Agricultural Water Management 148 (2015) 223–231

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Irrigation-induced nitrate losses assessed in a Mediterranean irrigation district

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ARTICLE INFO

Article history:
Received 21 February 2014
Accepted 6 October 2014
Available online 5 November 2014

Keywords:
Irrigation return flow
Nitrate loss
Temporal nitrate variability
Mediterranean agriculture

ABSTRACT

Irrigated agriculture is crucial for productivity of major crops (mainly cereals) grown in Mediterranean countries, where extended and prolonged drought conditions adversely impact productivity. Under such conditions, irrigation and rainfall events combined with nitrogen (N) fertilization can induce nitrate (NO_3) losses in irrigation return flows (IRFs). Such water-induced NO_3 losses in IRFs were assessed during the 2007–2010 hydrological years in the 9495 ha of the Akarsu Irrigation District (AID) of southern Turkey, with daily monitoring at three drainage gauging stations to quantify flow rates, NO_3 concentrations and loads. Climatic data, soil characteristics, fertilizer N application rates to major crops, cropping patterns, and irrigation and rainfall depths were also recorded. Nitrate concentrations were higher in IRFs during winter months, ranging between 37 and 44 mg NO_3 L^{-1} on average, compared to the concentrations in the irrigation season (10–23 mg NO_3 L^{-1}). Since most of the fertilizer N was applied in winter and early spring to wheat (2/3 of 195 kg N ha^{-1}) and first crop corn (1/3 of 340 kg N ha^{-1}) as preplant and surface applications; NO_3 concentrations were high during these seasons because of the limited N consumption of these crops in their early growth stages. However, the NO_3 load distributions in winter and summer months were similar. Annual loads of 39.7, 29.3, 55.3 and 55.2 kg NO_3–N ha^{-1} were measured in the 2007–2010 IRFs, respectively, with 45 to 57% occurring during the irrigation seasons. The consistent high NO_3 over 4 years point to the potential to reduce losses and associated N pollution through better crop, irrigation and N fertilizer management. Well-established fertilizer and irrigation water management plans are critical to reduce NO_3 pollution risks in Mediterranean irrigated lands.

1. Introduction

Rainfed agriculture dominates the Mediterranean region in terms of crop area acreage, but irrigated agriculture has a disproportionate influence on productivity of the major crops grown in this region. Mediterranean countries, including Turkey, have significant areas of both rainfed and irrigated agriculture which is characterized by two contrasting seasons: mild and relatively wet winters and hot and dry summers (Kassam, 1981) with limited rainfall (300–650 mm). While dryland cropping is practiced in winter and early spring, irrigation is needed in late spring and summer (Ryan et al., 2009).

With increasing land use and intensive crop production, rainfed and irrigated agriculture cannot be sustainable without fertilization. Nitrogen (N) fertilizers are extensively used in the Mediterranean region, and N consumption worldwide and in the region is increasing. Thus, N fertilizer use increased from 50 Mt in 1977 (Bumb, 1995) to 101 Mt in 2006 (FAO, 2008) worldwide. Given the attention to escalated dynamics of N under irrigation, mismanagement of these two major agricultural inputs has led to increasing concerns of environmental N pollution, i.e., NO_3 accumulation in water resources and eutrophication in rivers, lakes and coastal areas (Galloway and Cowling, 2002). Therefore, on-site and off-site nitrate pollution is also a common problem in the Mediterranean area, and should be considered accordingly.

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http://dx.doi.org/10.1016/j.agwat.2014.10.007
0378-3774/

The extent to which N pollution can occur depends on many factors, particularly fertilizer characteristics and its subsequent reactions in the soil, application dates, amount of precipitation as well as intensity, irrigation management and disposal of irrigation return flows (IRFs) (Barros et al., 2012a). Ammonium fertilizers and urea can be easily transformed to nitrate especially in dryland soils (Li et al., 2009). A large portion of NO_3 is taken up by plants for metabolic processes while much of it is either leached from the topsoil to deeper horizons and ultimately to surface and groundwater (Ma, 1992) or washed off by runoff. High nitrate concentrations in Europe, USA, China (Pratt, 1984; Laegreid et al., 1999; Luo et al., 2008) and northeastern Australia (Keating et al., 1996) have been found in groundwater systems dominated by intensive agriculture with high N fertilizer application rates. Considering the low N fertilizer recovery (generally less than 50% and less than 33% in cereals) (Hardy and Havelka, 1975), the remaining portion of the applied N is a potential source of pollution for both the atmosphere and water resources.

Irrigation return flows have been recognized as the major diffuse or non-point pollution contributor to surface and groundwater bodies (Aragüés and Tanji, 2003). Water quality of IRFs is predominantly affected by salt and NO_3 concentrations (Barros et al., 2012b). Nitrate concentrations up to 250 mg L^{-1} were recorded for shallow aquifers, but the concentration rarely reached 50 mg L^{-1} for surface waters of irrigated areas, the European limit for waters intended for human consumption (European Union, 1998). High NO_3 concentrations have been measured in IRFs, especially during N fertilization to corn (Barros et al., 2012a). Seasonal patterns of N fluxes are influenced by fertilization, irrigation scheduling and rainfall distribution. For example, Isidoro et al. (2006) found that 75% of the total NO_3-N load was exported after the irrigation season in an irrigation district in Spain. Consequently, optimizing N fertilization, irrigation scheduling and irrigation efficiency were shown to reduce N exports to drainage water (Cavero et al., 2003; Isidoro et al., 2006; Quemada et al., 2013) and groundwater (Thorburn et al., 2003).

