REDUCE NITRATE POLLUTION OF WATERS DUE TO FERTILIZATION AND IRRIGATION

GLOBAL PROBLEM

Despite the abundance of water in the earth, only 0.3% is actually suitable for human consumption. Besides the scarcity of suitable fresh water resources, water quality has been progressively deteriorated in many countries, reducing the quantity of water that is safe to use. Particularly, water pollution by nitrates, due basically to agricultural activities, has become one of the main environmental challenges all over the world[1]. Regions and countries such as Europe, United States or China, with a developed agriculture based on a high use of fertilizers and other resources, show already higher rates of nitrate pollution on their waters. Moreover, the problem has been extended to other countries due to the global extension of modern high-input agriculture[1]. Besides, the livestock sector is growing and intensifying faster than crop production in almost all countries. Uncontrolled manure can have a serious impact in nitrate pollution of waters.

Fertilizers and manure applied to the soil are the main source of soluble nitrates and the origin of nitrate pollution of waters[1]. The nitrate pollution problem at the world level arises particularly in recent years, due to the global increment in the use of fertilizers associated as well to a rise in total agricultural pollution. As shown in Fig. 1, particularly Asian agriculture means an important user of fertilizers. Other regions have kept similar levels of fertilizer use, but still higher than before 1950.

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[1] FAO (2017). Water pollution from agriculture: a global review (http://www.fao.org/3/a-i7754e.pdf)

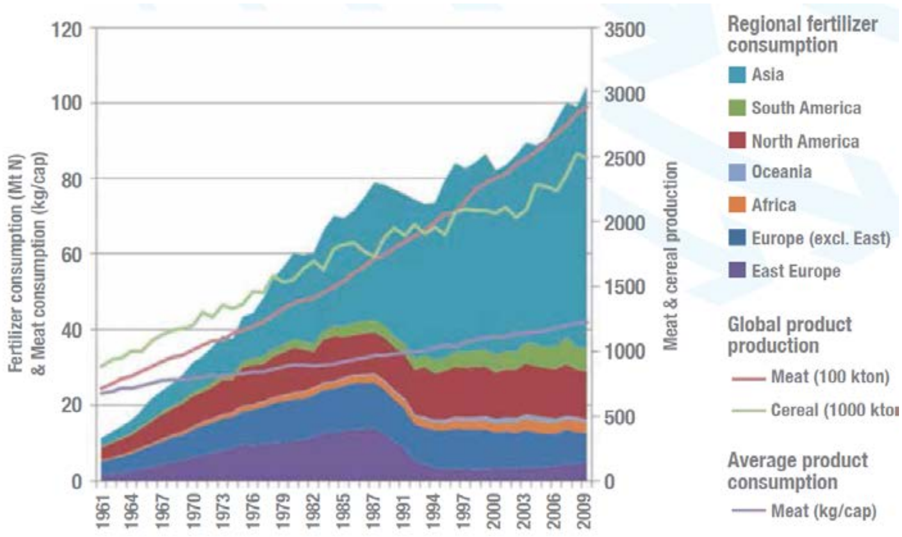

Fig. 1. Total mineral fertilizer consumption in major world regions (from FAO report[1])

Even though fertilizer excess could bring nitrate pollution of waters, fertilizers are indeed needed in order to obtain reliable agricultural yields. Likewise, water excess in the soils, creating infiltration and nitrate leaching can be due to heavy rains, but also to irrigation. Still, reliable yields require irrigation in many countries and crops. The challenge lies in reducing the risk of nitrate leaching, with a proper management of fertilizers, while keeping reliable crop yields and suitable farmer's incomes.

According to FAO[1], combining regulations with economic incentives seems to work better than regulations alone. Policies addressing water pollution in agriculture should be part of an overarching water policy framework at the national or river-basin scale, with all pollutants and polluters considered together. Economic instruments are increasingly employed to improve or replace simple legal provisions or regulations. They include taxes, "set-asides", and payments to limit production or the intensity of land use.

Actually, the process associated to nitrate pollution from agricultural lands to surface freshwaters and groundwater is very complex from the physical point of view. Part of the nitrogen in the soil is soluble. It is concentrated in the soil solution and therefore available for the crop's roots. Under soil moisture excess conditions, high levels of soluble nitrates leak through soil into groundwater or runoff to rivers and lakes.

Fig. 2 shows a simple explanation of nitrate leaching through the soil. Soluble nitrates in the "root zone" are in the water solution, contained in the soil pores. When the average water content in the soil pores is below the so-called "Field Capacity" water remains in the soil unsaturated zone. However, when soil moisture is excessive, higher than "Field Capacity", infiltration occurs and nitrates move away with the soil water. Once nitrates reach the saturated zone they dissolve, creating a pollution problem. This freshwater resource might be not suitable for human consumption anymore, depending on their nitrate concentration.

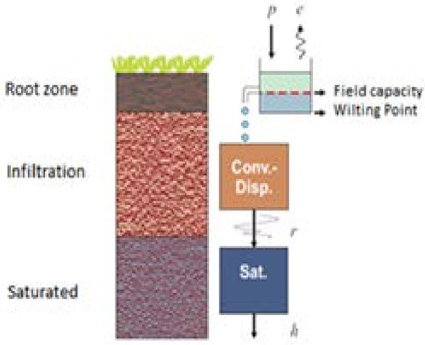

Fig. 2. Simple explanation of nitrate leaching

Accordingly, many of the actions aimed to avoid nitrate leaching are based on reducing fertilizer use during the rainy season. Furthermore, irrigation must be properly managed, avoiding excessive infiltration rates, especially after applied fertilizers or manure.

The nitrate leaching and the soil water movement processes are actually more complex than the depicted in Fig. 2. Water and solutes movement in the soil unsaturated zone depends on potential gradients which in turn are functions of moisture, soil texture and structure, organic matter contents, solute concentration, soil compaction, water table depths and many other factors. Likewise, nitrogen solubility in the soil water solution depends on the chemical compound where nitrates are present, as well as temperature, soil moisture, etc.

Due to its social and environmental relevance, the nitrate pollution challenge has attracted the attention of soil physicists, agronomists and environmental scientists all over the world during the last decades. Scientists have tried to identify the spatial variability of nitrate leaching and the factors it depends upon.

Several models have been developed in the last years, aiming to simulate the soil water movement, including soil solutes such as nitrates. Nolan et al. (2010)[2] used the RZWQM2 model to identify nitrate leaching rates in several crops and regions of the United States, comparing the modelling results with lysimetric measurements. Jego et al. (2012)[3] used the model STICS for estimating nitrate leaching under agricultural fields in France and Perego et al. (2011)[4] used the model SWAP with similar goals in Italy.

