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# Irrigation return flow and nitrate leaching under different crops and irrigation methods in Western Mediterranean weather conditions

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ABSTRACT

Agriculture constitutes a major source of non-point pollution (e.g., nitrates) where overall water resources are affected, in particular, aquifers. Intensive agricultural practices take place in regions with appropriate weather conditions that are usually deficient in water resources. The preservation of water resources in these types of regions depends on the evaluation of the efficiency of agricultural practices for specific crops and conditions. Although water scarcity is a characteristic feature in the Western Mediterranean, it is one of the most appropriate regions in the world for intensive agriculture development for climatic reasons. In the current work, percolation and N leaching from different crops (corn, potato, and rotation of lettuce and melon) under different irrigation methods (surface, sprinkler and drip) were evaluated through experimental plots. Water (irrigation + precipitation) and fertilizer inputs were accurately controlled. Soil water content and nitrate concentration were monitored from time domain reflectometry measurements, and cup lysimeters and destructive sampling, respectively. Percolation and nitrate leaching was simulated from different numerical codes (STICS and GLEAMS, tipping bucket method; HYDRUS-1D, Richards' equation), which were chosen based on the available information and the specific purposes of each experiment. For the studied periods, the obtained results showed high percolation values: 34, 58 and 37% of total applied water for corn, potato, and rotation of lettuce and melon, respectively. Also, high N leaching values across all experiences were observed, even higher than the applied doses in some periods as consequence of remobilizing mineralized N, despite following the recommended agricultural management practices. Percolation and N leaching were mostly controlled by the precipitation regime, namely, unevenly distributed intensive rainfall events, mainly in autumn and spring, which have a great impact in irrigated agriculture due to the permanent high soil water content. In detail, irrigation water applied for frost prevention on potato crops and plastic cover for melon crops, played a very important role for both percolation and N leaching. Whilst for the corn crop, N leaching mainly took place in the fallow period (autumn and winter), where the rain leached N present in soil from previous crops.

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## 1. Introduction

For decades, intensive agricultural practices have been associated with the increasing use of nitrogen fertilizers in order to increase crop productivity (Schepers et al., 1991). Agricultural activities are probably the most common diffuse pollution source (Candela et al., 2008), including several environmental impacts, with groundwater pollution being one of the most significant (Muhammetoglu et al., 2002). Intensive over fertilization results in elevated nitrate concentrations in groundwater. This problem has led the public administration, including the European Union, to legislate and enforce "Best Management Practices" (BMPs) in regions with a high risk of groundwater pollution by nitrates (Council of European Community, 1991).

The number of interrelated factors that control the dynamics of N in soil and its environmental impacts have motivated a broad scientific research on this topic. It is apparent that there are three main reasons for groundwater pollution by nitrates, these being high irrigation return flow (which turns into aquifer recharge in many cases), high doses of nitrate fertilizer applied, as well as the presence of residual nitrates in soil. Different methods have

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been used to estimate irrigation return flow and nitrate leaching, depending on the irrigation method (flood, sprinkler, and drip) and crop type, include experimental and tracer techniques, as well as numerical modeling approaches (García-Garizábal and Causapé, 2010; Abderrahim et al., 2011; Cavero et al., 2012; García-Garizábal et al., 2012; Skhiri and Dechmi, 2012).

The regions where intensive agriculture is practiced are not always the most appropriate areas to carry out this activity. In the last decades, semi-arid and arid regions have developed this activity due to the warm temperature and the high number of daylight hours. However, these regions have a structural surface water resources scarcity, making groundwater a strategic resource. Analyses of irrigation return flow taking into account land cover and irrigated cropland have shown the impact of heavy rainfall (Jiménez-Martínez et al., 2009, 2012). Similarly, numerous studies focused on nitrate leaching show that an excess of irrigation can be the cause of it (Jalali, 2005; and Wallis et al., 2011). Soil nitrate concentration and percolation by heavy rainfall or irrigation excess are the main factors that control nitrate leaching (Tamini and Mermoud, 2002). Comparative studies report the advantages of drip irrigation compared to sprinkler or flood irrigation (Darwish et al., 2003; Mack et al., 2005). Deficit irrigation has been proposed as an alternative to reduce nitrate leaching, but in this case, the amount of nitrogen fertilizer should be reduced in proportion to the amount of soil water available for plant water uptake (Gheysari et al., 2009).

For the management of limited water resources in semi- and arid-regions, agriculture has to improve the water and nutrient management of both irrigated and rain-fed crops, in order to reduce irrigation return flow and the leaching of fertilizers. The main objective of this work was to assess the soil water and nitrate balance for a wide spectrum of crops and irrigation methods in the Western Mediterranean, a region with unevenly distributed intensive rainfall events and where the primary land use is irrigated and rain-fed agriculture. Different numerical approaches were considered in each experiment based on the available information and the specific characteristics of each crop and management. A second objective was to identify possible non-adequate management practices and to propose measures in order to mitigate percolation and nitrate leaching.

