Agricultural Water Management 186 (2017) 40–50

Contents lists available at ScienceDirect

Agricultural Water Management

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

Soil vs. groundwater: The quality dilemma. Managing nitrogen leaching and salinity control under irrigated agriculture in Mediterranean conditions

Angela Libutti*, Massimo Monteleone

Department of Science of Agriculture, Food and Environment, University of Foggia, Italy, Italy

ARTICLE INFO

Article history:
Received 14 December 2015
Received in revised form 13 January 2017
Accepted 22 February 2017

Keywords:
Intensive cropping system
Nitrogen fertilisation
Nitrate leaching
Groundwater quality
Saline irrigation water
Irrigation management

ABSTRACT

A 3-year field trial was carried out in southern Italy on an agricultural farm close to the seacoast of Manfredonia Gulf (Apulia Region) where crop irrigation with saline water is standard practice. Seawater intrusion into the groundwater, and the consequent soil salinization represent a serious environmental threat. Each year, two crop cycles were applied, in spring-summer and autumn-winter seasons, respectively. The crop pairing over the three years was tomato and spinach; zucchini and broccoli; pepper and wheat. Cultivation was performed in a field-unit characterised by three adjacent plots. At the centre of each plot, a hydraulically insulated drainage basin was dug (0.70 m depth) to collect the draining water. The crops were irrigated with saline water and leaching treatments were applied with saline or fresh water whenever soil salinity reached a predetermined electrical conductivity threshold. Since soil salinity control might increase nitrate leaching, operational criteria should optimize the trade-off between the application of higher water volumes to reduce soil salinity and lower water volumes to protect groundwater quality from nitrate leaching. The amount of nitrogen leached from the soil root-zone was considerable (on average, 156 kg N ha^{-1} year^{-1}) and higher in autumn-winter than spring-summer (72 vs. 28% of the average annual value). In autumn-winter season, nitrogen losses were mainly due to plentiful nitrogen fertilisation and high rainfall. In spring–summer, extra irrigations promoted salt leaching together with nitrogen losses. To manage both irrigation and nitrogen fertilisation a "decoupling" strategy is recommended. This strategy suggests applying leaching preferably at the end of the spring-summer growing season, soon after crop harvesting or at the beginning of the autumn-winter season, before second crop cycle starting. In autumn-winter season, proper nitrogen supplies and timely top-dressing applications, still allow salts to be discharged by rainfalls but prevent nitrogen losses, thus preserving groundwater quality.

1. Introduction

Intensively managed crops usually take advantage of large agrotechnical inputs, such as irrigation water and fertilisers, together with pesticides and herbicides. Serious environmental burdens might result from these inputs so that intensive agriculture practices are recognized as major non-point contamination sources of aquifers (Antonopoulos, 2001; Chowdary et al., 2005; Candela et al., 2008; Moss, 2008; Poch-Massegú et al., 2014).

Nitrogen leaching, namely the downward transport of nitrate-nitrogen (NO_3^--N) out of the root zone by water percolating through the soil profile, is among the most common groundwater form of contamination (Oyarzun et al., 2007). NO_3^--N pollution occurs when nitrogen fertiliser inputs greatly exceed the amount of nitrogen needed by the crops (Asadi et al., 2002; Thompson et al., 2007; Zhu et al., 2005). Nitrate form of nitrogen (NO_3^-) is highly soluble, easily mobile within the soil water solution and poorly adsorbed by the soil particles (Shamrukh et al., 2001). If the rate of NO_3^- uptake by the crop is not great enough, it accumulates into the root zone and is easily leached by irrigation water and rainwater in the deeper soil layers, finally reaching groundwater (Yuan et al., 2000). The greater the nitrogen surplus, the greater the risk of NO_3^-loss from the soil (Gheysari et al., 2009). The amount of leached NO_3^-, however, is directly related to the deep drainage process (Sánchez-Pérez et al., 2003). Several factors could influence this process: the textural characteristics of the vadose zone (Arauzo and Valladolid, 2013), the crop growth features, with specific regard

* Corresponding author.
E-mail address: angela.libutti@unifg.it (A. Libutti).

http://dx.doi.org/10.1016/j.agwat.2017.02.019

to nitrogen uptake by the root system (Askegaard et al., 2011; Zhou and Butterbach-Bahl, 2014), climatic and weather conditions, nitrogen biochemical transformations in the soil (Schmidtke et al., 2004), and management practices (Ruidisch et al., 2013; Virgílio Cruz et al., 2013; Meisinger et al., 2015). In particular, nitrogen fertilisation (Sánchez-Pérez et al., 2003) and irrigation (Rajput and Patel, 2006; Gheysari et al., 2009; Jia et al., 2014; Wang et al., 2014) are very influential.

NO_3^--N leaching results in the loss of a mineral nutrient source for the plants, widely ranging from 2 kg N to 100 kg N ha $^{-1}$ year $^{-1}$ (Echeverría and Sainz Rozas, 2007) or even more, thus representing a significant economic issue for farmers. Moreover, when groundwater is used as drinking water, high NO_3^- concentrations represent a health concern, because of the associated risk of diseases, like methaemoglobinaemia or blue-baby syndrome in infants, and gastrointestinal cancer in adults (Merrington et al., 2002; Pavoni, 2003; Wolfe and Patz, 2002). To prevent this potential human health hazard, the World Health Organisation (WHO) established a contaminant level that should not exceed 50 mg NO_3^- l^{-1} (11.5 mg NO_3^--N l^{-1}) in drinking water (WHO, 2004). Nevertheless, groundwater NO_3^- concentrations exceeding or approaching this fixed standard have been observed in several countries (Koh et al., 2007; Liu et al., 2005; Min et al., 2002).

