MANAGEMENT OF AGRICULTURE LAND USE BASED ON GROUNDWATER SUSTAINABILITY SCENARIOS
A Case-Study in Portugal

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ABSTRACT

WFD states "MS shall implement the measures necessary to prevent or limit the input of pollutants into groundwater and prevent the deterioration of all bodies of groundwater status". This will only be possible if more sustainable and integrated water management procedures are taken at basin scale, where the land cover - land use options consider downgradient water quality.

This project gathers and integrates knowledge of the processes that interfere in the migration of pollutants originated by soil fertilisation, for different media (soil, vadose, and groundwater), encouraging future use of more sustainable agriculture practices, helping a better prevention and control of diffuse pollution, at basin scale.

The results of two years monitoring are presented, for several cultures and soils, at Ferreira do Alentejo, Portugal. The data gathered were modelled in a prospective way aiming to evaluate the effect that different land cover scenarios would have in the regional groundwater quality by 2015.

Key-Words: diffuse pollution; groundwater; sustainability.

1 INTRODUCTION

This paper presents the results of the project POCI/AGR/57719/2004 "Methodologies for a better rural land use planning and management considering aquifer vulnerability to diffuse pollution", based on the final report of the project (cf. Leitão *et al.*, 2009).

This project concentrates efforts in gathering and integrating the knowledge of the processes that interfere in the migration of pollutants originated by soil fertilisation, for the different media, encouraging the future utilization of environmentally more sustainable crops and fertilisation practices.

This was done based on an experimental work developed in three irrigated plots in a small basin of Ferreira do Alentejo, Portugal, where it was analysed, for the years 2006 and 2007, the migration of agriculture pollutants in different media (soil, vadose zone, and groundwater), with experiments done for different cultures (corn, sunflower, melon and cantaloupe melon) and two different soils.

The results presented cover the following issues:

- Case-study and experimental plots characterization.
- Inventory of crops, identification of associated fertilisers and pesticides, irrigation schemes for each crop.
- Description of the monitoring plan inside the experimental plots concerning soils and water quality, as well as in the surrounding areas, for irrigation water, runoff, drainage ditches, vadose zone, and groundwater.
- Monitoring the evolution of soils and water quality for different agriculture practices resulting from corn, melon, and sunflower cultivation practices.
- Analysis and interpretation of the results obtained.
- Groundwater flow and transport model.
- Analysis of different agriculture land cover scenarios for the region (with their specific agriculture practices), considering their effects in downgradient groundwater.

The data gathered allowed concluding that different agricultures practices have different effects in soils and groundwater downgradient.

2 CASE-STUDY AREAS AND AGRICULTURE PRACTICES

The field work was developed in two irrigated plots with center pivot in the same area of the project RECOQUAR "Rede de Controlo da Qualidade da Água de Rega", carried out by COTR between February 2005 and 2007 (COTR, 2008), in a watershed located in "Infra-estrutura 12" of the Alqueva irrigation perimeter (Ferreira do Alentejo). The plots are located in Mancoca and Pinheirinho (cf. Fig. 1).

These two areas have the necessary characteristics required to work out the experiments, namely:

- They are located in the Alqueva irrigation perimeter.
- The field conditions concerning the crops, facilities and local support.
- Soils with favourable permeability rates for the study of pollutants migration in depth.
- They are located in a small watershed with possibility of accessing surface flowrate data and groundwater monitoring infrastructures (wells and large wells).
- Possibility of access to the precipitation and evapotranspiration registers in the Estação Meteorológica do Outeiro, by COTR, to irrigation volumes and fertilisers applied.

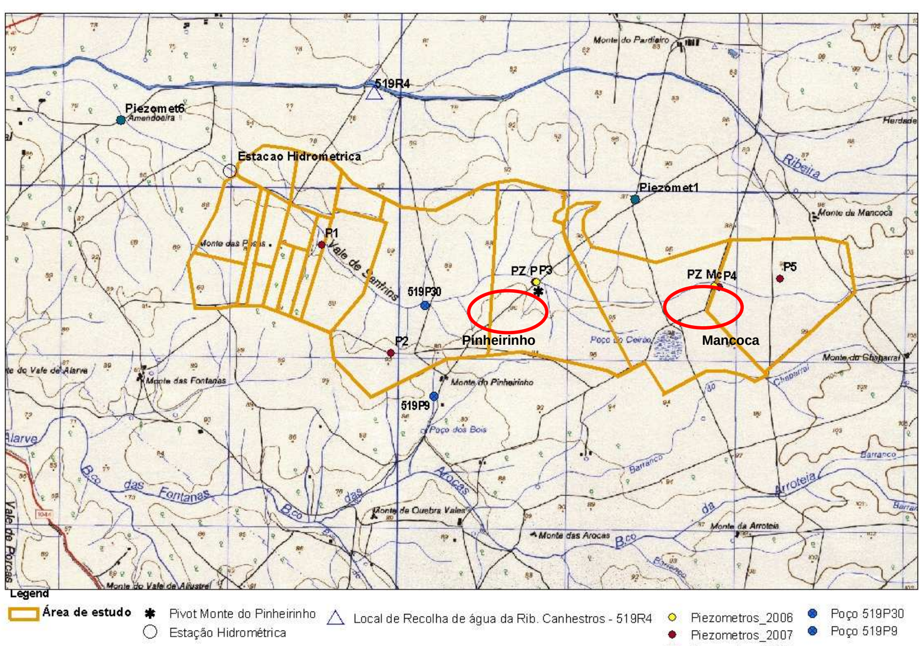


Fig. 1 - Case-study area and monitoring infra-structures (in red are Mancoca and Pinheirinho sites)

The choices of the crops as well as general cultivation management options were established by the farmers. Three different plots were selected in which different crops were seeded each year (cf. Fig. 2 and Table 1).

