Europ. J. Agronomy 29 (2008) 108–115

Contents lists available at ScienceDirect

European Journal of Agronomy

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

# Nitrogen balance and losses through drainage waters in an agricultural watershed of the Po Valley (Italy)

M. Ventura[a], F. Scandellari[a], F. Ventura[b], B. Guzzon[c], P. Rossi Pisa[b], M. Tagliavini[d,*]

[a] Department of Fruit Trees and Woody Plant Sciences, Alma Mater Studiorum Università di Bologna, Viale Fanin 46, 40127 Bologna, Italy
[b] Department of Agroenvironmental Sciences and Technologies, Alma Mater Studiorum Università di Bologna, Viale Fanin 44, 40127 Bologna, Italy
[c] 2◦ Circondario Polesine - S. Giorgio Waterboard, Via Mentana 7, 44100 Ferrara, Italy
[d] Faculty of Science and Technology, Free University of Bolzano/Bozen, Via Sernesi 1, 39100 Bolzano/Bozen, Italy

ARTICLE INFO

*Article history:*
Received 26 November 2007
Received in revised form 30 April 2008
Accepted 2 May 2008

*Keywords:*
Nitrate leaching
Nitrogen balance
Nitrogen loss
Watershed

ABSTRACT

Sustainable agriculture requires assessments of nitrogen fluxes and monitoring of potential nitrate losses. Watershed studies are particularly valuable to calculate nitrogen balances and quantify the relative importance of different sources of inputs and outputs. A nitrogen balance was calculated from September 2004 to October 2006 in an agricultural watershed named Valle Volta (Northern Italy) located in a Nitrate Vulnerable Zone. The area, consisting of 17.4 km$^2$ of arable land, with limited presence of urban areas and roads, is entirely below the sea level (3 m b.s.l. in average). Soils are typically Vertic Cambisols and Thionic Fulvisols with fine texture (silty clay or silty clay loam). About 45% of the agricultural soil is pipe-drained. The ground water level is maintained at 4.6 m b.s.l. by the activity of pumps that raise excess waters into a river. Water fluxes in and out from the basin were daily registered, and dissolved inorganic nitrogen concentration ($N–NO_3 + N–NH_4$) analyzed periodically. Data about fertilizers applications, seeds and crop yield were obtained from farmers' interviews. Biological nitrogen fixation (BNF) was estimated on the base of dry matter yield. Major N inputs derived from fertilizers (174–188 Mg watershed$^{-1}$ year$^{-1}$), followed by BNF (126–131 Mg watershed$^{-1}$ year$^{-1}$). Maize was the crop receiving the highest fertilization rates, accounting for more than 40% of total fertilizer inputs. Saleable products were the main form of N leaving the watershed (317–338 Mg watershed$^{-1}$ year$^{-1}$). Nitrate was the main N form in irrigation and efflux water; its concentration was higher from autumn to spring, with peaks of 10–20 mg N L$^{-1}$ in efflux water, while it was low in summer. Nitrogen losses with efflux water were higher in spring and in autumn. Overall, losses of nitrate by efflux water were limited if compared with literature data. Water balance in the area remained near zero at the beginning and the end of the first year, confirming the suitability of the area for this kind of study. The potential net contribution of each hectare of agricultural soil of Valle Volta basin to the N load toward the Adriatic sea is about 5.5 kg N. Our study demonstrated that in the Valle Volta watershed, total N outputs and inputs are of similar magnitude, indicating that crop management and especially N fertilization techniques has reached good levels of ecological sustainability.


