Water Pollution Induced by Rainfed and Irrigated Agriculture in Mediterranean Environment, at Basin Scale

António Canatário Duarte[1,2]
[1]Escola Superior Agrária, Instituto Politécnico de Castelo Branco, Castelo Branco, PORTUGAL
[2]CEER – Biosystems Engineering, Instituto Superior de Agronomia, Lisboa, PORTUGAL

Abstract

The pollution of the superficial and subsuperficial water occurred from the agricultural areas, can assume a great importance in the context of all sources of water pollution. In fact, the intensification of the agricultural activity, in particular the irrigated agriculture increases the use of the agrochemical products, and the problems in the soil and water bodies. When the climatic conditions are favorable, or the irrigation systems are not well operated, this is an economic problem from the farmers and an environmental problem from the society. The study area is a small basin (190 ha), located in centre of Portugal, near the Natural Park of International Tagus. It is well drained, and the agricultural activity is developed in two different seasons; the winter season where the farmers produce especially winter cereals, and the irrigation season where they produce typical crops in this region (corn, sorghum, tobacco), and recently bioenergetics crops like soybean.
This study is focused in the water pollutants, nitrates and ammonium, sediments and total dissolved solids. Their dynamic in the basin, more or less dependent of the runoff, is different between pollutants and between both seasons. So, the nitrates load depends, all time, of the availability in the soil and the runoff volume, due to its solubility. The ammonium shows a different dynamic; when it is present in large amount in the soil, their load depends of the sediments load and the extremes peak flow, with high power to carry outside the basin. The total daily load of sediments not shows a direct relation with de runoff volume, except when it has a sufficient energy to detach and carry out, as in the extremes events. Therefore, the total daily load accumulated curve of this pollutant along the time, develops by levels related with each extreme event. Another aspect important to accentuate is the clear dependence of the amount of sediments to the conditions in the watershed, for similar intensity storms. For total dissolved solids, this study allows to conclude a very clear relation between the runoff volume and the load of this pollutant, in both seasons. In the other hand, this study not allows to conclude if the loss of this pollutant is higher in the winter or irrigation season.

Key-words: non point source, water pollution, rainfed agriculture, irrigated agriculture, watershed.

Introduction

The rational use of water should be have a moderated consumption, as well as the quality conservation after used and returned again to the water environment. This is a concern that has emerged as fundamental to the Water Framework Directive of the European Union, considering that water is not a resource like others, but an heritage that must to protect. According to the principles of this directive, transposed to the legislation of each country of the European Union, water quality is no longer focused exclusively on physical-chemical-biological variables related to various water uses, to also provide an incalculable ecological value necessary for the proper functioning of ecosystems. The water has not an absolute quality, but a few qualities that depend on the requirements of its use (Novotny, 2003).
Given the need to study the quality of water drained from agricultural basin, it should be important to see that the quality depends on the pollution in the basin, and the quality it had before to be delivered for that territorial unit; in some situations the quality of drained water from irrigated basins is poor in part because the quality gets deteriorated (Aragués and Tanji, 2003).
The main purpose for this work is to study the dynamic of the nitrogen, salts and sediments in a typical Mediterranean agricultural watershed, under different agricultural conditions (irrigated and rainfed agricultural systems) and different climatic and hydrologic conditions (climatic and hydrologic normal year and a very dry year with a hydrologic behavior marked by a few extreme events).

Methodology applied

Description of the study watershed

The study watershed is located within the *Idanha Irrigation Scheme,* Idanha-a-Nova, Portugal, near the border with Spain and just north of the Tagus river (Figure 1).

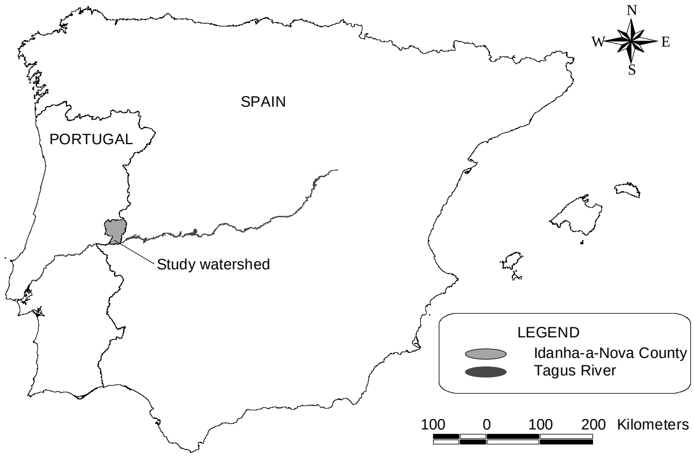

Figure 1. Location of the study watershed.