Fig. 2 – Corn crop in Mancoca, two weeks after sow

Table 1 – Type of crops in 2006 and 2007

Local	Designation	Crop type
2006		
Mancoca	MMAFC	Corn, with basal and top dressing (fertigation)
Pinheirinho	PMAFLC	Corn, with basal and top dressing (fertigation)
	PGSAFC	Sunflower, without basal and top dressing (although with
2007		
Mancoca	MM	Corn, with basal and top dressing (fertigation)
Pinheirinho	PML1	Melon, drip irrigation (fertigation)
	PML2	Melon, drip irrigation (fertigation)

The experimental setup built in the three irrigated plots, as described in the next sections, aimed at soil and water sampling for chemical analysis throughout the experimental period, inside and outside the plots, although just the first ones are referred to in this article. In what concerns the agriculture management practices adopted, details are given in Leitão *et al.* (2009). Shortly:

1) In 2006, the irrigation method used in the plots was the centre-pivot, for about 23 hectares irrigation.

In Mancoca there were 62 irrigation periods done between May 24th and September 11th 2006, with a total of 574 mm. In Pinheirinho and for corn crop there were 77 irrigations done until September 4th, with a total of 630 mm. For the sunflower crop, the irrigation applied was 109 mm done in 12 irrigation periods.

In Mancoca in was done basal dressing before seeding and during the irrigation with the liquid fertilizer Humifosfato 15 (30% de N, nitro-zinc and calcium+magnesium). In Pinheirinho, and for the sunflower, there was no fertilisation.

2) In 2007, the irrigation method used in Mancoca was the centre-pivot. In Pinheirinho it was drip irrigation.

In Mancoca there were 87 irrigation periods, between April 28th and September 8th, totalizing 672 mm. In Pinheirinho there were 65 irrigation periods, between June 8th and September 5th, totalizing 213 mm. The fertilization in Mancoca was similar to the one described for 2006.

3 METHODS

Specific physico-chemical characterization works refer to the development of the following tasks:

- Physico-chemical characterization of the plots in terms of:
  - o Soils (at the depths of 0 -15 cm, 15 - 30 cm, 30 - 45 cm, 45 - 60 cm and 60 - 75 cm) (Fig. 3): texture, soil bulk density, porosity, humidity, specific soil water retention and hydraulic head, root density, pF curves, ionic concentration and cation exchange capacity.
  - o Water: irrigation, drainage ditches, surface runoff, vadose zone, groundwater. In them it was analysed the water levels/volume, physico-chemical parameters and ionic concentrations.
- Observation and quantification of the corn root development, in different pedological units, comparing the effects of different seeding techniques. Use of the Minirhizotron (cf. Fig. 4) by Évora University.
- Data results analysis and its interpretation.


Fig. 3 – Soil collection and classification by Évora University


Fig. 4 – Tube for insertion of the transparent tube and endoscope BTC Minirhizotron Camera Systems, Évora University

The water sampling sites were selected considering the expected water quality evolution along the experiments. This analysis was completed at a macro scale, *i.e.* in the plots surrounding area, as well as inside the plots. In this paper only the latter will be analysed.

The water quality inside the plots was analysed for each case-study for: surface runoff; vadose zone at three depths (2 Teflon® cups were installed at each depth); and the saturated zone, in wells installed for this study. Fig. 5 to Fig. 7 illustrate the installation procedure of these equipments.

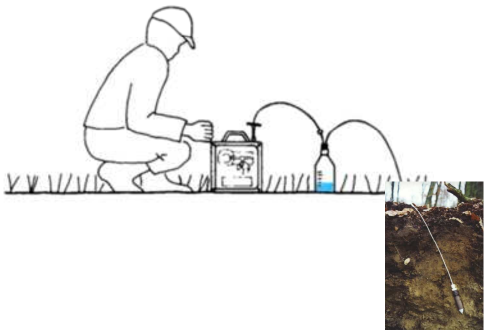


Fig. 5 – Surface runoff sampler

Fig. 6 - Teflon® capsules – vadose zone

Fig. 7 - Piezometer – groundwater

The values for electrical conductivity, pH, Eh and temperature were measured on site. The parameters NO_2^-, NO_3^-, PO_4^{3-}, Ca^{2+}, Mg^{2+}, Na^+, K^+, CO_3^{2-}, SO_4^{2-}, Cl^- and COT were analysed in the lab, monthly.

4 MONITORING FINDINGS AND DISCUSSION

4.1 Soils

Mancoca soil has a texture which is mainly sandy in the first 45 cm of the soil. After that, a layer of clay-sandy soil appears, becoming more clay with depth. This change has as consequence the formation of a level where the accumulation of irrigation water can be seen, together with the accumulation of salts in the same horizon.

Pinheirinho soil has a texture which is mainly clay-sandy, becoming more clay at 60 to 75 cm depth. The permeability of these soils in lower that the ones of Mancoca, making it more difficult the infiltration and favouring the surface runoff.

Fig. 8 presents a graphic with the soil water quality characteristics in 2006, before the experiments, for major cations and nitrates for the depths of: 0 - 20 cm, 20 – 40 cm and 40 – 60 cm.

