SUBSURFACE DRIP IRRIGATION WITH TREATED WASTEWATER

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Abstract

Rapid growth in the demand for potable and irrigation water coupled with natural shortage and continuous restrictions in supply, primarily in arid and semi-arid regions, have accelerated the search for alternative sources. Wastewater reuse is one possible solution that is being implemented, especially in agricultural and landscape irrigation. The aim of the present work was to investigate the effects of irrigation with treated municipal wastewater through subsurface drip method, on growth characteristics of three ornamental coniferous plants, namely Juniperus of chinensis *cv. Stricta,*, Thuja orientalis *cv. Compacta Aurea nana,* Cupressus macrocarpa *cv. Gold Crest, to detect any changes on irrigated soil properties and consequently, to evaluate the use of wastewater in water saving terms compared to freshwater use.*

The experiment was conducted in the farm of University of Thessaly, during 2002 farming period. An automated subsurface drip irrigation system with laterals buried at a depth of 0.15 m was used for water application. The experiment involved two water quality treatments. The first treatment accepted only fresh water. The second one, was irrigated periodically with treated wastewater and fresh water.

The experimental results revealed that freshwater treatment exceeded wastewater in stem and canopy diameters as well as in the conifers' height, yet no statistically significant differences were observed between the two treatments. The lower growth of plants received wastewater is probably to high chloride concentration of waste. Also, from the soil analysis that conducted in treatment that received wastewater, not any concentration of toxic elements was recorded. No significant changes in pH, electrical conductivity Fe, Zn, Cu, and Mn concentration were recorded after soil analyses in treatment received wastewater before and after the irrigation. As regards the water consumption, the use of wastewater resulted in a 38 % saving of fresh water.

1 INTRODUCTION

As the demand for potable water resources increases, wastewater is receiving attention as an alternate irrigation source (Gushiken, 1995; Tanji, 1997; Angelakis et al., 1999; Panoras and Ilias, 1999; Angelakis and Bontoux, 2001). In Australia (Myers et al., 1996), in experiment on irrigation of *eucalyptus grandis* and *pinus radiata*, was observed a higher increase of biomass of eucalyptus and three times higher leaf area index value from that of pinus plant. In irrigation of lemon trees in Spain (Lapena et al., 1995) with wastewater after secondary treatment was found that wastewater application did not assemble toxic elements in the leaves and did not increase considerably the content in N, P, and K. Charfi et al., (1999) in experiment of irrigation with treated wastewater in olive trees found higher N content in the plant parts, higher yield and oil content in the fruits, in treatments that received wastewater.

Research studies in Greece have investigated the possibility of use of liquid wastes for irrigation of agricultural row crops (Vakalis and Tsadilas, 2002; Panoras et al., 2001; Panoras et al., 2000), greenhouse tomato and pepper, as well as for gerbera flower (Panoras and Ilias, 1999). From these works has been evident that the irrigation with treated liquid wastes has given better or the same results in crop yield compared to fresh water while there was no important differences in the yield qualitative characteristics between wastewater and fresh water irrigated crops. Experiments on irrigation of forest plantation (Vourdoubas, 2000) with treated municipal sewage (secondary treatment), were revealed an increase of biomass in eucalyptus plants irrigated with sewage with 108% and 76% of water in relation to the control (fresh water) in two planting densities.

Presently, effluent used in irrigation is normally delivered through surface or sprinkle irrigation systems; however, in recent years interest in microirrigation systems for this purpose has increased. According to Shrivastava et al. (1994) and Ruskin (1993), prevention of pollution and efficient use of water from wastewater effluent can be achieved with microirrigation systems. Oron et al. (1993) reported that subsurface microirrigation reduced the risk of pollution associated with wastewater to a minimum since the soil acts as a living filter, cleaning the water.