The watershed has 189 ha and 28 natural channels with density 12.2 m ha^{-1} and fluvial hierarchy of three levels (Figure 2). Altitude varies from 248 m, in a plateau north east, to 212 m at the control section. The slopes are in the interval 0 and 4%, thus the topography is flat to slightly sloppy (Figure 2) (Duarte *et al*., 2006).

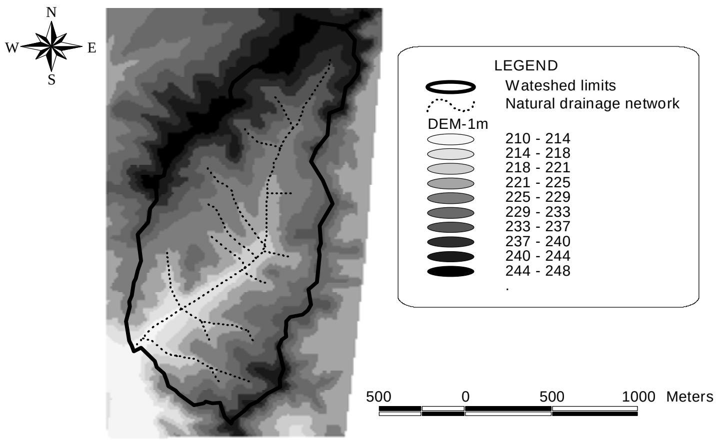

Figure 2. Topography and natural drainage network of the study watershed.

The predominant soil classes are *Cambisols* and *Luvisols,* originated from deposits of the tributaries of the Tagus river (Figure 3). Other soil class in the watershed is *Fluvisols,* originated by alluvial deposits of the main creak that crosses the watershed. An impermeable soil layer underlies the three soil classes at approximately 0.4 m in depth, which greatly determines the hydrology of the watershed.

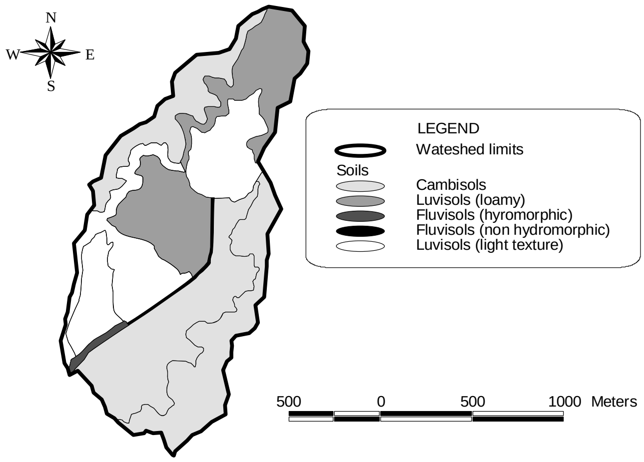

Figure 3. Soil classes in the study watershed (FAO nomenclature).

Climate is Mediterranean continental, with average annual rainfall 624 mm, and average temperature varying from 8.3 ^{o}C in January to 24.5 ^{o}C in August (INAG, 2007).

Land use can be differentiated in three areas (Figures 4 and 5): forest (oaks), intensive agricultural use (mostly corn in year 2003/04 and fallow in year 2004/05), and marginal agricultural use.

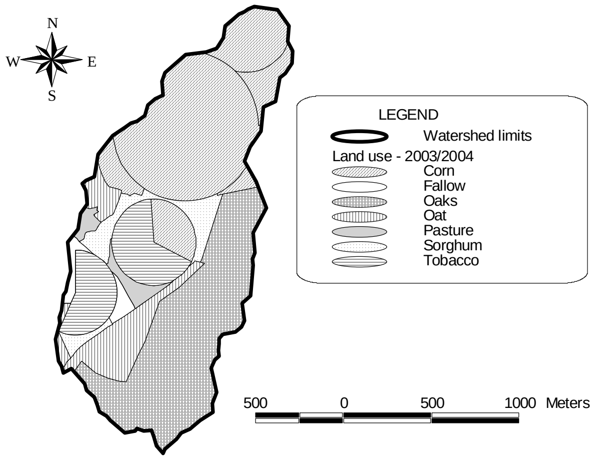

Figure 4. Land use in the study watershed, year 2003/2004.

Soil use varied significantly from year 2003/04 to year 2004/05 (Figure 5) due to a 52% reduction of the irrigated area and to a crop intensification in the upper and lower part of the watershed, respectively.

