Turfgrass plant quality response to different water regimes

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Abstract: This scientific work aims to contribute to the sustainable management of water resources in golf courses of arid and drought-prone regions of Mediterranean, through the evaluation of water demands, regarding to different ways of environmental and socio-economic development and water resources, and through examining the possibilities to reuse treated effluent as an alternative source for potable water. Its main objective is to reach the response of fairway turfgrass of golf courses to several levels of sprinkle irrigation water. Bermudagrass (*Cynodon dactylon*) was selected as the most common turfgrass used in the many golf courses of the Algarve (southern Portugal), where this water consumption is responsible, for the decreasing of the level of aquifers and of their salinity elevation. Sprinkle point source experimental design was used to simulate several water regimes, expressed by the crop coefficients. Irrigation water sources were well potable water and two treated wastewater origins. Standard crop coefficient Kc values were evaluated between 0.92 and 0.99, being non standard crop coefficient Ks values for good appearance (GA) of lawn grass, very similar and computed between 0.52 and 0.55. Thus, significant economy of water could be achieved, in golf courses, if Ks values are used related to GA, instead of the usual standard Kc. The yield of the three experimental lawns was determined for several values of the crop coefficient under non standard conditions, due to the management of the sprinkler point source experimental design Ka, between 0.2 and 1.6. On the other hand, it was shown that the quality of turfgrass was independent of salinity of irrigation water for levels of ECw lower than 2.1 dS m^{-1} to the studied turfgrass. As concluding remarks, as the principal objective is the quality of the turfgrass of the golf courses and not the yield, it was shown that it is possible to consider treated final effluents as an alternative disposal to potable water, to be applied in golf courses. The application of wastewater in golf courses is important in terms of water and fertilization savings and represents a more correct environmental alternative to the dumping of this waste in the rivers, lakes and seaside, since all cares are taken.

Keywords: crop coefficient, evapotranspiration, fertilisers, golf courses, good visual appearance, sprinkler point source

1 Introduction

In the last years, especially in the last decade, the increased population and the expansion of urbanism created competition on the limited water [1]. In arid and semi-arid areas, such as the Mediterranean regions, supplies of good quality water allocated to agriculture are expected to decrease because most of available fresh / potable water resources have been already mobilized. The factors driving the development of Mediterranean regions will be tourism due to their beaches and mild and sunny climate [2]. Current technologies that Mediterranean countries are applying to solve these problems include exploiting non-conventional water resources such as the reuse of the municipal treated wastewater [3]. Due to the lack of water around the Mediterranean regions, potable water luxurious uses – are increasingly contested. In order to solve this problem, non conventional water resources (effluent, recycled, reclaimed, brackish), like treated wastewater gained increasing role in the planning and development of additional water supplies in agriculture, horticulture, parks and golf courses in Mediterranean regions [4]. The rate of Mediterranean coastal salination increases every year, about 0.1-0.2 dS m^{-1} $year^{-1}$ and groundwater table declining about 0.1-0.5 m $year^{-1}$, due to the sea water intrusion and due to the dry climate of this region [5]. Finding feasible alternatives for water became more and more difficult. The traditional policies of irrigation management are questionable when restricted to natural water. Fundamental aspects of economy of water, such as recycling, should be considered, following the principle that water resources are not unlimited. The reuse of treated wastewater is considered as an alternative to the use of potable water in the Mediterranean agriculture and landscape [6], especially in golf courses [7]. In the Algarve, were is possible to find more than 30 golf courses, their irrigation demand reaches 10 millions of m3, the equivalent to 5% of the total region water consumption [8]. Together, with the increase of citrus and other irrigated crops and the population growth during summer time, golf courses contributed for the multiplication of water consumption, in the last 5 decades, more than ten times. One positive aspect of the seasonal population growth is the production of more wastewater in summer time when irrigation demands are higher. The climatic change, which can be observed around the World, has some peculiar aspects in the Algarve region, where lately the temperatures have tendency to rise and the precipitation to decrease, being the rain fall less frequent. All these aspects contribute for higher irrigation demands. Actually, only one golf course is completely irrigated with treated wastewater, but much more should follow this example, once that, in this region, the amount of treated wastewater should be enough to supply the irrigation demands of the most part of them. Another very important growth and quality crop factor is wastewater nutrient content, which its economic importance must not be overlooked [9, 10, 11, 12]. On the other hand, this are the crop nutrients, that when are dumped in rivers, lakes, seaside and aquifer are named as pollutants. The intense use of effluent for sprinkle irrigation attracted public awareness of environmental pollution and the impact of water quality [13, 14]. Besides, the purification efficiency of the system soil-water-plant is considered very efficient on the elimination of the pathogenic microorganisms (biologic phase) and the nutrients and trace elements (mineral phase) included in wastewater [15]. The present work compares the fairway grass response, at the quality and yield levels, to wastewater and to potable water application. The trials took place at real scale and the used methods were not destructive. The good support received by the golf course managers to this work is an indication of their interest for these important subjects (to reuse and to save water) and represents an encouragement to continue additional research.

