BUFFERING CAPACITY AND PHYTOREMEDIATION POTENTIAL OF DRAINAGE CANALS AS A LOW COST AGRI-ENVIRONMENTAL MEASURE

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SUMMARY

Drainage canals are areas of accumulation of organic debris due to erosion and growth of plants such as Phragmites australis. Denitrification is one of the main biological processes responsible for the buffering capacity against diffuse nitrate pollution due to anaerobic conditions and suitable electron donors. In addition, nitrates and phosphates decrease due to plant uptake. It has been shown in the literature that plants like reeds uptake P throughout the year and then (March – April) release it back in the aquatic environment and their roots. This work aims to estimate the efficiency of drainage canal's sediments to reduce nitrate pollution from ground water as well as the timing of the cutting of the reeds that will maximize the removal of phosphates by plant uptake but also keep the N/P ratio high enough to avoid toxic algal blooms.

The drainage canal is located in Evrotas River Basin, Greece and drains fields of orange groves. To monitor the 3-dimensional variability of hydrology and chemistry of surface and ground water in the drainage canal, eleven multi-level (3, 4 and 5 m) wells were installed. The probes and the drainage canal water were sampled every 2 months (based on the velocity of movement of contaminants) and analyzed for inorganic nitrogen species, phosphates, phenols, dissolved organic carbon (DOC) and nitrogen (DON) and chemical oxygen demand (COD). Plant (reed) samples were collected on a monthly basis to determine the uptake rates by the plants. Laboratory studies on sediment samples from the bottom and the bank of the drainage canal were conducted to study the predominant processes in the N and P cycles.

Field studies and water chemistry monitoring: The ground water underneath the orange grove is anoxic with high COD, phenols, DOC and DON and NH3-N and seasonally with NO3-N. The high organic load is due to the type of soil which is tyrf. There was generally a consistent decrease of pollutants between the ground water and the drainage canal suggesting natural attenuation mechanisms in action. The molar ratio of DIN/DIP for the drainage canal ranging on average from 6 to 849 suggesting P limitation to eutrophication. The drainage canal phosphate concentrations were also highly variable, ranging from less than 9 μg/L to 399 μg/L, and exceed the eutrophication criteria for lakes, after the cutting of the reeds. The Nitrate concentrations in the drainage canal are less than the ground water with the exception when there was significant contribution from surface runoff .

Laboratory processes studies: The redox potential of the sediment sample was lower than -50 mV suggesting potential for denitrification. Batch leaching experiments also indicated potential conditions for denitrification under anaerobic conditions. Potential mineralizable nitrogen was estimated to be 15 ppm. Sediment had a very large capacity to absorb phosphorous. The partition coefficient (Kd) was estimated to be 300 mL/g.

Estimation of phytoremediation potential and nitrate buffering capacity: The reeds have a maximum accumulation of N and P during spring. In May 2008 where the biomass and the nutrient content have reached maximum values for the growing season and N/P ratio of surface water is high enough to avoid toxic algal blooms, cutting of the above ground biomass of the reeds would totally remove, for the whole length of the drainage canal, 1.4 kg P and 6.3 kg N. The drainage canal sediments have a significant reductive capacity reducing in this way the concentration of nitrate from groundwater. It was estimated that the nitrate load from groundwater to the drainage canal was reduced by 88%. In totally, for the whole length of the drainage canal, 92 kg N were removed (estimation for the period November 06 to January 08). Overall, drainage canal management is suggested as an efficient low cost – high gain agri-environmental measure, which is easy to be adapted by farmers, to reduce diffuse nutrient pollution.

Figure 1. Views of drainage canals at Skala area.

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ABSTRACT

In riparian areas like drainage canals denitrification is one of the main biological processes responsible for the buffering capacity against diffuse nitrate pollution due to anaerobic conditions and suitable electron donors. In addition, nitrates and phosphates decrease due to plant uptake. Plants like Phragmites australis uptake phosphorous through out the year and then (March – April) release it back in the aquatic environment and their roots. Cutting the reeds the proper time, results in the reduction of P in the receiving surface water bodies. This work aims to estimate the nitrate buffering capacity of a drainage canal's sediments as well as the phytoremediation potential, due to Phragmites australis.

