Science of the Total Environment 499 (2014) 448–462

Contents lists available at ScienceDirect

Science of the Total Environment

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

Determining water and nitrogen balances for beneficial management practices using lysimeters at Wagna test site (Austria)

Gernot Klammler *, Johann Fank [1]

JOANNEUM RESEARCH Graz, RESOURCES, Institute for Water, Energy and Sustainability, Elisabethstraße 18/II, A-8010 Graz, Austria

HIGHLIGHTS

- The presented lysimeter design did not show any oasis or fringe effects.
- N-leaching from investigated BMPs did not endanger groundwater quality.
- Comparison between calculated ET_0 and $ET_0$was determined with a lysimeter.

ARTICLE INFO

Article history:
Received 9 January 2014
Received in revised form 29 April 2014
Accepted 2 June 2014
Available online 27 June 2014

Keywords:
Low nitrogen input farming
Organic farming
Nitrogen/nitrate leaching
Evapotranspiration
Grass-reference evapotranspiration
weighable, monolithic lysimeter

ABSTRACT

The shallow Murtal aquifer south of Graz, Austria, provides easily withdrawable groundwater, which is supplied as drinking water without any chemical treatment. The aquifer is also used intensively by agriculture. Common agricultural management practices are the main source for diffuse nitrogen leaching and high groundwater nitrate concentrations. To safeguard the coexisting use of these two important resources, lysimeters are operated at the agricultural test site Wagna, Austria, and the influence of two beneficial management practices – low nitrogen input and organic farming – on nitrogen leaching towards groundwater is investigated. The technical lysimeter design as presented here consists of: (1) high-resolution weighing cells, (2) a suction controlled lower boundary condition for sucking off seepage water, thus emulating undisturbed field conditions, (3) comparative soil temperature, water content and matrix potential measurements inside and outside the lysimeter at different depths, (4) an installation of the lysimeters directly into test plots and (5) a removable upper lysimeter ring enabling machinery soil tillage. Our results indicate that oasis effects or fringe effects of the lysimeter cylinder on unsaturated water flow did not occur. Another lysimeter cultivated with lawn is operated for observing grass-reference evapotranspiration, which resulted in good agreement with calculated grass-reference evapotranspiration according to the FAO-Penman–Monteith method. We conclude that lysimeters installed at Wagna test site did not show any fringe effects and, thus, are appropriate tools for measuring water balance elements and nitrogen leaching of arable and grass land at point scale. Furthermore, our results for the period of 2005 to 2011 show that beneficial management practices reduced nitrate leaching and, hence, may allow for a sustainable coexistence of drinking water supply and agriculture in the Murtal aquifer.

1. Introduction

Since agriculture is the largest non-point source of groundwater pollution (Sutton et al., 2011), the need for water quality and nutrient management as well as the need for a better understanding of water drainage and chemical leaching through the vadose zone is continuing to grow. The Murtal aquifer between Graz and Bad Radkersburg, Austria (Fig. 1), is an important resource for regional and supraregional drinking water supply, but the region also provides excellent agricultural conditions. This dual use implicates conflicts due to high groundwater nitrate concentrations (cNO_3) caused by diffuse nitrogen (N) pollution, which have to be harmonized for a sustainable coexistence. Therefore, monitoring and measuring techniques, that can determine drainage fluxes from undisturbed soil profiles, are critical for the determination of nutrient budgets and the evaluation of land-use practices on water quality (Masarik et al., 2004).

Accurate crop evapotranspiration (ET) data are required to improve agricultural water resources management. Lysimeters are still considered to be the standard method to determine ET from measurements. If the lysimeters are weighable, the current ET can be deduced from their weight change (Young et al., 1996). Furthermore, Meissner et al. (2007) show that also a precise measurement of dew, fog, and rime is possible using a high-resolution weighing system. Thus, a large

* Corresponding author. Tel.: +43 316 876 6000.
E-mail addresses: gernot.klammler@joanneum.at (G. Klammler), johann.fank@joanneum.at (J. Fank).
[1] Tel.: +43 316 876 6000.