In 1991, the European Union (EU) adopted the Nitrates Directive 91/676/CEE, with the aim to protect water quality by preventing nitrate leaching from agricultural activities and promoting the adoption of a code for "Good Agricultural Practices". The Directive includes the definition of Nitrate Vulnerable Zones (NVZs) as areas of land that drain into polluted waters, whereby farmers are required to comply with specific limits of inorganic fertiliser and organic slurry application rates. Although the Nitrates Directive has been implemented in all EU Member States, the problems of nitrate pollution of aquifers still persists throughout Europe (EEA, 2012). Across many European monitoring stations of groundwater quality, 14.4% showed over 50 mg NO_3^- l^{-1} concentrations, and 5.9% showed between 40 and 50 mg NO_3^- l^{-1} from 2008 to 2011 (EC, 2013).

The detrimental consequences of nitrate leaching affecting groundwater quality are much more evident in intensive agricultural areas and, particularly, in arid and semi-arid regions (Jalali, 2005; Ibrikci et al., 2015). In such areas, the use of saline water is a further likely option to meet crop water requirements, with the better quality water primarily allocated to civil uses (Feikema et al., 2010; Verma et al., 2012).

Irrigation with saline water often causes soil salinization (Schoups et al., 2005; Tedeschi and Dell'Aquila, 2005; Wang et al., 2011). Periodic applications of water volumes in excess of crop evapotranspiration are required to leach out soluble salts that have accumulated in the root zone (Ayers and Westcot, 1985). This leaching application results in high volumes of drainage water that are often enriched not only in salts, but also in nutrients (Jalali and Merrikhpour, 2008), including nitrogen (Feng et al., 2005). Therefore, under irrigation conditions where saline water is used, soil salinity management might increase the risk of nitrogen losses from the active soil profile.

In most Mediterranean coastal areas where irrigated agriculture is possible only using brackish water, soil salinization is widely spread. Furthermore, several countries in the Mediterranean basin are affected by non-point source nitrate pollution of aquifers (Zalidis et al., 2002), which frequently occurs in areas of intensive agriculture, such as horticulture, floriculture and citriculture (De Paz and Ramos, 2004; Ramos et al., 2002). Salinization and nitrate leaching are two of the leading threats of the European Mediterranean regions: two sides of the same coin, so to speak. Nevertheless, only a few studies have addressed these two related problems of simultaneous salt and nitrogen leaching (Causapé et al., 2006; Merchán et al., 2015).

Considering the experimental area (Apulian Tavoliere plain – Southern Italy), crop irrigation with saline water is a standard practice, and soil salinization represents a serious environmental threat. To control soil salinity, salt leaching is required but, in this way, groundwater contamination by nitrate becomes very likely. A double bound (in the form of dilemma) is constraining farmer operational choices: less or more irrigation water? On this respect, an optimization strategy is needed.

The here applied experimental trial was already reported in a previous paper (Libutti and Monteleone, 2012), but it was focused on the salt-leaching process only. The present work has turned its attention on nitrate leaching. The specific objectives of this study were to assess the amounts of nitrogen removed from the soil profile through drainage water under saline irrigation conditions, to identify the periods during which nitrogen leaching is most likely to occur, and to suggest agricultural management practices to reduce nitrogen losses and to minimise the risk of nitrate pollution from agricultural sources. At the same time, salt accumulation into the active soil layer should be effectively prevented.

2. Materials and methods

2.1. Site description and experimental layout

A three-year period of continuous field experiments was carried out from spring 2007 to spring 2010 in a Mediterranean area in the north-eastern part of the Apulia Region (southern Italy), at San Giovanni Rotondo in the Foggia district. The experimental field (41°34′N, 15°43′ E; altitude, 15 m a.s.l.) was located on an agricultural farm producing cereals and vegetables. The farm is 15 km from the coast of Manfredonia Gulf (Adriatic Sea), and only a few hundred meters far from the San Severo NVZ, one of the nine Apulian NVZs.

In autumn 2006, a special experimental set-up (Fig. 1) was arranged. This included three adjacent and identical plots of approximately 100 m^2 (6.4 m wide, 15.6 m long). At the centre of each plot, an artificial draining basin was dug, with the removal of the soil to create a trench of approximately 50 m^2 (3.2 m wide, 15.6 m long), with a depth of 0.7 m. The bottom of the trench had a slope gradient of 0.5%. The vertical walls and the bottom of each trench were covered with a plastic sheet to hydraulically isolate the basin and to prevent lateral fluxes and percolation of water. A set of 52-mm-diameter corrugated draining pipes was installed at the bottom of the trench, over the plastic cover, to collect the percolating water. Each plot had six draining pipes that were longitudinally arranged into two groups per trench (three draining pipes per group) and covered with a polypropylene textile. At one end of the trench, the three draining pipes of each group were respectively connected to an unperforated PVC pipe and finally assembled to a connection pipe to channel the percolating water into a 1000-l tank. Each plot had two tanks (i.e., one tank per group of draining pipes) that were buried at the 'downstream' end of the plots. The trenches were then filled with the same soil previously dug out, as near as possible with correct reproduction of the original soil stratification. As a result of this experimental set-up, the natural hydraulic gradient of the soil was disrupted, while a water-saturated zone was formed at the bottom of each draining basin, before the water drained away. This condition mimicked the presence of a shallow water table at a depth of 0.7 m.

During natural or intentional water-leaching processes (i.e., caused by precipitation or irrigation, respectively), the water that percolated along the soil profile was entirely collected in the tanks. The drainage water was then discharged from each tank using an