2 Materials and methods

2.1 Climate

The climate of the Algarve can be considered as Mediterranean and in particular the south shore, according to Köppen is classified as Csa, with semi-arid characteristics, identified by mild rainy winters and by warm and dry summers. Snow and frost are not expected. The annual average temperature, in Faro, ranges between 12º C in January and 23º C in August, a difference of only 11º C. The annual average value for potential evapotranspiration ETp is 1280 mm, and the precipitation around 450 mm. Additionally, the values of potential evapotranspiration ETp and precipitation show opposite distribution during the year. During the hottest semester, when the photosynthesis is more efficient and the water is more essential for plant growth, this resource is less available; irrigation is the only solution to balance this situation. The average of the shortage of water, defined by the difference between the values of evapotranspiration and precipitation rates, verified between March and October, may reach 940 mm per year. The water balance equation for the root zone was given by:

$$I + P = ETa + Dr + \Delta S \text{---------------------------}(1)$$

Where I is the net irrigation, P is the precipitation, ETa is the actual evapotranspiration, Dr is the drainage below the root zone, and ΔS is the change in water storage within the root zone; all the units are meters. Other water balance components (for example run-off and capillary water rise from the ground water table into the root zone) were negligible under the experimental conditions.

The crop evapotranspiration under standard conditions ETc is the evapotranspiration from disease-free, well-fertilized crops, under optimal soil water conditions, producing maximal yield, in specific climatic conditions; it is given by [16]:

$$ETc = Kc \,.\, ET_0 \text{-----------------------------------}(2)$$

Where Kc is the crop coefficient under standard conditions and ET_0 is the reference evapotranspiration (Penman-Monteith).

When the crop is under water stress conditions, crop evapotranspiration under non standard conditions ETc adj, is expressed by [17]:

$$ETc\ adj = Ks \,.\, Kc \,.\, ET_0 \text{------------------------}(3)$$

Where Ks describes the effect of water stress on crop transpiration ETc adj.
For the experimental procedure, the simulated actual evapotranspiration ETa is expressed by:

$$ETa = Ka \,.\, ET_0 \text{-----------------------------------}(4)$$

Where Ka was the crop coefficient under non standard conditions, due to the management of the experimental design (see subsection 2.5), and ET_0 is the reference evapotranspiration (Penman-Monteith).

The experiments were carried out, respectively, in Vale de Lobo Golf Course and in Herdade dos Salgados Golf Course, Algarve, Southern Portugal and was considered that the climate differences in the two places were not significant.

2.2 Soil

2.2.1 Soil characteristics of Vale de Lobo Golf Course

The soil was classified as Arenossol Haplic [18], and its profile is described as:
- Horizon A - thick layer (1 - 1.2 m); without structure; loam sandy soil (sand 80,7 %; silt 12,4 %; clay 6,9 %); some rolling stones; pH = 7.6; colour (dry) = 7 / 6 Y and (wet) = 5 / 7 Y; bulk density = 1.71;
- Horizon C - originated from the alteration of clay iron materials, not consolidated. This impermeable horizon may induce drainage problems to grass growth, but on other hand it increases the water storage capacity of soil available for plants.

