



Assessment of LEACHN and a simple compartmental model to simulate nitrogen dynamics in citrus orchards

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ABSTRACT

A simple compartmental model using a tipping bucket approach for the water dynamics coupled with a nitrogen–carbon transformations model has been adapted to simulate the soil nitrogen and water balance in mature orange groves on a daily step. This model has been compared with the more mechanistic LEACHN model (the N module of the LEACHM model), which uses Richards' equation to simulate soil water movement in unsaturated conditions, the convection–dispersion equation for solute transport, and that, in addition to including evapotranspiration, N transformations and N plant uptake as in the compartmental model, it also considers gaseous losses due to denitrification and ammonia volatilization, that are not considered in the compartmental model. This comparison was made using data from a three-year experiment in a citrus orchard with two nitrogen fertilization rates. After calibration using the first year data, a reasonable match between simulated and measured values in both models was observed for soil water storage in the whole profile for the validation period (2nd and 3rd year), but the agreement was not so good for the soil mineral nitrogen content. In spite of the differences in the nature and in the complexity of the two models, the soil water dynamics and drainage were well simulated during the whole period by both models. However, the LEACHN model predicted nitrate leaching better than the compartmental model, probably because it considers the nitrogen cycle in a more detailed way. This work is the first calibration and performance evaluation of the LEACHN model for citrus in the Mediterranean area and the results obtained in this study indicate that this model can be a valid tool to evaluate the effects of irrigation and N management on nitrate leaching. The compartmental model has a lower data requirement and calibration is less complex than the LEACHN model and, therefore, may be more appealing for advisory N management purposes.

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1. Introduction

Nitrogen is an important nutrient in agricultural systems but inadequate management of nitrogen fertilizers and irrigation, especially in areas of intensive agriculture under irrigation and with important inputs of nitrogen fertilizer, may result in major environmental problems such as nitrate leaching or nitrous oxide emissions to the atmosphere (Alva et al., 2006; Neeteson and Carton, 2001; Quiñones et al., 2007). Nitrate pollution of groundwater is a worrying problem in many irrigated areas in Spain (MMA, 2006). Ground water is used for irrigation in 27% of the irrigated agricultural land, and also provides 40% of the drinking water. In some areas of the coastal plain in the Valencia region nitrate concentration in groundwater is greater than 100 mg NO₃[−] L^{−1} (MMA,

2004). In this region there are 1,78,000 ha of citrus, representing about 32% of the cultivated land, of which about 77,000 ha are sweet orange with a fruit production of about 1.9 Mt year^{−1}. The most common irrigation system in this area is flood irrigation although drip irrigation is increasing. The irrigation water use for this crop in this region is about 750–900 mm year^{−1} (Castel et al., 1987). With respect to nitrogen fertilization, some authors have established that the annual nitrogen requirement of citrus in the Valencia region is between 600–800 g N tree^{−1} (Primo-Millo and Legaz, 1993), approximately equivalent to 240–300 kg N ha^{−1}, that is somewhat higher than the 200–250 kg N ha^{−1} year^{−1} recommended by the Valencian Code of Good Agricultural Practices (VCGAP) (DOGV, 2010) for citrus under flood irrigation. However, there is still a large variation in the nitrogen fertilization rates applied by farmers.

Different studies dealing with nitrate leaching in citrus have quantified the losses of nitrate for different fertilization practices (Lamb et al., 1999; Paramasivam et al., 2001; Ramos et al.,

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2002). These studies show that for nitrogen application rates up to $400 \text{ kg N ha}^{-1} \text{ year}^{-1}$, nitrate leaching rate was, in most cases, less than $100 \text{ kg N ha}^{-1} \text{ year}^{-1}$. In general, nitrate leaching losses increased with fertilizer nitrogen application rate and the amount of water drained, and accounted for up to 33% of the total applied nitrogen. Although in different agricultural systems there seems to be a direct relationship between nitrogen inputs and the increasing concentration of nitrate in groundwater (Babiker et al., 2004; Bouwer, 1990; Canter, 1996), nitrogen transport is difficult to measure, since it is affected not only by water flow but also by all the N transformations that take place in soil (mineralization, immobilization, denitrification, plant uptake, etc.).

To attain higher nitrogen use efficiency, it is necessary to improve both nitrogen fertilization and irrigation management. Computer simulation models can help in this improvement because they integrate the different processes affecting the nitrogen dynamics in the soil–plant system. Some nitrogen models in the soil–plant system are LEACHM (Wagenet and Hutson, 1989), SOILN (Hoffmann and Johnsson, 1999), STICS (Brisson et al., 1998) and WAVE (Vanclooster et al., 1996). These models, after calibration, allow the estimation of nitrate leaching, soil mineral nitrogen and water content for different crops under different conditions of irrigation, rainfall and fertilization, being an inexpensive and rapid technique to evaluate the effects of various agricultural management practices on nitrate leaching (Cannavo et al., 2008; Kersebaum et al., 2007).