1. INTRODUCTION

Drainage canals are areas of accumulation of organic debris due to erosion and growth of plants such as Phragmites australis (common reeds). Denitrification is one of the main biological processes responsible for the buffering capacity against diffuse nitrate pollution due to anaerobic conditions and suitable electron donors (Hiscock and Grischek, 2002). In addition, nitrates and phosphates decrease due to plant uptake. Phragmites can also promote phosphorus absorption onto the sand by the release of oxygen from the roots. It has been shown in the literature that plants like reeds uptake phosphorous through out the year and then (March – April) release it back in the aquatic environment and their roots (Graneli et al., 1988). Cutting the reeds the proper time, results in the reduction of P in the receiving surface water bodies (Nikolaidis et al., 1996). This work aims to estimate the efficiency of drainage canal's sediments to reduce nitrate pollution from ground water as well as the timing of the cutting of the reeds that will maximize the removal of phosphates by plant uptake but also keep the N/P ratio high enough to avoid toxic algal blooms (Nikolaidis et al., 2005).

2. MATERIALS AND METHODS

The drainage canal is located in Evrotas River Basin, Greece and drains fields of orange groves. To monitor the 3-dimensional variability of hydrology and chemistry of surface and ground water in the drainage canal, eleven multi-level (3, 4 and 5 m) wells were installed (figure 1). The water depth was monitored on a monthly basis. The hydraulic characteristics of the subsurface were determined by conducting single well pumping tests and the infiltration capacity of the fields was estimated by conducting in situ infiltration experiments. The probes and the drainage canal water were sampled every 2 months (based on the velocity of movement of contaminants) and the basic physicochemical parameters (pH, temperature, conductivity, dissolved oxygen, and, redox potential) were measured in situ. The samples were analyzed for inorganic nitrogen species (DIN) – nitrates (NO3-N), nitrites (NO2-N) and ammonia (NH3-N), phosphates (DIP), total phenols (T.phenols), dissolved organic carbon (DOC), chemical oxygen demand (COD) and Kheldalh nitrogen (TKN). Dissolved organic nitrogen was derived by the abstraction of ammonia from the TKN. The canal was cleared of all plants in December of 2006 and May 2007. Plant (reed) samples were collected on a monthly basis to determine the uptake rates by the plants regarding nutrients (nitrogen and phosphorus). Laboratory studies on sediment samples from the drainage canal were conducted to study the predominant processes in the nitrogen and phosphorous cycles.

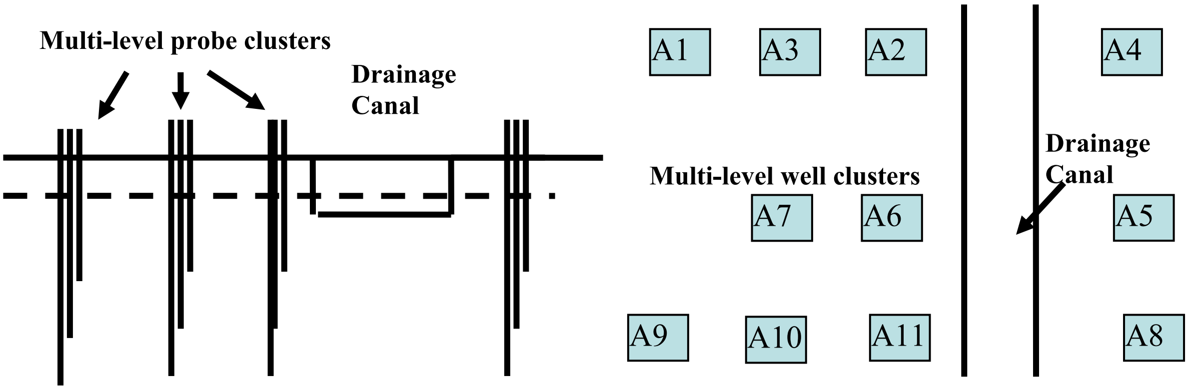

Figure 1. Multi-level probe design in relation to drainage canal.