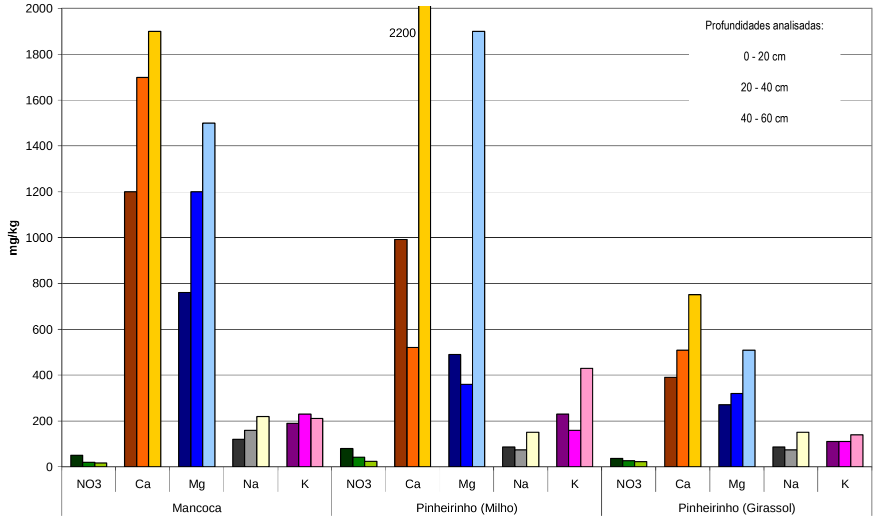


Fig. 8 – Soil quality for major cations and nitrates, in the three study areas before seeding

Fig. 8 allows seeing that the higher concentrations of nitrate are observed for the first soil horizons, decreasing with depth. The nitrates concentration before seeding show to be already high, as a result of previous agriculture in the area, with values ranging from 17 to 80 mg NO_3^-/kg.

The results for corn root development show a stronger root density at 30 cm for horizon A, MMAFC, when compared to PMAFLC (cf. Table 1). This is a result of the difficulty of roots to penetrate clay soils, forcing therefore their development in the first soil horizon, which avoids appropriate plant water suction from deeper levels.

4.2 Water

4.2.1 Surface runoff

Fig. 9 and Fig. 10 present the results obtained in the four experiments done with sprinkler irrigation. In can be clearly seen an increase of nitrates along the experiment due to the soil fertilisation, although it was not always possible to directly connect the results with the irrigation periods due to lack of sampling (cf. Leitão *et al.*, 2009). These runoff concentrations have their effects in the downgradient water quality at the vadose zone, surface water ditches as well as in some piezometers located close to the plots, as seen in the next sections.

In order to have a comparison level, the irrigation water quality values, prior to fertilisation, are also presented in Fig. 9. In some cases the irrigation surface runoff water was collected in stagnant waters, therefore increasing the ionic concentration values due to evaporation.

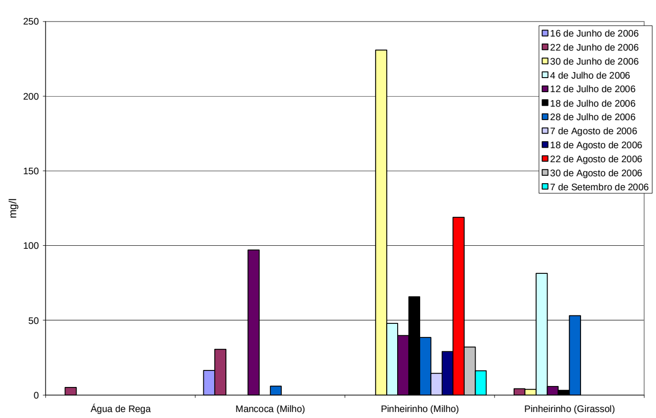


Fig. 9 – Nitrate content in the runoff water for the three case-study areas, 2006

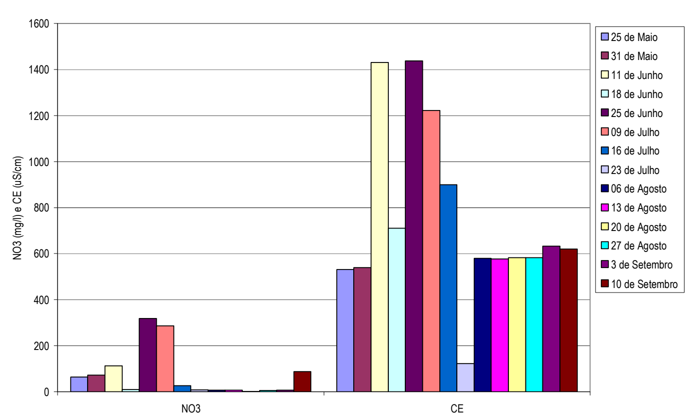


Fig. 10 - Nitrate content and electrical conductivity in the runoff water for Mancoca, 2007

4.2.2 Vadose zone water

Fig. 11 and Fig. 12 present the results of the analysis of electrical conductivity measured in a weekly basis from May to September, in the years 2006 and 2007, at three depth 20, 40 and 60 cm, in the vadose zone, for 4 of the 6 experiments carried out.

The water electrical conductivity shows its higher values for Mancoca and the year 2006, where it is possible to see EC values increasing along the irrigation period in all the 3 soil horizons analysed, with the highest value (10,79 mS/cm) being attained at August 7th at the depth of 60 cm. In fact, it is at this depth that the highest levels of ions concentration are found (also for 2007) due to their lixiviation until a level where a more impervious layer in found, *i.e.* about 60 cm (cf. Fig. 11). In 2006, it is also possible to see a small decrease after August 7th, in a period where no more fertilisers are applied to the irrigation water.

In 2007 the samples that where collected at Mancoca are much less due to the destruction of the sampling equipment. Nevertheless, from the existing results it seams that the concentrations are lower than in 2006.