The volumetric soil water content at field capacity θ_{fc} was 0.36 m^3 water m^{-3}, soil and the porosity 40 m^3 m^{-3}.

2.2.2 Soil characteristics of Herdade dos Salgados Golf Course

The soil was an alluvial saline soil, classified as a "Fluviosol-thionic" [18], and its soil profile is described as:

Horizon A – thin soil (0.00-0.20 m depth) - texture: sandy soil (sand – 96 %; silt – 1 %; and clay – 3 %), pH (water) = 8.5; colour (dry) = and (wet) =; bulk density - 1.88 g cm^{-3}); gravimetric soil water content at different soil matric potential ψ_m values were, respectively: θ_w at - 10 kPa = - 0.050 kg water kg^{-1} dry soil, θ_w at – 330kPa = 0.040 kg kg^{-1}; and θ_w at - 1500 kPa = 0.018 kg kg^{-1}.
Horizon B – (0.20 – 0.60 m depth) - texture: loam-clay sandy soil (sand – 66 %; silt – 3 %; and clay – 22 %); gravimetric soil water content.at different soil matric potential ψ_m values were, respectively: θ_w at - 100 kPa = - 0.080 kg kg^{-1}; θ_w at – 330 kPa = 0.070 kg kg^{-1}; θ_w and at - 1500 kPa = 0.050 kg kg^{-1}.
Horizon C – (depth > 0.60 m) texture: clay soil, Cat-clay soil known as thyosol (rich in Sulfur), very low hydraulic conductivity.

2.3 Irrigation water and experiments

According to water sources and to the location of the experimental sites, there were three experimental trials, as follows: 1) VLPW (well potable water, in Vale de Lobo Golf Course), 2) VLWW (treated wastewater, in Vale de Lobo Golf Course), and 3) SGWW (treated wastewater, in Herdade dos Salgados Golf Course).

Table 1 shows the fertilization supplied by the irrigation water, according to its composition; note that there was nutrient gradual differences due to the water gradient provoked by the sprinkler point source (see subsection 2.6).

The lower levels of P and NO_3^- are explained by the algae consumption of these nutrients in the ponds where the wastewater was partially treated. Salinity values were higher in wastewater, as expected.

Table - 1 Concentration of main chemical parameters of the different irrigation water

Irrigation Parameters	Trial VLPW	Trial VLWW	Trial SGWW
Ph	7,3	7,2	7.3
EC (dS m^{-1})	1,2	2,1	1.5
SAR	3,9	-	5.6
CO_3^{2-} (ppm)	0,0	-	0.0
HCO_3^- (ppm)	292,9	341,0	469.8
Na^+ (ppm)	114,1	-	197.8
K^+ (ppm)	5,9	119,2	14
Mg^{2+} (ppm)	8,8	0,0	42.3
Ca^{2+} (ppm)	121,8	108,5	69.7
Cl^- (ppm)	198,8	154,0	13.0
NO_3^- (ppm)	7,5	0,0	0.0
P (ppm)	0,7	0,0	2.4

2.4 Fertilization

Table 2 shows the mineral fertilization applied to the soil on the experimental sites, along the year.

Table 2 Mineral fertilization applied to the soil along the year (kg ha^{-1} $year^{-1}$)

Mineral fertilization	Trial VLPW	Trial VLWW	Trial SGWW
N	115	115	460
P_2O_5	75	75	22
K_2O	180	180	33
Mg	2	2-	24

2.5 Turfgrass

The turfgrass used for the experiments was bermudagrass (*Cynodon dactylon*), the most used grass in golf courses in the Algarve and were the good quality of this lawns is the dominant characteristic [19].

As a hot season grass, to optimise the development, it needs temperatures around 35 to 38ºC and the growth stops under 10ºC [20].

