Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2016.1180479

57 (2016) 23343–23364
October

Taylor & Francis
Taylor & Francis Group

Reuse of urban-treated wastewater from a pilot-scale horizontal subsurface flow system in Sicily (Italy) for irrigation of Bermudagrass (*Cynodon dactylon* (L.) Pers.) turf under Mediterranean climatic conditions

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Received 20 May 2015; Accepted 7 April 2016

ABSTRACT

Constructed wetlands (CW) are one of the most important biological technology for the treatment and reuse of wastewaters. The aim of this study was to evaluate the reuse of treated wastewater (TWW) from CW for irrigation of Bermudagrass turf (*Cynodon dactylon* (L.) Pers.) and assess the effects of TWW on the biometric and qualitative parameters of the turfgrass and on chemical–physical soil properties. The research was carried out in Sicily (Italy) in a pilot-scale horizontal subsurface flow system which was fed with urban TWW following secondary treatment from an activate sludge wastewater treatment plant. The pilot-system included three separate parallel units. The outflow TWW flowed downhill into three storage tanks which were connected to sprinkler systems. Bermudagrass plots were irrigated with freshwater (FW) and with TWW from planted units and unplanted unit. The TWW quality did not affect the visual turf quality and colour. The above-ground biomass yield of Bermudagrass was on average 1.31 kg m^{-2} in the TWW-irrigated plots. There was not a significant variation of soil pH, but an increase in organic matter content and salinity were recorded in TWW-irrigated plots. The results confirm that TWW provides an additional water source and fertilisers where the supply of FW is limited.

Keywords: Treated wastewater; Horizontal subsurface flow constructed wetland; Bermudagrass turf; Water saving; Fertiliser saving

1. Introduction

In recent years, a fall in rainfall levels and an increase in air temperatures in Italy have had a significant impact on water resources in the southern regions of Italy, creating long periods of water shortage and highlighting the precariousness of the water supply system [1]. In various areas of Southern Italy, other factors such as the nature of the territory and

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Presented at EuroMed 2015: Desalination for Clean Water and Energy Palermo, Italy, 10–14 May 2015. Organized by the European Desalination Society.

the precarious infrastructure of the water networks have led to a severe water shortage which, in turn, has strongly influenced the agricultural sector itself. Demand for water in this sector has also increased yearly, both in order to satisfy the water requirements for crops which were once only rain fed, and as a result of climate change over the last few years, which has led to an increase in water requirements during autumn for the crops [2]. More in general, in arid and semi-arid areas of the Mediterranean basin, supplies of good quality water allocated to agriculture are expected to decrease because most of freshwater resources have been already mobilised [3]. Water is a limited natural resource, so the irrigation with treated wastewater (TWW) may be a viable means of coping with shortages and/or the rising cost of fresh/potable water [4]. The reuse of TWW seems to be one of the most attractive prospects for sustainable water management in agriculture for a number of reasons [5]. These include making a significant impact on reducing global water consumption, reducing pollution in water bodies, improving economic conditions for farmers and retaining better quality water for human consumption [6]. TWW can increase crop yields due to significant concentrations of organic and inorganic micro and macronutrients which are necessary for crop growth [7] and for maintaining fertility and productivity levels of the soil [8]. Despite numerous examples of possible applications of TWW for crops irrigation in the Mediterranean countries [9–12], little attention has been paid to the reuse of TWW for non-food crops such as turfgrass for sports and leisure activities [7,13,14], probably due to the health risks, though minimal, associated with micro-organisms which are considered dangerous to human health [15,16]. Harivandi [4] reports that the use of TWW for turfgrass irrigation is extremely beneficial for various reasons. Firstly turfgrass can absorb large amounts of nutrients found in higher quantities in wastewater than in freshwater (FW); secondly, wastewater can be produced continuously and represents a continuous source of water for turfgrass; thirdly, most soil and plant-related problems concerning the use of wastewater may have a smaller environmental and economic impact on turfgrass than on food crops. However the long-term continuous use of wastewater for turfgrass irrigation could determine various effects on soil and grass amongst which two seem to be most critical. The first is the plant behaviour in long-term, measured in terms of growth and micronutrient accumulation (e.g. sodium) in the plant tissue, and the second is soil response to prolonged irrigation using wastewater (e.g. changes of pH and soil salinity, trace elements accumulation, etc.) [17,18]. In the Mediterranean area, the warm season turf species are of considerable interest due to their high temperatures and salt tolerance [19,20]. Furthermore, they show low water needs and an excellent recovery rate from biotic and abiotic stress [21,22]. Bermudagrass (*Cynodon dactylon* (L.) Pers.) is the most commonly used warm season turf species in the world for high quality turfs, such as golf courses and athletic fields [23–25]. It is well adapted to a wide range of soil conditions and its growth is more vigorous than other species [26]. In the Mediterranean area, several studies have demonstrated the effects of TWW on the yield and quality of Bermudagrass turf [27–30] highlighting that TWW are a precious source of water for turfgrass. Most of these studies were carried out using TWW from sewage treatment plants. In Italy, the reuse of TWW is regulated by Ministerial Decree no. 185/2003, which does not make a distinction between the irrigation of food and non-food crops. However, the quality of TWW at the outflow of sewage treatments plants is often not of an adequate standard under Italian law because conventional technologies do not effectuate all the treatments necessary in order to guarantee high quality level of wastewater. One of the most important biological technology for the pollution control of wastewater and reuse are constructed wetland systems (CWs). They are engineered systems designed to treat wastewater and an alternative to the more widespread conventional treatment technologies using higher energy inputs [31]. As reported in various studies, CWs may play an important role in the treatment and reuse of agricultural wastewater, particularly in those areas where agriculture is highly dependent upon irrigation [32,33]. In the international literature, the reuse of TWW from CWs for turfgrass irrigation is not very documented [34] and can be considered an innovative agronomic and engineering topic.

The aims of this study were: (i) to evaluate the pollutants treatment performance of a pilot-scale HSSFs and calculate the water balance, (ii) to assess the effects of irrigation with TWW from a pilot-scale HSSFs comparing to irrigation with FW on biometric, productive and qualitative parameters of Bermudagrass turf, (iii) to assess the effects of irrigation with TWW from a pilot-scale HSSFs comparing to irrigation with FW on chemical and physical soil properties.

2. Materials and methods

2.1. Test site

Tests on the reuse of urban wastewater for irrigation of Bermudagrass turf (*C. dactylon* (L.) Pers.) were carried out in 2014 in the experimental area of the pilot HSSFs in Piana degli Albanesi, a rural community (6000 inhabitants) in the west of Sicily (37°59′56′′40 N-13°16′50′′16 E, 740 m a.s.l.). The climate of the area is humid with a mean annual rainfall of about 800 mm, mainly distributed between October and April. With reference to time series 2002–2014, the annual average temperature was 15.3°C, average maximum temperature was 19.9°C and average minimum temperature was 10.5°C. The summer drought was severe and the dry period was between June and September.

2.2. Description of the pilot HSSF system

The system was designed by the Department of Agricultural and Forestry Sciences at the University of Palermo (Italy) in 2004 and was located downhill from the town's sewage plant (Fig. 1). The system included three separate parallel units (A, B and C) each 33 m long and 1 m wide, providing a total surface filter bed area of 99 m^2 (Fig. 2). Filter bed depth was 0.5 m to allow for greater root development and to create a larger rhizosphere. The slope was 1.5%, needed to obtain regular flow. The walls of the three units were made of concrete and the floor was levelled with fine sand. The units were filled with a substrate of evenly sized 20–30 mm silica quartz river gravel (Si 30.32%; Al 5.23%; Fe 6.87%; Ca 2.79%; Mg 1.01%). Each unit was lined with sheets of IDROEVA. In March 2012, Unit A and B were, respectively, planted with *Cyperus alternifolius* L (umbrella sedge) and *Typha latifolia* L. (reedmace), while unit C was unplanted. The treated urban wastewater from the outflow tank of the municipal sewage plant was initially fed into a reinforced storage tank. This water was pumped through a 1 m wide perforated pipe into each of the three units to ensure even distribution of the wastewater throughout the filter bed section, reducing the risk of hydraulic short-circuiting. In each unit, the pipe was placed 10 cm from the surface of the substrate. The homogeneous distribution of wastewater in each unit was ensured through a timer-controlled pumping system. The flow inlet was measured by a flow metre in each unit. The pumping was continuous throughout the day without variations in time. The outflow tanks, located downhill from the three units, were installed with a filter grill between the tanks and the substrate in order to avoid blockage. The outflow wastewaters flowed downhill into three 64 m^3 storage tanks, one for unit, which were connected to sprinkler systems and used to irrigate the Bermudagrass turf. The units operated under the same hydraulic conditions and were tested under a hydraulic loading rate of 12 cm d^{-1}.

2.3. Urban wastewater analysis

Urban wastewater samples were taken twice per month during the period April–September 2014,

Fig. 1. A view of pilot-scale HSSF system located downhill from the sewage plant in Piana degli Albanesi (Sicily, Italy).