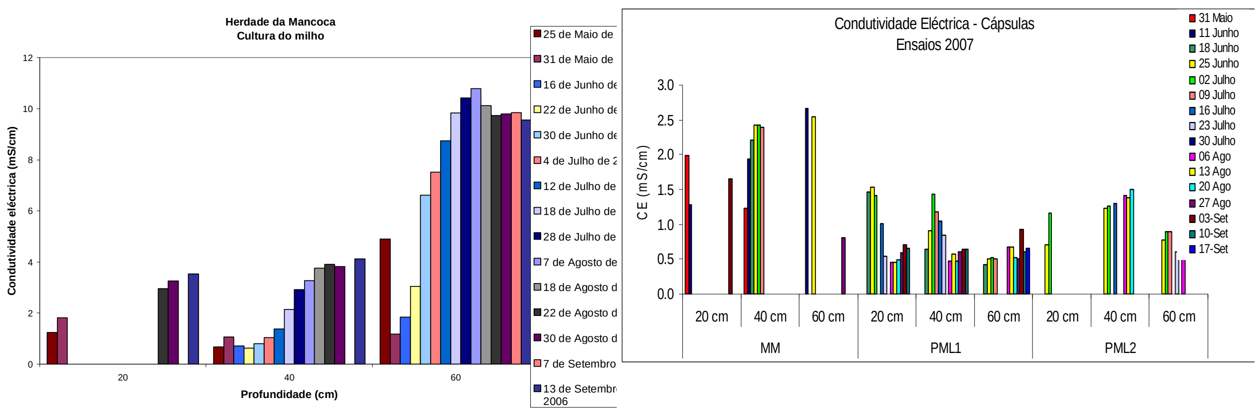


Fig. 11 - Electrical conductivity in the vadose zone for different plots in 2006 for Herdade da Mancoca (right) and in 2007 in the three case-study areas (left)

For Pinheirinho plots the higher values for EC are clearly lower than those found for Mancoca, in both years. It is also possible to observe that EC values are higher in the first soil centimetres due to the low infiltration rates of these soils, allowing salts accumulation.

Among the other chemicals monitored for this study, only nitrate content was selected as an example for this paper. Leitão *et al.* (2009) present in a more detailed way the results for all other monitored ions. In general terms, the corn crop at Mancoca shows the highest values for cations and anions, especially for nitrate in 2006. In 2007, even with the absence of data for several periods, it is clear the decrease in ionic concentrations.

For the melon crop at Pinheirinho, in 2007, the results obtained show a great increase in nitrate due to the initial fertilisation procedures applied during the month of June. During the end of July and the beginning of August a decrease in concentration can be observed (cf. Fig. 12) due to their dilution with the fresh irrigation water. After that period, some increase can be again observed, possibly due to the soil washout induced by the rain events occurred.

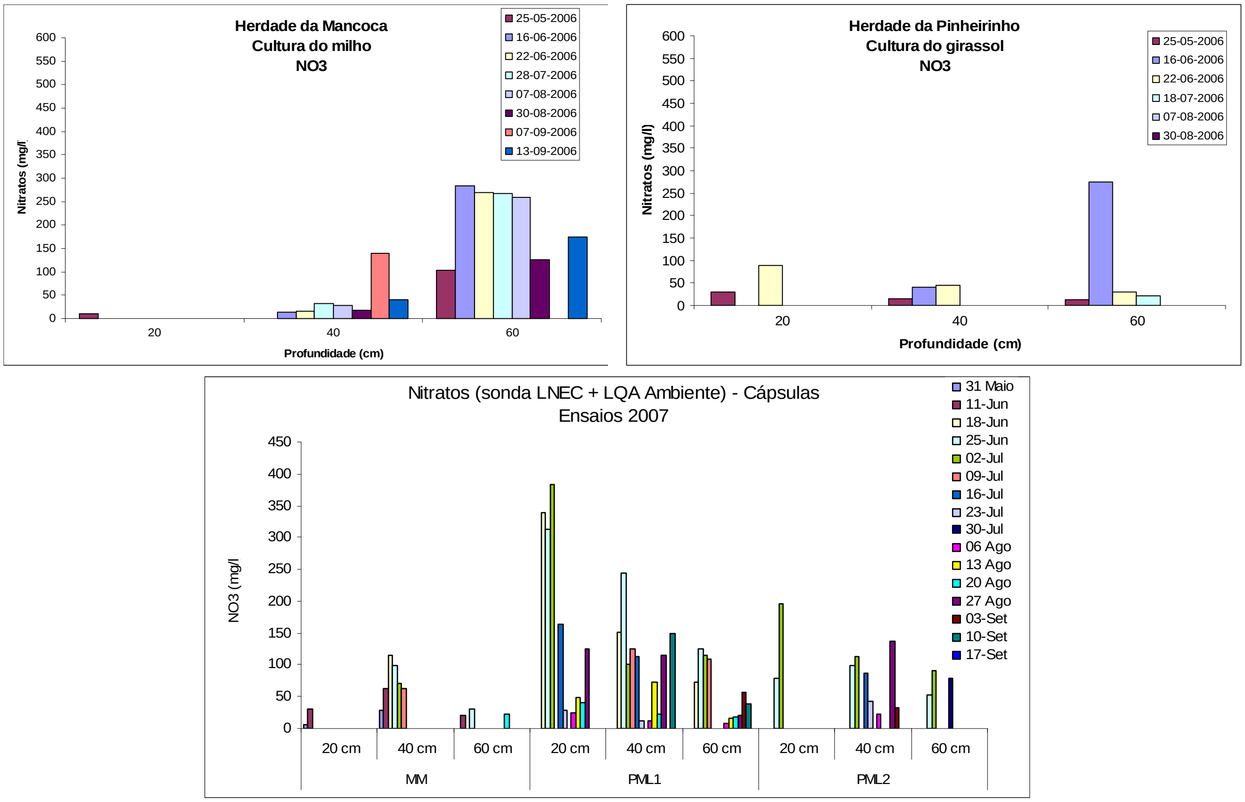


Fig. 12 – Nitrate concentration in the vadose zone, at three depths, during 2006 (above) and 2007 (below) experiments

4.2.3 Groundwater

Leitão *et al.* (2009) present in detail the results obtained for the groundwater quality of Mancoca and Pinheirinho experimental plots as well as the surrounding area, for the two years of experiments. In this article only the results concerning nitrates and EC are presented.

2006 results allowed confirming that the groundwater EC are extremely high, with a clear increase during the experimental period. Fig. 13 presents the evolution of nitrate ion concentration in 2006, during the crop growing. The effect of nitrate increase due to the application of fertilisers is clear, with a time delay to reach groundwater of about 1 to 2 month after its application.

