AGRICULTURAL WATER MANAGEMENT 96 (2009) 267–281

available at www.sciencedirect.com

ScienceDirect

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

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Agricultural Water Management

Evaluation of the DRAINMOD–N II model for predicting nitrogen losses in a loamy sand under cultivation in south-east Sweden

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ARTICLE INFO

Article history:
Received 24 January 2008
Accepted 22 August 2008
Published on line 14 October 2008

Keywords:
Controlled drainage
Subsurface drainage
DRAINMOD
Modelling
Nitrate loads

ABSTRACT

The DRAINMOD–N II model (version 6.0) was evaluated for a cold region in south-east Sweden. The model was field-tested using four periods between 2002 and 2004 of climate, soil, hydrology and water quality data from three experimental plots, planted to a winter wheat–sugarbeet–barley–barley crop rotation and managed using conventional and controlled drainage. DRAINMOD–N II was calibrated using data from a conventional drainage plot, while data sets from two controlled drainage plots were used for model validation. The model was statistically evaluated by comparing simulated and measured drain flows and nitrate–nitrogen (NO_3–N) losses in subsurface drains. Soil mineral nitrogen (N) content was used to evaluate simulated N dynamics. Observed and predicted NO_3–N losses in subsurface drains were in satisfactory agreement. The mean absolute error (MAE) in predicting NO_3–N drainage losses was 0.16 kg N ha^{-1} for the calibration plot and 0.21 and 0.30 kg N ha^{-1} for the two validation plots. For the simulation period, the modelling efficiency (*E*) was 0.89 for the calibration plot and 0.49 and 0.55 for the validation plots. The overall index of agreement (*d*) was 0.98 for the calibration plot and 0.79 and 0.80 for the validation plots. These results show that DRAINMOD–N II is applicable for predicting NO_3–N losses from drained soil under cold conditions in south-east Sweden.

1. Introduction

Drained agricultural land has been recognized as a major source of pollution to both surface waters and groundwater (Randall and Mulla, 2001; Stoate et al., 2001). Intensive use of fertilizers and manure to increase food production can enhance the risk of nitrogen (N) contaminating surface waters and groundwater, stimulating eutrophication (Carpenter et al., 1998). Nitrate–nitrogen (NO_3–N) contaminated drainage waters have been reported to be a main non-point source pollution for surface waters (Jacobs and Gilliam, 1985; David et al., 1997). In coastal areas of southern Sweden, which are prone to N leaching (SJV, 2007), N transport in lowland rivers has resulted in serious coastal eutrophication problems (Larsson et al., 1985; Stålnacke et al., 1999). This ongoing eutrophication has led to widespread hypoxia and large permanently reducing bottom areas in marine costal ecosystems in southern Sweden (Vahtera et al., 2007).

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0378-3774/$ – see front matter
doi:10.1016/j.agwat.2008.08.008

Research has shown that groundwater management practices can be used to minimize N loads from drained lands (Skaggs et al., 1994). Controlled drainage, which involves raising the water level in the drainage outlet, is a groundwater management technique used to conserve water in soil and reduce N loads from drained lands (Skaggs, 1999). The major impact on NO_3–N loading is the effect of controlled drainage on total outflows (Skaggs et al., 1994). Studies have also demonstrated that groundwater management practices provide water quality benefits by enhancing NO_3–N removal through denitrification in the water-saturated zone (Gilliam et al., 1979; Elmi et al., 2000). Controlled drainage has been subject to extensive research and implementation in the United States (Gilliam et al., 1979; Skaggs and Gillian, 1981; Deal et al., 1986; Evans et al., 1995). The technique has also been implemented on an experimental basis in many countries such as Canada (Drury et al., 1996; Lalonde et al., 1996; Tan et al., 1998; Elmi et al., 2000), Italy (Borin et al., 2001), Finland (Paasonen–Kivekäs et al., 1996) and Sweden (Wesström and Messing, 2007).