3. RESULTS AND DISCUSSION

Field studies and water chemistry monitoring: Based on the vertically averaged values of the hydraulic conductivity (table1) and the hydraulic gradient established by the piezometric heads of the water table, the velocity of the ground water is determined and then the travel time of the water. The travel time of the ground water was 16 d/m and near the drainage canal (where the gradient is steeper) was 3 d/m. The infiltration rate under steady state of moisture was estimated using Horton's equation to be 0.0135 cm min-1. Seven sampling sessions were conducted. A few wells were sampled in November 2006 and January of 2007 and many wells were sampled in March, May and July and November 2007 and March 2008. The total averages and seasonal averages results of these sampling sessions are presented in table 2 and figure 2, respectively. The ground water underneath the orange grove is anoxic with high COD, phenols, DOC and DON and ammonia and seasonally with nitrates. The high organic load is due to the type of soil which is tyrf. The surface water has significantly lower concentrations of nitrates, ammonia, COD, and DOC. There was generally a consistent decrease of pollutants between the ground water and the drainage canal suggesting natural attenuation mechanisms in action. The organic N fraction of the total N is significantly high ranging on average from 43% to 84% of the total N for the ground water. The average ratio of DOC to DON in ground water is relatively low ranging from 3.6 to 20.8 with a total average of 15, suggesting abundance of organic N. The molar ratio of DIN/DIP for the ground water was highly variable ranging on average from 10 to 288, with a total average of 67 and of drainage canal 6 to 849 suggesting P limitation to eutrophication. The drainage canal phosphate concentrations were also highly variable, ranging from less than 9 μg/L to 399 μg/L, and exceed the eutrophication criteria for lakes (20 μg/L), after the cutting of the reeds. This variability can be explained by comparing the P concentrations in the ground water, drainage canal together with the timing of cutting the reeds (December 2006). The drainage canal was oligotrophic due to P uptake and once the reeds were cut (December 2006) it became successively mesotrophic to eutrophic. The Nitrate concentrations in the drainage canal are less than the ground water with the exception when there was significant contribution from surface runoff .

Table 1. Sediment physicochemical characteristics.

Variable	Mean value
Hydraulic conductivity, m/d	
Groundwater	0.691
Drainage canal recharge	0.587
Darcy velocity, m/day	
Groundwater	0.062
Drainage canal recharge	0.354
Drainage canal Length, m	180
Latitude of reeds zone	1.5
Density of reeds, clones/m2	15

Table 2. Hydraulic and Drainage canal characteristics

Variable	Mean value
pH	7.62
Conductivity, μS/cm	218
Dry bulk density, kg/m3	1156
Porosity, %	30.9
Organic carbon, ppm	14217
Kheldalh nitrogen, ppm	2143
Total P, ppm	3124
C:N	4,55
Texture	sandy clay loam

Table 3. Averages from seven sampling sessions (November 2006 to March 2008) of physicochemical parameters (standard deviation in parenthesis) of surface water and ground water underneath Drainage Canal at Skala.

	Ground water	Drainage Canal
Number of samling sessions	7	5
Number of total samples	105	7
Temperature (oC)	19.6 (2.5)	18.9 (2.3)
pH	7.23 (0.11)	7.31 (0.20)
DO (mg/L)	1.6 (0.6)	6.1 (1.7)
Conductivity (μS/cm)	941 (227)	758 (255)
Eh (mV)	111.0 (37.7)	171.4 (26.0)
COD (mg/L)	23.9 (19)	7.4 (5.4)
NO2-N (mg/L)	0.049 (0.078)	0.006 (0.002)
NO3-N (mg/L)	1.380 (2.144)	1.875 (1.594)
NH3-N (mg/L)	0.373 (0.125)	0.037 (0.015)
PO4-P (mg/L)	0.087 (0.049)	0.120 (0.168)
T.phenols (mg/L)	1.828 (0.885)	1.259 (0.811)
DOC (mg/L)	13.8 (4.2)	3.6 (2.8)
DON (mg/L)	2.316 (1.334)	2.324 (2.512)
DIN (mg/L)	1.677 (1.936)	1.917 (1.582)
DON/TDN	0.67 (0.17)	0.26 (0.40)
DOC/DON	15.4 (10.7)	2.9