European legislation generally addresses concentration levels of contaminants in waters (European Union, 1998). In addition, most works measure NO_3 concentrations in IRFs, few studies have quantified NO_3 loads in IRFs and their relationships with soil factors and agricultural management characteristics (Cavero et al., 2003; Isidoro et al., 2006; Barros et al., 2012a) due to the fact that it has been not an easy task to quantify IRFs purely generated by an agricultural catchment. The aim of this work was to analyze irrigation-induced NO_3 losses in the Akarsu Irrigation District (AID) of southern Turkey and to assess existing irrigation and fertilization management practices aimed at minimizing such losses.

2. Materials and methods

2.1. General characteristics of the study area

2.1.1. Location

The study area is located in the Mediterranean coastal region comprising the most intensively cropped area of Turkey. The *Akarsu Irrigation District* covers an area of 9495 ha (Fig. 1) within the Lower Seyhan Plain, and lies between 36°57′ and 36°51′N latitude and 35°40′ and 35°29′E longitude. The area has been irrigated for over 40 years with conventional irrigation and drainage infrastructures. The drainage waters flow through open ditches along the downstream areas and discharge into the Mediterranean Sea. The Akarsu Water User Association has been responsible for the irrigation management in the area since 1994.

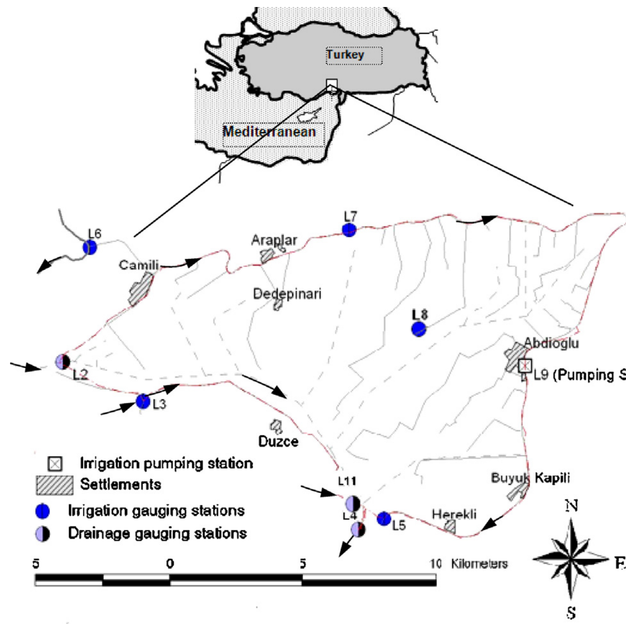

Fig. 1. Location of study area in Turkey, layout of irrigation and drainage systems, meteorological station (L8); drainage (L2, L4, L11) and irrigation (L3, L5, L6, L7, L9) gauging and monitoring stations in the *Akarsu Irrigation District*. Dotted lines, solid lines and arrows stand for the drainage and irrigation canals, and water flow directions in the District, respectively.

2.1.2. Climate

A Mediterranean-type climate prevails in the study area, typically with hot and dry summers and mild and rainy winters. The seasonality and irregularity of rainfall and the high summer temperatures (Fig. 2) necessitate irrigation, mainly from April to September. In the AID, the annual averages of mean, maximum and minimum temperatures for the period 1930–2008 were 18.9, 31.0 and 9.0 °C, respectively. Average relative humidity is around 66% and the rainfall and evapotranspiration averages are 644 mm and 1538 mm, respectively.

2.1.3. Soils

The soils of the *District* are mainly alluvial, deep, high in clay (over 30%), calcium carbonate (20–35%) and pH (7.5–8.5), low in organic matter (0.8–1.2%), and deep cracks are common during the dry summer season (Dinç et al., 1995). There are total of 14

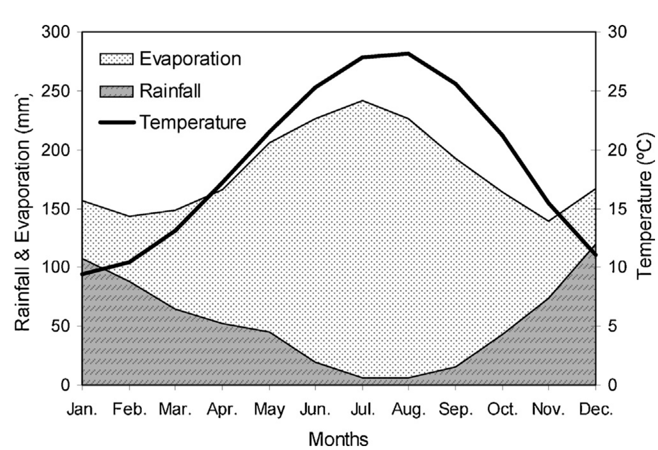

Fig. 2. Typical seasonal rainfall, free-surface water evaporation (E_{pan}) and temperature variations in the Lower Seyhan Plain. Daily data from 1970 to 2010 were obtained from archives of the Turkish State Meteorological Affairs Organization, and processed for monthly averages.