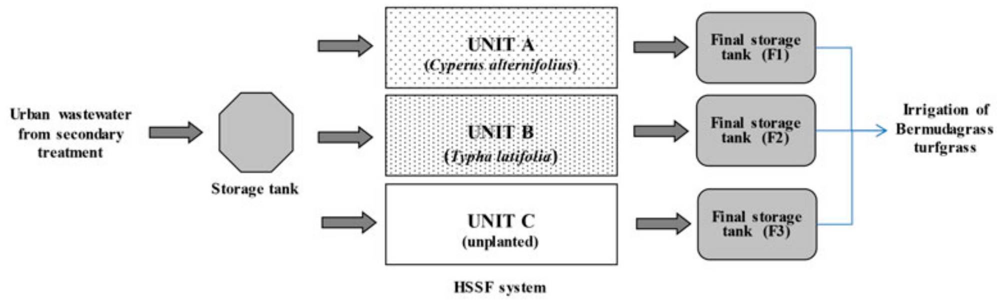

Fig. 2. Layout of pilot-scale HSSF system in Piana degli Albanesi (Sicily, Italy).

amounting to a total of 12 times. The samples were collected at the inflow (0 m) and at the outflow (33 m) of each unit. A litre of wastewater was collected from each of the two points during each sampling. There was only one influent sampling point for each unit. The influent sample was taken close to the pipe while the effluent sample was collected at the mouth of the outflow pipe. The influent and effluent samples were instantaneous samples. The pH value, electrical conductivity (EC), temperature (T) and dissolved oxygen levels (DO) levels were determined directly on site using a portable Universal metre (Multiline WTW P4), following the calibration protocol for each of the four parameters being studied. Using Italian water analytical methods [35], total suspended solids (TSS), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), ammonia-nitrogen (NH_4-N), total phosphorus (TP), sodium (Na), potassium (K), calcium (Ca), magnesium (Mg) and chloride (Cl) levels were determined. Total coliform (TC), faecal coliform (FC), faecal streptococci (FS), *Escherichia coli* (Ec) and *Salmonella* spp. levels were determined by membrane filter methods, based on standard methods for water testing [36]. Removal efficiency (RE) of a pilot HSSFs was calculated based on pollutant concentrations according to [37]:

$$\mathrm{RE} = \frac{C_i - C_0}{C_i} \times 100 \tag{1}$$

where C_i and C_0 are the mean concentrations (mg/L) of the pollutants in the influent and effluent.

2.4. Water balance

The FAO Penman-Monteith method was used to calculate ET_0 [38]. The Penman-Monteith equation was used to calculate daily ET_0 (mm/d) based on microclimate data taken from an automatic weather station belonging to the Sicilian Weather and Climate Service located near to the pilot system.

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma(900/T + 273)u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \tag{2}$$

where R_n is net radiation at the crop surface (MJ m^2/d), G is soil heat flux density (MJ m^2/d), T is average air temperature (℃), u_2 is wind speed at 2 m height (m/s), e_s is the saturation vapour pressure (kPa), e_a is the actual vapour pressure (kPa), $e_s - e_a$ is the saturation vapour pressure deficit (kPa), Δ is the slope of the vapour pressure curve (kPa/℃) and γ is the psychrometric constant (kPa/℃). The ET_0 values were calculated using the cool-season turfgrass *Festuca arundinacea* Schreb. The water balance for each unit was determined separately every 10 d from April to November 2014. This period was chosen according to the growth dynamics of the two species.

For the planted units, an estimate of the water balance was calculated, in agreement with [37], using the following equation (Eq. (3)): $Q_o = Q_i + (P - ET_c)A$ where Q_o = output wastewater flow rate (m^3/d), Q_i = wastewater inflow rate (m^3/d), P = precipitation rate (mm/d), ET_c = crop evapotranspiration (mm/d), A = wetland top surface area (m^2).

For the unplanted unit, the water balance was calculated using the following equation: $Q_o = Q_i + (P - ET_{con})A$, where ET_{con} = evapotranspiration from unplanted control (mm/d).

The amount of water at the inflow and outflow of each unit was determined using a volumetric flow metre. Rainfall was determined with a pluviometer. ET_c was estimated using Eq. (3): $ET_c = Q_i + P(A) - Q_o$. ET_{con} was estimated using Eq. (3): $ET_{con} = Q_i + P(A) - Q_o$. Crop coefficients ($K_c$) values for *C. alternifolius* and *T. latifolia* were calculated, in agreement with [38] and [39], using the equation (Eq. (4)) $K_c = ET_c/ET_0$. Crop coefficients were calculated every 10 d in 2014 for each growth stage of the two macrophytes.

2.5. Description of the experimental field and main cultivation practices

Experimental field of Bermudagrass was set up close to the pilot HSSFs. Two seeded Bermudagrass varieties, Princess 77 and Yukon, were used for the tests. The date of sowing was June 2013. The plots were 4 m^2 and were spaced 50 cm apart. The inter-plot spaces were periodically treated with glyphosate (N-(phosphonomethyl) glycine) at 4 kg ha^{-1} y^{-1} in order to avoid the spread of plants between plots. One year before the date of sowing the experimental area was treated with the same herbicide twice a year at 2.88 kg ha^{-1} in order to minimise the weed competition. The experimental field was equipped with a sprinkling irrigation system and was irrigated with FW. In 2014, irrigation was applied from April to September three times per week both with TWW and FW in order to maintain active growth of the turf. The water needs of Bermudagrass were defined by the differences between the amount of water lost by evapotranspiration and the rainfall rates. Crop evapotranspiration (ET_c) of Bermudagrass was calculated according to [40] using the equation: $ET_c = K_c\ ET_0$, where K_c is the crop coefficient of Bermudagrass and ET_0 is the reference evapotranspiration (Penman–Monteith equation). In 2013 plots received 50 kg N ha^{-1}, 10 kg P_2O_5 ha^{-1} and 40 kg K_2O ha^{-1} per month of growth from June to September using 100 kg ha^{-1} of granular fertiliser 15.5.22., 100 kg ha^{-1} of granular fertiliser 18.5.18. and 80 kg ha^{-1} of ammonium sulphate 21.0.0. In 2014, the FW-irrigated plots were managed with the same N and K fertilisation programme used in the past year. In treated wastewater-irrigated plots, we estimated the amounts of N and K, supplied by irrigating with TWW, which should be taken into consideration for the commonly used fertilisation programme of bermudagrass, based on previous analyses. Both for FW and TWW, the sodium adsorption ratio (SAR) was calculated according to formula:

$$\mathrm{SAR} = \frac{(\mathrm{Na}^{+})}{\sqrt{\frac{1}{2}(\mathrm{Ca}^{2+}) + (\mathrm{Mg}^{2+})}} \tag{5}$$

The turf was maintained at a mowing height ranging from 30 to 35 mm and it was mowed by a helicoidal mower during the Bermudagrass vegetative stage. The mowing was carried out twice per week during intense growth periods with the subsequent removal of grass clippings. No insecticide and fungicide treatments were carried out during the test period.

2.6. Turf and soil analysis

The biometric, qualitative and productive parameters determined for Bermudagrass turf were: leaf texture, shoot density, colour, turf quality and above-ground dry biomass. The leaf texture was determined monthly from April to October by randomly removing 100 flattened leaves per subplot and measuring the leaf width at a distance of 1 cm from its ligule [25]. The shoot density was calculated in June and September by counting the number of shoots in 50 cm^2 core that was collected to a depth of 30 cm and close to subplot centre, where the turf was assumed to be fully established [41]. The turf colour was based on a 1 (=light green) to 9 (=dark green) visual rating scale after the mowing [42]. The visual turf quality was based on a 1 (=poorest or dead) to 9 (=outstanding or ideal) visual rating scale [42]. Turf quality was based on colour, leaf texture, uniformity of coverage and shoot density. Turf colour and quality were determined monthly during the vegetative growth of bermudagrass. The above-ground dry biomass was calculated by removing all plant tissues from the core top and drying the collected material in an oven at 60˚ to constant weight [26]. A grass sample was taken randomly in each subplot of each treatment level of irrigation. Sampling was carried out in June and September 2014.

The soil parameters were: pH, EC, organic matter (OM), total nitrogen (TKN), assimilable phosphorus (P), assimilable potassium (K), active calcareous (active $CaCO_3$), magnesium (Mg) and sodium (Na) content. The soil measurements were carried out only in the topsoil (0.30 m) close to the rhizosphere of bermudagrass. Before the sowing three soil samples was randomly collected in each replicate and analysed. At the end of the tests, one soil sample was collected in each subplot for each replicate and analysed. Soil samples were air dried, ground and sieved to pass through a 2-mm sieve screen and then analysed for chemical and physical characteristics. The samples were analysed for pH and EC in the ratio of 1:2 dry soil:water extract, pH was determined with a calibrated pH-meter, EC with a calibrated conductivimeter, OM with the Walkley and Black method, TKN by the Kjeldahl procedure, assimilable P by the Olsen method and active calcareous using the Drouineau method. K, Mg and Na contents were determined by atomic absorption spectrophotometer. All the analyses were carried out at Corissia Research Centre of Palermo.

2.7. Climatic data

Data on rainfall, temperature and potential evapotranspiration (PET) were collected from a meteorological station belonging to the Sicilian Agro-Meteorological Information Service situated close to the pilot HSSF system. The station was synchronised with GMT in order to operate using synoptic forecast models. It was equipped with a MTX datalogger (model WST1800) and various sensors: wind speed sensor MTX (model Robinson cup VDI with an opto-electronic transducer), global radiation sensor (model PHILIPP SCHENK-8102 thermopile pyranometer) to measure cumulative direct and diffuse solar irradiance, temperature sensor MTX (model TAM platinum PT100 thermoresistance with anti-radiation screen), relative humidity sensor—MTX (model UAM with capacitive transducer with hygroscopic polymer films and antiradiation screen), rainfall sensor MTX (model PPR with a tipping bucket rain gauge) and leaf wetness sensor MTX (model BFO with PCB). This equipment provided data on the wind speed (m/s), minimum daily relative moisture levels (%), average daily soil temperature (℃), average daily air temperature (℃), total daily solar irradiance (MJ/m^2), total daily rainfall-frequency (d mm > 1) (%) and rainy days per year (d mm > 1) (%). Furthermore, using the Penman–Monteith equation, the PET was calculated.

