Soil profile characteristics and response of Bermuda turfgrass (*Cynodon dactylon* L.) to the combined effects of nitrogen / potassium fertilization, irrigated with different wastewater levels

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Abstract: - The aim of this work was to study the combined effects of nitrogen and potassium fertilization on turfgrass and on the soil profile irrigated with different wastewater levels. Bermuda grass (*Cynodon dactylon* L) was selected because is the most common turfgrass used in many golf courses of the Mediterranean basin, especially grown in the fairways, roughs and tees, due to its tolerance to drought, high temperatures and damages. In order to express the wastewater irrigation amounts, it was used a crop factor Ki (non conventional crop factor under non standard conditions, adapted to the experimental irrigation design; dimensionless). The experimental work showed that for higher nitrogen amounts, the good visual appearance of Bermuda grass GVA was obtained in April and May for a Ki > 0.5 and in July and August for a Ki > 0.7 / 0.8. Greater amounts of nitrogen fertilizations presented higher soil nitrate concentrations. Soil nitrites content was always very low, once that they represent an transient from the ammonium to the nitrate stage of nitrogen. There were no significant differences among potassium treatments; however, for greater depths, potassium content was slightly higher, mainly for higher potassium fertilization. On the other hand, when there was no fertilization, the Ki value was larger, from Ki > 1.0 up to Ki > 1.4. Therefore, in spite of the higher Ki, it was shown that the nutrients of the irrigation wastewater were enough to be obtained a GVA of the Bermuda grass. In this way, often there is no need to increase the grass yield, once that production factors (such as the cuts frequency, water and nutrients), will enhance the expenses of the lawns maintenance and have a negative impact on the environment. Thus, in order to be obtain a good visual appearance of turfgrass, often there is no need to increase the grass yield, when wastewater irrigation is used, once that production factors (such as the cuts frequency, water and nutrients), will enhance the expenses of the lawns maintenance and contamination of the environment.

Keywords: good visual appearance GVA; environment; grass quality, nutrients, crop coefficient Ki.

I.INTRODUCTION

The reuse of treated wastewater is considered as an alternative disposable to potable water in the Mediterranean agriculture and landscape [1]. Municipal wastewaters are normally collected and treated near the cities and, therefore, for economic reasons, the first uses are in the cities and around them; so, irrigation of parks, playgrounds and sport fields constitute the first priority [2]. Experience suggests that reuse of wastewater could increase the amount of available water and help control of water quality [3]. It can be successful used for golf courses in the Mediterranean Basin, under careful monitoring of irrigation water quality: both chemically and microbiologically [4, 5]. On the other hand, the influence of the tourists and the discharge of organic matter increases during the summer months [6] and the accumulation of nutrients may occur in inner regions where water circulation is restricted, which may lead to episodes of water quality degradation [7]. The concentrations of nitrogen and potassium fertilization have, as well, a clear and pronounced influence on the Bermuda turfgrass yield. [8]. It is well known that scarcity of nitrogen may produce chlorosis on the leaves, and, therefore, the photosynthetic rate and its effect on biomass accumulation. Efficient N applications are necessary to maximize Bermuda grass production [9]. It is known the influence of potassium on the quality and growth of Bermuda grass, once that it is directed related to the stomatal physiological mechanisms, to the synthesis of the carbohydrates [10], on the development of the root system [11], and on the special case of Bermuda grass, its influence on the week resistance to low temperature [12]. In general, the use of K nutrition is an efficient method on regulating sodium induced stress in many crops, and, additionally, its use is a potent tool precluding chloride-induced stress in many crops [13]; these aspects were demonstrated through several physiological mechanisms [14]. Beside growth, and total nonstructural carbohydrate concentration, the quality of Bermuda grass is also influenced by nitrogen and potassium [15, 16].

These attributes of Bermuda grass may be also conditioned by other additional factors, such as the different wastewater regimes [17]. In this way, the objective of this work is to study the yield and quality response of Bermuda grass (*Cynodon dactylon* L.) to the combined fertilization of nitrogen and potassium, irrigated with different wastewater levels. This kind of research works contributes to the development of theoretical and empirical tools for planning and implementing efficient policy regarding water resources in the Mediterranean Basin [18],

II. MATERIAL AND METHODS

A. Experimental site

The experiments were carried out in the Quinta dos Salgados golf course, Algarve, Southern Portugal, during Spring and Summer from April up to August.

B. Climate

The climate of Algarve can be considered as Mediterranean and in particular the south shore. After Köppen, is classified as <u>Csa</u>, with semi-arid characteristics, identified by mild rainy winters and by warm and dry summers. Climatic parameters are presented in Table 1.

Table 1. Monthly climatic parameters

MONTH	TEMPERATURE (º C)	ETP (mm)	RAIN (mm)
April	16	117	0
May	17	165	17
June	20	184	1
July	22	208	0
August	22	184	0

C. Soil

The soil was an alluvial saline soil, classified as a "Fluviosol-thionic" and its soil profile is described as [19]:

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 contentat different soil matric potential ψm values were, respectively: θw at - 10 kPa = - 0.050 kg water kg^{-1} dry soil, θw at – 330kPa = 0.040 kg kg^{-1}; and θw at 1500 kPa = 0.018 kg kg-1.

Horizon B – (0.20 – 0.60 m depth) - texture: loamclay sandy soil (sand – 66 %; silt – 3 %; and clay – 22 %); gravimetric soil water content.at different soil matric potential ψm values were, respectively: θw at - 100 kPa = - 0.080 kg kg^{-1}; θw at – 330 kPa = 0.070 kg kg-1; θw 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.