The irrigation methods used in the study watershed are sprinkler centre pivot and stationary sprinkler (in the areas not covered by the pivot machines).

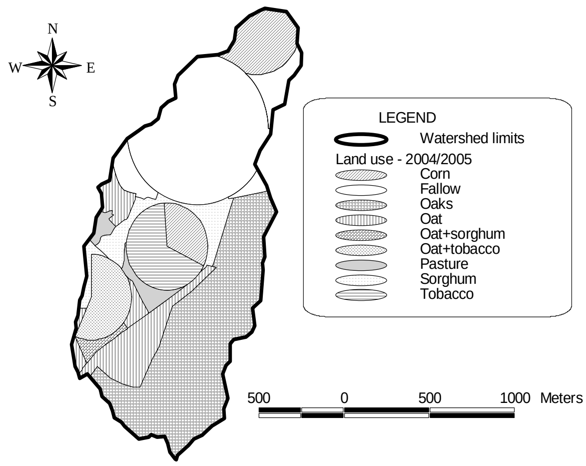

Figure 5. Land use in the study watershed, year 2004/2005.

Hydrological station and water samples

A hydrological station was installed at the outlet of the watershed. The station consisted of i) a long-throated flume, with control section triangular for small water depths and triangular/trapezoidal for large water depths, designed and calibrated following the procedure in Bos *et al*. (1991), and ii) an ultrasonic sensor connected to a datalogger for measuring and recording water depth.

Water samples were collected at the hydrological station almost once a day. The samples were transported to the laboratory in a cold environment to determine the concentration of sediments, nitrogen (in its three mineral forms: ammonium, nitrate and nitrite) and total dissolved solids. We assumed the pollutant concentration constant along the day, thus knowing the runoff rate we could determinate sediment and nitrogen losses (Duarte, 2006).

Agricultural practices were recorded by the farmers and verified by direct observations during visits to the watershed.

Results obtained

The water delivered to the Idanha Irrigation District have, concerning the study pollutants, a very good quality, as it are not exposed to source or non point source pollution. Also the water drained from the study watershed largely met the quality criteria for some applications, namely agricultural use. Exception to the extremes events, when the quality limits of water are exceeded for ammonium nitrogen and sediments. In this context, it´s so important to attend the kind of pollutants that affect the organisms and their environment included the time and space aspects (Fereres and Connor, 2004). It is pertinent to mention that are other ways of relating the presence of contaminants in water, beyond the water concentrations. We refer for example indicators that combine agricultural and environmental aspects or the establishment of a maximum daily load for certain contaminants losses from agricultural watersheds, called Total Maximum Daily Load in American literature. This is a question studied in the U.S. with the intention to include this issue in a more appropriate regulatory framework for agricultural activity that general rules apply to other activities (Lea-Cox *et al*., 2002).

Solutes and sediments load at the irrigation season

Nitrogen load

The analysis of the Figure 6 show a similar evolution from the curve of nitrate+nitrite and the runoff volume curve in the two years of irrigation. For ammonium nitrogen this dependence is less clear, especially in the 2005 irrigation season, when runoff volumes are substantially reduced compared to the 2004 irrigation season. The runoff reduction combined with the lower solubility of ammonium nitrogen determine that the corresponding accumulated load curve to remain almost constant from middle August, which in 2004 irrigation season was the same behavior only a month later.

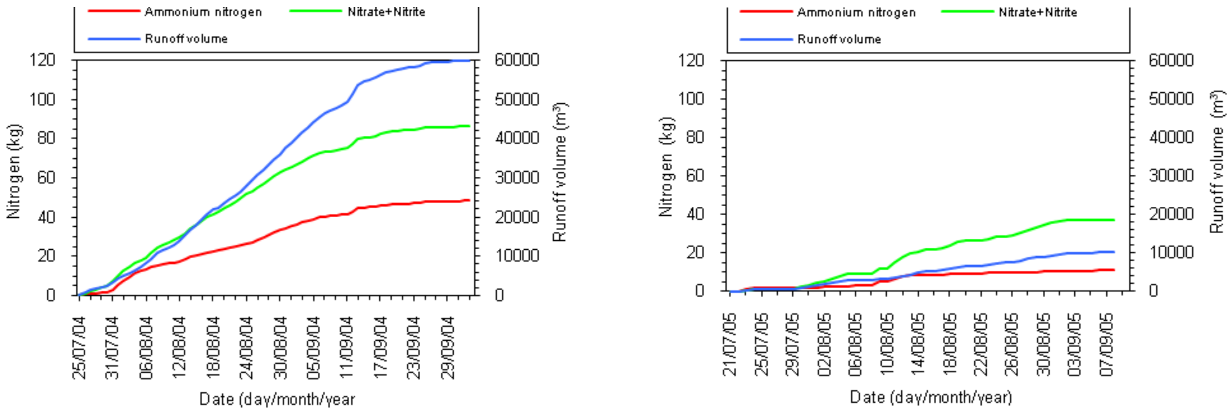

Figure 6. Comparison between the evolution of accumulated nitrogen daily load and runoff volume in the main stream, during the irrigation seasons 2004 and 2005.