2.8. Experimental design and statistical analysis

A split-plot design for a two-factor experiment [43] was used with four replications. The main plot factor was irrigation (I) with four treatment levels: (1) I1 with FW; (2) I2 with TWW from *C. alternifolius* planted unit; (3) I3 with TWW from *T. latifolia* planted unit; (4) I4 with wastewater from unplanted unit. The subplot factor was Bermudagrass variety (CV) with two treatments levels: (1) CV1 Princess 77; (2) CV2 Yukon. Statistical analysis was performed with the package MINITAB Release 14 for Windows and included analysis of variance (one-way ANOVA). The difference between means was carried out using the Tukey test. All the representative values were presented using mean ± standard error calculations.

3. Results and discussion

3.1. Removal efficiency of pollutants in the pilot-scale HSSFs

Results of pollutant removal levels of the pilot HSSFs obtained from testing carried out from April to September 2014 are shown in Tables 1 and 2. As regards the planted units, differences in pH value, T, EC and DO levels were not high. The pH value at the inflow pipe was slightly alkaline, but at the outflow it was more alkaline in both of the planted units with an even higher increase in the unplanted unit. This phenomenon was in contrast with findings from [31]. In the unplanted unit, the absence of vegetation stimulated greater atmospheric aeration in the substrate and, in some cases, the growth of algae, with consequences on the hydrogenisation of the water, as found by [44]. Differences were found regarding EC when comparing the planted units with the unplanted unit. The EC was found to be higher in the planted-units and the highest level was observed at the outflow of the reedmace-unit due to evapotranspiration processes which determined a greater loss of water and, therefore, an increase of the solute in the solution. DO in both planted units were not found to be different. We did not find significant differences in DO levels between the two macrophytes despite the differences in the root apparatus. An increase in dissolved oxygen which was not high was found in the unplanted unit due to greater atmospheric aeration and to the release of oxygen during algal photosynthesis. At the outflow the chemical–physical pollutant levels were found to be lower in both of the planted units compared to the unplanted unit. The large difference found between the planted and unplanted units highlights the influence of vegetation on pollutant removal rates. The improvement in the quality of the wastewater at the outflow in the planted units could be due to the direct absorption of the nutrients by the plants and the action of the aerobic micro-organisms located in the rhizosphere. RE was higher in the planted units compared to the unplanted unit, although lower compared to data found in the literature. When comparing only the planted units, removal levels for SST, BOD_5, COD, TKN, $N\text{-}NH_4$ and TP were higher in the reedmace unit, due to a greater level of adaptability of the species to the climatic and substrate conditions of the study area. In both planted units, RE for TSS, BOD_5 and chemical oxygen demand were higher than those of nitrogen and phosphorous. The lower plant and root density in the umbrella sedge unit influenced filter mechanisms for TSS, leading to lower levels of sedimentation at the roots and the substrate and to a greater release into the outflow waters. In our research, the differences between the planted and unplanted units show that the interaction of the macrophyte root systems with the substrate influences the total suspended solid reduction process to a greater extent than the substrate alone. The BOD_5 and COD removal rates were higher in the planted units and they stayed within limits consistent with findings by other authors for HSSFs. As [45] report, in CWs the macrophytes use phosphorous as an essential element, their root tissues contain phosphorous, although levels are significantly lower than the carbon and nitrogen

Table 1
Variation of pH, T, DO and ECw in the pilot units from April to September 2014. Average (± standard error), minimum and maximum values are shown (n = 12)

Parameters	Main inlet	Unit A		Unit B		Unit C		
		Cyperus alternifolius		*Typha latifolia*		Unplanted		
		Outlet	Variation (%)	Outlet	Variation (%)	Outlet	Variation (%)	Threshold values for Italian Ministerial Decree 185/2003
pH	7.6 ± 0.03 (7.4 − 7.7)	7.7 ± 0.03 (7.5 − 7.8)	−1.3	7.9 ± 0.04 (7.7 − 8.1)	−3.9	8.1 ± 0.03 (7.9 − 8.2)	−6.6	6 − 9.5
T (°C)	22.4 ± 0.1 (21.7 − 23.1)	22.6 ± 0.1 (21.9 − 23.3)	−0.9	22.5 ± 0.1 (21.7 − 23.2)	−0.4	22.8 ± 0.1 (22.1 − 23.1)	−2.2	–
EC (μS cm^{-1})	544.2 ± 10.9 (485.5 − 616.7)	636.5 ± 6.4 (623.3 − 684.4)	−16.9	719.8 ± 7.2 (699.3 − 772.3)	−32.2	556.7 ± 12.1 (504.6 − 643.8)	−2.3	3,000
DO (mg L^{-1})	1.4 ± 0.09 (1.3 − 1.4)	0.9 ± 0.02 (0.8 − 1.0)	35.7	1.0 ± 0.01 (0.9 − 1.1)	28.6	1.1 ± 0.01 (1.1 − 1.2)	21.4	–

Table 2
Main chemical and physical composition of the urban wastewater from the inflow and outflow of the pilot units. Removal efficiency (RE) from April to September 2014. Average (±standard error), minimum and maximum values are shown (n = 12)

Parameters	Main inlet	Unit A		Unit B		Unit C		Threshold values for Italian Ministerial Decree 185/2003
		Cyperus alternifolius		*Typha latifolia*		Unplanted		
		Outlet	RE (%)	Outlet	RE (%)	Outlet	RE (%)	
Colour	NP*	NP	–	NP	–	NP	–	–
Odour	NU**	NU	–	NU	–	NU	–	–
Coarse matter	–	–	–	–	–	–	–	–
TSS (mg L^{-1})	29.3 ± 0.8 (26.0 − 34.3)	10.3 ± 0.2 (9.1 − 12.1)	65.5	9.1 ± 0.1 (8.4 − 10.2)	69.4	21.8 ± 0.5 (20.1 − 27.8)	26.5	10
BOD_5 (mg O_2 L^{-1})	24.1 ± 0.8 (19.6 − 28.9)	7.7 ± 0.2 (6.8 − 10.1)	68.0	7.1 ± 0.3 (6.0 − 9.2)	70.5	12.6 ± 0.1 (11.5 − 13.4)	47.0	20
COD (mg O_2 L^{-1})	50.1 ± 4.1 (32.1 − 73.2)	12.4 ± 0.6 (9.8 − 16.6)	74.2	10.9 ± 0.5 (8.3 − 13.3)	77.0	27.1 ± 1.5 (22.3 − 37.4)	43.5	100
TKN (mg N L^{-1})	17.5 ± 0.7 (14.1 − 22.3)	9.7 ± 0.03 (9.6 − 10.8)	42.7	8.2 ± 0.1 (7.3 − 9.4)	51.8	15.2 ± 0.4 (13.3 − 18.5)	11.8	15
N-NH_4 (mg NH_4 L^{-1})	12.9 ± 0.3 (11.1 − 15.1)	7.4 ± 0.2 (6.7 − 9.5)	42.3	6.5 ± 0.2 (5.2 − 7.4)	49.4	10.3 ± 0.2 (9.4 − 11.3)	19.6	2
TP (mg P L^{-1})	7.4 ± 0.06 (7.1 − 7.8)	4.8 ± 0.09 (4.2 − 5.2)	35.6	4.5 ± 0.03 (4.3 − 4.9)	39.0	7.0 ± 0.03 (6.7 − 7.1)	5.9	2
Cl (mg Cl L^{-1})	126.4 ± 0.3 (117.1 − 126.8)	115.2 ± 0.5 (100.4 − 118.1)	8.6	114.9 ± 0.9 (104.2 − 121.1)	8.8	123.2 ± 0.4 (115.6 − 125.2)	2.2	250
Ca (mg Ca L^{-1})	80.7 ± 0.4 (78.2 − 82.3)	60.5 ± 0.7 (57.1 − 67.3)	25.0	58.1 ± 0.6 (55.3 − 62.3)	27.9	71.4 ± 0.4 (68.5 − 72.5)	11.5	–
K (mg K L^{-1})	93.1 ± 0.9 (90.1 − 97)	73.5 ± 1.2 (68.1 − 82.2)	21.0	68.5 ± 0.4 (66.3 − 74.4)	26.3	85.3 ± 0.4 (83.1 − 88.2)	17.1	–
Mg (mg Mg L^{-1})	23.5 ± 0.4 (21.2 − 26.3)	21.2 ± 0.3 (19.1 − 23.9)	9.8	21.0 ± 0.4 (15.5 − 24.1)	10.7	23.0 ± 0.4 (20.8 − 25.9)	1.9	–
Na (mg Na L^{-1})	150.4 ± 1.7 (143.2 − 159.3)	139.4 ± 0.4 (138.1 − 142.1)	7.3	139.7 ± 0.7 (137.6 − 144.5)	7.1	147.6 ± 1.5 (141.2 − 155.3)	1.8	–

*Not perceptible.
**Not unpleasant.