Bermuda is more resistant to drought then most of the species used in golf courses, but the shortage of water must be avoided when the quality of the lawn is the objective. The water demands range between 100 and 200 mm per month during the hot season, corresponding to annual amounts of water between 600 and 1200 mm.

Concerning fertilizers, Bermuda is exigent in relation to nitrogen (40 to 60 kg ha^{-1} $month^{-1}$), along the hottest season, when the cuts are more frequent. Once the quality of the lawn is the target, the amount of nitrogen applied per month must be always superior to 20 kg ha^{-1}. The amount of phosphorus, as fertilizer, may double the nitrogen amount and potassium levels should range between 50% and 75% of the nitrogen's [21]. On the other hand, Bermuda is very tolerant to soil salinity (6.9 dSm^{-1}) and to water salinity (4.6 dSm^{-1}) [22].

2.6 Experimental Procedure

The irrigation experimental design was based on sprinkle point source [23]. This method can apply different irrigation amounts with minimal cost. The method is characterized by a linear gradient of water application, were a high degree of irrigation uniformity can be obtained in parallel isohyets, according to Fig. 1. The wettest zone occurs near the sprinkler and zones near the output fringes are the driest. A "Naan" sprinkler 323/92 with 2,4 x 4,8 mm diameter nozzles was used for irrigation. Sprinkler pressure was 250 kPa, with a wetting radius about 10 m. Actual evapotranspiration rates (ETa, mm day^{-1}) related to each controlled isohyet were compared to a non standard crop coefficient Ka times the daily potential evapotranspiration ETo (Penman-Monteith method). The six experimental values of Ka, generated by the point source were - 0.1, 0.5, 0.8, 1.2, 1.6, from the dry zones near the output fringes until the wet zones near the sprinkler. The colour is one of the best indicators of the appearance-quality of turfgrass [24]. Hence, it was used as a colour visual method to define the turfgrass quality [25], associated to the sprinkler point source design. The appearance of the lawn was compared with the observation of the colour values of "Standard Soil Colour Charts" [26]. The grass yields, under different irrigation amounts, were sampled monthly. The grass was mowed with scissors and collected at the predetermined distance from the sprinkler. The size of each sample was 0.25 m^2 and the mowed grass was dried at 105±1ºC, till constant weigh. The weight of the samples were divided by the number of days before the previous mechanical cut. The well potable water and the wastewater were collected respectively from underground and tertiary effluent ponds of the two sewage plants, located in Vale do Lobo and in Salgados.

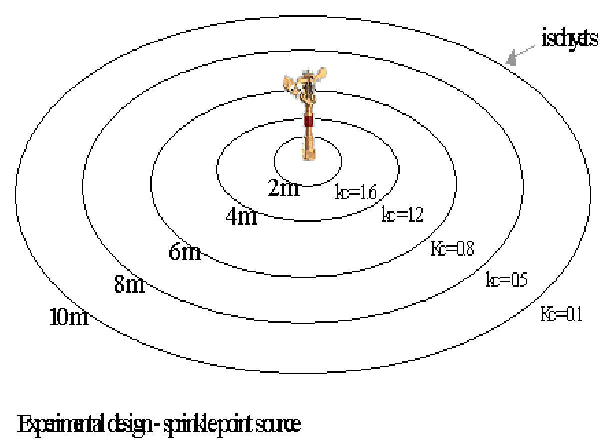

Fig. 1. Experimental design known as sprinkle point source used on the trials.

2.7 Statistical analysis

The effects of treatments were evaluated using the analysis of variance (ANOVA) and it was chosen the statistical test Dunnett T3, in order to identify the statistical difference among multiple mean values, at the 95% significance level, using the SPSS 11.0 [27].

3 Results

3.1. Appearance

Standard crop coefficient values of Kc were computed near the unit, more precisely, between 0.92 (VLPW and SGWW) and 0.99 (VLWW) and they were obtained through the best appearance (BA) of the lawn; which was compared with the observation of the colour values of "Standard Soil Color Charts"; for this turfgrass stage, it was obtained the value 4.5 of those charts.