A first important idea that can be obtained from the values listed in Table 1 is that there was not proportionality between the reduction in irrigated area and return flows, maintaining the same irrigation practices. In fact, the irrigated area in 2005 was 48.1% of the area in 2004, and the runoff was only 15.3%. The runoff reduction in the 2005 irrigation season resulted in a reduction of more than half the losses of nitrogen per unit area, whereas the average concentration in water increased slightly, resulting overall in 20.0% of the losses occurring in 2004 irrigation season. Relatively to nitric nitrogen, the same reduction in runoff and area caused a reduction of this pollutant in the watershed of the 61.1%. Given this significant reduction of runoff, loss of nitrate nitrogen remained almost proportional to the decrease in area, due to an increase in its concentration in water (1.44 mg l^{-1} to 3.65 mg l^{-1}). These results are consistent with what has already mentioned above, on the solubility characteristics of these two forms of nitrogen in the water, and therefore its dynamics in the basin under different irrigation conditions (Causapé *et al*., 2004).

Table 1. Reduction of irrigated area and consequent alteration of nitrogen load, between irrigation seasons 2004 and 2005.

Irrigation season	Irrigation area		Runoff volume		Ammonium nitrogen				Nitric nitrogen			
	(ha)	(%)	(m³)	(%)	(kg)	(%)	(kg ha^{-1})	(mg l^{-1})	(kg)	(%)	(kg ha^{-1})	(mg l^{-1})
2004	100,1	100,0	68008	100,0	55	100,0	0,55	0,81	98	100,0	0,98	1,44
2005	48,1	48,1	10420	15,3	11	20,0	0,23	1,06	38	38,9	0,79	3,65

Suspended solids load

During the 2004 and 2005 irrigation seasons, the analyses of Figure 7 inform us that only occasionally the evolution of the total suspended solids curve has the same tendency of the runoff curve. In fact, this pollutant is predominantly load with superficial runoff. In irrigations systems well operated have not a noted influence, as seems the case of this watershed as the global efficiency of water application. This information have support in that happened between 9 and 15 September 2004, when it there was a runoff event more intense (majority superficial runoff), it was in this period when the tendency of the curves in the first picture on Figure 7 have a good approximation.

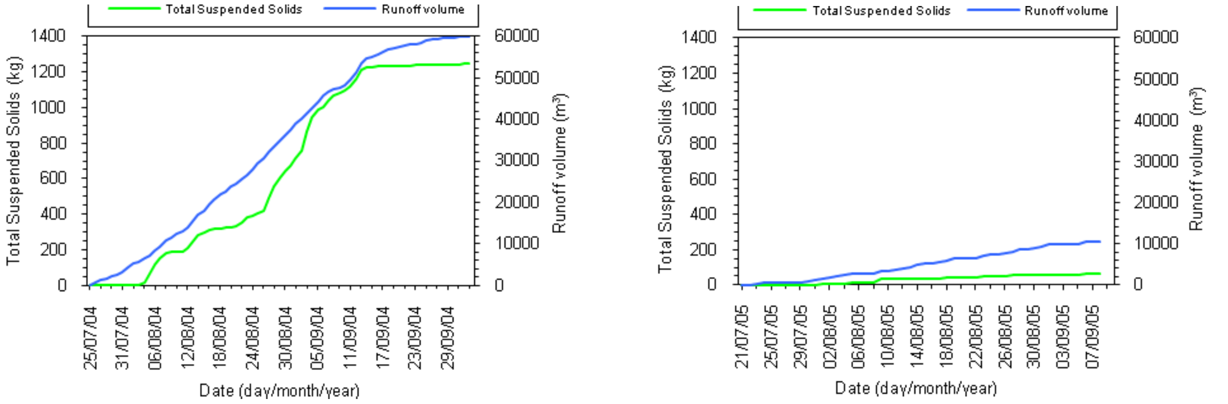

Figure 7. Comparison between the evolution of accumulated total suspended solids daily load and runoff volume in the main stream, during the irrigation seasons 2004 and 2005.