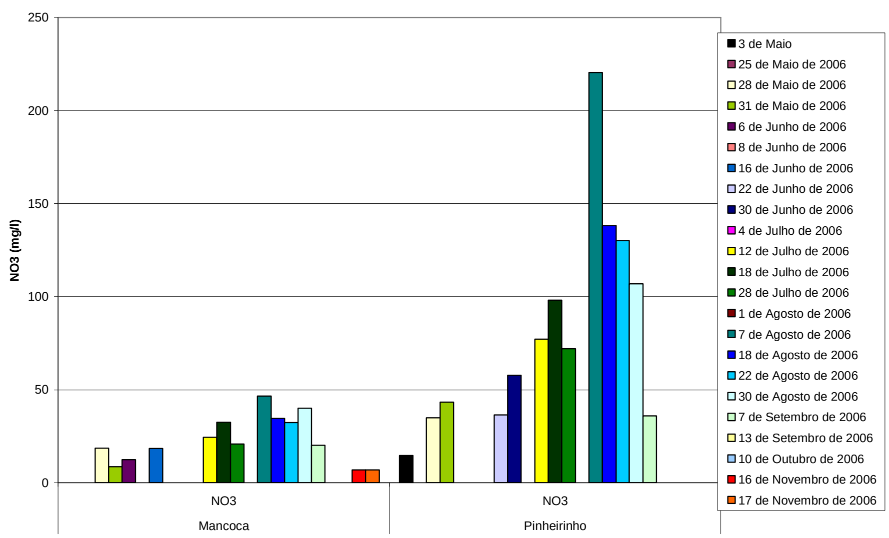


Fig. 13 – Nitrate concentration in the two piezometers (< 2 m) inside the experimental plots, 2006

Fig. 14 and Fig. 15 present a synthesis of the results for 2007 concerning EC and nitrate concentration for new wells, of about 10 m depth, installed in 2007 along the watershed (Fig. 1).

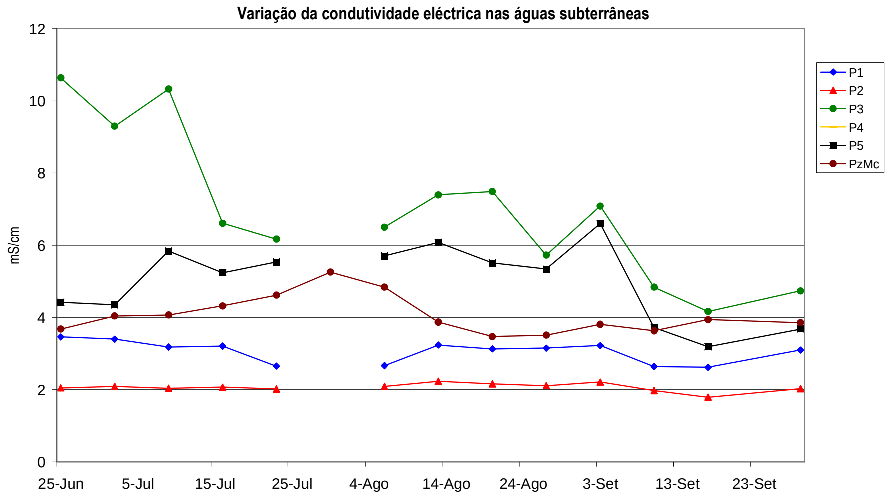


Fig. 14 – Electrical conductivity in groundwater, 2007

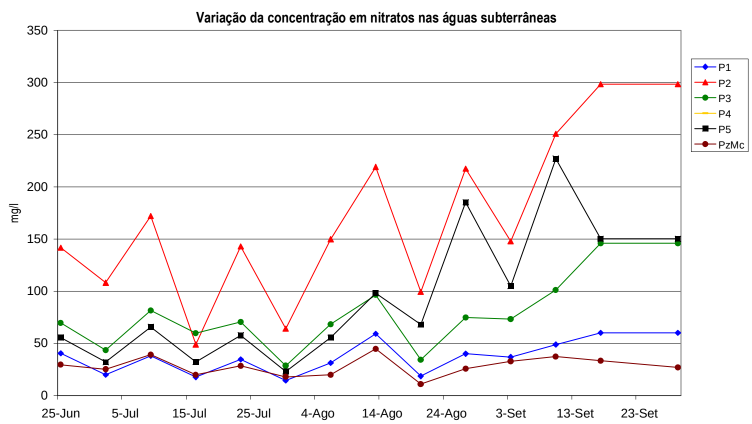


Fig. 15 – Nitrate concentration in the groundwater, 2007

The EC values (cf. Fig. 14) show to be relatively stable when compared to the old piezometers installed inside the plots at 2 m depth. Only piezometers P3 and P5 show an increase in EC during the irrigation period.

Fig. 15 allows concluding that, from the end of August on, there is an increase in the nitrate concentration, especially for the piezometers P2, P3, and P5. This is possibly due to the fertilisers application, again with a time delay of about 2 month since they were applied.

5 LAND USE SCENARIOUS MODELLING

The purpose of flow and transport modelling for this study was to perform an analysis of the possible effects that different crops, and associated cultivation practices, can have in the quality of downgradient groundwater. The model (cf. Fig. 16) was developed in permanent conditions.

