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Sensitivity analysis and field testing of the RISK-N model in the Central Valley of Chile

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ABSTRACT

We present the results from a sensitivity analysis and a preliminary short-term, site-scale performance assessment of the analytical soil and groundwater nitrate transport RISK-N. The study was carried out in the Central Valley of Chile, on a 2.6 ha corn (*Zea mays* L.) field underlain by a shallow unconfined aquifer during the cropping season 2000–2001. Nitrogen levels in soils as well as NO_3^-–N irrigation water and groundwater concentrations were monitored through the crop-growing period, the latter by a network of 16 monitoring wells. A sensitivity analysis shows that both the nitrate flux from the vadose zone and NO_3^-–N groundwater concentration are mainly influenced by the initial soil nitrogen levels, water input, and soil porosity. Also, simulated groundwater NO_3^-–N levels are sensitive to changes on the saturated zone denitrification constant. An additional analysis further reveals the significance of the latter parameter, in conjunction with the amount of applied nitrogen fertilizer. We obtained a good agreement between observed average and simulated values. While the model performs well when spatially averaged values are used (root mean square error, RMSE = 1.4 mg l^{-1} of NO_3^-–N), the prediction error increases (RMSE = 1.9 mg l^{-1} of NO_3^-–N) when the concentration in each well is considered. This fact could be explained by the time and space scale of the experiment and the characteristics of the RISK-N model. The model is easy to use and seems appropriate for mid- and long-term studies of nitrogen contamination in groundwater for agricultural conditions in the Central Valley of Chile and under limited field data availability conditions. However, it needs to be tested for longer periods and under different climatic conditions, soil types, and aquifer characteristics, before its range of applicability can be fully established and recognized.

1. Introduction

Modern agriculture is characterized by the intensive use of irrigation water and agrochemicals, such as fertilizers and pesticides, that can become important environmental pollutants when applied inadequately. Furthermore, the use of low-efficiency irrigation methods, i.e., an excess of applied water, increases the leaching and transport of these substances to

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both surface waters and aquifers (Ng et al., 2000). In fact, the agricultural activity is recognized as a major nonpoint contamination source of both nutrients and pesticides to groundwater (Goderya et al., 1996; Brevé et al., 1997; Antonopoulos, 2001).

In Chile, the only country producing natural nitrate fertilizer, and an important consumer as well, little research has been carried out on the topic of nitrate contamination. Besides, the amount of data published on surface and groundwater nitrate concentrations is scarce (Arumí et al., 2005). Nevertheless, according to these data, industrial spills instead of agricultural activities seem to be the main source of NO_3^-–N groundwater contamination problems identified in some areas of the country (Schalscha et al., 1979; Falcón and Matutano, 2000). Moreover, there seems to exist special local characteristics in soils and aquifers that have prevented an extensive occurrence of high groundwater NO_3^-–N levels, despite the intensive use of fertilizers in Chilean agriculture (Arumí et al., 2005). In contrast, in the USA and Europe, the problem of groundwater contamination has been studied for more than 25 years, identifying the nitrate ion as the most ubiquitous chemical contaminant in the aquifers (Spalding and Exner, 1993; Canter, 1997; Gusman and Mariño, 1999). Thus, it as been reported the occurrence of NO_3^-–N groundwater contamination problems in agricultural areas, such as the so-called ''corn belt'' of Central USA, developed in relatively brief periods of time. The main factors producing these problems correspond to inadequate and excessive water and fertilization strategies (Watts et al., 2001). Thus, the evaluation of agricultural management practices and their consequences, with the use of tools, such as physically based models, can be of great importance in the prevention of nitrate contamination problems and in the assessment of soils and groundwater pollution risks (Antonopoulos, 2001; Mahmood et al., 2002).

Nitrogen transport and fate models are numerous and diverse, ranging from simple leaching equations to complex mechanistic models (Canter, 1997). These models usually describe nitrate transport either in the vadose zone or in the saturated zone, but there have been few attempts to link both zones in a single model. The models considering the whole system are usually of the numerical type, and therefore, tend to require large amount of input data, which restricts their utilization (Canter, 1997). However, Mehran et al. (1984), in Canter (1997), pointed out that ''for field-scale problems, one-dimensional transport in the vadose zone with two-dimensional flow in the saturated zone allows a realistic description of transport processes in the overall flow region''. They remarked that this type of modeling approach provides an efficient and practical tool for long-term predictions of the impact of agricultural activities on aquifer systems and evaluation of potential nitrate management alternatives. Similarly, Hutson and Wagenet (1991) indicated that given the inherent variability of many field soils, a simple model including all the relevant processes at an appropriate scale, is easier to use, requires few and simple data, and can be as accurate as a more complex model.

Taken all this into account, the analytical RISK-N model of Gusman and Mariño (1999) was developed to simulate nitrogen cycling in soils and nitrate transport and fate in soils and groundwater. This model was used by these researchers to simulate N-fate in a hypothetical corn plot, using meteorological, soil, hydrologic, and hydrogeological data from the South Platte River region of northeastern Colorado, and a conventional fertilizer management scheme. They concluded that the RISK-N model was capable of simulating nitrate leaching rates and groundwater concentrations that are consistent with those obtained by numerical models, while requiring fewer input variables. Also, Tabachow et al. (2001) presented a comparison between four biogeochemical models, APS, DAISY, NLEAP, and RISK-N, which simulated N cycling in the plant–soil–water–atmosphere environment. These authors concluded that RISK-N ''seems best suited for modeling biogeochemical N cycles that are associated with N losses''. However, at the same time they suggested that ''future work must include comparison of RISK-N simulations to laboratory and field studies at agricultural sites''. Indeed, to the best of our knowledge, RISK-N has not been tested yet in its performance and sensitivity behaviour considering actual field cases.

Therefore, the purpose of this paper is to test the RISK-N model usefulness under representative conditions of the Central Valley of Chile (33–40°S), which concentrates most of the Chilean agricultural activity (ca. 90%), using easy to obtain field-data and literature-derived information. Also, the effect of uncertainty in model input was studied, to assess the suitability of using RISK-N as a practical tool at the field-scale when limited field information is available, that is, a very frequent case in most agricultural sites. Thus, this paper presents a sensitivity analysis of the model, and compares observed and predicted groundwater nitrate levels for the agro-environmental conditions of Central Chile.

2. Materials and methods

2.1. Model description

RISK-N is a physically based, analytical nitrate transport model that includes both the unsaturated and saturated zones. In the following paragraphs, the model is briefly described. For a more detailed explanation on water transport and nitrogen processes covered, see Gusman and Mariño (1999). Instead of using the Richards equation commonly found in numerical models, a simplified water-balance approach for soil water transport, i.e., infiltration and percolation, is used for the unsaturated soil zone. All water fluxes are assumed as one-dimensional, in a steady-state condition, and calculated as seasonal averages. Soil properties are assumed to be uniform in each zone. Nitrogen transport in each unsaturated soil zone is simulated on the premise of complete mixing, i.e., spatial average, of nitrogen concentrations. In the saturated zone, complete mixing is not assumed. Instead, a two-dimensional advective–dispersive equation is solved analytically. In simulating nitrogen-related processes, RISK-N separates the unsaturated soil into (1) upper root, (2) lower root, and (3) intermediate-vadose zones, considering that nitrogen transformation processes predominantly occur in the top 0.3 m of the soil, while roots often extend to a deeper level (Shaffer et al., 1991; Gusman and Mariño, 1999). Nitrogen