Subsurface drip is an emerging alternative wastewater technology with a great deal of merit. Advantages over other subsurface and surface effluent distribution systems include the potential for highly uniform distribution of effluent over the entire irrigated area; shallow distribution enabling effluent to be placed at maximum vertical distance above unsuitable soil horizons or wetness conditions, while keeping effluent from being exposed at the ground surface; injection of effluent from emitters at extremely slow rates which allow for soil uptake without the need for temporary storage or ponding; the potential to maximize nutrient attenuation by placing the effluent in the most biologically active soil/root zone; since the drip system is buried, irrigation system performance is unaffected by surface infiltration characteristics; the relatively dry soil surface permits farm equipment access and movement during the whole irrigation period and eliminates weed growth. Research supporting these beneficial attributes includes works of Oron et al., (1988, 1991); Rubin et al., (1994); Lesikar et al., (1998); Phene et al., (1983); Solomon (1993); Sakellariou-Makrantonaki et al., (2000, 2001, 2002).

Limited research has been reported from operating subsurface drip wastewater systems, as the basis for evaluating and refining system design criteria, and to further assess the potential role of subsurface drip as a viable wastewater management option. Recent results reported by Persyn et al. (1999) and Jnad (2000) provide a detailed assessment of hydraulic conductivity changes in soils surrounding drip emitters at two sites in use over five years. Other aspects of system design which have been evaluated include the importance of laterals being installed level, and concerns related to drainback of effluent into the lower laterals at the end of each scheduled irrigation event (Amoozegar et al., 1994, Berkowitz, 1999).

The aim of present work was to investigate the effects of irrigation with treated municipal wastewater through subsurface drip method, on growth characteristics of three ornamental coniferous plants, to detect any changes on irrigated soil properties and consequently to evaluate the use of wastewater in water saving terms compared to freshwater use.

2 MATERIALS AND METHODS

The experiment was conducted at the farm of the University of Thessaly. The experimental field occupied an area of approximately 150 m^2, separated in two parts. Each part constituted a treatment in 4 replications. The first part, constituted the first treatment, which was irrigated only with fresh water from the borehole of the farm (Freshwater, FW). The second part, constituted the second treatment, and was irrigated periodically with water provided by the wastewater treatment plant of the city of Volos and with fresh water (Wastewater, WW), due to the lightly increased salinity that existed in the wastewater and also because of its increased concentration of ions of chloride. Each irrigation with wastewater was followed by two irrigation applications with fresh water.

An excavation of the field in 15 cm depth took place for the placement of subsurface drip laterals. The lateral pipes that were placed in the depth of excavation, having 0.4 m spacing, 24 m length, were of RAM type manufactured by Netafim, with 0.17 m nominal diameter with integrated emitters. Emitters were self-regulated and shelf-cleaned, having 0.3 m spacing, discharging 1.6 l/h in operation pressure range from 50 to 400 Kpa. The head of irrigation network consisted of a control panel and the reservoir of wastewater made of PE, with a capacity of 5,000 l. The control panel contained the central control valve, a disk filter enriched with *trifluralin* for avoiding root intrusion, electrovalves for controlling the initiation and the end of irrigation, manometers for pressure monitoring and two screen filters. The irrigation was initiated by an irrigation controller. In each manifold a water-meter was placed for the recording of consumed volume of water. In the end of manifolds, special relief valves had been placed for avoiding clogging of subsurface lateral pipes.

Three species of Cupressaceae family were planted, *Juniperus of chinensis* cv. Stricta, *Thuja orientalis* cv. Compacta aurea Nana, *Cupressus macrocarpa* cv. Gold Crest, namely. The plants were transplanted from flowerpots on 10-4-2002, (Day of the year, DOY 100). Forty-eight plants of each species were planted, 24 in the freshwater and 24 in the wastewater treatment. The plant rows spaced 1 metre apart while plants' in-raw spacing was also 1 metre. There was not any fertilizer treatment applied.