Actually, nitrate pollution of water involves two different environments: soil unsaturated zone and saturated region. There are specific models for each one. Accordingly, Xu et al. (2012)[5] combined the model SWAP for the unsaturated zone with the model MODFLOW for the

[2] Nolan et al. (2010). Predicting Unsaturated Zone Nitrogen Mass Balances in Agricultural Settings Of the United States. J. Environ. Qual. 39:1051–1065.

[3] Jego et al. (2012). Predicting soil water and mineral nitrogen contents with the STICS model for estimating nitrate leaching under agricultural fields. Agricultural Water Management, 107:54-65.

[4] Perego et al. (2011). Nitrate leaching under maize cropping systems in Po Valley (Italy). Agriculture, Ecosystems and Environment, 147:57-65.

[5] Xu et al. (2012). Integration of SWAP and MODFLOW-2000 for modeling groundwater dynamics in shallow water table areas. Journal of Hydrology, 412-413:170-181.

saturated zone to conduct a regional analysis of nitrate pollution in China. Some other papers in the same issue have appeared in the last years, considering different model approaches. Although there are several models available, only few of them have been considered validated enough. Utset (2009)[6] compiled the main agricultural simulation models that have been used in Europe, according to their relevance. Disappointingly, Groenendijk et al. (2014)[7] found bad modelling performance when compared lysimetric data with simulations from several models. However, they point out that all the models were able to identify years and crops with high and low leaching rates.

The referred papers were based on grants aimed to improve the knowledge about nitrate leaching. Most of the national and international funding sources consider this issue among their priorities and many projects have been funded already in this regard.

For instance, a local project funded by the Rural Development Program of a Spanish region, helped to identify the major risks regarding nitrate leaching. All the agricultural management of the farm was registered (seeding, harvest, irrigation, manure applications, etc.) and soil moisture was estimated. A modelling approach was followed, but similar results could be achieved conducting a simple water and nitrogen balance.

Several farms were studied and only one case of significant nitrate leaching was found, associated to an occasional high infiltration rate. Fig. 3 shows the water balance and the infiltration excess. The reason was climate variability. A relatively high rainfall late summer raised the soil moisture above Field Capacity. Irrigation should have been suspended, but the farmer kept the same irrigation frequency. Improper irrigation or unexpected rainfall could increase soil water content over the Field Capacity, with the corresponding infiltration and nitrate leaching.

Utset et al. (2006)[8] and Utset and Del Rio (2011)[9] highlighted the effects of climate variability on irrigation management. This might be particularly relevant for nitrate leaching in the case of shallower water tables[9], with or without irrigation.

Climate variability might be enhanced in the following years, due to climate change. According to the IPCC assessment on climate variability and extreme events[10], climate change might change the statistical distributions of temperatures and precipitations in their means, variances and skewness. Fig. 4 shows these changes. In practice, the probability of heavy rains after usual fertilization will rise.

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[6] Utset, A. (ed). 2009. Climate Variability, Modelling Tools and Agricultural Decision-Making. Nova Sci. Publisher, New York, 361pp.

[7] Groenendijk et al. (2014). Performance assessment of nitrate leaching models for highly vulnerable soils used in low-input farming based on lysimeter data. Science of the Total Environment, 499:763-480.

[8] Utset, A., Martinez-Cob, A., Farre, I., Cavero, J. Simulating the effects of extreme dry and wet years on the water use of flooding-irrigated maize in a Mediterranean landplane. Agricultural Water Management 85:77-84, 2006.

[9] Utset, A., Del Rio, B. 2011. Reliability of current Spanish irrigation designs in a changed climate: a case study. J. Agric. Science. 149:171–183.

[10] https://www.ipcc.ch/site/assets/uploads/2018/03/SREX_FD_SPM_final-2.pdf

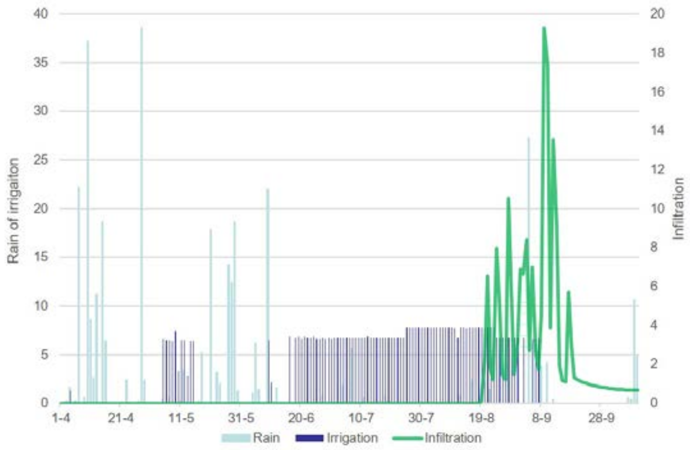

Fig. 3. Water balance in a farm, showing the combined effect of irrigation and rainfall on soil infiltration

Basically, extreme events would be more frequent and intense in the near future. Therefore, any plan aimed to reduce nitrate leaching, adapting the fertilization to the rainy season, should take into account the eventual rise on climate variability as well.

STATE OF PLAY IN THE EU

Nitrate pollution and impacts in the EU territory

The European Union has one of the most developed agriculture of the world, based on a high input of machinery, fertilizer, irrigation and other inputs. Nitrate pollution affects water of all member states of the EU, due to its intensive agriculture.

The EU Nitrates Directive (91/676 / EEC)[11] aims to prevent nitrates from agricultural sources polluting ground and surface waters and to promote the use of good farming practices. The Nitrates Directive (ND) is an essential part of the EU Water Framework Directive (2000/60/EC)[12]. The Water Framework Directive (WFD) aims to keep the good status of European waters. Both, the WFD and the ND have specific goals and activities. All the EU member states are committed to meet the WFD and the ND, as key instruments to protect European waters.

The EU Nitrates directive forces member states to develop action programmes, aimed to prevent, monitor, minimize and ameliorate the nitrate pollution in water. The ND goal is that surface freshwater and groundwater should not contain a concentration of more than 50 mg/l of nitrates. The member states must develop a monitoring network of their water resources, measuring regularly the nitrate concentrations.

The member states must also design Nitrate Vulnerable Zones (NVZs) in areas or regions where their agricultural activity mean polluting local surface freshwater or groundwater with nitrates, yielding a concentration higher than 50 mg/l. Specific plans will apply to these areas. Fig. 5 shows the current NVZs all over the European Union.