levels. In our research, the lower phosphorous removal rate in planted units was mainly due to the granular saturation of most of the substrate sorption sites, whose adsorption capacity in HSSFs, according to [46], can be used to obtain significant phosphorous removal rates, although adsorption would seem to decrease over time. The nitrogen removal efficiency was lower than the OM removal in all the units, due to low oxygen levels in the system. This had a significant effect on the ammonium nitrification process, believed by many researchers to be one of the most important nitrogen removal mechanisms. The planted units produced significantly higher removal levels for TKN and $N–NH_4$ compared to the unplanted unit. Vymazal and Krőpfelová [47] highlight the fact that the planted units outperform the unplanted ones in as much as the rhizosphere contributes to the development of the microbe community, providing a valuable source of carbon compounds though root exudates and releasing oxygen though the roots. Ammonia-nitrogen levels in the wastewater at the inflow were not high, and, hence, given also the limited oxygen levels in the substrate, it is reasonable to assume there was an incomplete transformation of ammoniacal nitrogen into nitrites and nitrates and, therefore, a low nitrification rate. The planted units did not showed high removal levels for metals Ca, K, Mg and Na. We did not find great differences of removal levels of studied metals between the two planted units. For example, the removal efficiency of Na was found to be 7.3 and 7.1%, respectively, at the outlet of umbrella sedge unit and reedmace unit. Our findings were consistent with the literature. Kadlec and Wallace [48] stated the removal of 21, 6, 12 and 9% for Ca, K, Mg and Na, respectively, in a CW in California. Maine et al. [49] reported the removal of 34, 5, 5 and 34% for Ca, K, Mg and Na, respectively, in a FWS CW in Argentina. Vymazal and Šeha [50] claimed that HSSFs were not effective in retentions of the studied elements and reported removal of Ca, K, Mg and Na averaged only 1.4, 10.6, 6.1 and 7.4%, respectively, in two HSSF CW in the Czech Republic. Cooper and Findlater [51] highlight that in the CWs the main processes for the remove of metals are sedimentation, filtration, precipitation, adsorption and biological reactions. International literature reports that not all the macrophytes can uptake high amount of metals due to structural damage of plant tissues. Moreover, high concentrations of these metals could be toxic for bacteria that are close to the rhizosphere. Kadlec and Wallace [48] explained why there is not much change in alkali metals concentrations from inlet to outlet in a CW. In our research, despite the low removal efficiency of metals, the highest removal percentages were found in the planted units and this confirms that a significant removal rate of pollutants in the CWs depends on the interaction between plants, substrate and micro-organisms, as reported by [52]. On a microbiological level (Table 3), the three units showed marked differences for all the parameters in the study. Both of the planted units produced pathogen levels which were lower at the outflow than the unplanted unit. *E. coli* levels were found on average to be between 96.6 ± 4.2 CFUs $100\ ml^{-1}$ (reedmace unit) and 671.4 ± 48.2 CFUs/ $100\ ml^{-1}$ (unplanted unit). The TWW at the inflow and outflow pipes of the pilot HSSFs did not contain *Salmonella* spp. At the outflow reedmace unit had lower FC, TC, FS and *E. coli* levels compared to umbrella sedge unit. In the planted units, removal efficiency of pathogens was high for each parameter in the study and consistent with international literature. For example, the removal efficiency of *E. coli* was on average higher than 90% in reedmace unit. This was due to a combination of physical, chemical and biological processes carried out by the plants, nematodes, virus and bacteria, as illustrated by Brix (1997). The best aerobic conditions in the planted units, due to atmospheric air circulation and the translocation of oxygen from the root system of macrophytes, eased the production of a greater bacteria biofilm and promoted pathogen load removal than unplanted unit, as claimed by [53]. In our research, the average values of the chemical and microbiological parameters at the outflow of the pilot HSSFs were not all within the legal limits of the Italian Ministerial Decree 185/2003 regarding to the reuse of treatment wastewaters for irrigation purposes. The age of the pilot HSSFs influenced the high concentration of total phosphorus at the outflow of planted and unplanted units due to saturation of most of the substrate sorption sites. The concentrations of *E. coli* were not always acceptable in terms of law despite the high removal efficiency by the system. However, a high *E. coli* removal level was observed (>90%), which must be taken into consideration as most conventional treatment systems in Sicily, such as activated sludge or trickling filter systems, demonstrate low removal capacity of microbiological pollutants due to the fact that often not all three main treatment processes are effectuated. It is also for these reasons that the use of HSSF CW are encouraged in the arid and semi-arid areas of the Mediterranean region, as their use overcomes the problem of the high microbiological component in wastewater, which does not occur with the direct use of wastewater. It is evident the need to find an adequate solution to improve the removal efficiency of bacteria and respect the legal limits of the law. One of the most important mechanism to reduce significantly the concentrations

Table 3
Main microbiological composition of the urban wastewater from the inflow and outflow of the pilot units. Removal efficiency (RE) from April to September 2014. Average (±standard error), minimum and maximum values are shown (n = 12)

Parameters	Main inlet	Unit A		Unit B		Unit C		Threshold values for Italian Ministerial Decree 185/2003
		Cyperus alternifolius		*Typha latifolia*		Unplanted		
		Outlet	RE (%)	Outlet	RE (%)	Outlet	RE (%)	
Log_{10} (MPN 100 ml^{-1} – CFUs 100 ml^{-1})								
Total coliforms (MPN 100 ml^{-1})	4.32 ± 0.01 (4.23 − 4.37)	3.52 ± 0.02 (3.40 − 3.66)	83.6	3.30 ± 0.01 (3.20 − 3.33)	90.4	4.04 ± 0.01 (3.97 − 4.13)	47.5	–
Faecal coliforms (MPN 100 ml^{-1})	4.17 ± 0.01 (4.12 − 4.24)	3.47 ± 0.02 (3.35 − 3.64)	79.6	3.19 ± 0.05 (3.03 − 3.50)	88.8	3.95 ± 0.02 (3.87 − 4.07)	38.9	–
Faecal streptococci (MPN 100 ml^{-1})	3.85 ± 0.0 (3.81 − 3.87)	3.22 ± 0.02 (3.13 − 3.34)	76.4	3.05 ± 0.02 (2.94 − 3.22)	84.1	3.63 ± 0.01 (3.57 − 3.64)	42.7	–
Escherichia coli (CFUs 100 ml^{-1})	3.08 ± 0.02 (2.95 − 3.21)	2.17 ± 0.01 (2.14 − 2.22)	87.7	1.98 ± 0.02 (1.87 − 2.08)	92.1	2.81 ± 0.03 (2.64 − 2.99)	45.1	10 (80% of samples) and 100 (maximum value point)
Salmonella spp. (MPN 100 ml^{-1})	–	–		–		–		–

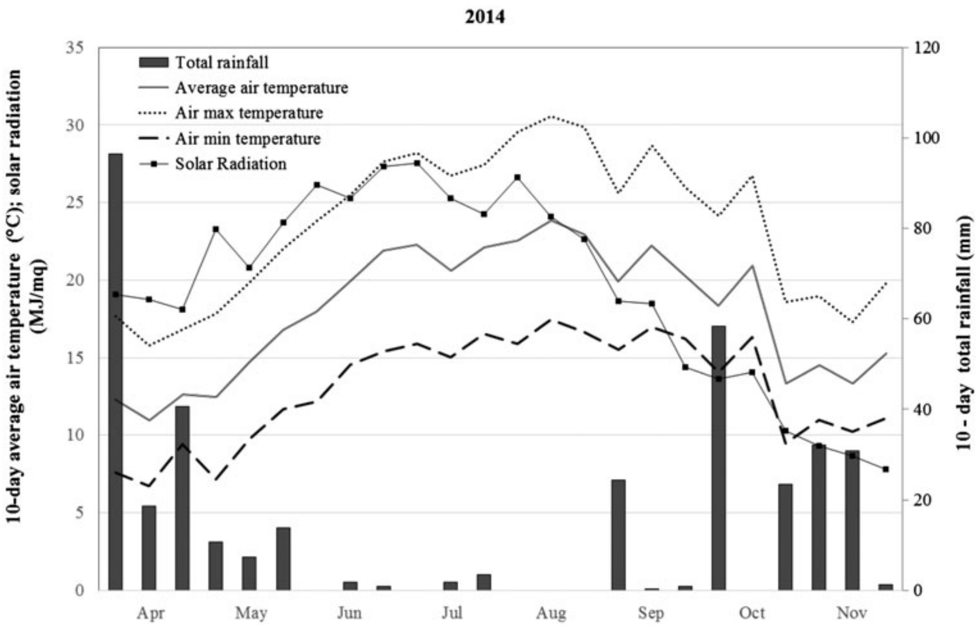

Fig. 3. Trends of 10-d minimum, maximum and average air temperature, solar radiation and total rainfall during the test period.

of micro-organism is the chemical oxidation [54]. The use of different retention times in the pilot HSSFs could positively affect the removal rate of *E. coli* due to change of aerobic/anaerobic conditions of the substrate.

3.2. Microclimatic conditions

Trends on air maximum temperature, air minimum temperature, air average temperature, solar radiation and total rainfall are shown in Fig. 3. Between April and September 2014, average air temperature trends were consistent with ten-year averages. Maximum average air temperature was 30.5°C in the first 10-d of August and minimum average air temperature was 7.5°C in the first 10-d of April. Air temperature trends increased from the beginning of April to the first 10 d of August and decreased up to the end of November. Rainfall was highly concentrated in April and in November. In the summer period, average monthly rainfall was 30.1 mm. Relative humidity trends were similar to 10-year averages due to similar temperatures and rainfall. The highest total solar radiation was recorded in the first 10 d of July at 28.7 MJ/m^2, while the lowest was in the third 10-d of November at 6.5 MJ/m^2. Climate conditions of the area, air temperature and total solar radiation, in particular, did not influence significantly the treatment performance of the pilot-scale HSSF. The highest treatment performance of the system was found from June to September when air temperature and total solar radiation affected positively the plant growth and microbiological activities. During summer months, higher values of RE were observed both for chemical and microbiological pollutants. However, during autumn months, we observed a not very high decrease of RE for all the TWW parameters. In fact, the climate conditions in the area allowed plant growth to continue up to late Autumn, delaying the dormancy period of both macrophytes and, consequently, their phyto-extraction potential. In this context, it could be very interesting highlight how the climate change scenarios can affect RE of pilot-scale HSSF. In the Mediterranean region, climate change projections derived from global climate model results in an increase of temperature and in a decrease of rainfall in most of the territories as reported by [55]. This indicates an increase in periods of droughts that can influence significantly the water availability. In these scenarios, the management of wastewater with CWs are encouraged, especially when climate change coincides with high agricultural demands. In CWs, one of the most important parameter that can be highly susceptible to climate change is evapotranspiration. ET can affects the redox conditions in the HSSF system, thereby affecting the pollutant RE and increased ET could have a damaging effect on pollutant RE. When ET rises considerably, a decrease in apparent RE of organic compounds, in particular, can be expected, as found by [56]. However, a correlation between ET and RE is apparent, there is no influence or causation relating to changes in ET on RE. Then, when considering the climate changes projections, the most important effect of increased ET in a CWs is not a significant decrease of RE, but a great loss of TWW at the outflow of the system. As a consequence, above all in arid and semi-arid regions of the Mediterranean, where the main aim of wastewater treatment is to provide water for use in irrigation, ET dynamics must be taken into consideration carefully when designing a HSSF system.