The read of the Table 2 results clear the reduction of this pollutant during the 2005 irrigation season (95.8%), was more marked than the reduction of runoff (84.7%). Also it was recorded important reduction in this contaminant load per unit of area (kg ha^{-1}), and its concentration in water. Thus, the sediments load in the 2005 irrigation season, was practically nonexistent.

Table 2. Reduction of irrigated area and consequent alteration of total suspended solids load, between irrigation seasons 2004 and 2005.

Irrigation season	Irrigation area		Runoff volume		Total Suspended Solids			
	(ha)	(%)	(m^3)	(%)	(kg)	(%)	(kg ha^{-1})	(mg l^{-1})
2004	100,1	100,0	68008	100,0	1503	100,0	15,01	22,10
2005	48,1	48,1	10420	15,3	63	4,2	1,31	6,05

Dissolved solids load

The curves evolution in Figure 8 shows a strong dependence of the total dissolved solids load to the runoff volume drained from the basin, which also noted others authors (Tedeschi *et al*. 2001). Given its chemical nature, the dissolved solids are load indifferently with surface runoff or base flow, can this process be improved when the water moves in the soil profile (Ghassemi *et al*., 1995). The more soluble salts are chlorides and nitrates, but have a different influence on the water electrical conductivity (Evangelou, 1998).

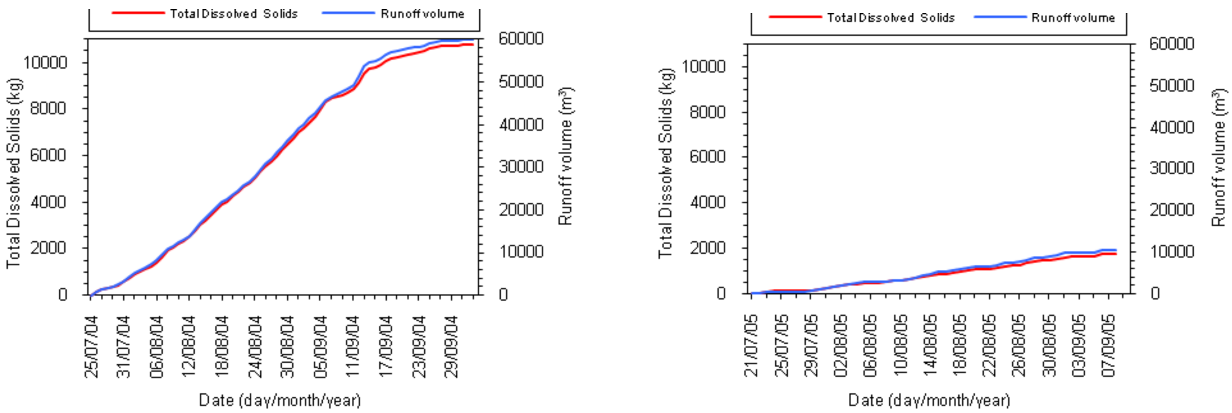

Figure 8. Comparison between the evolution of accumulated total dissolved solids daily load and runoff volume in the main stream, during the irrigation seasons 2004 and 2005.

The values in Table 3 reflected the impact of irrigated area reduction in the transport of salts in solution outside the basin, on the second irrigation season. The strong dependence of the salts load to the runoff volume, observed in Figure 8, have on Table 3 correspondence in the loss of sales reduction (85.7%), a value close to reducing runoff (84.7%).

Table 3. Reduction of irrigated area and consequent alteration of total dissolved solids load, between irrigation seasons 2004 and 2005.

Irrigation season	Irrigation area		Runoff volume		Total Dissolved Solids			
	(ha)	(%)	(m^3)	(%)	(kg)	(%)	(kg ha^{-1})	(mg l^{-1})
2004	100,1	100,0	68008	100,0	12255	100,0	122,43	180,20
2005	48,1	48,1	10420	15,3	1749	14,3	36,36	167,85

Solutes and sediments load at the rainfall season

The hydrologic behavior of the basin during the rainfall season was profoundly different from what occurred during the irrigation season. Generally in the agricultural basins in irrigated areas, the irrigation season is the period of agricultural intensification. Therefore, is the period with intensive application of fertilizers and other agro-chemicals, with the maintenance of high humidity conditions in the soil. Rainfall season is therefore a period of low agricultural intensification, even considering that in some fields it have winter cereals for livestock feed. The fertilizations are basically made at sowing, incorporating the fertilizer nitrogen forms less oxidized. It is also true that during this period remain in the soil some nutrients of the irrigated crops fertilizations, which have not been absorbed by plants or have not lost with runoff in the watershed. As in the 2005/2006 rainfall season we only have available data until 31 December, this is the date until which the values are reported in the respective graphs and tables.