The number of samples were 48 per trial, and was used the statistical test Dunnett T3, with the objective of to identify the mean similar values per trial.

Table 3. Standard monthly crop evapotranspiration ETC adj. values (mm month^{-1}), according to the water sources, (Trials VLWW, VLPW, and SGWW) and related to the best appearance (BA) of the turfgrass.

Month	VLWW	VLPW	SGWW
June	92	92	146
July	166	166	104
August	151	151	151
September	113	105	105
October	70	108	108
November	31	50	50
December	23	12	12
January	35	40	16
February	31	37	25
March	156	126	126
April	187	195	195
May	210	93	143
Year	1265	1175	1182

The values of the monthly standard cultural evapotranspiration (ETc) distribution are presented in Table 3, considering the best appearance of the lawns (BA).

These values are also shown in the Figure 2, were the respective computed curves presented similarity among each other. These results show that BA and consequently the standard crop coefficient values of kc were not related to the water salinity and to the nutrients in presence, once these values were different among the different trials (see Tables 1 and 2).

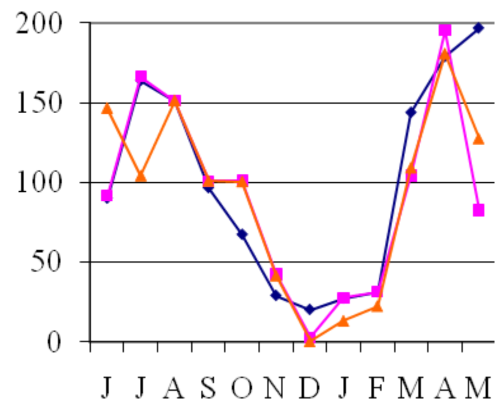

Fig. 2 – Monthly distribution of the values of crop transpiration ETc adj (mm month^{-1}), in the trials– VLWW, VLPW e SGWW, related to the best appearance (BA) – colour value of the lawn <4,5.

Non-standard crop coefficient Kc values were computed between 0.52 (VLPW) and 0.55 (VLWW and SGWW); it was obtained through the a good appearance (GA) of the turfgrass; according to "Standard Soil Color Charts" (value 5.5). Table 4 shows the non standard monthly crop evapotranspiration ETc adj. values of the combinations of turfgrass, according to the water sources (Trials VLWW, VLPW, and SGWW) related to be obtained a GA of the turfgrass.

The values of the monthly no-standard crop evapotranspiration (ETc adj) are shown, in Figure 3, considering the good appearance of the lawns (GA). The computed curves in presence are very similar, along the year, to each other. These results show that for GA, the non-standard crop coefficient Kc values were not dependent of the salinity of the water and of the nutrients in presence once these values, as mentioned before, were different among the different trials (see Tables 1 and 2).

Table 4. Non standard monthly crop evapotranspiration ETC adj. values (mm month^{-1}), according to the water sources (Trials VLWW, VLPW, and SGWW) and related to a good appearance GA of the turfgrass.

Month	VLWW	VLPW	SGWW
June	92	92	92
July	104	104	104
August	95	95	95
September	29	69	69
October	45	40	74
November	20	25	36
December	15	12	12
January	11	16	16
February	20	9	9
March	53	30	30
April	113	85	85
May	107	93	77
Year	703	669	698

It was observed that the non-standart crop coefficient ks values needed to achieve the good appearance (GA) of the lawns, were much lower than the standard crop coefficients ks values, related to the best appearance (BA).
It was shown that nitrogen and potassium fertilization levels were higher, respectively in trials SGWW and VLWW. The phosphorus fertilization level was higher in trial VLPW (see subsections 2.3 and 2.4); however, apparently there were not positive effects in terms of quality (see Tables 1 and 2).

It was shown that the quality of turfgrass was independent of the salinity levels of the irrigation water. Note that maximal electrical conductivity of irrigation water EC was of the treated wastewater, respectively 1.5 and 2.1 dS m^{-1}, on the trials VLWW and SGWW (see Table 1), which are less than the values presented to the tolerance of Bermuda grass [28, 29, 30].