3.3. HSSF water balance

At the outflow of the units the amount of TWW was significantly influenced by evapotranspiration processes. In both of the planted units, cumulative ET_c was found to be substantially higher than total rainfall in the period April–September 2014 (Fig. 4). In unplanted unit, average 10-d Q_o was found to be 58.4 m^3: maximum 63.2 m^3 (first 10-d April) and minimum 56.9 m^3 (third 10-d June). In the planted units, we found differences in cumulative ET_c, highlighting the effect that vegetation has on the system. We did not observe high differences of average 10-d Q_o between the two planted units. In the reedmace unit average 10-d Q_o was found to be 50.6 m^3, while in the umbrella sedge unit was found to be 51.8 m^3 (Fig. 5). As Q_i was constant for all of the 10-d periods (60 m^3/10 d), in the reedmace unit, water loss was on average 9.4 m^3/10 d in the study period. In the umbrella sedge unit, water loss was on average lower at 8.2 m^3/10 d. The higher levels of water loss found in the two planted units during the summer months were mostly due to higher ET_c values for the same period (Fig. 6). Taking the growth stages into consideration, greatest water loss in the two planted units occurred during crop development stage and mid-season stage of macrophytes, whereas least loss occurred during late-season stage. In July, with a total monthly rainfall of 5.2 mm, water loss in the reedmace unit was around 15.0 m^3/10 d. For the umbrella sedge unit in the same month, water loss was found to be lower at 13.4 m^3/10 d. Despite identical growth, climatic and hydraulic conditions in the system, the greater water loss occurred in reedmace unit and it was due to greater growth of reedmace compared to umbrella sedge (average leaf surface and foliar density) of the reedmace, as sustained by [57]. It is important to highlight that reedmace consumed more water, but used water with greater efficiency than umbrella sedge, also due to a preliminary greater above-ground biomass production. In arid and semi-arid regions of the Mediterranean, the high water loss levels due to evapotranspiration must not be undervalued, but it is indubitable that CWs represent an innovative approach which could guarantee continuity for irrigation, even with large water losses during summer months.

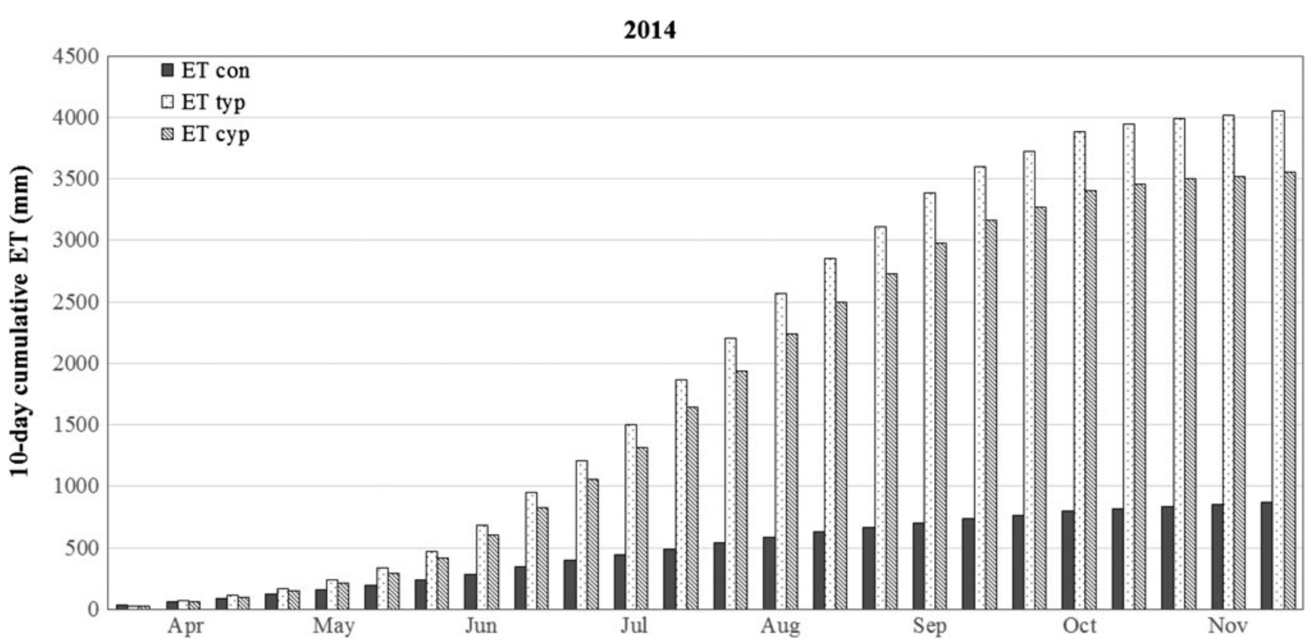

Fig. 4. 10-d cumulative evapotranspiration (ET_{con}, ET_{typ} and ET_{cyp}).

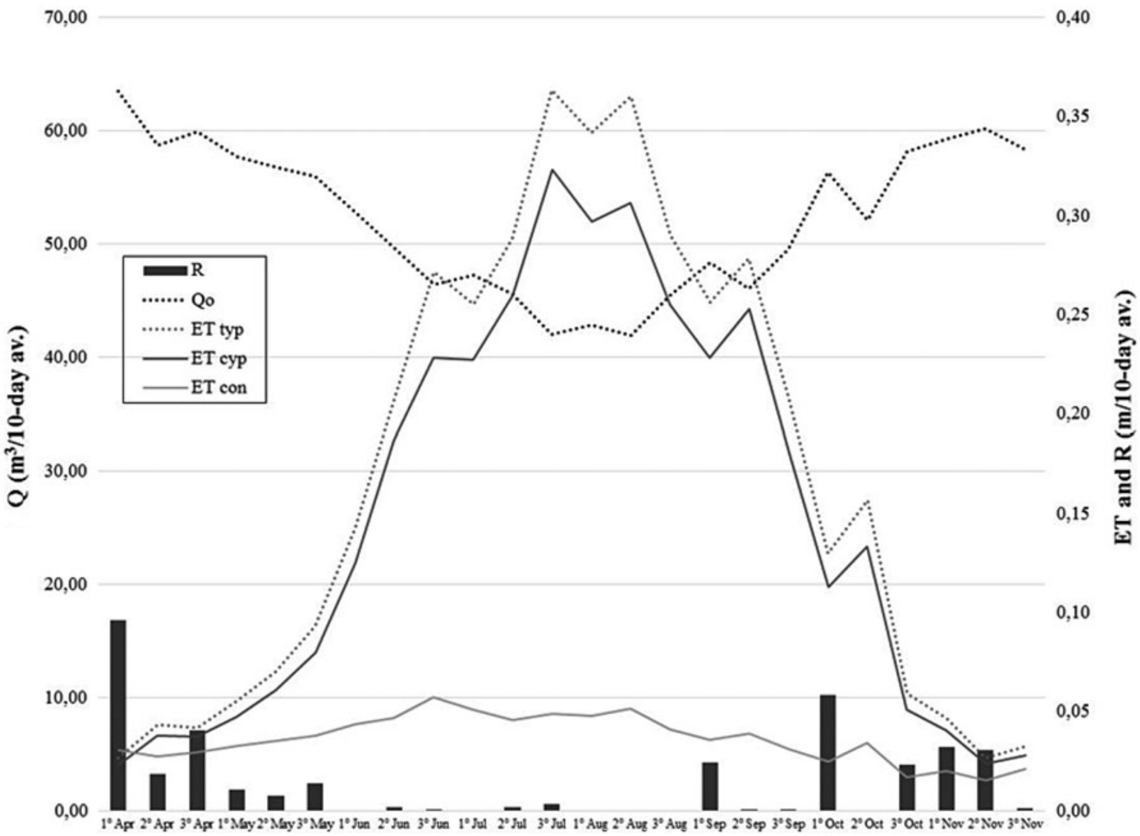

Fig. 5. Q_o trends relative to Q_i, cumulative ET_{con}, cumulative ET_{typ}, cumulative ET_{cyp} and total rainfall.