The meteorological data were recorded in hourly base by a completely automated meteorological station installed in the University farm. Irrigation was applied every two days, unless rain had preceded and therefore the irrigation was applied less frequently. The irrigations were applied during the period from May to September 2002. Soil water content monitoring and measurement was done using Time Domain Reflectometry (TDR) instrumentation (ESI model manufactured by Soil Moisture Corp.), (Sakellariou - Makrantonaki et al., 2000). TDR is a non-radioactive method, fast and independent of soil type (except extreme cases of soils), the working principle of which is based on the direct measurement of the dielectric constant of soil and its conversion to water volume content.

Observations of plant growth parameters included the measurements of canopy diameter and height in regular time intervals and the measurements of the stem diameter at the beginning and the end of irrigation period. Measurements of qualitative characteristics of wastewater were taken, as well as soil analyses at the beginning and at the end of period.

3 RESULTS AND DISCUSSION

3.1 Climatic data

The collected meteorological data of 2002 show that the period May-October was exceptionally humid since rainfall (286 mm) was higher compared to the mean value (138 mm) of a period of twenty-five years. Also, the same period was characterized by lower temperatures compared to mean temperatures of the corresponding months of the same historical data obtained from Crop Protection Institute of Volos. The cumulative daily evapotranspiration is presented in Figure 1. The highest evapotranspiration values were observed on 17/7/02 and 18/7/02 (9.3 mm and 8.2 mm) while the lowest one was observed on 9/9/02 (0.5 mm).

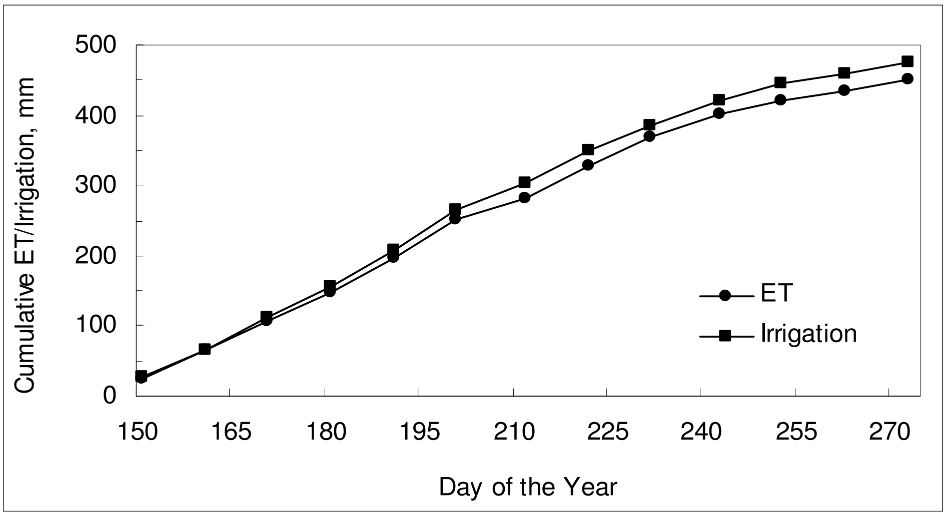

Figure 1. Cumulative Evapotranspiration and irrigation for the conifers.

3.2 Soil moisture

Soil moisture distribution during the irrigation season for the wastewater treatment blocks, is presented in Figure 2, for five successive soil depths.