[11] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:01991L0676-20081211&from=EN
[12] https://eur-lex.europa.eu/resource.html?uri=cellar:5c835afb-2ec6-4577-bdf8-756d3d694eeb.0004.02/DOC_1&format=PDF

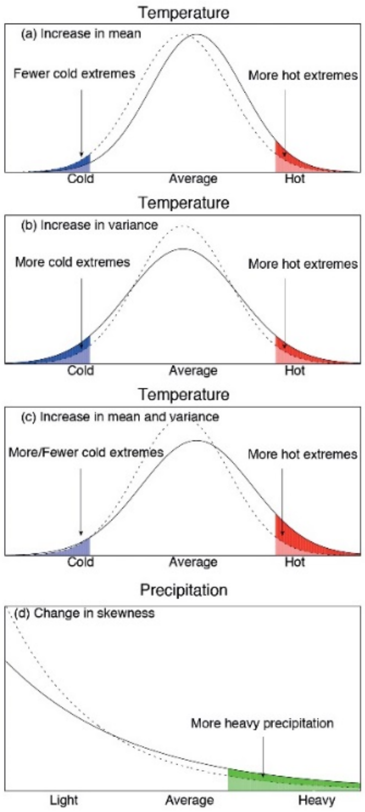

Fig. 4. Changes on the statistical distributions of temperatures and precipitations due to Climate Change

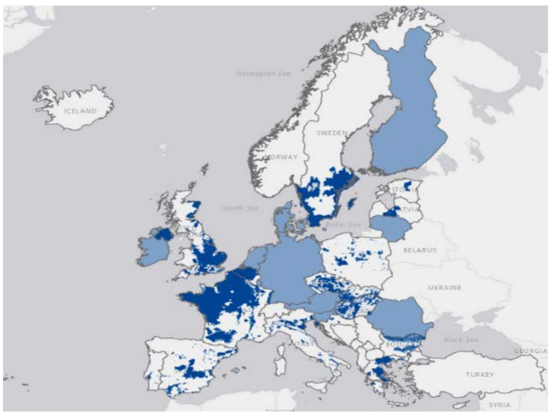

Fig. 5. Nitrate Vulnerable Zones in the EU member states.

The area of NVZs, where action programmes apply, constitutes about half of the total EU land area now. Some member states, such as Germany, The Netherlands, Ireland, Romania and Finland, have declared the whole country as NVZ.

The member states have to develop as well "Codes of Good Agricultural Practice" (CoGAP), aimed to reduce nitrate leaching. These codes are compulsory for farmers located in NVZs, but they can be followed on a voluntary basis by farmers located in other areas. Besides the CoGAP, the member states have to develop "Action Plans" for these NVZ, aimed to reduce the nitrate pollution risks. They have also to review the effectiveness of their action plans every 4 years, reporting to the EU Commission. The EC publishes the results of the 4-year revision of ND fulfilment at each country. The last report available corresponds to the period 2012-2015[13].

According to the report[13], the data on nitrates concentration show that freshwater and groundwater quality has slightly improved in 2012-2015 as compared to the previous reporting period (2008-2011). At the same time the situation is variable across the EU, with Member States where action programmes are achieving good results and Member States where further actions to reduce and prevent pollution are needed. Overall and despite some positive progress, nutrients overload from agriculture continues to be one of the biggest pressures on the aquatic environment. The report indicates that it needs to be addressed in order to achieve the good ecological status of waters as established by the WFD. The reports states that although the total area of NVZ has been increasing since 2012, there are still improvements to be made in some Member States in designating NVZs to include all areas draining into waters where they cause pollution. They have also to ensure the effectiveness of the action programmes. Specific actions for specific areas are needed.

Furthermore, according to the report, the quality of action programmes has improved overall, with tightened measures and improved methodologies to reach balanced fertilisation. However, in some Member States with the action programme applied throughout the whole territory, the measures need to be adequately adapted to different regional pressures and hotspots. The report recommends action programmes that allow for a more flexible approach at farm level can increase farmers' ownership and engagement. The EC warns that this approach can however only bring results if accompanied by clear environmental objectives and targets coupled with effective advice and support to the farmers to select and implement the right measures, stricter enforcement mechanisms and accurate nutrient management planning.

EU Institutional and legislative framework

Besides the WFD, several other EU policies and legislations are related to reduce nitrate leaching to the European water resources.

The EU Common Agriculture Policy (CAP) matches directly with the Nitrates Directive through the CAP cross-compliance[14]. Farmers located in NVZ must fulfil the CoGAP and the activities outlined in the action plans in order to receive the income support aids. CAP also obliges farmer to register all their activities (fertilization, pesticides, etc.) in an official book. These activities must comply with the conditions set in the ND action plans and the CoGAP.

[13] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018DC0257&from=en
[14] https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/income-support/cross-compliance_en

Besides the cross-compliance and combining regulations with incentives, the EU has introduced the “green direct payment” (or “greening”[15]). The “greening payment aims to support farmers who adopt practices that help meet environmental and climate goals. Several practices are included in the “greening” and each member states decides how to implement these aids.

Moreover, after the EU CAP reform in 2013[16], Rural Development Programs (RDP) support introducing agro-environmental measures, receiving free advises through an official “Farm Advisory System”, as well as knowledge transfer through collaboration projects with agricultural research centres and universities. Fig. 6 shows the combination of all these CAP regulations, incentives and supports.

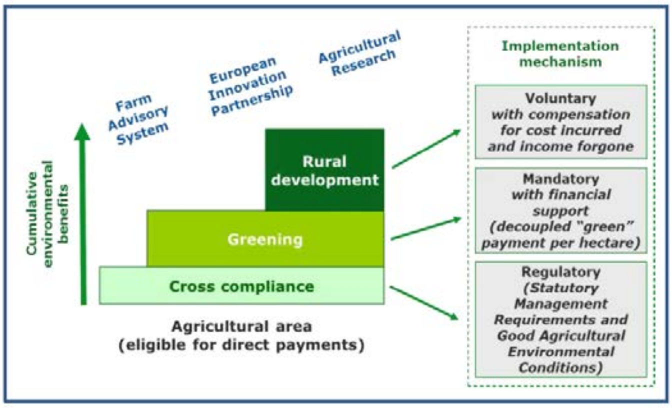

Fig. 6. CAP cross-compliance, greening and rural development

All these environmental actions must mean about 30% of the whole RDP, and they are an additional income for farmers, which are considered as “guardians of the environment”. Adopting reliable agricultural practices in order to reduce nitrate pollution is one of the issues eligible for funding in the RDPs.