Nitrogen load

The curves evolution in Figure 9 related to the 2004/2005 rainfall season is quite different from the curves evolution for the 2005/2006 season. In addition to other factors favoring this difference, the hydrological year 2004/2005 was very abnormal with respect to the total volume of precipitation and its distribution. This determined that the runoff and pollutants load curves were conditioned by a few precipitation events, basically only one very extreme event (Delgado, 2002; Hatfield and Prueger, 2004). So, the accumulated pollutant load curves of ammonium and nitrate nitrogen, had during the more intense hydrological events large dependence to the runoff volume, and then, especially ammonium nitrogen, remained practically constant until the end of rainfall season. The enormous loss of nitrogen in the 27 October 2004 event, due to two reasons: one is related to the higher amount of nitrogen in the soil on the date of this event happened (result of fund fertilizations), and another is related to the very large volume of runoff that was generated, with high power to detach and transport the soil particles. Different situation occurred in the 2005/2006 rainfall season until 31 December (period in which they occurred most important hydrological events). The cumulative runoff curve shows a gradual evolution, marked by a greater number of events with smaller amplitude. Nitrogen curves show a trend related to runoff, including the ammonium nitrogen, which is not so evident.

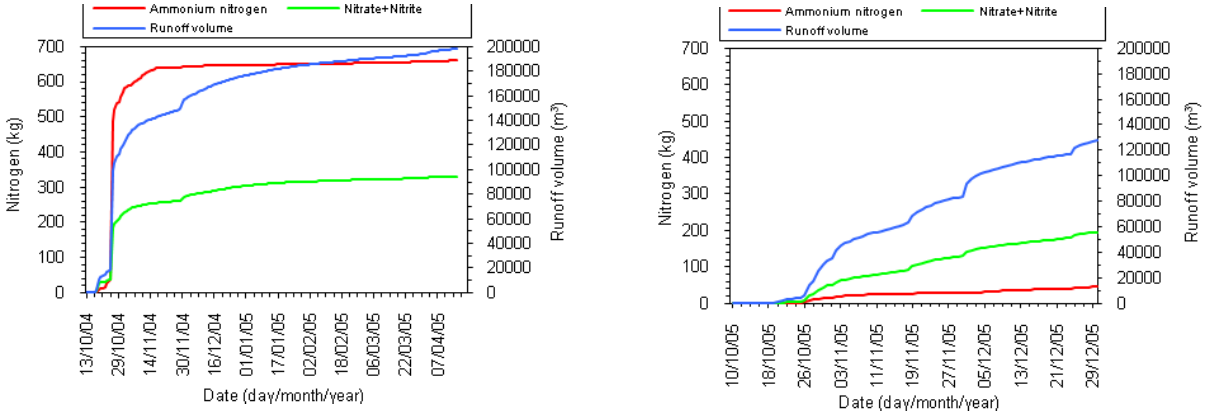

Figure 9. Comparison between the evolution of accumulated nitrogen daily load and runoff volume in the main stream, during the rainfall seasons 2004/2005 and 2005/2006 (until 31/12/2005).

From October to December 2005, had drained from the basin 72.9% to the volume of water drained in the same period in the previous rainfall season. This proportion is quite different from the nitrogen load (646 kg in 2004 and 45 kg in 2005), from the nitrogen load per area unit (3.42 kg ha-1 in 2004 and 0.24 kg ha-1 in 2005), and from the concentration in water (3.68 mg l-1 in 2004 and 0.35 mg l-1 in 2005). This difference was mainly due to the 27 October 2004 event, which was amplitude not normal for this extension of basins. Regarding the nitrate nitrogen, given their solubility characteristics and therefore more dependent on the runoff volume, the reduction of the pollution load have a value similar to the reduction of the runoff volume value (Follet, 2001).

Table 4. Runoff volume in the rainfall seasons 2004/2005 and 2005/2006 (until 31/12/2005), and consequent alteration of nitrogen load.