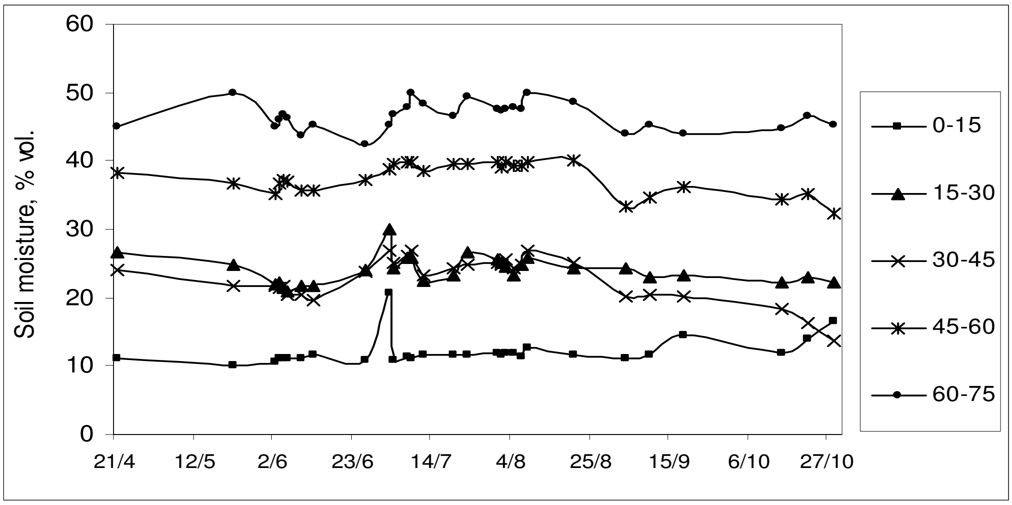

Figure 2. Soil moisture distribution during irrigation season.

Soil moisture profile before and after irrigation of August 6, 2002, in wastewater blocks is presented in Figure 3. Water was distributed subject to the emitter location. Since the water source was at 15 cm, an increase of moisture in 0-45 cm depth is noted, a fact that benefits the plants, which develops the 70 % of its roots up to 50 cm depth.

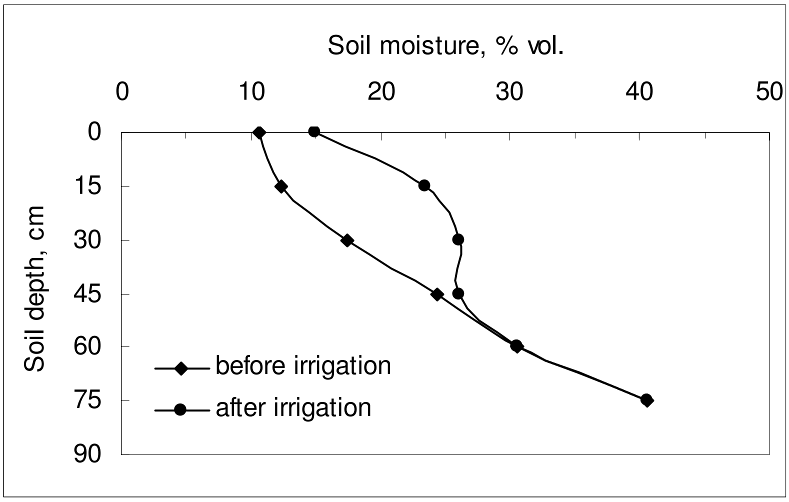

Figure 3. Soil moisture profile before and after irrigation of 6-8-02.

3.3 Physical and chemical properties of soil and water

According to soil analyses and taxonomy conducted by the Institute of Soil Classification and Mapping of Larissa prior to irrigation, the soil is well-drained, calcareous, clay loam that belongs in the subgroup of Typic Xerochrepts of Inceptisols. Main physical and chemical properties of soil are given in Table 1.

Table 1. Soil analysis of the experimental field

Depth (cm)	Soil type	$CaCO_3$ (%)	pH	P (mg kg^{-1})	C.E.C. (meq 100^{-1} g^{-1})	K (meq 100^{-1} g^{-1})	Organic matter (%)
0-30	CL	4.92	7.7	9	26.9	0.31	1.44
30-60	CL	7.92	7.8	16	28	0.26	1.27
60-90	CL	13.2	7.8	4	27.6	0.32	1.44

The analyses of water from the treatment plant (Table 2) show that the electric conductivity (E.C.) was marginally suitable for irrigation of crops, and also, the concentration of ions of chloride was very high (ranged from 1000 mg/l to 1650 mg/l, with allowable limits 355 mg/l according to Bahri and Brissaud, 2002). Chloride ions' concentration was high due to the chlorination of wastes in treatment plant for decontamination. For this reason alternate irrigations were applied with fresh water in wastewater treatment.