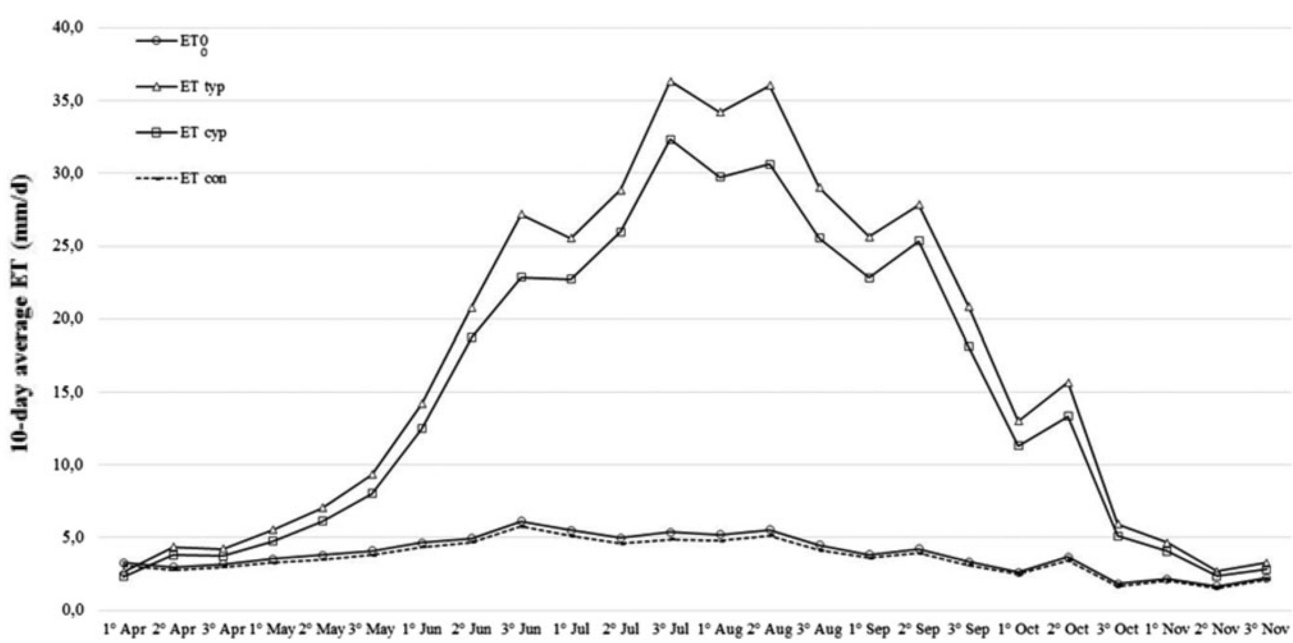

Fig. 6. 10-d average ET_0, ET_{typ}, ET_{cyp} and ET_{con}.

3.4. Freshwater and treated wastewater characteristics

In arid and semi-arid regions, where water is a limited natural resource, irrigation of turfgrass with TWW may represent a sustainable means of coping with shortages of FW. Harivandi [4] highlights that the main factors that affect the decision to use recycled water for turfgrass irrigation include: human health considerations, seasonal and annual variations in water quality, soil conditions and dissolved salts and nutrient content of water. The same author sustains that turfgrass may be the best plants for recycled water irrigation because it is better adapted to use it than other plants. Significant differences exist among cool and warm season turf species with regard to tolerance to dissolved salts in the water and total salinity. Bermudagrass (*Cynodon* spp.), Seashore Paspalum (*Paspalum vaginatum*) and St. Augustinegrass (*Stenotaphrum secundatum*) tolerate levels of soil salinity—influenced by the salinity level of recycled irrigation water—that are higher than $10\ dS\ m^{-1}$ [58]. These findings highlight that international literature supports the opportunity to use TWW for irrigation of Bermudagrass in arid and semi-arid regions such as many regions of Mediterranean area.

The chemical characteristics of TWW and FW used in this study are shown in Table 4. The composition of the two types of water varied significantly over the tests period. TWW had on average higher values of OM, EC, N, P, K and other alkali metals than FW. With comparing the TWW and FW from April to September, the lowest variations of nutrients and salts concentrations were found during the summer months. In this period, the growth of above and below ground biomass of reedmace and umbrella sedge was highest than other seasons and affected significantly the removal rates of pollutants in the planted units of the pilot HSSFs reducing significantly the concentrations of chemical and microbiological parameters at the outflow. For example, by comparing the concentrations of TKN of the effluents at outflow of the planted units between May and August we observed the decrease in a large amount of nitrogen in wastewater due to plant uptake and microbial nitrogen processes. The quality of TWWs is important for irrigation of turf. Nitrogen, phosphorus and potassium are the primary elements present in wastewaters and are essential to turfgrass growth. Other alkali metals, such as calcium and magnesium, can also affect several vital physiological processes within the plants. However, the suitability of TWW for turf irrigation depends on the type and quantity of dissolved salts and nutrients. Harivandi [15] affirms that even if the amounts of nutrients in a TWW are usually not high, they are efficiently used by turfgrass because they are applied on a frequent and regular basis. Turgeon [22] highlights, instead, that high concentrations of nutrients, dissolved salts and OM cause direct injury to turfgrass or indirect injury from effects on soil properties, especially in the root zone. Evanylo et al. [17] affirms that irrigation of Bermudagrass turf with saline wastewaters can cause stresses and injuries by water deficiency, ion toxicity and ion imbalances despite the fact Bermudagrass is salt tolerant. High quantity of dissolved salts in wastewater can limit water uptake by

Table 4
Chemical composition of FW and treated wastewater that were applied for Bermudagrass irrigation

Parameters	Freshwater	Treated wastewater from *Cyperus alternifolius*-planted unit	Treated wastewater from *Typha latifolia*-planted unit	Treated wastewater from unplanted-unit
pH	7.0 ± 0.01	7.7 ± 0.03	7.9 ± 0.04	8.1 ± 0.03
EC ($\mu S\ cm^{-1}$)	279.1 ± 1.7	636.5 ± 6.4	719.8 ± 7.2	556.7 ± 12.1
DO ($mg\ L^{-1}$)	Not available	0.9 ± 0.02	1.0 ± 0.01	1.1 ± 0.01
BOD_5 ($mg\ O_2\ L^{-1}$)	1.4 ± 0.4	7.7 ± 0.2	7.1 ± 0.3	12.6 ± 0.1
COD ($mg\ O_2\ L^{-1}$)	2.1 ± 0.8	12.4 ± 0.6	10.9 ± 0.5	27.1 ± 1.5
TSS ($mg\ L^{-1}$)	Not detected	10.3 ± 0.2	9.1 ± 0.1	21.8 ± 0.5
NO_3-N ($mg\ N\ L^{-1}$)	0.3 ± 0.1	2.3 ± 0.2	2.2 ± 0.2	3.7 ± 0.3
TP ($mg\ P\ L^{-1}$)	0.5 ± 0.2	4.8 ± 0.09	4.5 ± 0.03	7.0 ± 0.03
Cl ($mg\ Cl\ L^{-1}$)	20.1 ± 0.7	115.2 ± 0.5	114.9 ± 0.9	123.2 ± 0.4
Ca ($mg\ Ca\ L^{-1}$)	21.3 ± 0.9	60.5 ± 0.7	58.1 ± 0.6	71.4 ± 0.4
K ($mg\ K\ L^{-1}$)	3.3 ± 1.2	73.5 ± 1.2	68.5 ± 0.4	85.3 ± 0.4
Mg ($mg\ Mg\ L^{-1}$)	15.2 ± 1.1	21.2 ± 0.3	21.0 ± 0.4	23.0 ± 0.4
Na ($mg\ Na\ L^{-1}$)	10.2 ± 0.7	139.4 ± 0.4	139.7 ± 0.7	147.6 ± 1.5
SAR ($meq\ L^{-1}$)	0.9 ± 0.3	3.9 ± 1.7	4.1 ± 1.4	4.4 ± 1.2

Table 5
General guidelines for interpretation of water quality for turfgrass irrigation (modified from McCarty [61]; Westcot and Ayers [60])

Item		Minor problems	Increasing problems	Severe problems
Soil permeability/infiltration				
EC (water)	(mmhos cm^{-1} or dS m^{-1})	<0.75	0.75–3	>3
EC (soil)	(dS m^{-1})	2–4	4–12	>12
Sodium (SAR)	(meq L^{-1})	<6	6–9	>9
TDS	(mg L^{-1} or ppm)	<450	450–2,000	>2,000
Bicarbonates (HCO_3)	(ppm)	0–120	120–180	180–600
RSC	(meq L^{-1})	≤1.25	1.25–2.5	>2.5
Turf toxicity from root absorption				
Sodium	(meq L^{-1})	<3	3–9	>9
Chloride	(meq L^{-1})	<2	2–10	>10
	(mg L^{-1})	<70	70–355	>355
Boron	(mg L^{-1})	<1	1–2	>2
Turf toxicity from foliar contact				
Sodium	(meq L^{-1})	<3	>3–9	>9
	(mg L^{-1})	<70	>70	–
Chloride	(meq L^{-1})	<3	3–10	>10
	(mg L^{-1})	<100	100–350	>350
Boron	(meq L^{-1})	<0.75	0.75–3	>3
Ornamental plant tolerance				
Ammonium-N (NH_4-N)	(mg L^{-1})	<5	5–30	>30
Nitrate-N (NO_3-N)	(mg L^{-1})	<5	5–30	>30
Bicarbonates (HCO_3)	(meq L^{-1})	<1.5	1.5–8.5	>8.5
Unsightly foliar deposits	(mg L^{-1})	<90	90–520	>520
Residual chlorine	(mg L^{-1})	<1	1–5	>5
pH		Normal range 6.0–8.4		

Notes: EC = electricak conductivity; TDS = total dissolved salts; RSC = residual sodium carbonates.

plants and reduce cell turgor, leaf area and several processes such us photosynthesis, carbohydrate storage and rooting as reported by [59]. It is possible to evaluate the water quality for crops irrigation using the guidelines edited by [60]. With reference to turfgrass, McCarty [61] improved these guidelines adding other information and the combined guidelines are given in Table 5. The limits of use of TWW and FW are shown in Table 6, according to [7]. Observing the nutrient contents in the effluents of the pilot HSSFs, we found that the concentration of TKN was on average below the recommended guidelines while the concentrations of Na and Cl showed a degree of slight to moderate restriction on use for irrigation. The average values of EC for FW (0.31 dS m^{-1}), TWW from umbrella sedge unit (0.62 dS m^{-1}), TWW from reedmace unit (0.73 dS m^{-1}) and TWW from unplanted unit (0.6 dS m^{-1}) were not critical for Bermudagrass growth. All the values of EC may be considered with none degree of restriction on use for irrigation according to the recommended guidelines.