## 1. Introduction

Nitrogen is likely the most important element in plant nutrition and intensive, high productive agriculture is largely dependent on addition of N fertilizers (Tilman et al., 2002). Excess of nitrogen supply respect to the plant demand can lead to nitrogen losses, especially in the form of nitrate ($NO_3^-$), dissolved in leaching water (Addiscott et al., 1991), and to contamination of surface and ground waters. Agriculture is a diffuse source of nitrate pollution, whose importance must be identified before control priorities are set (Merrington et al., 2002). Nitrate contamination of drinking water is considered to increase the risk of diseases like methaemoglobinemia and stomach cancer (Magee, 1982; Addiscott et al., 1991; Merrington et al., 2002; Pavoni, 2003). World Wealth Organization recommends not exceeding 50 mg L$^{-1}$ of nitrate in drinking waters, and UE has set this concentration as the maximum allowable in drinking water (Council of the European Communities, 1980).

Nitrogen pollution of waters is also an environmental concern because of lake acidification and eutrophication of estuaries and costal marine environments. Excessive growth of algae may affect marine life and cause fish mortality (Vitousek et al., 1997; Merrington et al., 2002). Trough the nitrate directive (91/676/CEE), UE aims to reduce water pollution caused or induced by nitrates from agricultural sources. Member states have to identify areas

* Corresponding author. Tel.: +39 0471 017120; fax: +39 0471 017009.
*E-mail address:* massimo.tagliavini@unibz.it (M. Tagliavini).

1161-0301/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.eja.2008.05.002

where there is high risk of nitrate pollution (vulnerable zones) and set specific limits on mineral and organic fertilizer applications. Countries and/or regions should also take steps to monitor nitrate content in waters and make growers adopt codes of good agricultural practice.

Northwest Adriatic sea is one of the regions in Europe suffering most from eutrophication (de Wit and Bendoricchio, 2001) and Po is the main river flowing into this sea. The Padana Plane mainly corresponds to the Po river basin and includes cities and intensively cultivated agricultural land. Being agriculture a diffuse source of pollution, watershed studies are particularly valuable to calculate nitrogen balances, quantify the relative importance of different sources of N inputs and outputs (Leach et al., 2003) and evaluate the influence of soil use on the quality of surface water (Osborne and Wiley, 1988; Rossi Pisa et al., 1996; Gardi, 2001). Nitrogen losses are affected by many factors, including soil type, climate, and type, timing and amounts of fertilizers (Owens, 1994). Studies carried out at watershed level under different conditions in Europe and United States have reported a wide range of N losses, from less than 10 kg $ha^{-1}$ (Beaudoin et al., 2005), to more than 100 kg $ha^{-1}$ (Bechmann et al., 1998).

Nutrient balances are widely used as tools for studying nutrient fluxes in agroecosystems, but are also regulatory policy instruments and agro-environmental indicators for nutrient use efficiency (Oenema et al., 2003). Nutrient budgets are build up with different approaches (Oenema and Heinen, 1999; Watson and Atkinson, 1999; Oborn et al., 2003): soil surface budgets, that consider nutrients that enter the soil with fertilizers and animal manure, and outputs with crop uptake, are often used as indicators of the environmental performance of agriculture; soil system budgets also try to assess fluxes due to nitrogen leaching through soil or denitrification, and are mainly used in research in order to identify the fate of nutrient surplus.

In this study, we report a soil surface balance calculated over two agricultural years in an agricultural watershed of the Po Valley, located in the Province of Ferrara, and representative of a vulnerable zone for nitrate directive. The balance was also integrated with direct measurements of N losses by leaching from the watershed over the same period, which allowed to relate agricultural practices and environmental characteristics with leaching losses.

## 2. Materials and methods

### 2.1. Watershed description

The study was carried out in an area of 19.4 $km^2$ named Valle Volta, located in the eastern Po river valley (Province of Ferrara, 44°48′N 10°56′E, Fig. 1), in a Nitrate Vulnerable Zone. The climate of the area is sub-humid, with yearly rainfall average of 665 mm in the last 15 years. In the watershed there is a limited presence of urban areas and roads, and 17.4 $km^2$ are of agricultural land. Typical soils are Vertic Cambisols and Thionic Fulvisols (FAO classification), with fine texture (silty clay or silty clay loam). Soil organic matter concentration ranged from 2.4 to 9.6% and total N from 0.1 to 0.6%.