Table 2. Analysis of treated wastewater used in the experiment

Parameter	Average	Parameter	Average	Parameter	Average
Cl^- (mg l^{-1})	1457.7	$N\text{-}NO_3$ (mg l^{-1})	5.73	Fe^{3+} (mg l^{-1})	0.303
SS (mg l^{-1})	10.3	C.O.D. (mg l^{-1})	40.5	Cu^{2+} (mg l^{-1})	0.011
P_t (mg l^{-1})	3.9	B.O.D. (mg l^{-1})	17.5	Zn^{2+} (mg l^{-1})	0.058
$N\text{-}NH_4$ (mg l^{-1})	1.54	E.C. (dS m^{-1})	3.3	pH	8.38

3.4 Stem diameter

Measurements of the stem diameter of conifers at a 10 cm height were taken on 8/7/2002 and 10/04/2003. From the results was revealed that the percentage of final increase of the stem diameter in *Juniperus* plants was higher in freshwater treatment, while in *Thuja* and *Cupressus* plants the final increase was higher in wastewater treatment. In any case and in both treatments the difference was not statistically significant at the level of 0.05 (Table 3). As it can be seen, the higher diameter increase occurred in *Cupressus* plants.

Table 3. Increase of stem's diameter in conifers

Conifer	Treatment	Initial diameter (cm)	Final diameter (cm)	Increase (%)	t-test	Significance (p=0.05)
Juniperus	FW	0.696	1.096	62.9	1.258	NS
	WW	0.729	1.075	50.8		
Thuja	FW	0.929	1.558	72.2	-0.452	NS
	WW	0.825	1.450	76.7		
Cupressus	FW	1.196	2.300	95.5	-0.731	NS
	WW	1.150	2.317	102.4		

3.5 Conifers' height

Measurements of conifers' change in height were conducted during the period from 11/4/2002 to 16/11/2002 (Table 4). Nineteen measurements were taken in 2-week time intervals.

Table 4. Increase of height in conifers

Conifer	Treatment	Increase of height (%)	St. Deviation	t-test	Significance (p=0.05)
Juniperus	FW	36.9	9.8	0.25	NS
	WW	36.0	15.3		
Thuja	FW	85.9	27.9	2.41	S
	WW	66.4	28.0		
Cupressus	FW	83.6	15.9	1.10	NS
	WW	77.9	19.6		

In all the three conifers the final height was higher in freshwater treatment, with statistically significant difference only in *Thuja* plants. The high concentration of wastewater in chloride ions is probably the reason of lower plant growth in wastewater treatments since chloride is considered as one of the most toxic elements for the plants (Panoras and Ilias, 1999; Ayers and Westcot, 1985).

3.6 Canopy diameter

Measurements of canopy diameter for the three species of conifers were taken during the period from 11/4/2002 until 16/11/2002 (DOY 100 – 320). Fifteen measurements in 2-week intervals were conducted. The increase in canopy diameter refers to measurements started on DOY 100 when the plants were transplanted. Figures 4, 5 and 6, show the increase in canopy diameter for *Juniperus*, *Thuja* and *Cupressus* respectively. In *Juniperus* plants the total increase of canopy diameter was 15.7 cm and 15.2 cm in freshwater and wastewater treatments, respectively. For *Thuja* plants, the final diameter increase was 15.9 cm in freshwater treatment and 15.5 cm in wastewater treatment while for *Cupressus* plants the final increase was 23.6 cm in freshwater and 21.7 cm in wastewater treatment. In all the coniferous, was not observed any statistically significant difference at 0.05 level.