D. Crop

Cynodon dactilon, L. Pers (Bermuda 419, savanna) are the most used varieties on the Mediterranean golf courses [20]. "Savana" is exclusively applied on the roughs; on the other hand, "Bermuda 419", the most used turfgrass, is used on tees, fairways and greens; they are warm-season species, adapted to a wide range of soil conditions; although Bermuda grass generally not very cold tolerant, the pole ward limits of adaptation have been extended with the development of several new cultivars; its intolerance of shade necessitates the use of alternative warm-season species on sites where trees and other structures restrict sunlight penetration [21]. These species are perennial, have a long life, quick growth at 18-35 ºC, but become brown when temperature decreases. Its growth is extremely vigorous, when compared to other species [22].

D. Wastewater chemical parameters

Chemical parameters of treated wastewater are shown in Table 2 and were determined by a reflectometry (Merck RQ – Flex Plus), according to the different manufacturer instructions, specific to each ion. The pH and the electrical conductivity of wastewater were determined by a portable potenciometer and a conductivimeter, respectively.

Table 2 – Irrigation water parameters.

Irrigation water parameters	Values
pH	7,4* - 8.1**
ECw (dS m^{-1})	1,54* - 1.65**
SAR	5,6
CO_3^{--}(ppm)	0,0
HCO3- (ppm)	469,8
Na^+ (ppm)	197,8
K^+ (ppm)	12* - 14**
Mg^{++} (ppm)	42,3
Ca^{++} (ppm)	69,7
Cl^- (ppm)	243* - 258**
NO_3^- (ppm)	1.2
NO_2^{--} (ppm)	0.6* - 0.7**
P (ppm)	7* - 9**

*May; ** July

E. Experimental design, plot and treatments

It was used an experimental design known as sprinkle point source [23, 24], which is characterized by the assumption that a point creates a linear irrigation gradient from the water point source, producing a gradual change in water application, and a high degree of irrigation uniformity must be obtained in parallel isohyets (Figs. 1 and 2).

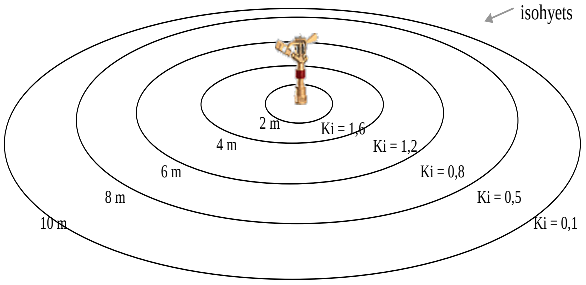

Fig. 1 - Point source experimental design [23, 24]. Irrigation gradient expressed by a crop coefficient under non standard conditions Ki, due to the management of the experimental design.

Fig. 2 – Use of Point source experimental design [23, 24] in the golf course.

The wettest zone was near the sprinkler and the treatments near the borders were the driest. The irrigation system was stopped when wind speed was larger than 1 m s^{-1}. It was used a 323/92 Naan sprinkler, 2.5 x 4.5 mm diameter nozzles, using a 300 kPa sprinkler pressure, with a wetting radius about 10 m. Sprinkler diagram was trianglar.

Christiansen uniformity coefficient CUC [25] was used to determine the uniformity of water distribution as follows:

$$CUC = 100 \{1 - [(\Sigma | x_i - m |) / (m . n)] \} \quad (1)$$

where:

CUC – Christiansen’s uniformity coefficient, percent;
n - number of collecting cans in the overlapped isohyets;
x_i - water measurements in the i-th collecting can (i = 1, 2,…, n); m - mean of n measurements in the overlapped isohyets;

The uniformity of water distribution was determined at 2; 4; 6; and 8 m from the sprinkle point source; it was obtained, respectively, CUC's values of 92.5; 92.7; 91.9; and 73.2 %. The plot was irrigated once a day. When the crop is under stress conditions, crop evapotranspiration under non standard conditions ETc_{adj} (mm d^{-1}) is expressed as follows {26]:

$$ETc_{adj} = Ks . Kc . ET_0 \quad (2)$$

where Kc is the crop coefficient under standard conditions (dimensionless), ET_0 is the reference evapotranspiration (Penman-Monteith), in mm d^{-1}, being its average value 6 mm d^{-1}; and Ks (unitless) describes the effect of crop stress on crop evapotranspiration under standard conditions ETc (mm d^{-1}), which is given by [27]:

$$ETc = Kc . ET_0 \quad (3)$$

More detailed information on crop coefficients and crop factors is presented by Allen and Pereira [28]. During the experimental period the net irrigation water I (mm d^{-1}), was applied daily. The precipitation was negligible, being the water balance given by:

$$I = ETc_{adj} + Dr \quad (4)$$

where Dr is the drainage water amount (mm d^{-1}). Due to the management of the experimental design (Figs. 1 and 2), an unusual crop factor under non standard conditions Ki (dimensionless) was used to establish the relation between net irrigation water I and the yield, expressed by:

a) For Dr = 0, no drainage effects; I < 6 mm d^{-1}

$$Ki = Ks\ Kc = I\ ET_0^{-1} \quad (Ki < 1) \quad (5)$$

b) For Dr > 0, drainage effects; I > 6 mm d^{-1}

$$Ki = I\ ET_0^{-1} = (ET_0 + Dr)\ ET_0^{-1} \quad (Ki > 1) \qquad (6)$$

The wastewater plot was divided into 5 subplots of combined nitrogen and potassium treatments, similiarly to other point source experiments [29]. Nitrogen and potassium application levels in the plot were: 1) N0K0 (0 kg N ha^{-1} $month^{-1}$ and 0 kg N ha^{-1} $month^{-1}$); 2) N1K1 (25 kg N ha^{-1} $month^{-1}$ and 25 kg K ha^{-1} $month^{-1}$; 3) N1K2 (25 kg N ha^{-1} and 100 kg K $month^{-1}$); 4) N2K1 (100 kg N ha^{-1} $month^{-1}$ and 25 kg K ha^{-1} $month^{-1}$) and 5) N2K2 (100 kg N ha^{-1} $month^{-1}$ and 25 kg K ha^{-1} $month^{-1}$). Wastewater irrigation treatments (5) were expressed by the crop coefficient adapted to the irrigation design. Ki (0.1; 0.5; 0.9; 1.2; and 1.6). Replications number was 4. The colour is one of the best indicators of the appearance-quality of turfgrass [30]. Hence, it was used a a colour visual method to define the turfgrass colour [31], associated to the sprinkler point source design. Accordingly, the appearance of the lawn was compared with the observation of the colour values of "Standard Soil Colour Charts" [32], complemented by “The Royal Horticultural Society’s Colour Chart RHS [33]. Grass quality was analysed by the minimal value of the Yield and of the Ki, enough to be obtained a good visual appearance GVA of the lawn, defined by the colour of the turfgrass. [34].

F. 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 [35].

Because of lack of randomization of the point source irrigation design the normal analysis of variance could be not used to evaluate significance. When problems of lack of randomization were known due to the point source experimental design, a geostatistical approach was applied [36]. All the regression parameters were found to be significant at 0.05 to 0.01 level.

III. RESULTS

A. Bermuda grass yield

Tables 3, 4, 5 and 6 show the Bermuda grass yield response to the combined effects of nitrogen and potassium fertilization and to the 5 levels of wastewater application, during Spring (April and May) and Summer (July and August). Bermuda grass yield is expressed by the dry matter absolute yield (kg ha^{-1} d^{-1}).

It may be seen on table 3 that, during April, the subplot N0K0 showed the lowest yield of all plots, and yield maintained constant with the increase of the crop coefficient adapted to the irrigation design Ki. On the other hand, yield increased on all the other subplots with the enhance of the Ki value.

Table 3 - Bermuda grass yield response to the combined effects of nitrogen and potassium fertilization and to the 5 levels of wastewater application, during April. Bermuda grass yield is expressed by the dry matter absolute yield (kg ha^{-1} d^{-1}).

Ki	N0K0	N1K1	N1K2	N2K1	N2K2
0.1	18	32	18	15	17
0.5	21	28	23	18	26
0.9	17	41	31	12	19
1.2	13	39	36	27	32
1.6	22	44	43	37	45

Table 4 showed, that in May, yield increase was negligible with the enhance of the Ki in the subplot N0K0. On the other subplots, there was an increase with the enhance of Ki, being this increase much more sharply pronounced on the plots fertilized with higher amounts of nitrogen (N2K1 and N2K2).

Table 4 - Bermuda grass yield response to the combined effects of nitrogen and potassium fertilization and to the 5 levels of wastewater application, during May. Bermuda grass yield is expressed by the dry matter absolute yield (kg ha^{-1} d^{-1}).

Ki	N0K0	N1K1	N1K2	N2K1	N2K2
0.1	10	5	5	8	9
0.5	7	13	8	22	19
0.9	7	28	19	30	32
1.2	6	36	33	45	43
1.6	8	34	42	48	58

During the month of June, there were problems of lack of control and management of the experiment and, therefore, the results are not considered neither presented. Along July, yield enhanced lightly with the increase of the crop coefficient adapted to the irrigation design Ki in the subplot N0K0. On the other hand, in the subplot N2K2 the yield was higher, and increased sharply with the enhance of the Ki.

Table 5 - Bermuda grass yield response to the combined effects of nitrogen and potassium fertilization and to the 5 levels of wastewater application, during july. Bermuda grass yield is expressed by the dry matter absolute yield (kg ha^{-1} d^{-1}).

Ki	N0K0	N1K1	N1K2	N2K1	N2K2
0.1	21	20	15	14	27
0.5	22	20	15	17	55
0.9	20	24	17	27	56
1.2	22	32	19	23	49
1.6	20	35	36	51	68

Table 6 shows that yield, during August, enhanced with the increase in all subplots. However, the yield enhance was more sharply pronounced in the subplots higher fertilized with nitrogen (N2K1 and N2K2), being the maximum yield of the five subplots obtained on the subplot N2K2.

Table 6 - Bermuda grass yield response to the combined effects of nitrogen and potassium fertilization and to the 5 levels of wastewater application, during August. Bermuda grass yield is expressed by the dry matter absolute yield (kg ha^{-1} d^{-1}).

Ki	N0K0	N1K1	N1K2	N2K1	N2K2
0.1	45	18	32	47	44
0.5	66	31	64	65	97
0.9	71	78	72	77	116
1.2	95	117	86	136	146
1.6	93	107	122	145	198

The linear relation between grass dry matter absolute yield Y (kg ha^{-1} d^{-1}) and the crop coefficient adapted to the irrigation design Ki, is given by the follwing equations:

April – N0K0 $Y = 4.44\ Ki + 41.50$ $R^2 = 0.09$ (5)
N1K1 $Y = 47.23\ Ki + 32.25$ $R^2 = 0.94$ (6)
N1K2 $Y = 54.15\ Ki + 28.92$ $R^2 = 0.95$ (7)
N2K1 $Y= 65.53\ Ki + 23.90$ $R^2 = 0.95$ (8)
N2K2 $Y = 61.62\ Ki + 37.71$ $R^2 = 0.84$ (9)

May – N0K0 $Y = 6.21\ Ki + 14.31$ $R^2 = 0.42$ (10)
N1K1 $Y = 97.95\ Ki – 7.16$ $R^2 = 0.95$ (11)
N1K2 $Y = 134.86\ Ki + 30.68$ $R^2 = 0.90$ (12)
N2K1 $Y= 175.16\ Ki – 13.84$ $R^2 = 0.97$ (13)
N2K2 $Y = 186.99\ Ki - 31.71$ $R^2 = 0.94$ (14)