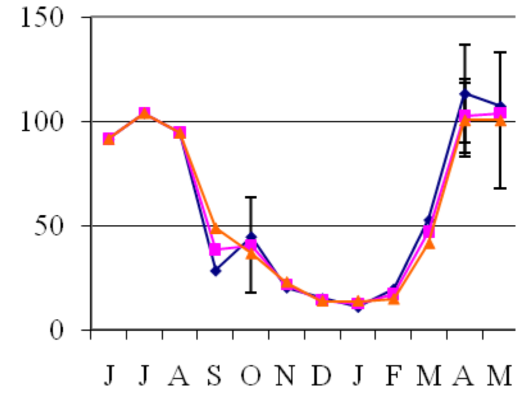

Fig. 3 – Monthly distribution of the values of crop evapotranspiration (ETc, mm month^{-1}), in the trials– VLWW, VLPW e SGWW, related to the grass good appearance (GA) of the turfgrass – colour value <5,5.

3.2. Yield

The grass yields, was collected under different irrigation amounts (kc 1.6, 1.2, 0.8, 0.5 and 0.1), for the different trials (VLWW, VLPW and SGWW). The number of samples were 60 per trial, and was used the statistical test Dunnett T3, with the objective of to identify the mean similar values.

In Table 5 are shown the annual dried yields, sampled monthly, for VLWW, VLPW and SGWW. It was observed that the productivity of the lawn irrigated with potable water (VLPW) was much higher than those were wastewater was applied (VLWW and SGWW).

This difference may be better explained by the lower salinity of the potable water, in relation to the two trials with wastewater (see Table 1), rather than by the differences of fertilisation applied.

This supposition is based on the fact that the applied fertilizations in the two trials of Vale do Lobo (VLWW and VLPW) were more similar then the applied in SGWW (see subsections 2.3 and 2.4).

Table 5. The grass yield (kg ha^{-1} $year^{-1}$), according to the trials VLWW, VLPW, and SGWW and related to (kc 1.6, 1.2, 0.8, 0.5 and 0.1)

kc	VLWW	VLPW	SGWW
1.6	5539	25915	3995
1.2	4177	19388	2627
0.8	2429	15452	4003
0.5	4065	16695	3005
0.1	2262	9653	2344

In Figure 4 are shown the regression curves for the annual yield of the lawns, in relation to the different trials (VLWW, VLPW and SGWW) and to the crop coefficients – kc (0,1, 0,5, 0,8, 1,2 e 1,6). The lines defined by the values of kc for good appearance (GA) – kc = 0,54 and for the kc for the best appearance (BA) – kc = 0,94 are also shown.

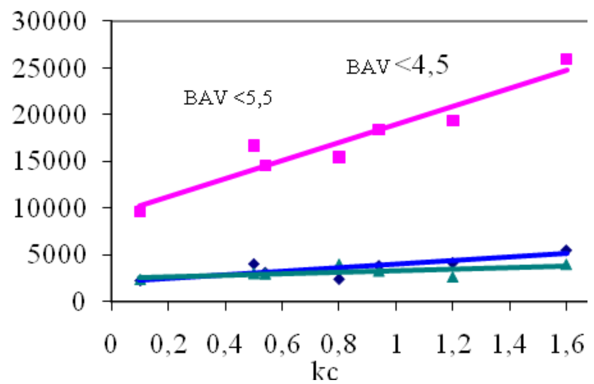

Fig. 4 – Regression curves for the annual yields (kg ha^{-1}) of the lawns (VLWW, VLPW and SGWW), in relation to the crop coefficients – kc (0,1, 0,5, 0,8, 1,2 and 1,6); and lines defined by the values of good appearance (GA) – kc = 0,54 and the best appearance (BA) – kc = 0,94.

The intersection of the lines defined by the appearance and by the yield of the lawns, show that no relation between quality and production was found, once, for the same appearance of the lawns, very different yields were reported.