The LEACHM model has been widely used and validated for several annual crops (Jabro et al., 1995; Webb and Liburne, 1999). However, it has hardly been used with perennial plants. Harrison et al. (1999) used the LEACHM model for evaluating the long-term impacts of alternative citrus nitrogen and water management practices on the Central Florida Ridge. Alva et al. (2006) used the LEACHM model to estimate the N budget components for different nitrogen and irrigation practices for citrus in sandy soils in Florida.

In this paper it is assumed that a simpler model capable to obtain good predictions of water and soil nitrogen dynamics in citrus orchards, would be more appealing for advisory purposes. From a practical point of view, the main problem of using simulation models such as LEACHM is that many experimental data are

needed for their calibration (Jung et al., 2010) and this is probably the reason why they are barely used for irrigation and N fertilization management in commercial orchards. Thus, simpler models with fewer data requirements could be of interest for estimating the water and nitrogen needs in farmer fields and at a regional scale (Nendel, 2009). For this reason, a compartmental model developed by Contreras et al. (2009) that combines a simple soil water capacity module with an analytical model for the carbon and nitrogen dynamics developed by Porporato et al. (2003) was selected. This later model was applied in the broad-leaved savannah at Nylsvley (S. Africa) (D'Odorico et al., 2003) coupled with an existing stochastic soil moisture model and provided good results.

The two main goals of this study were (1) to adapt the LEACHN and the compartmental models to be used in citrus orchards, and (2) to calibrate them and assess their performance using data from a three-year experiment with two N fertilization treatments. This work constitutes the first calibration and validation of LEACHN model in citrus orchards in the Mediterranean area.

2. Materials and methods

2.1. LEACHN model for citrus

LEACHN is the nitrogen module of the LEACHM model. LEACHM (Leaching Estimation And Chemistry Model) is a process-based, one-dimensional model that simulates water and solute movement, and related chemical and biological processes, in the unsaturated soil (Wagenet and Hutson, 1989). A summary of the main terms of water and nitrogen balance and their treatment by the LEACHN model is presented in Table 1. The model describes the one-dimensional water flow in the unsaturated zone using the Richards' equation. Solute transport is modeled by the convection–dispersion equation, and the main processes described in the nitrogen module are mineralization, nitrification, denitrification and volatilization.

Input data for the LEACHN model include soil physical and chemical properties for the different soil layers as well as weather and crop data. The soil physical properties include: bulk density,

Table 1

Main characteristics and processes related to water and nitrogen balance and their treatment by the LEACHN and compartmental models.

Processes	LEACHN	Compartmental model
Water related		
Evapotranspiration	Potential ET and considering soil water content, root resistance and root density	Potential ET corrected as a function of soil water content and a minimum soil water storage below which plants cannot extract water
Water flux	Richards' equation; water content and hydraulic conductivity based on Campbell's equation	A function of maximum soil water storage held against gravity. No lateral water flux to or from soil is assumed
Soil hydraulic parameters	The Campbell's coefficients estimated according to Hutson and Wagenet (1991) and saturated hydraulic conductivity estimated by Ahuja and Nielsen method (1991)	Estimated after Saxton et al. (1986) and Lidón et al. (1999)
Runoff	A function of maximum infiltration and the rate of water application	A function of maximum soil water storage
Nitrogen related		
Input	Rainwater, irrigation, fertilization, organic amendments	Rainwater, irrigation, fertilization, organic amendments
Nitrogen pools	Humus, litter, organic amendments, urea, ammonium and nitrate	Humus, litter, microbial biomass, ammonium and nitrate
Plant uptake	A function of N concentration in soil solution and root water uptake	A function of N concentration in soil solution and root water uptake
Mineralization	First order kinetics	Nonlinear kinetics
Nitrification	Depends on a given potential rate and the actual $\text{NO}_3^-/\text{NH}_4^+$ ratio	Nonlinear kinetics
Denitrification	First-order process with respect to nitrate concentration	Not considered
N rate constants adjustment	Temperature (Q_{10}), water content	Water content
Leaching	Convection–dispersion equation	Determined by concentration in soil solution and drainage
Adsorption	Adsorption isotherm	Not considered
Volatilization	First order kinetics with respect to ammonium concentration	Not considered

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