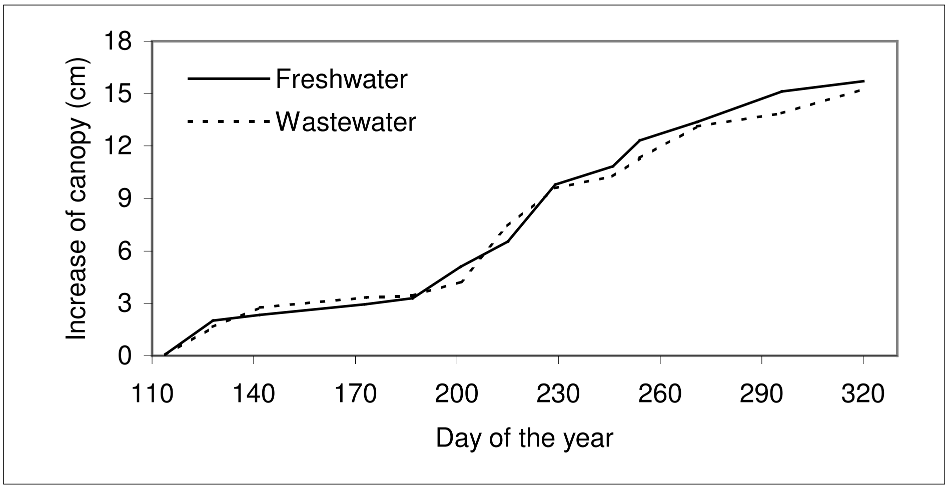

Figure 4. Mean canopy diameter of *Juniperus* plants for freshwater and wastewater treatments.

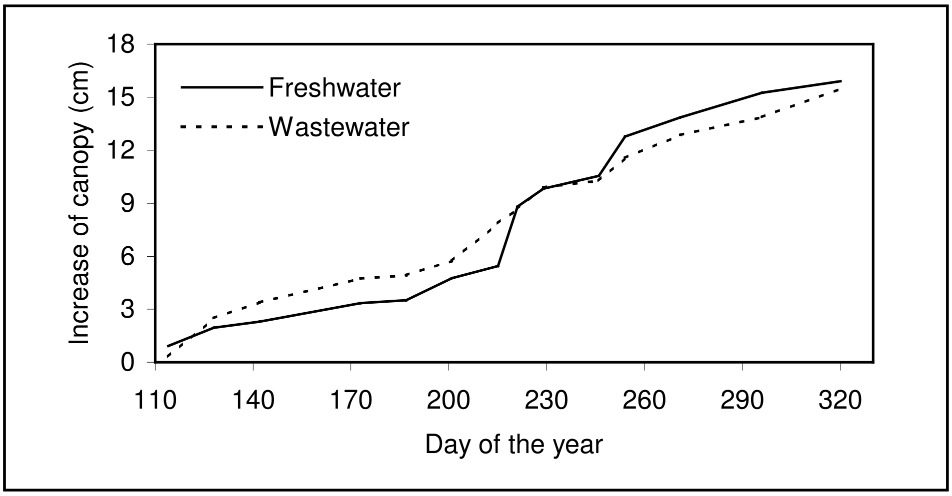

Figure 5. Mean canopy diameter of *Thuja* plants for freshwater and wastewater treatments.