## 2. The Western Mediterranean

The Western Mediterranean area presents particular climatic characteristics. Unlike the Eastern part of the Mediterranean Sea, temperatures are lower, humidity is higher and precipitation is from both a Mediterranean and Atlantic origin (Fig. 1). Due to the cooling process in the continent and the relative warmth of the Mediterranean Sea, over this area, intensive precipitations are frequent in September and October. The contribution of these precipitations to the aquifer recharge is greater that it might seem at first (Plata, 1994). On the contrary, the Atlantic precipitation regime is different from these typical Mediterranean precipitations. The Atlantic fronts come in warm, so that they produce commonly relative low intensity precipitations, which do not produce significant aquifer recharge.

The relative good weather conditions motivated the development of intensive agriculture during the twentieth century, with different types of crops (e.g., fruit trees, horticulture, or cereals) and irrigation methods (e.g., flood, sprinkler, or drip irrigation). The most intensive land use in terms of water and nutrient consumption corresponds to irrigated agriculture, frequently located on top of highly vulnerable aquifers, which are mainly located in zones of high water demand, such as coastal areas. Intensive fertilization is obtained with relatively heavy applications that frequently exceed crop needs. This change in the land use is a modifying agent of natural aquifer recharge, as well as a source of groundwater pollutants, mainly from fertilizers.

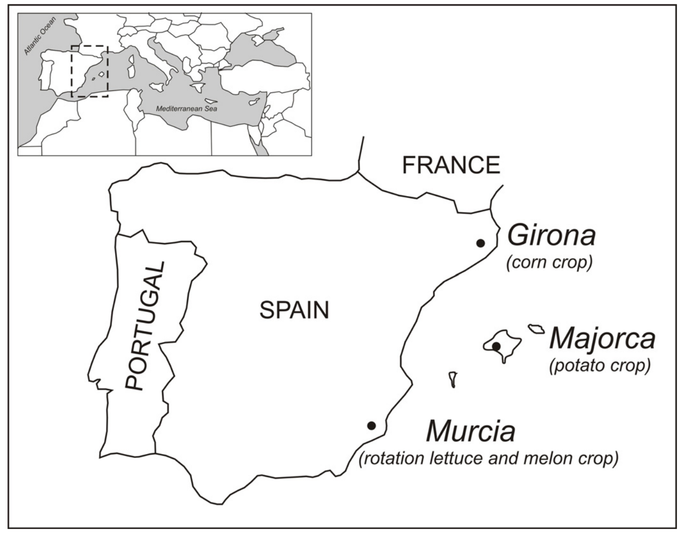


**Fig. 1.** Location of experimental sites in the Western Mediterranean and crops cultivated.

From a water resources point of view, the Western Mediterranean region presents several problems generated by water scarcity. Among them: high irrigation needs, changes in consumer demands (growing population), and the effects of climate change (Candela et al., 2009, 2012; Bindi and Olesen, 2011) have to be considered. In terms of water quality, groundwater pollution by agrochemicals (mainly nitrates) is an extended problem due to existing agricultural practices (Araus, 2004). Finally, note that environmental impacts of agriculture under a changing climate in the Western Mediterranean are considered as more and more important. The unevenly distributed rainfall regimen is expected to be accentuated, thus, for example, a recent study predicted N leaching increases for winter wheat crop in some locations of the Western Mediterranean (Olesen et al., 2007).

## 3. Field sites and experiments

The work includes three field experiments: (1) corn crop under furrow irrigation at the Girona (NE, Spain) experimental site; (2) potato crop under sprinkler irrigation at the Majorca (Balearic Islands, Spain) experimental site; and (3) lettuce and melon crop under drip irrigation at the Murcia (SE, Spain) experimental site.

### 3.1. Corn at the Girona experimental site

The furrow irrigated corn trial was conducted at the Agriculture Experimental Site IRTA-Mas Badia (La Tallada d'Empordà, Girona, NW Spain) (see Fig. 1). This area has an average annual precipitation of 690 mm and a mean annual temperature of 15 °C, with a mean cumulative water deficit of 440 mm between March and September (Poch-Massegú, 2012).

The soil at the experimental site is classified as an Oxyaquic Xerofluvent (Soil Survey Staff, 1998). According to the USDA textural classification system, it presents a homogeneous silty-loam texture between ground surface and 1.2 m depth (Table 1), as well as being a well-drained and non-salty soil. The unconfined aquifer, on which the agriculture takes place is only exploited for irrigation, and presents a groundwater level oscillating between 4 and 6 m depth below ground level, depending on the season.

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