Rainfall Season	Basin area		Runoff		Ammonium nitrogen				Nitric nitrogen			
	(ha)	(%)	(m^3)	(%)	(kg)	(%)	(kg ha^{-1})	(mg l^{-1})	(kg)	(%)	(kg ha^{-1})	(mg l^{-1})
2004/2005	189,0	100,0	175826	100,0	646	100,0	3,42	3,68	303	100,0	1,60	1,72
2005/2006	189,0	100,0	128105	72,9	45	6,9	0,24	0,35	195	64,4	1,03	1,52

Suspended solids load

In a normal precipitation year, the pictures in figure below should show a curve of cumulative total suspended solids with a tendency close to the curve of accumulated runoff volume, but with an evolution by levels (Kirkby, 1980). This is what can be seen from the graphs in the rainfall season 2005/2006. More particularly, in Figure 10 we can see the curve of cumulative total suspended solids of the 2004/2005 rainfall season, basically evolved into three levels, which were related to the three most erosive storms in this hydrological year (20 and 27 October and 1 December). In intermediate periods, mainly during base flows while significant, have a few small changes in level, which may be due to the erosive power at the drainage network (Merritt *et al.*, 2003). Since the extreme event occurred in 1 December, the curve of suspended solids remained practically horizontal, as a result of runoff produced were almost exclusively base flow; since this date there is no relationship between the two curves. The curve of suspended sediments load in the 2005/2006 rainfall season was also made by transition between levels, in a larger number than the previous rainfall season, and with a transition between levels less abrupt depending on the intensity of runoff in the descent phase and depletion of the event hydrograph (Logan, 1995).

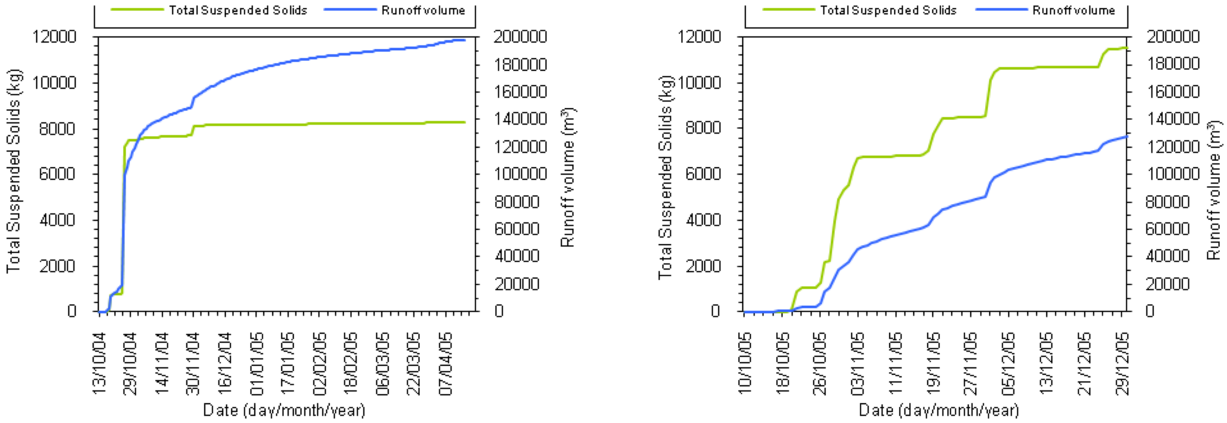

Figure 10. Comparison between the evolution of accumulated total suspended solids daily load and runoff volume in the main stream, during the rainfall seasons 2004/2005 and 2005/2006 (until 31/12/2005).

The lowest runoff generated until the end of December 2005 (27.1% lower in relation to the 2004/2005 rainfall season until the same date), however, led to a higher loss in suspended sediments (40.9%). This was due primarily to the volume of water drained from the basin in the 2005/2006 season was divide in a greater number of erosive hydrologic events, although in the 2004/2005 rainfall season occurred an extreme event very significant. This distribution of runoff volume by more erosive hydrologic events, also explains the higher average concentration of sediment in the water drained from the basin.

Table 5. Runoff volume in the rainfall seasons 2004/2005 and 2005/2006 (until 31/12/2005), and consequent alteration of total suspended solids load.

Rainfall Season	Basin area		Runoff volume	Total Suspended Solids				
	(ha)	(%)	(m³)	(%)	(kg)	(%)	(kg ha⁻¹)	(mg l⁻¹)
2004/2005	189,0	100,0	175826	100,0	8172	100,0	43,23	46,48
2005/2006	189,0	100,0	128105	72,9	11512	140,9	60,91	89,86

Dissolved solids load

The values of the dissolved solids load during the rainfall season, more precisely in the floods, should be taken with some reserve due to the dilution effect during floods (Sala and Farguell, 2002), because water samples were collected outside of the extremes events. However, if there were not a significant amount of salts in the soil, the error would be of little importance. If there availability of salts in the soil, as happens in the periods of fertilization, the error would have considerable importance.