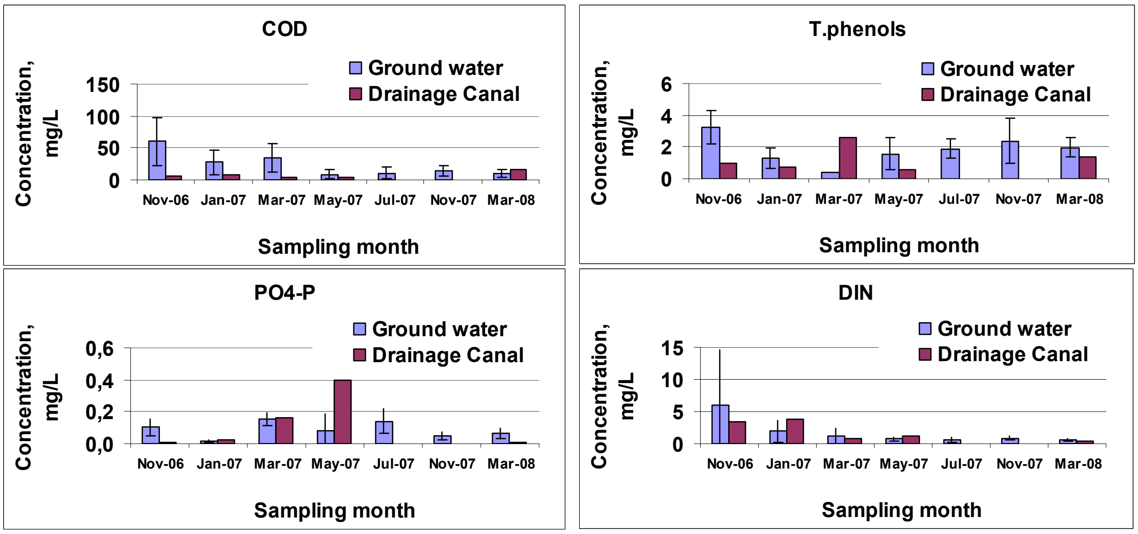

Figure 2. Comparison of COD, T.phenols, PO4-P, and DIN between ground water and drainage canal water at Skala from November 2006 to March 2008.

Laboratory processes studies: The potential for denitrification was examined was determined using two experiments; one was the evolution of redox potential of the sediment (batch experiment at 25 ^{o}C, where the oxygen was removed with constant flow of nitrogen gas) and the other batch leaching experiments. The redox potential (Eh) of the sediment sample was lower than -50 mV suggesting potential for denitrification (figure 3a). Batch leaching experiments were conducted to evaluate the potential of sediments to release dissolved N species and carbon (Figure 3b). Thed results suggested a 2-3 mg/L of nitrate N and DOC removal from the system, while there was a 5 mg/L increase in ammonia-N. The DON partitioning with the solid phase remained contant. Anaerobic conditions prevented the nitrification process. Short-term potential mineralizable nitrogen (PMN) was estimated, as ammonium-nitrogen production under waterlogged condition for 7 d (Bundy and Meisinger, 1994), to be 15 ppm. Studies of the sorption of phosphates suggested that the sediment had a very large capacity to absorb phosphorous. Sorption isotherm did not exhibit any plateau in the sorption capacity suggesting the possibility for surface precipitation. The partition coefficient (Kd) was estimated to be 300 mL/g and the Equilibrium P concentration (EPC_0) was estimated to be 0.08 mg/L (Smith et. al., 2005). The levels of phosphorous in the aqueous phase were seasonally below the EPC_0 making the process inactive.

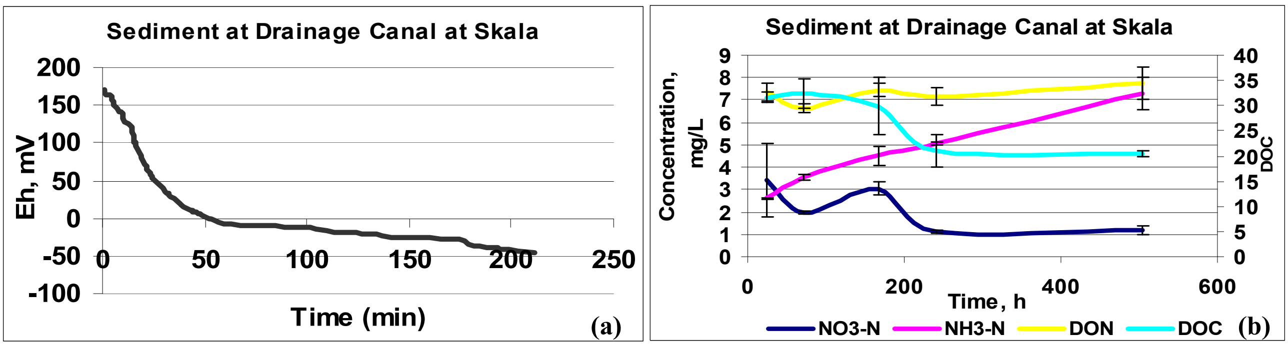

Figure 3. a) Sediment redox potential, and b) released concentrations of dissolved NO3-N, NH3-N, DOC, and DON from the sediment.