4. Conclusions

The mean annual values of non standard crop coefficient (ks) were significantly lower when the option was the good visual appearance (GA) in comparison with the best appearance (BA). Once it was confirmed that the usual water consumption, in golf courses, of BA (Ks between 0.92 and 0.99) was near the double of the minimal water needed by turfgrass to obtain a GVA (Ks between 0.52 and 0.55), the potential of water saving is significant.

It was shown that the quality of turfgrass was independent of salinity of irrigation water for levels of ECw lower than 2.1 dS m^{-1}, to the studied turfgrass (Bermuda).

The quality of the grass was also not affected by the fertilization applied, which was very different, in relation to the different trials, once the differences of the response were not significant.

Concerning the yield response of the different lawns tested, it was shown that the trial were potable water was applied was more productive, for the tested values of kc (1.8, 1.2, 0.8, 0.5 and 0.2), probably as a response to the lower salinity level of this water. Anyway, the principal objective for the golf courses is the quality of the turfgrass and not the yield of the lawn.

As final remarks, this research showed that it is possible to consider treated final effluents as an alternative disposal to potable water, to be applied in turfgrass, since all cares are taken.

References:

[1] Hamdy, A. (2002). Sustainable use and management of non conventional water resources in arid regions. *Acta Horticulturae* 573:119-128.

[2] Lydakis-Simantiris, N.; Pentari, D.; Katsivela, E.; Koutoulakis, D.; Perdikatsis, V.; Pavlaki, A. (2006). A chemical and

microbiological study of the water of the Agyia Springs in Western Crete. *WSEAS Transactions on Environment and Development* 2(6):816-822.

[3] Penkova, N.; Beltrão, J.; Oron, G.; Salgot, M.; Alexandrov, V.; Khaydarova, V.; Menzhulin, Pobereijsky, L. (2002). Secondary wastewater reuse as a component of integrated water resources management.Proceedings of the 5th Conference on Water resources Management in the ERA of Transition (September, 4 - 8, 2002). Athens, Greece. *European Water Resources Association*:366-374.

[4] Moura, B.; Dionísio, L.; Beltrão, J.; Borrego, J.J. (2006). Reclaimed wastewater for golf course irrigation. *WSEAS Transactions on Environment and Development* 2(5):652-658.

[5] Beltrão, J.; Aksoy, U.; Cuartero, J.; Ben Asher, J. (1997). Generating new techniques for horticultural crops in order to improve the control of salination and desertification effects in the Mediterranean regions.European Union.International Cooperation in Science and Technology. EU AVICENNE and INCO-DC Initiative (November, 25 – 29, 1997). Istambul, Turkey.

[6] Oron, G.; de Malach, Y; Hoffman, Z.; Manor, Y. (1992). Effect of effluent quality and application method on agricultural productivity and environmental control. *Water Sci. Technol*. 26, 1593-1601.

[7] Costa, M.; Dionisio, L.; Brito, J.; Matos, L.; Rebelo, J.; Guerrero, C; Gamito, P.; Beltrão, J. (2002). Response of fairway grasses of golf courses to potable irrigation as compared to wastewater irrigation. *Acta Horticulturae* 573:357-362.

[8] Costa, M. (2004). Use of treated wastewater on field irrigaton and urban sludge as soil fertlizer of Algarve region. Ph. D. thesis, University of Algarve, Faro, Portugal, 175 pp. (Portugese, with an English summary).

[9] Costa, M.; Beltrão, J.; Brito, J.; Dionísio, L. (2008). Effects of manure and sludge application on a citrus orchard. WSEAS Transactions on *Environment and Development* 4(7):567-576.

[10] Billis, V.; Stamatin, E. (2006). Waste management planning and new priorities and objectives. Greek Ombudsman's interventions and proposals. *WSEAS Transactions on Environment and Development* 2(6): 808-815.

[11] Cabecinha, A.; Guerrero, C.; Beltrão, J.; Brito, J. (2009). Carob residues as a substrate and a soil organic amendment. *WSEAS Transactions on Environment and Development* 6(5):317- 326.