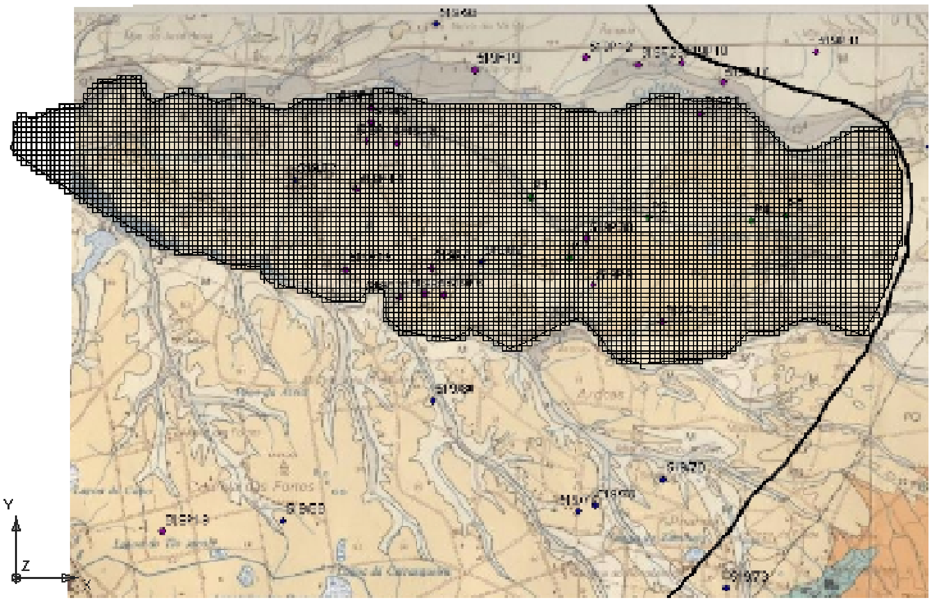


Fig. 16 – Modelled area (3 layers, 67 lines and 192 columns)

For modelling purposes, an initial enlarged area with 18,6 km^2 was considered. The upper limit is defined by ribeira de Canhestros, the lower by barrancos da Chaminé, Vale Alarve, Fontanas, Arocas, and Arroteia. The east boundary is the Bacia de Alvalade aquifer limit itself (Fig. 16). The model has 3 layers with a 50 x 50 m mesh and a variable depth. The surface drainage system was gathered in the military maps at the scale 1/25000. The regional model gave the initial conditions for the local small watershed model with 3,3 km^2 (Fig. 17).

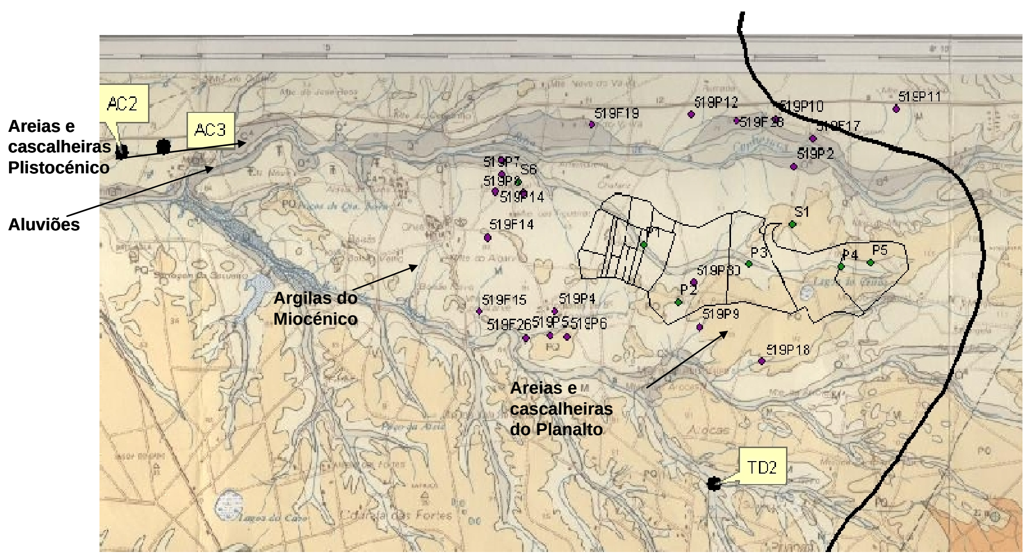


Fig. 17 – Geological map of the studied area

The site geological characterization was taken from carta geológica n.º 42-D Aljustrel, at the scale 1/50 000 (cf. Fig. 17), and three lithological columns: AC2, S6 and S1 (given by Dr. Eduardo Paralta, IST). Table 2 contains a synthesis of the hydrogeologic units of interest in the study area.

Table 2 – Hydrogeological characterization of the study area

Layer	Maximum thickness (m)	Lithological characteristics	Hydraulic conductivity (m/d) (kh ->kx=ky)
1	3,5	Alluvial (a) and other material of Pleistocene age (sand and pebbles – Q4 and Q3); Sand and pebbles of Planalto (PQ); Clay from Miocene age (M).	1 for alluvial (a) and other material of Pleistocene age; 0,7 for sand and pebbles of Planalto; 0,1 for clay
2	3,7	Clay	0,1
3	12,8	Sand	0,95

The values for recharge were obtained from the Watershed Planning of rio Sado (Lobo-Ferreira *et al.*, 1999), using BALSEQ model (Lobo-Ferreira, 1981). The artificial recharge due to irrigation was obtained from COTR (2008), considering that 20% of that water infiltrates. The regional calibration was done using the average groundwater levels in six calibration points (cf. Fig. 17), accordingly to Table 3.

Table 3 – Groundwater levels at the six calibration points used in the model

Wells	**M**	**P**	**Annual average**
519P2	195130	119030	78,61
519P6	192420	117130	76,54
519P8	191900	118730	76,39
519P9	194000	117230	88,02
519P5	192210	117140	76,73
519P14	191570	118750	76,77

The regional groundwater model developed for the study allows confirming that the regional flow is done towards the drainage channel that crosses the area, and from east to west (Fig. 18). Fig. 19 shows in detail the piezometric levels were it is possible to observe values ranging from 80 to 100 m. Locally there are different paths, depending on local topography and drainage.