However, one of the shortcomings found in the ND implementation is that it involves several administrations. Monitoring the water bodies, periodically measuring the nitrates contents is usually a competence of the River Basin or environmental authorities while developing the CoGAP is usually a competence on the regional authorities in charge of CAP cross-compliance control and RDP. While CAP has funds for its implementation, WFD relies only on legislation.

Fig. 7 depicts the potential lack of coherence between the WFD and the CAP, since they are different policies, implemented and controlled by different authorities. This lack of coherence has been considered as a serious risk of failure in implementing the ND and other EU water policies by the European Court of Auditors Report (ECA, 2014)[17].

The ECA report indicates that there is not enough knowledge or good mechanisms to evaluate the relationship between the CAP implementations and its water impact. That means that the

[15] https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/income-support/greening_en
[16] https://ec.europa.eu/agriculture/rural-development-2014-2020_en
[17] https://www.eca.europa.eu/Lists/ECADocuments/SR14_04/SR14_04_EN.pdf

competent administration has to improve or develop tools to allow a cause-effect analysis between agricultural development and the water quality and quantity and also to evaluate the effect of the introduction of corrective measures.

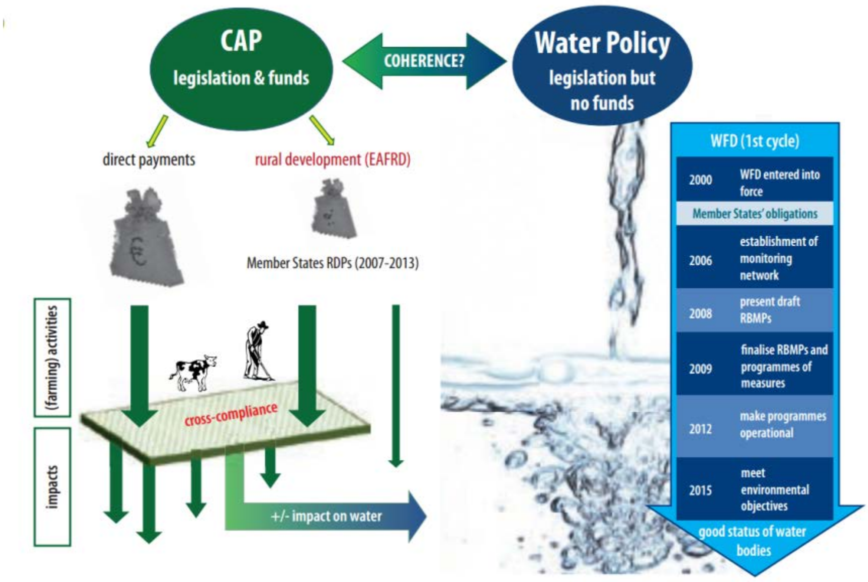

Fig. 7. Potential lack of coherence between CAP and WFD

There are several EU institutions dealing directly or indirectly with the risk of nitrate pollution of European waters. The ND competence, including taking action against member states not fulfilling the Directive, relies on the EU Directorate General for Environment[18]. The DG Environment produces the reports about ND implementation each 4 years, as well as factsheets and general information. There are also several studies commissioned by DG Environment to support implementation of the Nitrates Directive, which are free available usually. Besides, the European Environment Agency[19] (EEA) provides updated reports, figures and data about the water quality status all over Europe. These reports are valuable instruments to evaluating the problems and solutions for the EU Commission and to each country's government. Furthermore, the EU Joint Research Centre[20] (JRC) conducts global researches and assessments about nitrate pollution in European waters, among other activities. Usually, JRC actions aim to support decision at the EU level. For instance, JRC recently published a report about the safe use of processed manure[21] in NVZs above the ND threshold.

Besides the EU institutions involved and with competences over ND, there are many other EU instruments related to the water pollution problem. Some initiatives such as the European Innovation Partnership on Water or EIP-Water[22] in short, facilitated the development of

[18] https://ec.europa.eu/info/departments/environment_en
[19] https://www.eea.europa.eu/
[20] https://ec.europa.eu/jrc/en
[21] https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/technical-proposals-safe-use-processed-manure-above-threshold-established-nitrate-vulnerable
[22] https://ec.europa.eu/environment/water/innovationpartnership/index_en.htm

innovative solutions to address major European and global water challenges. At the same time, the EIP Water supported the creation of market opportunities for these innovations, both inside and outside of Europe. Similarly, the EIP-AGRI[23] promotes innovation in agriculture. While the EIP-WATER depends on the DG-Environment, the EIP-AGRI is a dependence of the EU Directorate-General for Agriculture and Rural Development. Again, although both innovation partnerships deal with nitrate pollution in agriculture, there is a lack of coherence between them, as pointed out above. The EIP-AGRI has the support of the CAP, particularly the RDPs, through the "cooperation" measure. Agricultural research can be organized at several EU member states as once through the EIP-AGRI. Precisely, the results shown in Fig. 3, which helped to understand the importance of climate variability in a proper irrigation management, came from an EIP-AGRI action, supported by the RDP of a Spanish region. EIP-AGRI and applied agricultural research aim to support farmers in Europe to improve their agricultural management sustainably.

Actually, dealing with nitrate pollution problem is one of the most important environmental challenges in Europe and elsewhere. Therefore, this is a priority subject of most of the environmental programs and instruments of the European Union. Particularly, the EU LIFE Program[24], the most important funding source for environmental and climate projects in Europe since 1992, has funded several projects aimed to clarify how nitrate pollution comes from agricultural lands to waters, as well as to improve the CoGAP and the actions plans accordingly. The current LIFE funding period 2014-2020 has a budget of €3.4 billion. LIFE is not a research program. Instead, LIFE promotes innovation and introducing existing knowledge.

The EU funds research through its Horizon 2020 Programme. The Horizon 2020 has a special subprogram for water innovation[25], which has funded many projects in this regard, including those aimed to reduce nitrate pollution of waters. The PRIMA[26] subprogram of Horizon 2020, on the other hand, is particularly addressed to agro-food systems in Mediterranean countries. PRIMA funds applied collaboration researches with several Mediterranean partners. Projects aimed to reduce nitrate pollution risks are indeed within the PRIMA scope. Similarly than LIFE, PRIMA promotes applied rather than basic researches, with clear and direct benefits for the Mediterranean population.

There are several other EU instruments and programs which might fund activities addressed to reduce nitrate pollution due to agricultural activities, such as INTERREG[27], WATER JPI[28] and others.