The area is a flat, intensively cultivated land, where typical farms have large size (>100 ha). About 45% of the agricultural soil is pipe-drained. The land use in the area for 2003/04, 2004/05 and 2005/06 agricultural years (October 1–September 30) is shown in Table 1: field crops such as maize, alfalfa, wheat, sugar beet and soybeans are more relevant in terms of surface but some horticultural crops are grown as well (apple, muskmelon, pear, tomato, watermelon). The entire alfalfa production is sold as hay out of the valley.

The whole area is entirely below the sea level (3 m b.s.l. on average). Irrigation water directly derives from the Po di Volano river and enters the watershed from three mechanically controlled gates. The water is then delivered to the fields through a system of open ditches. Efflux water is drained by the same network of ditches used for irrigation, and reaches a single main drainage collector, where excess water is pumped back into the Po di Volano river, at the rate of 1.5 $m^3\,s^{-1}$. A navigation lock along the Po di Volano separates the river into two parts: the upstream higher level from which water is drawn off for irrigation from the downstream lower level where efflux water is pumped back to the river to reach the Adriatic sea, 10 km downstream. The ground water level is maintained at an average depth of 4.6 m b.s.l (i.e. 1.6 m below field surface) by the activity of the same pumps used for drainage waters. Daily volumes of water entering and leaving the basin with irrigation and efflux water were automatically registered.

### 2.2. Nitrogen budget

A nitrogen balance was calculated for the agricultural years from October 2004 to September 2005 and from October 2005 to September 2006, taking into account the main fluxes of materials entering and leaving the area. Inputs included N in rain, fertilizers, irrigation water, biological fixation and seeds. Nitrogen in the efflux water and in the saleable products were considered as outputs. N volatilization from fertilizers (urea) and denitrification were also considered in the budget.

Data of N inputs from fertilizers for each crop were obtained from farmer's interviews. Five farms, representative for land use and agronomic techniques of the whole area, covering an acreage of 577 ha in total, were chosen. Farmer's interviews included data relative to land use, soil management, fertilizer amounts and timings. The average amount of N supplied per hectare of each crop was calculated and referred to the total acreage of each crop in the whole watershed. Data about agricultural land use were provided by AGREA (Regional Agency for financing in the agricultural sector).

Rainfall samples were regularly collected from a pluviometer weekly or at 2-week intervals, depending on the period of the year. Nitrogen entering the watershed by rain was calculated multiplying nitrate–N ($N–NO_3$) and ammonium–N ($N–NH_4$) concentration in the rainwater by the amount of rain fallen between two subsequent samplings. Similarly, volumes of irrigation water entering the watershed and volumes of efflux water leaving the watershed were multiplied by the $N–NH_4$ and $N–NO_3$ concentrations in water, in order to calculate N fluxes. Daily volumes of irrigation and drainage water were provided by the 2° Circondario Polesine - S.Giorgio waterboard (Ferrara, Italy). Samples of efflux water were taken at the end of the main drainage collector, just before the pumping station, while samples of irrigation water were taken from the Po di Volano river, near the main water entry gate. Irrigation and efflux water samples were taken in triplicate weekly or at 2-week intervals, depending on the period of the year. Water fluxes and relative mineral N concentrations were monitored from March 2004 to November 2006.

The amount of N deriving from biological nitrogen fixation (BNF) by alfalfa was estimated through the model proposed by Høgh-Jensen et al. (2004) which also considers the amount of N accumulated belowground and allow a locality-specific parametrization of user defined parameters. For the parameterization of the model, values of N concentration and % of fixed N on total N for alfalfa, were derived from Tabacco et al. (2003), obtained in the Padana Plane. To estimate the BNF associated with soybean cultivation, it was considered that about 50% of the N in harvest was derived from symbiotic fixation (Vance, 1998).

Data of N output by saleable products were based on data of crop yields, provided by farmer's interviews and on their N concentration obtained by regional databases, and referred to the whole