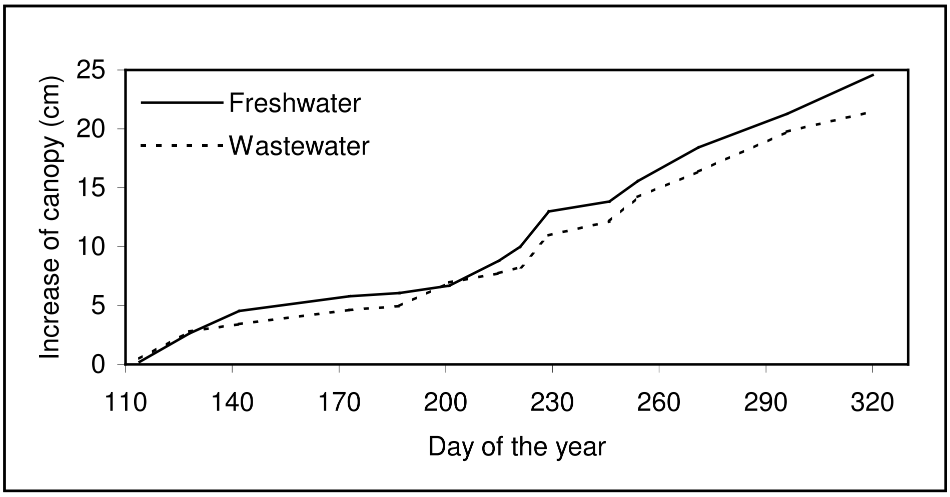

Figure 6. Mean canopy diameter of *Cupressus* plants for freshwater and wastewater treatments.

3.7 Soil attributes

At the end of the irrigation period no significant changes were observed in pH, E.C. and the trace elements as shown in Table 5. Because the irrigation was applied underground through the subsurface drip system and the wastewater did not come in direct contact with the humans, there were not any limits established regarding the microbiological characteristics of wastewater, (Bahri and Brissaud, 2002).

Beginning of irrigation period						
Depth	**Ph**	**E.C. (dS m-1)**	**Fe mg kg^{-1}**	**Zn mg kg^{-1}**	**Cu mg kg^{-1}**	**Mn mg kg^{-1}**
0-30	7.7	3	4.2	1.3	4.7	4.3
30-60	7.8	3	5.4	1.5	3.1	5.2
60-90	7.8	3	6.7	3.5	2.3	4.3
End of irrigation period						
0-30	7.8	<3	4.4	1.6	3.2	3.5
30-60	8.0	<3	7.0	2.5	2.5	4.8
60-90	7.8	3	6.0	11.6	2.5	4.5

Table 5. Soil analysis of wastewater irrigated treatment

3.8 Water saving

Figure 1 presents the cumulative irrigation depth applied through the subsurface irrigation system. The highest irrigation depths were given on the 1st and 2nd decade of July (50.5 and 56.6 mm, respectively), while the lowest was given on the 2nd decade of September (13.5 mm). A total amount of 475 mm water was supplied to each one of the two treatments. In wastewater treatment the 175 mm out of 475 were wastewaters. That resulted in a saving of fresh water of 38%.

4 CONCLUSIONS

The treated liquid municipal wastes by their utilisation for irrigation of crops constitute an important mean for saving fresh water for other uses. The use of treated wastewater is encouraged in crops where humans do not come in direct contact with them. Such cases are recreation areas, parks, ornamental plants in pavements. In this work the possibility of irrigation of ornamental species with treated wastewater was investigated. The wastewater contained small percentages of organic charge and various inorganic elements due to its third degree treatment.

The experimental results revealed that freshwater treatment exceeded wastewater in stem and canopy diameters as well as in the conifers' height, yet no statistically significant differences were observed between the two treatments. The lower growth of plants received wastewater is probably to high chloride concentration of waste. Also, from the soil analysis that conducted in treatment that received wastewater, not any concentration of toxic elements was recorded. No significant changes in pH, electrical conductivity Fe, Zn, Cu, and Mn concentration were recorded after soil analyses in treatment received wastewater before and after the irrigation. As regards the water consumption, the use of wastewater resulted in a 38 % saving of fresh water.

The interest in subsurface drip as a wastewater distribution system appears to be increased. The applicability of this method should increase for use in wastewater systems, as future research succeeds in establishing proper system sizing criteria and continuing improvements in the reliability of system components.

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