3.5. Effects of treated wastewater irrigation on soil

The soil was sandy, clay, loam (Aric Regosol, 54% sand, 23% silt and 23% clay) with a pH of 7.9, OM of 1.91%, EC of 0.52 dS m^{-1}, total calcareous of 5.81%, active calcareous of 3.71%, TKN of 1.30 g kg^{-1}, assimilable P of 18.11 ppm, assimilable K of 152.20 ppm, Mg and Na content of 138.31 and 84.78 ppm, respectively. In Table 7 the chemical characteristics of the FW-irrigated soils and TWW-irrigated soils are reported. In the topsoil (0.30 m) of the experimental plots, the short-term effects of TWW were not significant on soil pH. We did not observe variations of pH between plots irrigated with TWW and plots irrigated with FW and the main reason was probably the short duration of TWW application

Table 6
Restrinctions on use for irrigation with FW and urban-treated wastewater from pilot HSSFs (Castro et al. [7])

Item	Freshwater	Treated wastewater from *Cyperus alternifolius*-planted unit	Treated wastewater from *Typha latifolia*-planted unit	Treated wastewater from unplanted-unit
Salinity	None	None	None	None
Infiltration (SAR)	None	None	None	None
Specific ion toxicity				
Sodium	None	Slight to moderate	Slight to moderate	Slight to moderate
Chloride	None	Slight to moderate	Slight to moderate	Slight to moderate
Miscellaneous effects				
Nitrogen (NO_3-N)	None	None	None	None

Table 7
pH, EC, OM, TKN, assimilable P, active calcareous, assimilable K, Mg and Na content in FW-irrigated soils and treated wastewater-irrigated soils. Average values are shown

	pH	EC (dS m^{-1})	OM (%)	TKN (g kg^{-1})	TP (ppm)	Active $CaCO_3$ (%)	K (ppm)	Mg (ppm)	Na (ppm)
Bermudagrass variety									
Princess 77	7.90 a	0.60 a	1.94 a	1.71 a	18.21 a	3.79 a	152.42 a	139.22 a	89.66 a
Yukon	7.88 a	0.61 a	1.92 a	1.69 a	18.26 a	3.83 a	151.53 a	142.21 a	90.68 a
Irrigation									
FW	7.91 a	0.59 a	1.93 a	1.69 a	18.19 a	3.76 a	152.99 a	137.40 a	85.37 a
TWW (1)	7.88 a	0.62 a	1.96 a	1.73 a	18.27 a	3.78 a	151.14 a	142.65 a	93.35 a
TWW (2)	7.90 a	0.63 a	1.95 a	1.74 a	18.30 a	3.81 a	152.32 a	139.67 a	90.23 a
TWW (3)	7.86 a	0.62 a	1.95 a	1.70 a	18.26 a	3.77 a	151.45 a	143.15 a	91.74 a
Variety × irrigation	n.s.	n.s.	n.s.	*	n.s.	*	n.s.	n.s.	n.s.

Means followed by the same letter are not significantly different according to the Tukey test ($p \leq 0.05$). *significant, n.s. not significant.
*FW: freshwater-irrigated soils; TWW (1): treated wastewater-irrigated soils from *Cyperus alternifolius*-planted unit; TWW (2): treated wastewater-irrigated soils from *Typha latifolia*-planted unit; TWW (3): treated wastewater-irrigated soils from unplanted unit.

in the tests (six months). This low influence of TWW on soil pH was also reported in other studies. Castro et al. [7], in a two-year test of application of TWW on *F. arundinacea* turf, found that the pH of the soil profile was not affected by wastewater application. Rusan et al. [8], in a long-term test of TWW irrigation of several forage crops, stated that the duration of wastewater application (two, five, and ten years) had not significant effects on soil pH. However other researchers reported that, in similar long-term tests, the application of wastewaters affected significantly the soil pH due to high content of elements such as Ca, Mg and Na in the wastewaters or the oxidation of organic compounds and nitrification of ammonium [62,63]. OM content increased with application of TWW from planted units of HSSFs. The higher OM content in the topsoil of plots irrigated with TWW was found to be related to higher nutrient content and organic compounds. Similar results were also found in other studies with various duration of wastewater application and highlight that the effects of wastewater on topsoil OM is highly correlated to the amount of organic compounds in the wastewater. The application of TWW to soils with not high water-holding capacity, such as sandy clay loam soils, does not contribute significantly to the accumulations of salts in the topsoil. The increasing of salinity in the soil, measured as EC, is attributed directly not only to the chemical and physical properties of the soil, but also to the original level of total dissolved salts in the TWW as claimed by [8]. In our research, the higher amounts of total dissolved salts in TWW with respect to FW were the main reason which explains the higher salinity in TWW-irrigated plots. However, the differences among the treatments were not significant and this was consistent with other findings of international literature. The short-term application of TWW determines, in fact, a not significant effect on soil salinity compared to long-term tests or to longer period of irrigation. Moreover, dissolved salts tend to accumulate more in the deeper soil layers than topsoil due to leaching process. In our research, EC varied from 0.63 to 0.59 dS m^{-1} with an average of 0.62 dS m^{-1} in TWW-irrigated plots, while the average value of EC was 0.59 dS m^{-1} in FW irrigated plots. With regard to the nutrients, TWW irrigation increased the N, P and K concentrations in the topsoil but we did not find significant differences for nitrogen content compared to the FW-irrigated plots due to leaching process and plant uptake of nitrogen. Ca, Mg and Na also increased between the start and the end of the application of TWW. Of the alkali metals, Na was of great interest because of its negative effects on soil properties and Bermudagrass turf quality. Literature highlights that an excess of Na in the soils displaces divalent cations such us Ca and Mg and soil structure deteriorates. Turgeon [22] claims that macropores are destroyed, micropores dominate, pore continuity declines, water infiltration, percolation and drainage decrease and oxygen status declines. So the greater the sodium percentage on exchanges sites the more the soil permeability decreases. SAR characterises soils affected by dissolved salts. In our research, the SAR calculated for both the planted units of pilot HSSFs changed slightly after the passage through the system. Consequently, at the outflow of the HSSFs the concentration of Na in TWW did not decrease as well as nitrogen and phosphorus. However, for both TWW from the planted units of HSSFs the average values of SAR (3.95 meq L^{-1} for TWW-umbrella sedge unit; 4.1 meq L^{-1} for TWW-reedmace unit) remained below the values which may negatively affect the soil properties (SAR > 10). As reported by [7] wastewaters can be an adverse source of sodium for the soils and their uses must be controlled, especially when irrigation is applied on clay soils and in a long-term condition. In our research, despite the higher concentration of Na in TWW than FW, we did not observe significant differences among the treatments. The agronomic conditions of the tests, the short-term irrigation period and the low percentage of clay in the soil texture did not consent a significant accumulation of sodium in the topsoil and a probable displacement of calcium and magnesium in the structural aggregates of the soil.

3.6. Effects of treated wastewater irrigation on Bermudagrass yield and quality

The concentrations of N, P and K in the TWW influenced the yield and quality of Bermudagrass. Literature report that nitrogen, phosphorus and potassium can affect the characteristics of a turfgrass in a number of ways including shoot and root growth, shoot density, the green colour of leaves, heat, cold and drought hardiness, recuperative potential, stomatal physiological mechanisms and synthesis of the carbohydrates [19,64]. Turgeon [22] highlights that turfgrass contains from 3 to 5% of nitrogen on a dry weight basis, less than 0.5% of phosphorus while the tissues potassium levels may reach up to 5% of dry weight. Santos et al. [30] report that the low amount of nitrogen in the water can determine chlorosis of the leaves, a decrease in the green area of the leaves and in the photosynthetic rate, and negatively affect the biomass of the species. Turgeon [22] affirms that deficiencies of P can reduce the growth of root system and alter the colouration of leaves. Beard [19] sustains that deficiencies in K decrease the absorption and retention of water by plants, which influences heat, cold and drought hardiness of turfgrass. In our research, the different treatment levels of irrigation did not affect significantly the above-ground biomass yields of the two Bermudagrass varieties (Table 8). The fact that we did not observe differences in terms of N and K content and above-ground biomass yields was probably due to different fertilisation management programmes. In the TWW-irrigated plots, we did not manage the two varieties of Bermudagrass with an commonly used fertilisation programme, but we exploited the nutrients content in TWW to integrate the demand of N and K of Bermudagrass. An additional application of nitrogenous fertiliser was made to sustain a suitable plant growth but this did not happen for potassium due to or an excess amount of this nutrient in TWW (Table 9). It is possible to sustain that the irrigation with TWW also provides a combined fertilisation for Bermudagrass because of the nitrogen and potassium supplies. These results confirm that irrigation with TWW can decrease or even remove the need for mineral fertilisation, whilst maintaining high productive performance of Bermudagrass turf, according to [29]. The use of TWW permits to save water and fertiliser consumptions with respect to traditional turf management and this is an excellent way to manage Bermudagrass turf in arid and semi-arid regions. The different treatment levels of irrigation did not affect the quality of the two Bermudagrass varieties in terms of visual turf quality and colour of the leaves (Table 8). The two varieties

Table 8
Biometric, qualitative and productive characteristics of Bermudagrass varieties irrigated with FW and treated wastewater. Average values are shown

	Leaf texture (mm)	Shoot density (n cm^{-2})	Visual quality (1–9)	Colour (1–9)	Dry above-ground biomass (kg m^{-2})
Bermudagrass variety					
Princess 77	1.54 a	1.85 b	6.15 b	6.20 b	1.09 b
Yukon	1.51 a	1.93 a	6.48 a	6.40 a	1.52 a
Irrigation					
FW	1.51 a	1.86 a	6.29 a	6.26 a	1.26 a
TWW (1)	1.51 a	1.92 a	6.32 a	6.29 a	1.32 a
TWW (2)	1.53 a	1.89 a	6.34 a	6.32 a	1.33 a
TWW (3)	1.54 a	1.88 a	6.31 a	6.32 a	1.32 a
Variety × irrigation	n.s.	n.s.	*	*	n.s.