[12] Beltrão, J.; Santos, R.; Correia, P. (2008). Combined effects of potassium and wastewater application on the yield and quality of Bermuda grass (*Cynodon dactylon)* in the Mediterranean regions. *WSEAS Transactions on Environment and Development* 4(9):726-735.

[13] Oron, G.; Beltrão, J. (1993). Complete environmental effluent disposal and reuse by drip irrigation. Fragoso, M.A.C.; van Beusichem, M.L. (eds.). Optimization of Plant Nutrition. *Developments in Plant and Soil Sciences* 53: 153-156.

[14] Gamito, P.; Arsénio, A.; Faleiro, M.L.; Brito, J.M.C.; Beltrão, J. (1999). The influence of wastewater treatment on irrigation water quality. In: D. Anaç & P. Martin-Prével (Eds.). Improved Crop quality by Nutrient management, Chapter 61: 267-270. Kluwer Academic Publishers.Tapias, J.C. (1997).

[15] Tapias, J. C. (1997). Strategy of Management of water resources on golf courses. Ph. D. Thesis. University of Barcelona., Spain, 432 pp. (Spanish, with an English summary).

[16] Doorenbos, J.; Pruitt, W.O. (1984). Guidelines for predicting crop water

requirements. *FAO Irrig. Drain. Paper* 24, 144 pp.

[17] Allen, R.G.; Pereira, L.S.; Raes, D.; Smith, M. (1998). Crop evapotranspiration. Guidelines for computing crop water requirements. *FAO Irrig. Drain. Paper* 56, 300pp.

[18] FAO-ISSS-ISRIC (1998). World reference base for soil resources, 87pp.

[19] Trenholm, L.E.; Dudeck, A.E.; Sartain, J.B.; Cisar, J.L.(1998). Bermuda grass growth, total non structural carbohydrate concentration, and quality as influenced by nitrogen and potassium. Crop Science 38(1):168-174.

[20] Beard, J. (2002). Turf management for golf courses (2nd ed.). John Wiley & Sons, Inc., USGA, New Jersey, USA.

[21] Mc Carty, L.B.; Miller, G. (2002). Managing bermudagrass turf: selection, construction, cultural practices, and pest management strategies. Ann Arbor Press. Chelsea, Michigan, USA, 221 pp.

[22] Beltrão, J.; Brito, J.; Neves, M.A.; Seita, J. (2009). Salt Removal Potential of Turfgrasses in Golf Courses in the Mediterranean Basin. *WSEAS Transactions on Environment and Development* 5(5):394-403.

[23] Or, D. & Hanks R. (1992). A single point source for the measurement of irrigation production function. *Irrig. Sci*. 13:55-64.

[24] Turgeon, A. 1980. Turfgrass management. Engelwood Cliffs, Prentice Hall. USA.

[25] Mantell, A.; Stanhill, G. (1981). Lawngrass. In: Irrigation of field and orchard crops under semi-arid conditions (2nd edition). Shalhevet, J.; Mantell, A.; Bielorai, H.; Shimshi, D. (eds.). III C, Volcani Center, Bet Dagan, Israel, 132 pp..

[26] Munsell. (1991). Standard soil colour charts. Revised. Eijkelkamp Agrisearch Equipment (ed.), Giesbeek, Netherlands, 38 pp.

[27] SPSS 11.0. (2002). SPSS Inc., Chicago, Illinois, U.S.A.

[28] Ayers, R.S.; Westcot, D.W. (1985). Water quality for agriculture. FAO. *Irrig. Drain. Paper* 29, 174 pp.

[29] Dudeck, A.E.; Singh, S.; Giordano, C.E.; Nell, T.A.; Mc Connell, D.B. (1983). Effects of sodium chloride on *Cynodon* turfgrasses. *Agron. J*. 75:927-930.

[30] Carrow, R.; D.; Duncan, R. (1998). Salt-affected turfgrass sites. Sleeping Bear Press, Inc., Michigan, USA.