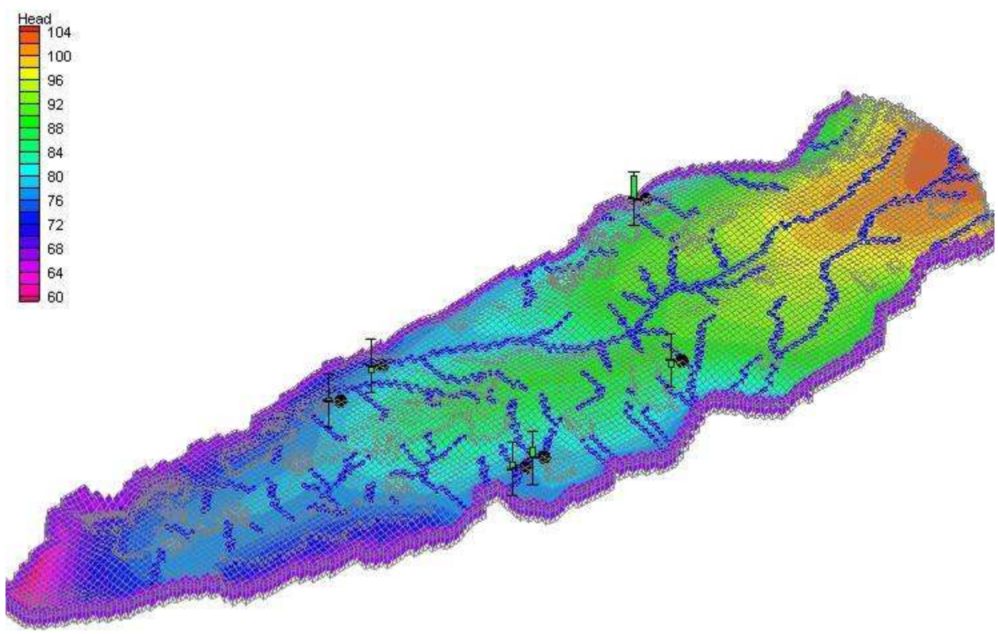


Fig. 18 – Regional Piezometry

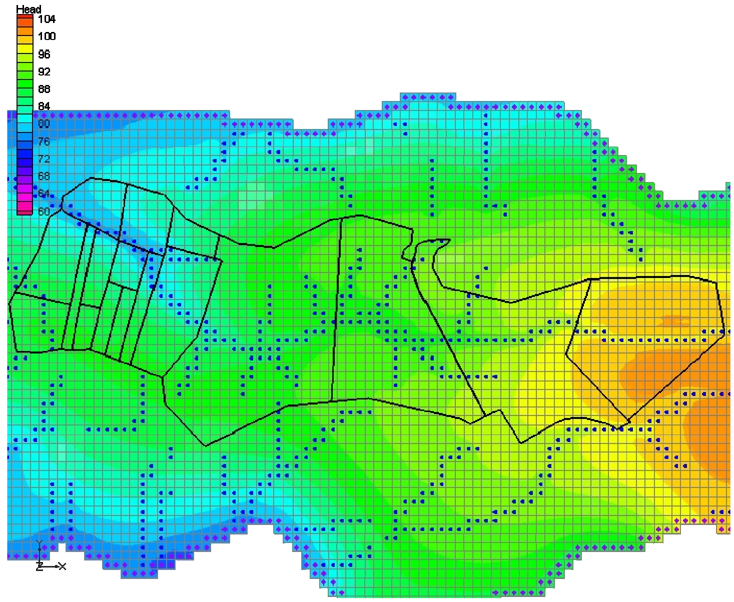


Fig. 19 - Piezometry in the studied area

Transport modelling was done using MT3D model (http://www.modflow.com/mt3d/mt3d.html) running in GMS interface. This modelling has started by simulating the year 2007, in terms of the existing crops. For that purpose, a set of initial conditions and assumptions were considered, as described in more detail in Leitão *et al.* (2009). Land cover situation in the year 2007 is described in Table 4.

Table 4 – Initial situation, corresponding to the year 2007 (see Fig. 1 to locate the plots)

Plots		Crops
9094	**Par1**	Corn
9096	**Par2**	Olive
9112	**Par3**	Melon
9111	**Par4**	Tomato
9115	***Par5***	*Cantaloupe melon*
9116	***Par6***	*Melon*
9133	***Par7***	*Tomato*
9134	***Par8***	*Beet*
Varios	***Par9***	Olive

In Table 4 the plots that were aggregated for modelling purposes are signed in italic (this was the case for the scenario 5 where various scenarios were considered for that last aggregated plot). Initially the model was calibrated for 2007, using the average values measured in the field during the monitoring period of 2007. It was considered a contamination residue due to previous agriculture practices. The calibration results served as initial conditions for future land cover scenarios.

The scenarios of crop land cover were developed for an occupation between the years 2007 and 2015. They correspond to the initial scenario of 2007 above which different agriculture soil occupation is analysed. Only one crop is tested at a time and in certain plot (cf. Table 5), and its consequences are accessed for the remaining plots. For example, in scenario 1A the plot 1 in changed to olive (initially it was corn), and the remaining stay the same, in what concern crops and agriculture practices for irrigation amount and fertilisers, as can be seen in Table 4. In scenario 1B the plot 1 in changed to melon and the remaining stay the same, and so on.

Table 5 – Crops considered for each scenario during the simulation period

Scenarios	A	B	C	D	E	F
1	Par1 - Olive	Par1 -	Par1 -	Par1 – Cantaloupe	Par1 –	
	Remaining plots are as in Table 4					
2	Par2 - Corn	Par2 -	Par2 -	Par2 - Cantaloupe	Par2 –	
	Remaining plots are as in Table 4					
3	Par3 - Corn	Par3 - Olive	Par3 -	Par3 - Cantaloupe	Par3 –	
	Remaining plots are as in Table 4					
4	Par4 - Corn	Par4 - Olive	Par4 - Melon	Par4 - Cantaloupe	Par4 -	
	Remaining plots are as in Table 4					
5	Par5 - Corn	Par5 - Olive	Par5 - Melon	Par5 - Cantaloupe	Par5 -	Par5 –
	Remaining plots are as in Table 4					

The NO_3^- values were measured for each plot at the end of each year, *i.e.*, the end of 2007 corresponds to a specific crop; the end of 2008 corresponds to two years of that same crop and so on.