Means followed by the same letter are not significantly different according to the Tukey test ($p \leq 0.05$). *significant, n.s. not significant. *FW: freshwater-irrigated plots; TWW (1): treated wastewater-irrigated plots from *Cyperus alternifolius* planted-unit; TWW (2): treated wastewater-irrigated plots from *Typha latifolia* planted-unit; TWW (3): treated wastewater-irrigated plots from unplanted-unit.

Table 9
Agronomic management of nitrogen and potassium fertilisation programme of Bermudagrass FW-irrigated plots and treated wastewater-irrigated plots

Fertilizers (kg ha^{-1} month of growth^{-1})	Freshwater-irrigated plots	Treated wastewater-irrigated plots (1)	Treated wastewater-irrigated plots (2)	Treated wastewater-irrigated plots (3)
Nitrogen (N)				
April	50.0	41.3	42.4	35.1
May	50.0	42.1	43.0	36.1
June	50.0	42.2	43.1	36.6
July	50.0	42.3	43.1	37.9
August	50.0	42.0	44.1	39.3
September	50.0	42.2	43.5	38.8
Total nitrogen	300.0	252.1	259.2	223.8
Potassium (K)				
April	40.0	0.0	0.0	0.0
May	40.0	0.0	0.0	0.0
June	40.0	0.0	0.0	0.0
July	40.0	0.0	0.0	0.0
August	40.0	0.0	0.0	0.0
September	40.0	0.0	0.0	0.0
Total potassium	240.0	0.0	0.0	0.0

Notes: (1) TWW from *Cyperus alternifolius*-planted unit; (2) TWW from *Typha latifolia*-planted unit; (3) TWW from unplanted-unit.

exhibited the best visual turf quality in summer when the air temperatures and other climatic factors were more favourable for Bermudagrass growth. The highest average value of visual turf quality (6.53) was recorded for Yukon which had the highest quality ratings both in spring and summer. In FW-irrigated plots, the values of visual turf quality varied from 6.11 (Princess 77) to 6.45 (Yukon). The different qualities of water did not influence significantly the colour of the leaves of Bermudagrass. The best turf colour performance was recorded in summer for both the varieties. Particularly in TWW-irrigated plots from unplanted unit, Yukon showed on average the darkest green colour (6.57). The lowest average value of turf colour (6.09) was recorded for Princess 77 in the TWW-irrigated plots from reedmace unit. The high available of nitrogen content in plots irrigated with different treatment levels of irrigation and fertilised with a different fertilisation management programme was probably the main reason that explain the slight differences of colour among the plants. Nitrogen is, in fact, an important component of the chlorophyll molecule as reported by [22,30]. Comparing the varieties, Yukon performed better than Princess 77 also in terms of leaf texture and shoot density. With regard to shoot density we did not find significant differences among the treatments. The highest shoot density was recorded in the plots planted with Yukon and irrigated both with TWW ($1.97\ \text{n cm}^{-2}$) and FW ($1.88\ \text{n cm}^{-2}$). Leaf texture was not affected by quality of water and no significant differences were observed among the treatments. In our research, TWW contained also calcium and magnesium. Ca and Mg are two nutrients that function in several vital physiological processes within the plants. Calcium is usually found in relatively large quantities in turfgrass tissues, it is a vital constituent of cell walls and a specific nutrient requirement for meristem growth by cell division. Magnesium is a constituent of chlorophyll, is a cofactor of many plant enzyme systems and influences the translocation of phosphorus. Magnesium is also essential for the maintenance of green colour and growth of turfgrass [22]. Castro et al. [7] affirm that calcium and magnesium concentrations determine an antagonistic effect with regard to potassium, so an excessive concentration of active calcium and available magnesium can produce potassium deficiency. In our study, we did not observe any symptoms of deficiencies of potassium in Bermudagrass plants in the TWW-irrigated plots for both the varieties. With respect to chloride and sodium concentrations, it is important to observe that TWW-irrigated plants did not show aesthetic anomalies for the higher concentrations of Cl and Na in TWW than FW. High concentrations of Na and Cl in wastewater may determine ion toxicity for Bermudagrass. Carrow and Duncan [59] report that injuries to root occur at 70 to 210 mg Na L^{-1} and 70 to 350 mg Cl L^{-1}. Evanylo et al. [17] highlight that high levels of Na and Cl can induce nutrient imbalances and deficiencies of Ca, K, Mg, N and P. Castro et al. [7] highlight that the toxic effects of sodium are more evident in cultivated crops than in turfgrass due the fact it is mowed periodically. In our research, the content of Na in TWW-irrigated plants was certainly higher than FW-irrigated plants, but we did not observe evident injuries on Bermudagrass turf during the test period. According to international literature, it is important to highlight that the continuous use of TWW with high Na content could increase the concentration of this element in the topsoil. To avoid an excess of sodium in the long-term, it is necessary to control the level of Na in the topsoil periodically and carry out agronomic practices, such as the application of good quality irrigation water for sodium removal purposes. In this study, we did not evaluate the effects of TWW on Bermudagrass turf in terms of health risks, associated with micro-organisms which are considered dangerous to human health. The Italian law on the reuse of TWW in irrigation is excessively restrictive regarding microbiological contaminant limits of the effluents compared to some Mediterranean countries. Furthermore, Italian law does not make a distinction in quantitative terms between the irrigation of food and non-food crops, and puts the irrigation of a crop for raw consumption on the same level as the irrigation of a turfgrass for recreational or sports use. Specific research on the risks involved in using TWW in public parkland carried out in various countries around the world did not show any major contraindications due to the mechanisms with which micro-organisms still present in the TWW are retained by the soil, such as soil surface filtering, sedimentation in the gaps in the ground and adsorption [4,16]. Moreover, if irrigation is carried out using low-impact irrigation systems—e.g. subirrigation—or irrigation occurs during period when the public does not use the green area or it is adequate time for the green surface to dry before fruition, direct human contact with the TWWs can be avoided. In this research, we did not find in the turfgrass any damage coming from bacteria but it is evident that research activity should be monitor the behaviour of Bermudagrass turf in a long-term irrigation with TWW in order to improve the evaluations of health risks due to significant exposure of turfgrass to microbiological contamination. The results of this study highlight also that TWW represents an important resource for the agronomic management of water and nitrogen demands of crop species and that CWs can be useful for the water management in attractive touristic areas of Sicily such as agritourisms, archaeological sites, minor islands, natural sites, etc. Tourism depends, in fact, to a considerable degree on water resources, which are an essential element also for a wide range of tourism activities such as sport and recreational activities. Furthermore, water is a central element of tourism landscapes in various forms from irrigated gardens to parklands. Limited water availability, poor water quality and no treatment of wastewater or periodic water shortages can consequently do great damage to the image of tourism destinations as reported by [65]. So the greater the water resources, as most attractive are the tourist sites. TWW is an important source of water and constitutes an essential element of water resources policy and strategy, especially in water-scarce regions. Then a high availability of TWW for irrigation purposes could be increase the economic value of an area and, consequently, its touristic attractiveness. In Sicily, the use of CWs may play an important role in the treatment of wastewater and would enhance the social and economic benefits of various touristic areas.

4. Conclusions

Urban TWW from horizontal subsurface flow CWs represents an important source of water and fertilisers for irrigation of bermudagrass. It contributes to obtain a saving in terms of water with respect to commonly used irrigation programme and a saving of fertilisers with respect to commonly used fertilisation programme. This consents to have evident economic and environmental benefits with respect to common management of Bermudagrass, especially in arid and semi-arid climatic conditions. In this research, the irrigation with urban TWW did not affect the pH of soil and not contribute to the accumulations of dissolved salts in the topsoil. Moreover, the productive and qualitative characteristics of Bermudagrass were not influenced by irrigation with TWW comparing to FW. The agronomic conditions of the tests and the use of a high salt tolerance turf species were probably the main reasons that affected the results. Despite the high removal levels of nitrogen, phosphorus and OM, the pilot HSSFs was not able to remove significantly the studied alkali metals due to low uptake of them by the macrophytes. It is evident that the periodic monitoring of soil fertility and Bermudagrass quality are required to avoid an excessive accumulation of salts and nutrients in the topsoil, salt injuries for Bermudagrass turf and microbiological risks for human health. The reuse of urban TWW for irrigation of turfgrass for golf courses, football pitches and public lawns represents an important topic to investigate in a short- and long-term period and this research contributes to the sustainable management of TWW resources for irrigation of Bermudagrass turf in arid and semi-arid areas of Mediterranean Region.

Acknowledgements

The authors would like to thank the Sicilian Regional Ministry of Food and Agricultural Resources, the Corissia Research Centre and the University of Palermo for having provided the funds for the study. A special thanks also goes to Branwen Hornsby for her continuing support to the research and linguistic contribution.

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