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[23] https://ec.europa.eu/eip/agriculture/en
[24] https://ec.europa.eu/easme/en/life
[25] https://ec.europa.eu/programmes/horizon2020/en/h2020-section/water-innovation
[26] https://prima-med.org/
[27] https://www.interregeurope.eu/
[28] http://www.waterjpi.eu/

Major Lesson Learned on EU level

The successes and shortcomings while implementing the EU Nitrates Directive can be followed from the published reports[29]. As pointed out in the last report[13], the measured nitrate concentration in European waters has been reduced significantly since the implementation of the EU ND. However, many NVZ still show nitrate concentrations above 50 mg/l.

Despite the ND is compulsory for all the EU Member States under the same conditions, the practical implementation of the Directive differs from one country to the other. While in North European countries such as Germany or the Netherlands the combination of rainy weather with shallower water tables possesses the main risks of nitrate pollution, countries of South Europe have to deal as well with the effects of irrigation excess. Furthermore, countries from East Europe more recently incorporated to the EU still struggle with some agricultural transformations from their past socialist times to the new CAP conditions. Therefore, CoGAP and Action Plans change among the EU countries and regions, as well as the designation of NVZs and the monitoring networks. However, all the countries must comply with the same goals of ND: To keep nitrate concentration in EU water below 50 mg/l and to establish reliable plans to reduce the nitrate concentration in places where it is higher than this limit.

Spanish example: Ebro River Basin

Ebro is the main Spanish River. Its roman term ("*Iber*") gave the current name to the whole Iberian Peninsula. Agriculture is the main activity in Ebro Valley since Roman times. Rainfed wheat and barley and particularly irrigated maize, alfalfa and vegetables are the main crops in the zone. Fruit trees and vineyards are also important in the area. Water availability has been always a serious concern for agriculture in the Valley, therefore most of the irrigated areas are nearby rivers. The region has, however, an important network of irrigation canals. Surface irrigation is up to now the most frequent method, although a huge investment in sprinkler irrigation has been conducted, under the support of the EU RDPs. The Spanish efforts in improving irrigation, particularly in Ebro Valley, are among the highest investments of the world in this regard.

Designing and controlling the basin Hydrological Plans, as well as implementing WFD rely on "*Confederacion Hidrografica del Ebro*" (CHEBRO)[30], the River basin administration. CHEBRO is an official dependency of the Spanish Ministry of Environment. CHEBRO's responsibilities comprise monitoring water quality status all over the basin, as well as forecasting risks of flood avenues, drought, etc.

CHEBRO has a network of automatic stations all over the basin[31]. Besides nitrates, the automatic stations register periodically pH, water temperature, electrical conductivity, dissolved oxygen, redox potential and other parameters. Fig. 8 shows the station's network all over the basin. Some stations provide shared services with the regional administrations (Catalonia, Aragon, Navarra, etc.). The data registered by the stations is collected in monthly reports, which are freely available. The reports indicate, among other issues, if nitrate concentration has increased

[29] https://ec.europa.eu/environment/water/water-nitrates/reports.html
[30] http://www.chebro.es/
[31] https://www.saicaebro.com/redalerta/inicio.php

in any particular station. These data is used to the periodic report the Spanish authorities have to deliver to the European Commission, as part of their ND duties.

Fig. 8. Network of automatic stations in the Ebro River Basin

According to the information provided by CHEBRO, as well as their own measurements, regional governments of the Ebro Valley (i.e. Aragon, Navarra, Catalonia and Basque Country) have to implement their ND plans.

For instance, GAN[32] ("*Gestion Ambiental de Navarra*") is the official institution in charge of controlling and measuring water quality in Navarra. They have the competence regarding ND at the regional level, with their own measurements and stations besides the CHEBRO information system. GAN responsibilities particularly comprise designing NVZs in Navarra, according to the nitrate concentration rates.

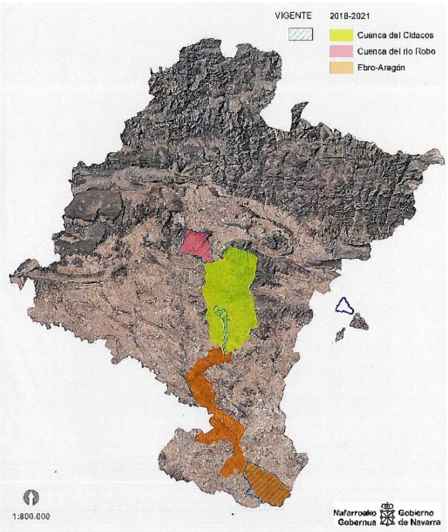

Fig. 9. Nitrate Vulnerable Zones of Navarra, Spain

[32] https://gan-nik.es/

The nitrate vulnerable zones of Navarra are shown in Fig. 9, after the Navarra's government decision on 2018[33]. The NVZ in brown corresponds to Ebro River, while the two other are affluent. Besides designing NVZ in Navarra, GAN supports the regional government regarding the ND action plans and particularly in the reports they have to submit to the Spanish central government and to the European Commission. GAN must guarantee that nitrate concentration in water in Navarra falls below 50 mg/l. In the case of higher values they must adopt the corresponding measures, updated each 4 years.

However, the development of the regional CoGAP relies on INTIA[34], which is the regional agricultural extension service. The Navarra's Action Plan and CoGAP of 2002[35] was reviewed in 2018[36], after recommendations of the European Commission, according to the report submitted and to the regional nitrate concentration records.

The Navarra's CoGAP[35] limits the amount of manure or other organic fertilizers that can be applied directly to the soil, as well as mineral fertilization in some periods for some crops. It indicates the fertilization procedure for each crop and season (seeding, etc.). Moreover, it forbids the application of manure in flooded soils or soils with inclinations higher than 15%, in order to avoid nitrate leaching with infiltration or runoff. The regional CoGAP also sets tough indications about manure storage. The 2018 revision of the regional CoGAP[36] sets higher limits to total fertilizers, as well as the periods when application is allowed. Furthermore, the revision forbids fertilization in frozen or snowy soils, which was not considered in the previous CoGAP. The revision comprises as well several other additional measures in the ND action plan, such as promoting "greening" practices in NVZs. Instead of CoGAP, which is compulsory in NVZs, "greening" is a voluntary decision of farmers (see Fig. 6).