In developing management practices that alleviate the undesirable consequences of NO_3–N losses to aquatic systems, a better understanding of the processes that regulate C and N dynamics in drained areas is needed (DeBusk et al., 2001). The mechanisms determining the hydrology and loss of nutrients from artificially drained soils are complex and depend on many factors, such as land use, management practices, soil and climate (Skaggs et al., 1994). The development of computer simulation models has provided methods to describe the mechanisms of nutrient retention and release in these drained areas. DRAINMOD (Skaggs, 1978; Skaggs, 1991) is a field-scale computer model that incorporates the effects of conventional drainage, subirrigation and controlled drainage systems in soils with shallow groundwater levels. The model has been successfully tested under a wide range of soil, crop and climatological conditions (Cooper and Fouss, 1988; Mostaghimi et al., 1989; Cox et al., 1994; Singh et al., 2006). Since its inception, DRAINMOD has been updated to further extend its capabilities. DRAINMOD 5.1 simulates processes controlling field hydrology under cold conditions, which include freezing and thawing components (Luo et al., 2000). It also includes predictions of soil temperature and snow accumulation/melting processes. The latest version has been tested under cold climates in Minnesota, USA (Jin and Sands, 2003), Canada (Wang et al., 2006), Turkey (Luo et al., 2001) and Sweden (Wesström, 2002), and predicted values have generally been found to be in good agreement with field data. DRAINMOD 6.0 incorporates the nitrogen model DRAINMOD–N II, which includes modules for simulating carbon (C) and N dynamics in shallow groundwater soils with artificial drainage (Youssef et al., 2005). It has been calibrated and validated for predictions of N concentrations in drainage water in North Carolina, USA (Youssef et al., 2006) and Germany (Bechtold et al., 2007).

The aim of this paper was to evaluate the DRAINMOD–N II model for south-east Sweden. The model was tested by comparing simulated results with field data from conventional and controlled drained plots for four periods between 2002 and 2004. Drain outflows, NO_3–N losses in subsurface drains and soil mineral N contents were estimated.

2. Materials and methods

2.1. *Site description and experiment procedure*

The data used in testing DRAINMOD–N II were obtained from a research site established at Gärds Köpinge (south-east Sweden, 55°56′N, 14°10′E, in the county of Skåne). The model was run for four periods: January 2002–June 2002 (Period 1), July 2002–June 2003 (Period 2), July 2003–June 2004 (Period 3) and July 2004–December 2004 (Period 4), which correspond to four different hydrological years.

The study area has a semi-humid climate with a mean annual air temperature of 7.6 °C (using 1961–1990 data from a meteorological network station at Kristianstad). The period March–April is regarded as spring, May–August as summer, September–November as autumn and December–February as winter. Two months (January and February) have a mean air temperature below zero degrees (Alexandersson et al., 1991). The mean annual precipitation is 562 mm, with 57% falling from July to December. Table 1 shows a summary of monthly

Table 1 – Monthly summary of measured precipitation (*P*) and calculated potential evapotranspiration (PET) for Periods 1–4

Month	Period 1		Period 2		Period 3		Period 4	
	P (mm)	PET (mm)	*P* (mm)	PET (mm)	*P* (mm)	PET (mm)	*P* (mm)	PET (mm)
July	–	–	52	106	71	101	31	90
August	–	–	31	111	22	100	49	95
September	–	–	20	68	6	58	31	60
October	–	–	128	21	46	25	92	22
November	–	–	71	12	64	10	49	10
December	–	–	61	8	56	7	39	7
January	64	13	32	11	53	5	–	–
February	118	20	4	7	19	13	–	–
March	26	43	8	40	42	33	–	–
April	27	50	51	53	28	60	–	–
May	76	82	36	90	57	89	–	–
June	48	123	58	112	88	99	–	–
Total	359	331	552	639	552	600	291	284