July - N0K0 $Y = 14.14.Ki + 46.02$ $R^2 = 0.77$ (15)
N1K1 $Y = 59.35\ Ki + 11.27$ $R^2 = 0.91$ (16)
N1K2 $Y = 44.47\ Ki + 15.78$ $R^2 = 0.79$ (17)
N2K1 $Y= 71.14Ki + 6.28$ $R^2 = 0.92$ (18)
N2K2 $Y = 92.00\ Ki + 68.98$ $R^2 = 0.91$ (19)

August –N0K0 $Y =106.16.Ki +113.23$ $R^2=0.82$ (20)
N1K1 $Y = 209.59\ Ki - 1.13$ $R^2 = 0.94$ (21)
N1K2 $Y = 200.99.Ki + 21.76$ $R^2=0.98$ (22)
N2K1 $Y =239.74.Ki + 52.15$ $R^2 =0.90$ (23)
N2K2 $Y =300.02.Ki + 63.84$ $R^2 =0.98$ (24)

With the exception of the treatments N0K0 in April and May, regression analysis between observed and simulated yield is acceptable for field conditions ($0.77 < R^{-2} < 0.98$).

B. Bermuda grass quality

Grass quality was expressed by the appearance of the grass. Hence the minimal yield and Ki values, enough to be obtained a good visual appearance GVA of the lawn for the different months along the experiment, is given in Tables 7 and 8, respectlively.

Table 7 – Minimal Bermuda grass yield enough in order to be obtained a good visual appearance GVA of the lawn. Grass yield is expressed by the dry matter absolute yield (kg ha^{-1} d^{-1}), during the experiment

Fertilization treatment	Months			
	April	May	July	August
N0K0	40	20	65	260
N1K1	81	75	65	260
N1K2	81	50	65	200
N2K1	60	75	65	200
N2K2	60	50	135	260

Table 8 –Minimal Ki value in order to be obtained a good visual appearance GVA of the lawn

Fertilization treatment	Months			
	April	May	July	August
N0K0	1.1	1.0	1.2	1.4
N1K1	1.0	0.8	0.9	1.2
N1K2	1.0	0.7	1.0	0.9
N2K1	0.5	0.5	0.8	0.7
N2K2	0.5	0.5	0.7	0.7

The minimal yield enough to be obtained a good visual appearance GVA of the lawn, during April, was 81 kg ha^{-1} d^{-1} in the subplots where the treatments received a lower nitrogen fertilization (N1K1 and N1K2), obtained with a Ki > 1.0. In the higher nitrogen fertilized subplots (N2K1 and N2K2), a GVA was obtained with a minimal yield of 60 kg ha^{-1} d^{-1} (Ki > 0.5). In order to obtain a GVA, in the non fertilized subplot (N0K0), it was needed a minimal yield of 45 kg ha^{-1} d^{-1} (Ki > 1.1).

In May, the the minimal yield enough to be obtained a good visual appearance GVA of the lawn, was 75 kg ha^{-1} d^{-1} in the subplots where the treatments received a lower potassium fertilization (N2K1 and N1K2), obtained with a Ki > 0.5 and Ki > 0.8, respectively. In the plots higher fertilized with potassium (N2K2 and N1K2) a GVA was obtained with a yield of 50 kg ha^{-1} d^{-1}, under a Ki > 0.5 and 0.7, respectively. The GVA was obtained in the non fertilized subplot (N0K0), with the minimal yield of 20 kg ha^{-1} d^{-1} (Ki > 1.0).

During July, The minimal yield enough to be obtained a good visual appearance GVA of the lawn, was 135 kg ha^{-1} d^{-1} (Ki > 0.7) in the subplot N2K2. In the other subplots, yield was 65 kg ha^{-1} d^{-1}, being Ki values for the subplots N2K1, N1K1, N1k2, and N0K0, respectively, Ki < 0.8, Ki < 0.9, Ki < 1.0 and Ki < 1.2.

In August, it was obtained 260 kg ha^{-1} d^{-1} for a good visual appearance GVA of the lawn, in the subplots N2K2, N1K1 and N0K0 for, respectively, Ki < 0.7, 1.2 and 1.4. On the other hand, in the other plots (N2K1 and N1K2), it was obtained 260 kg ha^{-1} d^{-1} for the GVA, at Ki > 0.7 and Ki > .0.9, respectively.

C. Soil Profile

Analysis of soil profile was done for soil depths of 0.00-0.20 m and 0.20-0.40 m.

Table 9 shows nutrient concentration (nitrate, nitrite, ammonium, and potassium) along the soil profile (0-0.2

m and 0.2-0.4 m depth) just before the beginning of the experiments.

Table 9 – Soil nutrient concentration (nitrate N-NO_3^-, nitrite N-NO_2^-, ammonium N-NH_4^+, and potassium K^+) along the soil profile (0.00-0.20 m and 0.20-0.40 m depth), in April, just before the beginning of the experiments.

