area is that the temperature gradient between the soil surface and a certain depth is maintaining approximately constant throughout the year. In other words, the temperature of the soil to a certain depth is greater than the temperature of the surface of the soil during the cold season and less than that in the hot season. Within the context of current climate change, this temperature difference became significant, reaching and even exceeding 10°C (http://rootssat.com).

Due to the cooling effect of the root area during the summer, is maintained soil moisture and evaporation rate is reduced. System energy requirements are minimal and are assured of unconventional energy sources, such as solar. It is a simple and reliable system that requires a low initial investment and low maintenance costs (Figure 10).

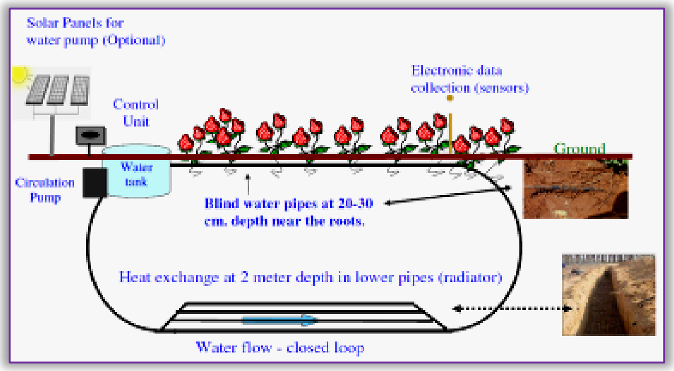

Figure 10 – The scheme of temperature optimization system in the area of plant roots (http://rootssat.com)

CONSTRUCTIVE SOLUTIONS

In US 6148559 patent document (Monte, 2000) are presented a system and a method for preventing the formation of premature buds of fruit trees during the transition period between seasons, when take place sudden temperature increases. The method consists of maintaining the temperature in the plant roots area to a value lower than the temperature at which the buds are formed under normal circumstances. Through a network of underground pipes circulates a cooling agent which, under normal conditions of pressure and temperature, is in gaseous state (eg. hydrocarbons, CO_2, noble gases, anhydrous ammonia); in the pipework there is an area of high pressure (10 – 17 bar) in which the cooling agent is in liquid state and an area of low pressure (2 – 2.7 bar in which the cooling agent is in gaseous state. Root area temperature control system is shown in Figure 11.

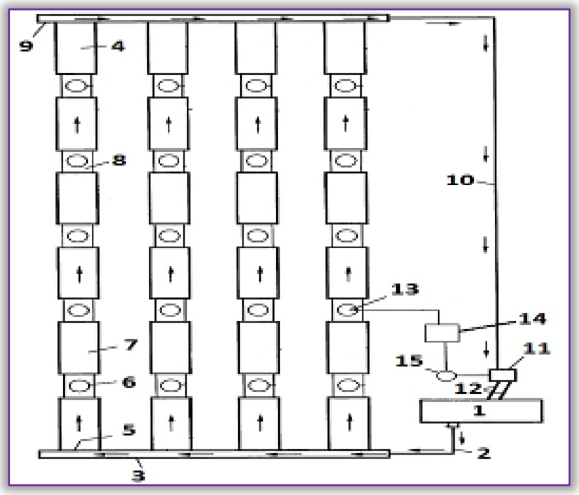

Figure 11 – The scheme of the temperature control system in the area of plant roots (Monte, 2000). 1 – reservoir; 2 – transfer pipe; 3 – high pressure collector; 4 – distribution lines; 5 – regulator; 6 – roots area; 7 – isolated area; 8 – area without insulation; 9 – low pressure collector; 10 – return pipe; 11 – compressor; 12 – heat exchanger; 13 – sap flow sensor; 14 – microprocessor; 15 – solenoid valve

The high pressure area comprises tank 1 in which the cooling agent is in liquid state, the pipe 2 for transferring of the cooling agent to the high pressure collector 3, to which are connected the distribution lines 4, each line having a regulator 5, which allows the adiabatic expansion by Joule–Thomson effect.
In general, the plant roots configuration includes a central spherical zone. Distribution lines of the cooling agent are located in the immediate vicinity of this zone, so that the cooling affect about one–third of the zone. To maximize cooling efficiency and to avoid its propagation in areas where there are no roots, distribution lines are provided at equal intervals with fiberglass insulations. The cooling agent in gaseous state is taken away from the low pressure collector 9 and sent to the compressor 11, passing again in liquid state and goes into the storage tank after previously passing through the heat exchanger 12 on freon basis. To monitor the sap flow departing from the plant roots to buds it is used a special sensor that sends an electrical signal to a microprocessor. The microprocessor drives a solenoid valve which controls the compressor so that when the sap begins to rise, the compressor is turned on and the root zone is cooled to stop the sap flow.
For a total length of the distribution lines of about 75 m and a diameter of 1/2 inch, buried at a depth of 13 cm, the flow rate of the cooling medium is 267 g/min, at a pressure of 2.3 bar. In these conditions, when the ambient temperature is between 10...44°C, the temperature of the soil at a distance of 20 cm from the distribution line is maintained in the range of 3...6°C. At a distance of 10 cm from the distribution line, the ground temperature is between –5...–1°C. It is recommended that the depth of burial of the distribution lines is between 13...20 cm. The flow rate of the cooling agent is between 84...300 g/min. In the US 4577435 patent document (Springer, 1984) is shown a device for both heating/cooling of the plant root system and for heating/cooling the air surrounding the plants (Figure 12). The power supply system is both from unconventional sources (solar, geothermal) and from conventional sources (boilers, chillers, wood or coal burners). The temperature control device is adaptable to a wide range of applications and operating conditions, it is easy to install and maintain and has improved efficiency in operation. The device is designed mainly to heat the root system of the plants in the pots, but can be used in germination beds, the heat transfer tubes being buried in the ground. The input/output collectors are located on the same side of the array of tubes which form U–shaped loops. This location mode enables the temperature gradient between the inlet collector and U loop have the opposite direction of the temperature gradient between the U loop and the output collector. In other words, adjacent tubes have temperature gradients with opposite directions, which leads to uniform temperature in the root zone.