An initial concentration of 10 mg/l of nitrate was considered within the plots and 0 mg/l outside them. Table 6 has information concerning the agriculture practices developed in the study area. The application rates (m^3/ha) for irrigation were obtained by calculating the mean for each registered crop along the years 2005 to 2007. These values, as well as the amount of nitrate applied to the crops per year, were obtained in COTR (2005) and COTR (2006).

The nitrate removed by the plant corresponds to the amount retained by the soil. These values were taken after Soveral Dias (1994 in Leitão *et al.*, 2009). The excess of nutrient remaining in the soil (column "Remaining N" in Table 6) is a result of the difference between the applied fertilizer and the quantity removed by the plant.

It is important to mention that the nitrate application is not constant along the year, *i.e.,* there are specific periods for that. For the case of corn, beet and tomato, the fertilisation is done between May and June. In the case of olive, that period is between April and October, and for the melon and cantaloupe melon it is between June and September. These dates were respected in the model input.

The column "Volume (per application)" (cf. Table 6) contains the amount of water that infiltrates in the soil, *i.e.* it represents the artificial recharge that results from the plot irrigation. This value corresponds to circa 20-40% of the precipitation. In this case, it was considered that 20% of the irrigation is recharge.

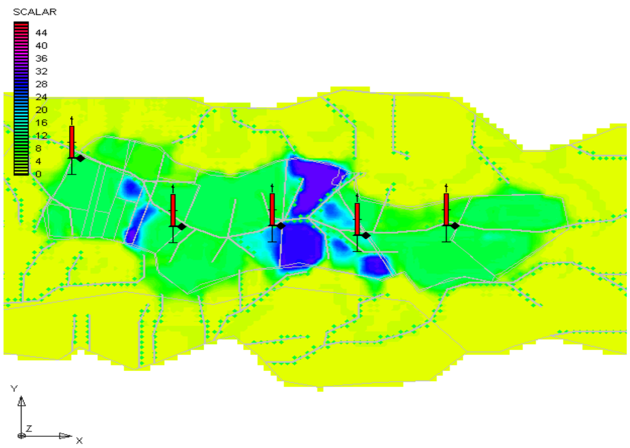
Finally, the initial nitrate concentration used for the model (last column of Table 6) was obtained through the dilution of the mass per hectare (kg/ha) remaining after the plant consumption by the volume (m^3/ha), which corresponds to 20% of the irrigation (it was considered that the N only enters in the soil through irrigation).

Table 6 – Irrigation volume and N quantity applied in the study area

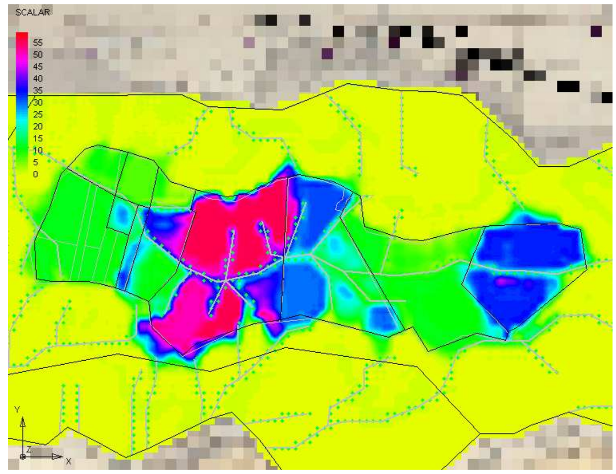
Crop	Water volume (m^3/ha)	Applied N (kg/ha)/ year	Removed (kg/ha)	Remaining N (kg/ha)	Volume (per application) (m^3/ha)	N (mg/l)
Beet	7100	189	132	57	1420	40,14
Melon	2875	120	49	71	575	123,48
Cantaloupe melon	1600	120	49	71	320	221,88
Corn	6800	360	83	277	1360	203,68
Olive	900	30	26	4	180	22,22
Tomato	6500	150	63	87	1300	66,92

Fig. 20 illustrates two examples of different scenarios obtained to 31 of December 2015 for the modelled plots as well as the output values of nitrate concentration (in mg/l). The output of the model gave rise to different scenarios (5 for each plot, except for plot 5 that has 6 scenarios).

Within the set of scenarios it is possible to confirm that the worst cases correspond to the cantaloupe melon crops, where nitrate level rise in comparison with the reference situation. The scenarios that present the best results correspond to the beet and olive crops.



Scenario 1A



Scenario 4D

Fig. 20 – Example of the nitrate concentration for two scenarios modelled

6 CONCLUSIONS

This paper presents the main results of the experiments carried out in the years 2006 and 2007 within the study of diffuse pollution originated by three different crops: corn, melon, and sunflower. The experiments were done in three irrigated plots at Ferreira do Alentejo, Portugal, one located in Mancoca and the other two in Pinheirinho, corresponding to two different soils.

The experiments have consisted in the analysis of the effects that different crops and respective cultural practices can have in the downgradient water produced by the irrigation water, by monitoring the: soil itself, runoff, drainage ditches, vadose zone, groundwater, and surface water. These media were sampled for physico-chemical analysis, for different periods and several depths, in order to follow the pollutants evolution along the experiments. Besides, it was also performed an analysis of the groundwater quality outside the plots in the whole watershed with five new piezometers installed in 2007, as well as in the drainage ditches located downgradient.

The data allowed to clearly defining the influence of irrigation rich in fertilisers in the water and soil downgradient. The monitoring results gathered for two years were modelled in what concerns groundwater flow and transport.

Based on the calibrated model, several scenarios for different crop cultivation were run in order to access their effects on the water quality downgradient, until the year 2015. These envisaged a better and optimized rural crop soil cover, taking into consideration the intrinsic vulnerability to agricultural pollution of the different soils studied.

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