Nutrient (ppm)	Soil depth (0.00-0.20 m)	Soil depth (0.20-0.40 m)
NO_3^-(ppm)	53	14
NO_2^-(ppm)	0.14	0.03
NH_4^+(ppm)	4	6
K^+(ppm)	97	82

Tables 10a and 10b shows, respectively, soil nitrate N-NO_3^- concentration (ppm) along the soil profile – 0.00-0.20 m and 0.20-0.40 m depth, on July – during the experiments (10a, 10b) and on September – just after the end of the experiments (10c, 10d), for the different experimental fertilization and irrigation levels

Table 10a – Soil nitrate N-NO_3^- concentration (ppm) on on July – during the experiments, 0.00-0.20 m soil depth, for the different fertilization and irrigation levels

Ki	N0K0	N1K1	N1K2	N2K1	N2K2
0.1	40	13	18	14	119
0.5	42	18	22	54	94
0.9	6	24	21	65	47
1.2	11	21	19	90	67
1.6	20	28	19	38	64

Table 10b – Soil nitrate N-NO_3^-, concentration (ppm) on on July – during the experiments, 0.20-0.40 m soil depth, for the different fertilization and irrigation levels

Ki	N0K0	N1K1	N1K2	N2K1	N2K2
0.1	2	8	16	10	38
0.5	12	11	16	20	48
0.9	3	10	12	67	16
1.2	2	12	13	70	17
1.6	2	9	11	22	15

Table 10c – Soil nitrate N-NO_3^-, concentration (ppm) on September – just after the end of the experiments, 0.00-0.20 m soil depth, for the different fertilization and irrigation levels

Ki	N0K0	N1K1	N1K2	N2K1	N2K2
0.1	0	17	8	4	8
0.5	1	16	17	8	27
0.9	2	13	16	36	18
1.2	7	9	20	22	13
1.6	9	9	33	19	14

Table 10d – Soil nitrate N-NO_3^-, concentration (ppm) on September – just after the end of the experiments, 0.20-0.40 m soil depth, for the different fertilization and irrigation levels

Ki	N0K0	N1K1	N1K2	N2K1	N2K2
0.1	0	7	7	7	2
0.5	1	9	14	24	11
0.9	10	6	9	16	12
1.2	5	8	12	9	9
1.6	4	5	13	12	5

Tables 11a and 11b shows, respectively, soil nitrite N-NO_2^-concentration (ppm) along the soil profile – 0.0-0.20 m and 0.20-0.40 m depth, on July – during the experiments and on September – just after the end of the experiments (11c, 11d), for the different experimental fertilization and irrigation levels.

Table 11a – Soil nitrite N-NO_2^- concentration (ppm) on July – during the experiments, 0.00-0.20 m soil depth, for the different fertilization and irrigation levels

Ki	N0K0	N1K1	N1K2	N2K1	N2K2
0.10	0.02	0.06	0.06	0.20	0.20
0.07	0.01	0.08	0.08	0.08	0.08
0.02	0.03	0.03	0.03	0.05	0.05
0.03	0.04	0.05	0.10	0.05	0.05
0.04	0.01	0.02	0.01	0.06	0.06

Table 11b – Soil nitrite N-NO_2^- concentration (ppm) on on July – during the experiments, 0.20-0.40 m soil depth, for the different fertilization and irrigation levels

Ki	N0K0	N1K1	N1K2	N2K1	N2K2
0.1	0.01	0.04	0.04	0.04	0.05
0.5	0.05	0.01	0.04	0.01	0.05
0.9	0.01	0.09	0.01	0.09	0.02
1.2	0.02	0.06	0.01	0.06	0.01
1.6	0.02	0.02	0.03	0.02	0.02

Table 11c - Soil nitrite N-NO_2^- concentration (ppm) on September – just after the end of the experiments, 0.00-0.20 m soil depth, for the different fertilization and irrigation levels

Ki	N0K0	N1K1	N1K2	N2K1	N2K2
0.1	0.02	0.05	0.04	0.03	0.14
0.5	0.02	0.00	0.13	0.15	0.11
0.9	0.04	0.02	0.11	0.11	0.07
1.2	0.06	0.01	0.12	0.11	0.17
1.6	0.05	0.02	0.02	0.05	0.03

Table 11d – Soil nitrite N-NO_2^- concentration (ppm) on September - just after the end of the experiment, 0.20-0.40 m soil depth, for the different fertilization and irrigation levels

Ki	N0K0	N1K1	N1K2	N2K1	N2K2
0.1	0.04	0.01	0.03	0.01	0.02
0.5	0.03	0.02	0.04	0.05	0.03
0.9	0.00	0.04	0.02	0.01	0.03
1.2	0.02	0.01	0.02	0.04	0.04
1.6	0.03	0.00	0.03	0.03	0.05

Table 12 shows, respectively, soil ammonium N-NH_4^+ concentration (ppm) along the soil profile – 0.00-0.20 m and 0.20-0.40 m depth, on July – during the experiments (12a, 12b) and on September – just after the end of the experiments (12c, 12d) for the different experimental fertilization and irrigation levels.

Table 12a – Soil ammonium N-NH_4^+ concentration (ppm) on July – during the experiments, 0.00-0.20 m soil depth, for the different fertilization and irrigation levels

Ki	N0K0	N1K1	N1K2	N2K1	N2K2
0.1	2.8	2.8	5.2	2.8	0.8
0.5	9.2	2.4	8.4	3.6	2.0
0.9	3.2	7.2	7.6	2.4	4.0
1.2	6.8	4.4	3.2	3.2	3.2
1.6	6.0	4.0	3.8	3.2	3.6

Table 12b - Soil ammonium N-NH_4^+ concentration (ppm) on July – during the experiments, 0.20-0.40 m soil depth, for the different fertilization and irrigation levels

Ki	N0K0	N1K1	N1K2	N2K1	N2K2
0.1	6.4	4.0	8.0	3.6	4.4
0.5	7.2	3.6	4.4	2.4	2.0
0.9	16.0	4.4	5.2	4.0	2.0
1.2	15.6	4.4	7.2	1.6	1.6
1.6	7.2	5.2	8.0	2.8	3.8

Table 12c – Soil ammonium N-NH_4^+ concentration concentration (ppm) on September - just after the end of the experiments, 0.00-0.20 m soil depth, for the different fertilization and irrigation levels

Ki	N0K0	N1K1	N1K2	N2K1	N2K2
0.1	0.4	1.2	2.4	0.0	0.0
0.5	0.0	1.2	1.6	0.0	0.4
0.9	0.4	1.2	0.8	1.6	0.8
1.2	0.8	1.6	1.2	1.2	2.0
1.6	0.8	0.8	1.6	2.4	1.2