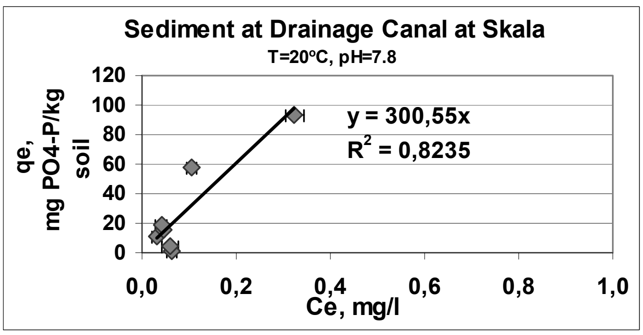

Figure 4. Phosphate sorption isotherm at 20^{o}C and pH value at 7.8.

4. CONCLUSIONS

Estimation of phytoremediation potential and nitrate buffering capacity: The analysis of monthly samples of reeds suggested that a significant accumulation of N and P was achieved of the order of 20 and 3 g/Kg respectively. Cutting of the reeds affects directly the P uptake and the eutrophication status of the drainage water. The reeds have a maximum accumulation of N and P during spring. In May 2008 where the biomass and the nutrient content have reached maximum values for the growing season and N/P ratio of surface water was high enough to avoid toxic algal blooms, cutting of the above ground biomass of the reeds would totally remove, for the whole length of the drainage cana, 1.4 kg P and 6.3 kg N. It has been suggested that 25-50% of P from the stems and leaves returns to the roots for next growing season fertilization (Graneli et al., 1988). This translocation ecotype pattern (Lippert et al., 1999) was observed also in this study. The drainage canal sediments have a significant reductive capacity reducing in this way the concentration of nitrate from groundwater. It was estimated, (calculation of fluxes with available field data), that the nitrate load from groundwater to the drainage canal was reduced by 88%. In totally, for the whole length of the drainage canal 92 kg N was removed (estimation for the period November 06 to January 08). Overall, drainage canal management is suggested as an efficient low cost – high gain agri-environmental measure, which is easy to be adapted by farmers, to reduce diffuse nutrient pollution.

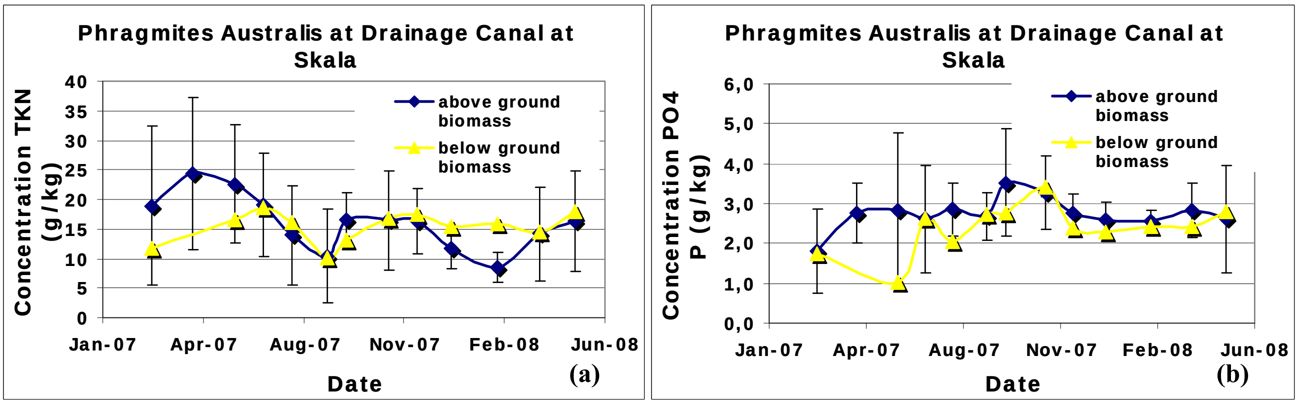

Figure 3. Seasonal pattern of a) total nitrogen, and b) phosphorus concentration in above (average of three vertical parts of shoot biomass of multi samples), and below (roots and rhizomes) ground reed biomass.

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