Similarly to the Navarra's case, Aragon government has designed its NVZs. Fig. 10 shows the regional NVZs in Aragon. The zones are distributed according to the water bodies and the specific agricultural activity. However, instead of Navarra, although the "*Instituto Aragones del Agua"* (IAA)[37] is the regional institution responsible for WFD competences, the agricultural regional service of Aragon (CITA)[38] plays a more important role regarding ND implementation than its corresponding Navarra's service. For instance, CITA is in charge of designing NVZ and developing not only CoGAP but also ND action plans. CITA, however, is a special case among the Spanish agricultural extension services since it is associated to a prestigious national agricultural research centre[39]. The last ND action plan of Aragon was released in 2013[40].

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[33] https://bon.navarra.es/es/anuncio/-/texto/2018/206/0/
[34] https://www.intiasa.es/en
[35] http://www.lexnavarra.navarra.es/detalle.asp?r=28149
[36] https://gobiernoabierto.navarra.es/sites/default/files/of_modificacion_programa_actuacion_zonas_vulnerables_nitratos_abril_2019.pdf
[37] https://www.aragon.es/-/instituto-aragones-del-agua
[38] https://www.cita-aragon.es/
[39] https://www.eead.csic.es/
[40] http://www.boa.aragon.es/cgi-bin/EBOA/BRSCGI?CMD=VEROBJ&MLKOB=754410362323&type=pdf

As well as in the Navarra's case, the Aragonese CoGAP[41] limits the amount of fertilizers and their application periods by crop, as well as in wet lands or near water bodies (wells, rivers, streams, etc.). The CoGAP obliges manure control and storage. It points out as well how to conduct irrigation, according to the soil features. The Aragonese CoGAP compels farmers in NVZs to keep records of fertilizations and all the agricultural management activities since 2007. This has been included as compulsory in the last CAP regulations of 2013[14].

The other regional administrations in the Ebro River Basin have developed similar actions than Aragon and Navarra.

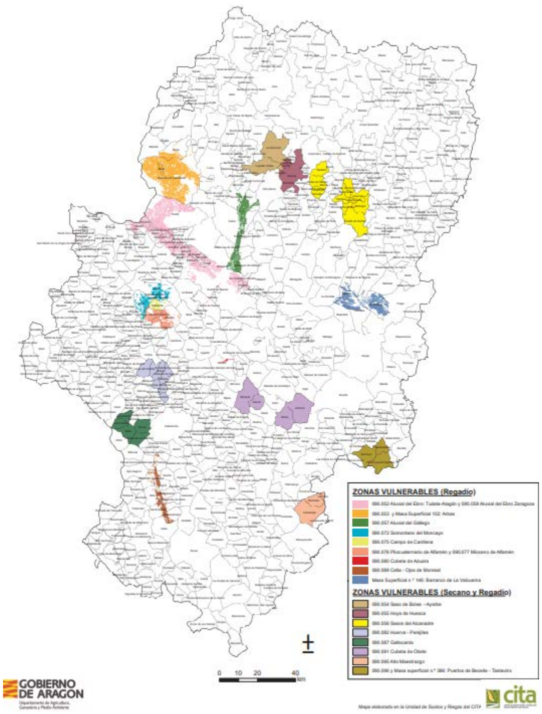

Fig. 10. Nitrate Vulnerable Zones in Aragon, Spain

Italian example: Tuscany region

Agricultural activities in Tuscany, Italy, started from ancient times, and they have never stopped, although its importance declines nowadays. Cereals, potatoes, olives and particularly grapes are grown in the inland areas of the region. The reclaimed marshy areas currently produce vegetables, rice, tobacco, beets, and sunflowers.

The "*Agenzia Regionale per la protezione ambientale della Toscana*" (ARPAT)[42] is the institution in charge of ND implementation in the Tuscany region, in Italy. Similarly to CHEBRO, in Spain,

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[41] https://www.aragon.es/documents/20127/674325/BOACodigo-buenas_practicas1997.pdf/79c5897e-2b7b-285a-0672-0659b2e86abc

[42] http://www.arpat.toscana.it/

ARPAT controls and regularly measures nitrate concentrations in a huge number of stations all over the Tuscany. Fig. 11 shows the network, taken from ARPAT's website. The measurements at each station are freely available through the ARPAT'S system. The designation of NZVs, as well as developing the action plans of ND and the CoGAP relies on the regional government: "*Regione Toscana*"[43]. The regional government of Tuscany has designated five NVZ in the region.

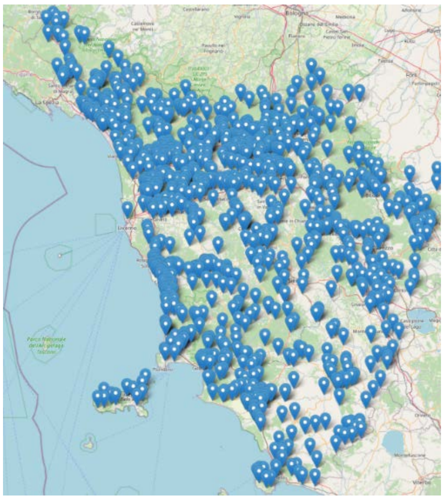

Fig. 11. ARPAT monitoring network for controlling nitrate contents in the Tuscany region, Italy

Nome della Zona vulnerabile	Superfice (ha)	% Superficie ZVN su tot. superficie regionale	% Superficie ZVN su SAU regionale
Zona vulnerabile del Lago di Massaciuccoli	14.417,63		
Zona Costiera tra Rosignano Marittimo e Castagneto Carducci	21.562,80		
Zona costiera della Laguna di Orbetello e del Lago di Burano	14.555,89		
Zona costiera tra S. Vincenzo e la Fossa calda	3.373,35		
Zona del Canale Maestro della Chiana	60.289,82		
TOTALE DESIGNATE	*114.199,43*	*5.03*	*15.12*
Superficie Regione Toscana	2.268.398,85		
SAU Regione Toscana (ISTAT - VI ° Agricoltura 2010)	755.295,00		

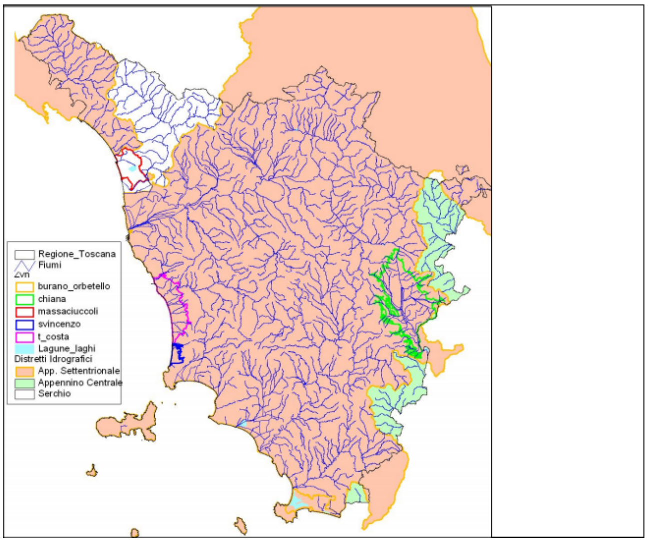

Fig. 12. Nitrate Vulnerable Zones in Tuscany, Italy

43 https://www.regione.toscana.it/home

Tuscany has a regional plan for water protection, approved in 2005[44]. On the other hand, instead of developing a regional CoGAP as in the Spanish practice, Tuscany has adopted the Italian CoGAP[45], "*Supplemento Ordinario n. 86 G.U. n. 102 del 04-05-1999*". The Italian CoGAP considers also limits to fertilization, as well as restrictions to manure applications and the periods when fertilization is allowed by crops. It considers as well some conditions for acceptable irrigation management.