Table 12d – Soil ammonium N-NH_4^+ concentration (ppm) on September - just after the end of the experiments, 0.20-0.40 m soil depth, for the different fertilization and irrigation levels

Ki	N0K0	N1K1	N1K2	N2K1	N2K2
0.1	0.4	1.2	1.2	0.0	0.4
0.5	0.0	1.6	2.0	0.0	0.8
0.9	0.0	0.8	2.0	0.8	0.4
1.2	0.4	1.6	1.6	1.6	1.6
1.6	1.2	0.8	2.0	1.6	1.2

Table 13 shows, respectively, soil potassium K^+ concentration (ppm) along the soil profile – 0.00-0.20 m and 0.20-0.40 m depth, on July – during the experiments (13a, 13b) and on September – just after the end of the experiments (13c, 13d) for the different experimental fertilization and irrigation levels.

Table 13a – Soil potassium K^+ concentration (ppm) on July – during the experiments, 0.00-0.20 m soil depth, for the different fertilization and irrigation levels

Ki	N0K0	N1K1	N1K2	N2K1	N2K2
0.1	51	45	49	30	78
0.5	44	49	42	39	50
0.9	27	46	54	60	23
1.2	23	48	88	49	32
1.6	54	29	69	24	28

Table 13b – Soil potassium K^+ concentration (ppm) on July – during the experiments, 0.20-0.40 m soil depth, for the different fertilization and irrigation levels

Ki	N0K0	N1K1	N1K2	N2K1	N2K2
0.1	77	72	66	59	97
0.5	80	71	79	70	84
0.9	57	83	102	95	66
1.2	91	93	98	91	59
1.6	92	58	107	82	53

Table 13c – Soil potassium K^+ concentration (ppm) on September - just after the end of the experiments, 0.00-0.20 m soil depth, for the different fertilization and irrigation levels

Ki	N0K0	N1K1	N1K2	N2K1	N2K2
0.1	31	56	27	29	38
0.5	38	20	30	35	25
0.9	35	20	33	25	26
1.2	18	38	32	23	23
1.6	46	24	31	19	16

Table 13d – Soil potassium K^+ concentration (ppm) on September - just after the end of the experiments, 0.20-0.40 m soil depth, for the different fertilization and irrigation levels

Ki	N0K0	N1K1	N1K2	N2K1	N2K2
0.1	73	73	66	76	76
0.5	73	50	49	76	76
0.9	59	32	58	53	53
1.2	70	43	83	47	47
1.6	72	77	77	53	53

Table 14 show the electrical conductivity ECe (dS m^{-1}) and the pH of soil saturation paste, using distilled water, along the soil profile (0.00-0.20 and 0.20-0.040 m depth), just before the beginning of the experiments.

Table 14 - Electrical conductivity ECe (dS m^{-1}) and the pH of soil using distilled water, along the soil profile (0.00-0.20 and 0.20-0.040 m depth), just before the beginning of the experiments.

Soil parameter	Soil depth (0.00-0.20 m)	Soil depth (0.20-0.40 m)
ECe (dS m^{-1})	0.57	0.55
pH	8.12	8.09

Table 15 shows, respectively, the electrical conductivity ECe (dS m^{-1}) and the pH of soil, using distilled water, along the soil profile – 0.00-0.20 m and 0.20-0.40 m depth, on September – just after the end of the experiments (15a, 15b), for the different experimental fertilization and irrigation levels

Table 15a - Electrical conductivity ECe (dS m^{-1}) of soil, using distilled water, 0.00-0.20 m, on September – just after the end of the experiments, for the different experimental fertilization and irrigation levels

Ki	N0K0	N1K1	N1K2	N2K1	N2K2
0.1	0.22	0.22	0.28	0.28	0.22
0.5	0.22	0.31	0.40	0.41	0.29
0.9	0.21	0.34	0.22	0.39	0.28
1.2	0.18	0.38	0.36	0.31	0.22
1.6	0.40	0.25	0.42	0.28	0.22

Table 15b - Electrical conductivity ECe (dS m^{-1}) of soil using distilled water, 0.20-0.40 m, on September – just after the end of the experiments, for the different experimental fertilization and irrigation levels

Ki	N0K0	N1K1	N1K2	N2K1	N2K2
0.1	0.32	0.66	0.63	0.74	0.25
0.5	0.32	0.74	0.55	0.65	0.35
0.9	0.35	0.54	0.46	0.56	0.27
1.2	-	0.54	o.64	0.48	0.29
1.6	-	0.50	0.73	0.52	0.33

Table 16 shows, respectively, the pH of soil using distilled water, along the soil profile – 0.00-0.20 m and 0.20-0.40 m depth, on September – just after the end of the experiments (15a, 15b), for the different

Table 16a - pH of soil with distilled water, 0.00-0.20 m depth on September – just after the end of the experiments, for the different experimental fertilization and irrigation levels .

Ki	N0K0	N1K1	N1K2	N2K1	N2K2
0.1	8.46	8.21	8.46	8.48	8.21
0.5	8.52	8.41	8.10	8..12	8.22
0.9	8.36	8.37	8.14	8.22	8.23
1.2	8.34	8.16	7.94	8.33	8.11
1.6	8.14	8.22	7.74	8.17	8.14

Table 16b - pH of soil with distilled water, 0.20-0.40 m depth on September - just after the end of the experiments, for the different experimental fertilization and irrigation levels .