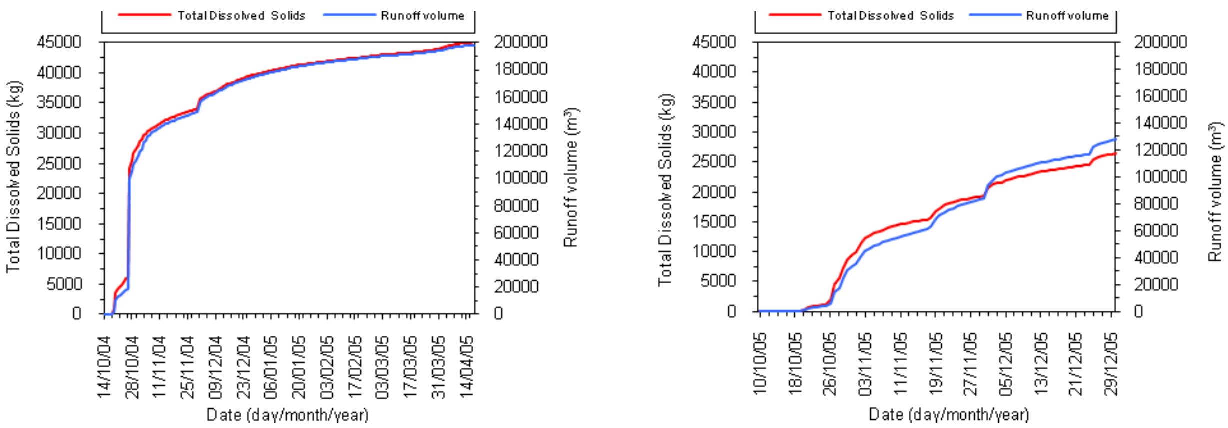

Figure 11. Comparison between the evolution of accumulated total dissolved solids daily load and runoff volume in the main stream, during the rainfall seasons 2004/2005 and 2005/2006 (until 31/12/2005).

From the pollutants analyzed in different parts of the agricultural year (irrigation season and rainfall season) this is the one most similar behavior to the runoff volume. We can see in Table 6 the reduction in the salt load in the 2005/2006 rainfall season relatively to the previous season (33.7%) was almost the same magnitude that the runoff volume reduction (27.1%).

Table 6. Runoff volume in the rainfall seasons 2004/2005 and 2005/2006 (until 31/12/2005), and consequent alteration of total dissolved solids load.

Rainfall Season	Basin area		Runoff volume	Solidos Disueltos Totales				
	(ha)	(%)	(m^3)	(%)	(kg)	(%)	(kg ha^{-1})	(mg l^{-1})
2004/2005	189,0	100,0	175826	100,0	39884	100,0	211,02	226,84
2005/2006	189,0	100,0	128105	72,9	26447	66,3	139,92	206,45

Conclusions

This study, although developed only in two years, and therefore has some limitations, allows to extract the conclusions that we note in the following text. These conclusions, while being provisional, should provide good indications about the dynamic of the pollutants in the study watershed, and in the others similar to this, and provide good agricultural practices to prevent pollutant events more accurate.

The evolution of the nitric nitrogen daily pollution load depends to the volume of runoff at any stage of analysis period and since availability of this nutrient in the soil. Its high solubility and mobility determine that appears in both surface runoff and in base flow.

The ammonium nitrogen reveals a different behavior, because, having a low solubility and forming a positive ionic form, is preferentially carried out with the sediments. Thus, the daily pollution load of this nitrogen form, being available in the soil, depends on the volume of runoff in the extremes hydrological events. The abundant presence of water in the soil, also cause additional load of this contaminant, by the increased dissolution capacity of this nitrogen form.

The daily pollution load of suspended sediment does not seem dependent on the volume of runoff, except when it has enough power to detach and load the particles out of the basin. Naturally, this is valid for the concentration of runoff distributed in the watershed area and in the natural channels network. If the 2004/2005 rainfall season had not been so abnormally, from the hydrological point of view, it would not have been able to observe so clearly as the curve of the cumulative daily pollutant load is developed by levels, associated with more significant extremes events. This also had the opportunity to observe in the 2005/2006 rainfall season, although less clear.

For the total dissolved solids daily pollution load, the situation shows, both in the irrigation season and in the rainfall season, a absolute dependence of the runoff volume; it is very clear for all time period. The data obtained in this study cannot allow to conclude a greater loss when surface runoff predominates or base flow; some studies suggest that the process is more efficient when water moves through the soil profile (Ghassemi *et al*. , 1995).

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