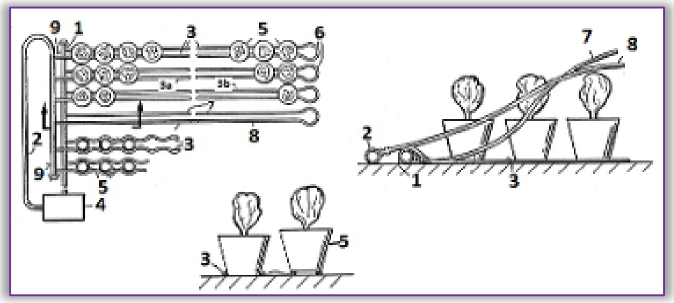

Figure 12 – Device for heating/cooling of the plant root system (Springer, 1984). 1,2 – inlet/outlet collector; 3 – heat transfer pipes; 4 – liquid pumping station; 5 – plant pots; 6 – terminal loop; 7 – portion of the pipe to the outside; 8 – the top portion of the tube; 9 – ventilation valves

The heat transfer tubes have circular section and are made of flexible plastic material (polypropylene, elastomeric polymers of ethylene, diene monomer – EPDM), capable of sustaining the weight of the pots with plants and to support temperatures from –45°C to 150°C. For a length of the transfer pipes of 30 m, water temperature in the inlet collector is 40°C, and those of the output collector reaches 32°C. The optimal distance between the tubes is between 2.5…7.6 cm.
When it's necessary heating the air around the plants during the cold season or cooling it down in hot season, transfer pipes can be removed and placed above the plant height. The loop can be supported in this position by some special supports. In this way, the system is not only used in the root area temperature control, but also to control the ambient air temperature.
The experiments described below were made by the company Netafim (http://www.netafim.com) and placed in three different climate zones in Israel (South – arid, Central and North).

- **Pilot installation for heating/cooling the melons (Arava melons) culture root area** (Figure 13), located on an area of 1000 m² in the South.

Figure 13 – Pilot installation for growing melons (http://www.netafim.com)

- **Pilot installation for growing cucumbers in a greenhouse** (Figure 14) (http://www.netafim.com), located in the North. Planting took place in December, and harvesting was carried out from February to May. It has been observed an increase in production of up to

240% with the optimization system of root zone temperature.

Figure 14 – Pilot installation for growing cucumbers in greenhouses: comparison between control culture and culture created with optimization system root zone temperature (http://www.netafim.com)

- **Pilot installation for growing strawberries in greenhouses in suspended layers** (Figure 15) (http://rootssat.com, http://www.netafim.com), the greenhouse being located in the central area. The experiment was carried out in winter, the temperature difference between the unheated soil of the control culture and the heated soil of the experimental culture was 10.8°C at an ambient air temperature of 1.2°C. It has been observed an increase in production between 20...25% and an early maturity of the fruit compared to the control culture, when using the temperature optimizing system in the root zone.

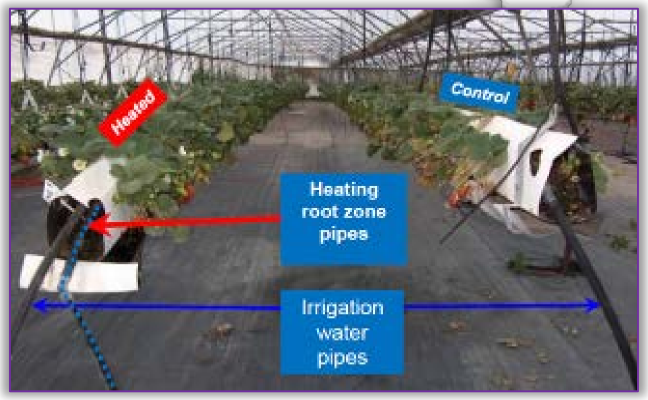

Figure 15 – Pilot installation for growing strawberries in greenhouses (http://rootssat.com, http://www.netafim.com)

CONCLUSIONS

If until recently drought was considered an accident climatic, weather conditions in the last 20 years shows that due to the global climate changes, drought tends to be a state of fact.

To prevent this, irrigation systems are needed in all areas with danger of desertification. It is also necessary to educate farmers in applying technologies appropriate to this crisis, which preserve water in the soil. Relative effectiveness of different methods of irrigation, traditional or new, must be reported also to soil characteristics, climate, hydrology, which can radically alter the terms of comparing a method to another.

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ISSN:2067-3809