Ki	N0K0	N1K1	N1K2	N2K1	N2K2
0.1	8.16	7.81	7.89	7.99	8.13
0.5	8..24	8.07	8.26	7.98	8.08
0.9	8.50	8.18	8.34	8.12	8.18
1.2	8.03	8.17	7.93	8.43	8.39
1.6	7.90	8.03	7.87	7.99	8.13

IV. DISCUSSION

A. Bermuda grass yield

The subplots where were applied higher amounts of nitrogen (N2K2 and N2K1) have had always a higher response to the increase of the irrigation amounts (higher Ki values), expressed by the higher grass yields than the subplots fertilized with lower amounts of nitrogen. The non fertilized subplot (N0K0) was the place where grass yield was lower and, simultaneously, was also the subplot where yield was less conditioned by the Ki. On the other hand, the higher amounts of potassium, applied with the same amount of nitrogen, increased the grass yield. However this increase was lower than the increase due to nitrogen fertilization, and simultaneously, there was lower influence of the Ki (water amounts). Hence, it was shown that the fertilization, namely the nitrogen fertilization, enhanced the response of the grass to the increased amounts of irrigation wastewater.

The grass yields obtained with large amounts of water (high Ki values) in low fertilized subplots, were lower than those obtained with lower Ki values on the higher fertilized subplots.

The low increases of grass yield in the non fertilized subplot (N0K0) are probably may related be probably to the effect of the nutrients of the wastewater [37]..

The pernicious effects of salinity of wastewater (ECw = 1.54 – 1.65 dS m^{-1}) on the Bermuda grass probably may be decreased by the increase of nitrogen and / or potassium fertilization [38]. This is due to the fact, that until a certain salinity concentration of irrigation water is reached, enhanced nitrogen / potassium nutrition, also enhanced the salinity threshold value at which yield starts to decrease with salinity [39]. The increase of yields with the enhance of irrigation wastewater amounts showed that the Bermuda grass consumed enough water, not only to compensate the transpiration water losses, but also to provide its own growth and development.

B. Bermuda grass quality

The different applied fertilizations had effects on grass quality, namely on the color of the leaves (the parameter used to define the grass quality). Thus, in the subplots fertilized with larger nitrogen amounts (N2K2 and N2K1), the good visual appearance GVA was obtained in April and May for a K1 > 0.5 and in July and August for a Ki > 0.7 / 0.8. On the other hand, the subplots where nitrogen fertilization was lower (N1K2 and N1K1), the GVA was obtained a larger Ki values, varying from Ki > 0.7 up to Ki > 1.2. This aspect shows the importance of the nitrogen when compared to potassium, in grass color (due to its component of the chlorophyll molecule).

When there was no fertilization (subplot N0K0), the Ki value was larger, from Ki > 1.0 up to Ki > 1.4. Thus, in spite of the higher Ki, it was shown that the nutrients of the irrigation wastewater were enough to be obtained a GVA of the Bermuda grass.

c. Soil profile

The N2K1 and N2K2 treatments presented higher soil nitrate concentrations, due to the fact that they received higher amounts of nitrogen along the trial period. Soil nitrites content, ranged between 0.00 and 0.17 ppm, was always very low, once that they represent an intermediary form from the ammonium to the nitrate stage of nitrogen, occurring this process generally very fast. The soil ammonium did not present significant differences, being lower in September than in July; this is due, probably, to the first significant rain occurred in September, during the soil sampling, resulting in a larger soil leaching.. The soil nitrogen content was higher on soil surface (0.00-0.20 m); it may be explained by the low soil permeability and by the nutrients content of the irrigation wastewater. Regarding to the soil potassium content there were no very significant differences among treatments however, for greater depths, potassium content was higher, mainly for higher potassium fertilization treatments.

Electrical conductivity of soil (ECe) ranged between 0.18 and 0.74 dS m^{-1}, increasing with fertilizers application.

The pH ranged between 7.8 and 8.4 and increased very slightly, with the increase of the nitrogen fertilization, decreasing also slightly with soil depth.

V. CONCLUSION

It was demonstrated that what is important in golf course, extended to all sport fields, is the quality of the lawns, which are not related only with the yield. The quality, expressed by the color, is, besides the yield, also depending on the irrigation water amounts, fertilization, climate, cultivars, salinity and soil and water characteristics. It is focused the importance of the concentration of the nutrients of the irrigation wastewater. Sometimes they are enough to be obtained a good visual appearance of lawns, without the application of fertilizers, if wastewater amounts are enhanced. Thus, for larger nitrogen amounts, the good visual appearance of Bermuda grass GVA was obtained in April and May for a crop coefficient adapted to the irrigation design Ki > 0.5 and in July and August for a Ki > 0.7 / 0.8. On the other hand, when there was no fertilization, the Ki value was larger, from Ki > 1.0 up to Ki > 1.4. Therefore, in spite of the higher Ki, it was shown that the nutrients of the irrigation wastewater were enough to be obtained a GVA of the Bermuda grass. Thus, often there is no need to increase the grass yield, once that production factors (such as the cuts frequency, water and nutrients), will enhance the expenses of the lawns maintenance and have a negative impact on the environment. Moreover, it was shown that very strong fertilizations may contaminate soil, along its profile, and, therefore, may reach groundwater. As concluding remarks, it was shown that these experiments have contributed to the development of the sustainable management of treated wastewater resources in golf courses of arid and drought-prone regions of the Mediterranean basin.

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REFERENCES

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

[2] Kyritsis, S. 1996.Waste-water reuse. In: Sustainability of irrigated agriculture (ed. L.Pereira, L.S.; R.A. Feddes; J.R. Gilley; B. Lesaffre): 417-428. NATO ASI Series, Kluwer Academic Publishers.

[3] Hamdy, A. 2002. Sustainable use and Management of non-conventional water resources in the arid regions. *Acta Horticulturae* 573:159-172

[4] 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.

[5] 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.

[6] Loureiro, S.; Newton, A.; Icely, J. 2005. Effects of nutrients enrichments on primary production in the Ria Formosa coastal lagoon (Southern Portugal). *Hydrobilogia* 550:29-45.