LIFE program: The Nitrates project.

As pointed out in the 4-years reports of the European Commission regarding the ND implementation, despite the progresses and achievements there are several NVZs all over Europe where nitrate concentration remains high. Therefore, the authorities in charge of ND must conduct specific actions aimed to reduce nitrate pollution in these particular zones. The actions to be conducted usually involve a more detailed study of the nitrate pollution causes, which needs funding. The LIFE program is the main EU funding source in this regard. The LIFE program funded the NITRATES[46] project (2011-2015) in the Navarra's part of Ebro catchment. The project was conducted in one of the Navarra's NVZ, shown in Fig. 9. The zone has been identified as one of the most risky areas in the country regarding nitrate pollution of waters. Furthermore, periodical measurements of nitrate concentrations in the water have not shown significant reductions of the risk. Therefore, the government of Navarra needed to assess deeply the situation and to develop specific actions for this NVZ.

Fig. 13 shows the general approach of the NITRATES project, which provided local information as input for the models SWAP and MODFLOW. The project followed the approach suggested by Xu et al. (2012)[5]. Farmers are obliged to keep records of their activities by CAP cross-compliance[14]. Furthermore, CAP direct payments are based on farm sizes and hence spatial information of farms is usually stored in regional GIS databases. This information was used to generate the inputs to the models, farm by farm.

[44] https://www.regione.toscana.it/-/piano-di-tutela-della-acque-della-toscana-2005
[45] https://www.gazzettaufficiale.it/atto/stampa/serie_generale/originario
[46] https://www.life-nitratos.eu/index.php/en/

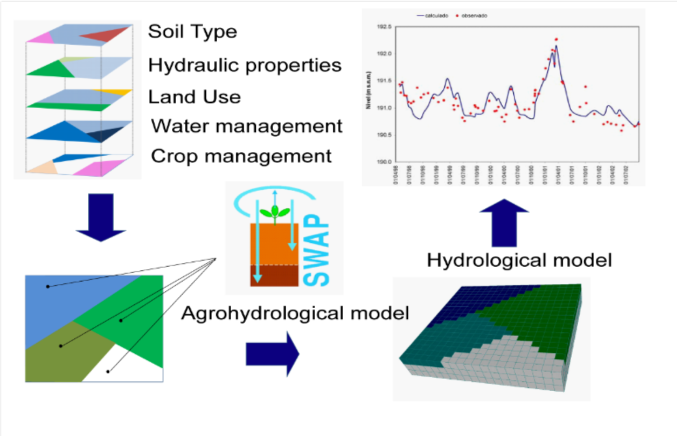

Fig. 13. General approach of the LIFE NITRATES project

Simulation results indicated where higher nitrate leaching rates might be expected, as shown in Fig. 14. Some parts of the NVZ have particularly higher nitrate leaching rates, according to the estimations.

Furthermore, the analysis show the influence of climate variability in nitrate leaching, since several years were considered. Fig. 15 shows the monthly averages of nitrate leaching. The nitrate leaching reaches peaks in the summer months, due to irrigation effects. However, it is not in the same extent every year. Heavy rains were recorded in 2007, especially in the winter. The results show the effects of such climate variability.

At the same time, the analysis indicated which crops contribute to higher nitrate leaching in the region, as shown in Fig. 16. Maize and cereals such as wheat and barley are the most important contributors to the leached nitrogen. Vegetables contribute with 18% of the total leached nitrogen, although they mean less than 10% of the cropped area. On the other hand, although maize area is lower than cereals, still maize is the main contributor to nitrate leaching. Both maize and vegetables are irrigated crops with high fertilization inputs.