http://dx.doi.org/10.1016/j.scitotenv.2014.06.009
0048-9697/

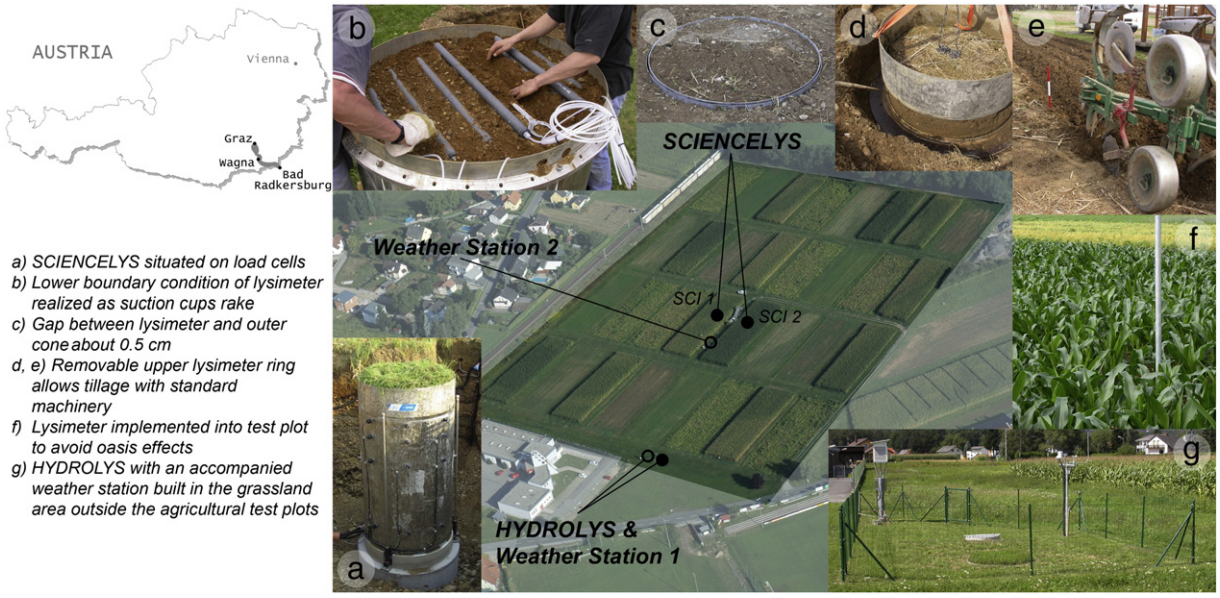

Fig. 1. Location and overview of the test site Wagna, Austria.

weighable lysimeter is the best method for obtaining reliable ET data and also seepage water (SW) quantity and quality. The evaluation of lysimeter data allows a much more reliable calculation of the solute load carried towards the groundwater than any other method (Klocke et al., 1993), e.g., hydrochemical investigations in the groundwater, isotopic analysis, and water and solute balancing. Due to these characteristics, lysimeters are also excellent tools to derive or calibrate water and solute transport models (Wriedt, 2004) for unsaturated zone simulation.

Lysimeters in Europe are predominantly used for agricultural research (approx. 63%; Lanthaler and Fank, 2005), but have also become important concerning climate change research. For example, the SoilCan project (soil can make a difference in climate policy) is designed as a long term large scale experiment to study the effects of climate change on soil systems. Based on 126 lysimeters, SoilCan focuses on water and matter fluxes in soil (Pütz et al., 2011; Zacharias et al., 2011), which also reflects the ability of lysimeters as an appropriate tool for water resources research.

In 2004 two monolithic, weighable lysimeters were implemented at the agricultural test site Wagna in southern Austria (Fank and Von Unold, 2007) for investigating the influence of beneficial management practices (BMPs) on groundwater quantity and quality. BMPs are management practices that reduce or eliminate environmental risks in general. At Wagna test site the BMPs on low nitrogen input farming and organic farming are cultivated at the test plots and lysimeter observations focus on diffuse nitrogen pollution of groundwater due to agricultural fertilization. Shortcomings assigned to lysimeter measurements (e.g., oasis effects, preferential flow paths at the walls of the lysimeter cylinders or the influence of the lower boundary condition on the outflow rates) are prevented by a special design of lysimeters installed.

In the present work, based on this new type of field-lysimeters – high-resolution, weighable, monolithic lysimeters directly installed into arable land – we determine exactly measured water balance parameters and best possible information about the influence of different farming systems on shallow groundwater. Furthermore, but not investigated here, the gathered data can be used to develop, calibrate and validate models for water and solute transport in the unsaturated zone in order to transfer point-data from the lysimeter to field and regional scales. The unsaturated zone models can also be coupled with groundwater flow and transport models to predict effects of different farming systems on saturated groundwater quality and quantity at regional scales. The objective of this paper is to present the lysimeter based measuring equipment at the agricultural test site Wagna and to summarize the results of a seven year period of water and nitrogen balance determination at the interface between atmosphere and groundwater. We will demonstrate that BMPs can significantly reduce N leaching into the groundwater, which may be of fundamental importance for avoiding conflicts between agriculture and groundwater protection in the highly sensitive Murtal aquifer, in Austria.

2. Material and methods

2.1. Description of the test site

The agricultural test site Wagna with a total area of 4.4 ha is located within the Mur Valley between Graz and Bad Radkersburg, Austria, and consists of 32 test plots with approx. 1000 m^2 each (Fig. 1) and is situated on a gravel terrace of Würm glaciation (aquifer thickness approx. 8 m). Clayey–sandy Cambisols are predominant (soil depths are very heterogeneous ranging between 15 and 230 cm) and the content of clay and sand is about 15% and 52%, respectively. The humus content ranges between 1.3% and 2.2%. All in all, the location is composed of very light soils with a low water storage capacity and its characteristics are representative for most parts of the Mur Valley between Graz and Bad Radkersburg.

Since 1987 different cultivation strategies have been researched concerning N fertilizer input, nitrate (NO_3) leaching and crop yields. Primarily, comparisons were made between maize-mono-cropping and crop rotations (maize-maize-winter grain-winter rape) with the objective of yield increase. In 1998, due to high NO_3 concentrations in the groundwater, the research question and cultivation strategy changed to reduction of N fertilizer, no fertilization in autumn, hardy grass catch crops (no legumes) and cultivation of oil pumpkin instead of winter rape (due to increasing importance of oil pumpkin in the Mur Valley). Since 2005 the difference between low N input farming and organic farming has been researched (crop rotations only). The two crop rotations are cultivated in four variations (i.e., crop rotation starts with different crop in the same year) and four repetitions. In this context, two of the test plots were equipped with high-precision lysimeters and soil hydrologic measuring profiles (SCIENCELYS; Fig. 1). An additional grass-reference lysimeter (HYDROLYS; Fig. 1) in combination with a weather station (weather station 1; Fig. 1) was also installed at the southeast limit of the test site. Since 2003, further weather data has been acquired at a weather station of the national