[7] Meyers, L.; Pedro, P.; Beltrao, J.; Giesche, C.; Dionisio, L. 2010. Anthropogenic effects in a coastal lagoon (South Portugal) related to tidal and spatial changes in nutrients. WSEAS *Transactions on Enviroment and Development* 6(11):529-538.

[8] Snyder, G; Cisar, J. 2000. Nitrogen / Potassium fertilization ratios for Bermuda grass turf. *Crop Science* 40(6);1719-1723.

[9] Westerman, R.; O'Hanton, R.J.; Minter, D.L. 1983. Nitrogen fertilizer efficiency in Bermudagrass production. *Soil Sci. Soc. Am. J.* 47(4):810-817.

[10] Miller, G.; Dickens, R. 1996a. Bermuda grass carbohydrate levels as influenced by potassium fertilization and cultivar. . *Crop Science* 36: 1283-1289..

[11] Miller, G.; Dickens, R. 1996b. Potassium fertilizers related to cold resistance in Bermuda grass. *Crop science* 36: 1290-1295.

[12] Achilea, O. 2002. Alleviation of salinity – Induced stress in cash crops by multi-K (potassium nitrate); five cases typifying the underlying pattern. *Acta Horticulturae* 573:43-48.

[13] Ben Asher, J.; Pacardo, E. 1997. K uptake by root system grown in saline soil: A conceptual model and experimental results. Food security in the Wana region, the essential need for balanced fertilization: 360-369 International Potash Institute, Basel, Switzerland.

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

[15] Beltrão, J.; Gamito, P.; Guerrero, Arsénio, A. & Brito, J.M.C.1999. Grass response to municipal wastewater as compared to nitrogen and water application. In: D. Anaç

& P. Martin-Prével (Eds.). Improved Crop quality by Nutrient management, Chapter 60: 263-266. Kluwer Academic Publishers.

[16] Carrow, R.; Johnson, B.; Burns, R. 1987. Thatch and quality of tifway bermudagrass turf in relation to fertility and cultivation. *Agronomy Journal* 79:524-530.

[17] 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 .

[18] Ben Asher, J.; Beltrao, J.; Costa, M,; Anac, S.; Cuartero, J.; Soria, T. 2002. Modelling the effect of sea water intrusion on ground water salinity in agricultural áreas in Israel, Portugal, Spain and Turkey. *Acta Horticulturae* 573:119-128.

[19] FAO-ISSS-ISRIC 1998. World referencebase for soil resources, 87p.

[20] Beltrao, 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.

[21] Mateo Box, J.M; Urbano, P. (1985). The Turfgrasses. 2ed. Madrid, Spain (spanish).

[22] Beard, J. B. (1982). Turfgrass management for golf courses. Prentice Hall. Englewood Cliffs, USA.

[23] Hartman, H. D.; Zengerle. K. H.. 1985. New method to optimize the irrigation. Gemuse 5:227-229. (German)

[24] Or, D.; Hanks, R. 1992. A single point source for the measurement of irrigation production functions. *Irrig. Sci.* 13:55-64.

[25] Christiansen, J. 1942. Irrigation by sprinkling. *Calif. Agron. Esp. Bulletin* 640. USA.

[26] Allen, R.G.; Pereira, L.S.; Raes, D.; Smith,, M. 1998. Crop evapotranspiration..Guidelines for computing crop water requirements. *FAO* Irrig. Drain. Paper 56, Rome, Italy.

[27] Doorenbos, J. & Pruitt, W.O. 1984. Guidelines for predicting crop water requirements. FAO Irrig. Drain. Paper 24. Rome, Italy.

[28] Allen, R.G.; Pereira, L.S.. 2009. Estimation crop coefficients from fraction of ground cover and height. Irrigg. Sci. 28:17-34.

[29] Beltrão, J. 1999. Irrigation experimental designs. Special Session on Non-conventional Water Resources Practices and Management. EU.DGI / CIHEAM-IAM.B, IAV Hassan II, Rabat, Morocco (pp. 209-227).

[30] Turgeon, A. 1980. Turfgrass management. Engelwood Cliffs, Prentice Hall. EUA.

[31] 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.

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

[33] RHS. 2001. The Royal Horticultural Society Colour chart. London, UK.

[34] Costa, M.; Beltrão, J.; Brito, J.; M.; Guerrero, C. 2011. Turfgrass plant quality response to different water regimes. *WSEAS Transactions on Environment and Development*. 7(6):167-176.

[35] SPSS 11.0. 2002. SPSS Inc., Chicago, Illinois, U.S.A.

[36] Panagopoulos, T.; Jesus, J.; Antunes, M.D.C.; Beltrao, J. 2006. Analysis of spatial interpolation for optimising management of a salinized field cultivated with lettuce. *European Journal of Agronomy* 24:1-10.

[37] Beltrao, J.; Correia, P.J, Costa, M. Gamito, P, Santos, J.; and Seita, J. 2013. The influence of nutrients on turfgrass response to treated wastewater application, under several saline conditions and irrigation regimes. EWRA.

[38] Beltrao, J.; & Ben Asher, J.1993.Simulation of maize yield response to combined effects of nitrogen fertilization versus irrigation and plant population. Fragoso, M.A.C.; Beusichem, M.L (eds.). Optimization of Plant Nutrition *Developments in Plant and Soil Sciences* 53: 589-592.

[39] Silberbush, M; & Ben Asher, J. 2002. Simulation of nutrient uptake by plants from hydroponics as affected by salinity buildup and transpiration. *Acta Horiculturae* 573 :97-106.

[40] Beltrao, J.; Ben Asher, J; & Magnusson, D. 1993. Sweet corn response to combined effects of saline water and nitrogen fertilization. *Acta Horticulturae* 335:53-58.