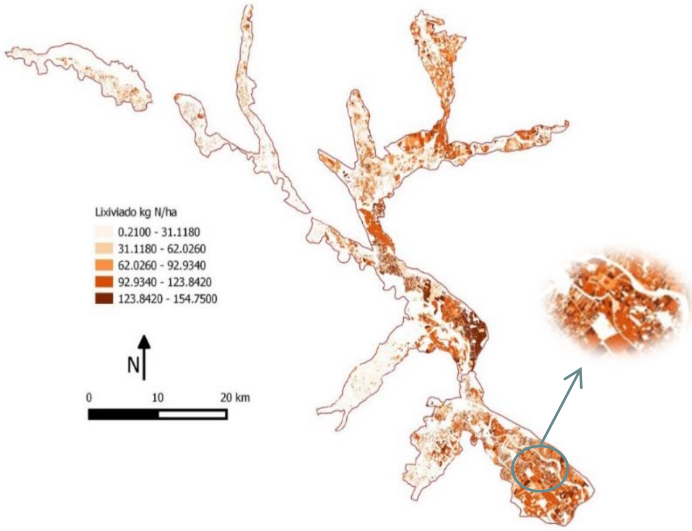

Fig. 14. LIFE NITRATES simulation results

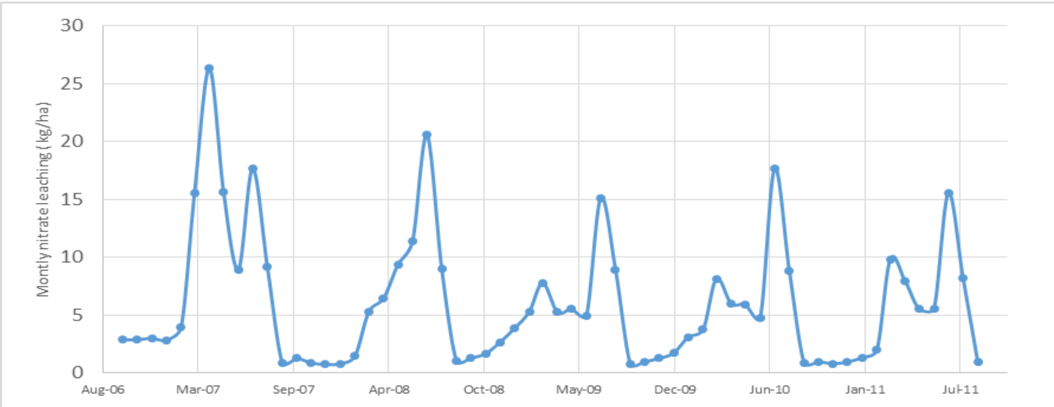

Fig. 15. Monthly nitrate leaching estimations

Despite the LIFE NITRATES project was based in modelling simulations, this approach is not absolutely needed to assess which crops and agricultural practices mean more serious risks regarding nitrate leaching. However, gathering data in the particular regions where environmental authorities want to stop nitrate pollution of waters, as well as conducting water and nitrate balances, are compulsory before arriving to any particular conclusion.

Moreover, besides the large amount of data provided by a spatial analysis, focusing on pilot farms, representatives of the agriculture management in a region, could achieve very good conclusions about nitrate leaching.

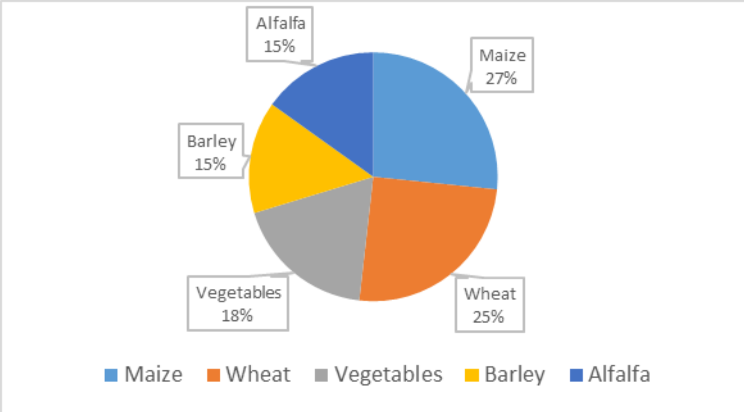

Fig. 16. Contribution of nitrate leaching by crop

As pointed out above, besides LIFE NITRATES, the LIFE program has funded hundreds of other projects related with the implementation of the ND and the WFD all over Europe. The LIFE REWAT[47] project is one of them. LIFE REWAT aimed to develop a participated strategy for integrated water resources management at sub-catchment level at the lower Val di Cornia, Tuscany. The project activities comprise demonstrating the technical feasibility, the economic advantage and the environmental sustainability of some technical solutions for the natural and managed recharge of the aquifer, as those considered in the CoGAP and in the regional actions plans for ND.

Horizon 2020: FREEWAT

Instead of the LIFE Program, which funds applied environmental solutions, the Horizon 2020 promotes research. Dozens of research projects have been funded related to nitrate pollution of waters, with specific objectives and results. Funded researches started in the eighties, developing methods for quantitatively assessing the impact of agricultural practices[48] in nitrate leaching, pointing out the factors responsible for nitrate pollution in European agricultural systems[49] or evaluating several models for simulating nitrate leaching[50]. Many projects have been addressed to developing and testing ICT tools. For instance, N-TOOLBOX[51] aimed to develop a "toolbox" of cost-effective technologies to be implemented at the farm level to protect water from nitrate pollution. Similarly, the INCA[52] project promoted an integrated catchment approach. Although many projects can be referred in this regard, we will briefly describe FREEWAT, which aimed to simplify and systematize the application of the WFD and other EU water related Directives, considering previous EU and national funded researches and results.

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[47] https://www.liferewat.eu/en/
[48] https://cordis.europa.eu/project/id/EV4V0098
[49] https://cordis.europa.eu/project/id/80010103
[50] https://cordis.europa.eu/project/id/EV5V0493
[51] https://cordis.europa.eu/project/id/227156
[52] https://cordis.europa.eu/project/id/EVK1-CT-1999-00011

Similarly to other projects, FREEWAT promoted a modelling solution, integrated in a GIS[53]. The main difference to other projects is that instead of developing models, FREEWAT promoted the use of existing and validated IT tools, making them open source and free.

FREEWAT case studies comprised implementing ND in Tudela-Cortes, Navarra (see Fig. 14) as well as in Lake Massaciuccoli (see Fig. 12). The approach considered for assessing nitrate pollution in the regions is the same recommended by Xu et al. (2012)[5] and particularly the one followed in the LIFE NITRATES project. FRREWAT results not only improved those obtained in the LIFE NITRATES project, but also brought a systematization on the nitrate pollution analyses and the evaluation of the reliability of current CoGAP and ND action plans.

Fig. 17 shows the land uses at each of the farms in the Tudela-Cortes NVZ, as obtained from the CAP reported data. Furthermore, Fig. 18 depicts the water uses at each farm (i.e. flood or sprinkler irrigation, water layers, etc.).

Fig. 17. Land uses in Tudela-Cortes NVZ

The land and water uses information is crucial in order to assess nitrate leaching contribution from each farm. Agricultural management (fertilization type, amount applied and dates, etc.) can be either taken from the CAP records or estimated from typical managements for each crop. Modelling approaches could be followed or not, but gathering the right data is compulsory in any assessment aimed to reduce nitrate leaching in specific regions. GIS and models, however, could indeed help.

[53] R. Rossetto, G. De Filippis, F. Triana, M. Ghetta, I. Borsi, W. Schmid. Software tools for management of conjunctive use of surface- and groundwater in the rural environment: integration of the Farm Process and the Crop Growth Module in the FREEWAT platform. Agricultural Water Management, 223:105-122.

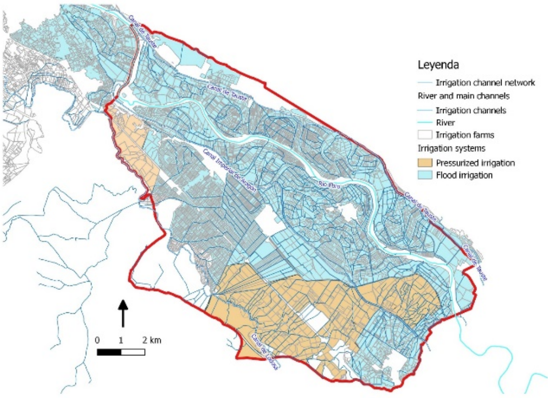

Fig. 18. Water uses at Tudela-Cortes NVZ