Cereal Research Communications 39(2), pp. 273–282 (2011)
DOI: 10.1556/CRC.39.2011.2.11

Influence of Drainpipe Spacing on Nitrate Leaching and Maize Yield

I. SIMUNIC[1]*, M. MESIC[1], M. SRAKA[1], T. LIKSO[2] and L. COGA[1]

[1]Faculty of Agriculture, University of Zagreb, Svetosimunska 25, 10000 Zagreb, Croatia
[2]Meteorological and Hydrological Service, Gric 3, 10000 Zagreb, Croatia

(Received 2 February 2009; accepted 19 July 2010;
Communicated by J. Johnson)

The objectives of the study were to determine the extent of nitrate leaching and maize yields in four drainpipe spacing variants (15 m, 20 m, 25 m and 30 m). The study was carried out at an experimental reclamation field during a period of five years (growing seasons). Maize was grown as the trial crop and the same agricultural practices were applied in all drainpipe spacing variants in all trial years. Nitrogen fertilization rates varied in different trial years (from 145 kg/ha/year to 175 kg/ha/year). The results indicate that nitrate concentrations in drainage water exceeded the allowable values in a larger part of the year (four to seven months) in all drainpipe spacing variants and maximum values were from 18.15 mg.dm^{-3} (drainpipe spacing of 15 m in 1999/00) up to 34.71 mg.dm^{-3} (drainpipe spacing of 25 m in 2002/03). Quantity of nitrogen leached differed from year to year and corresponded to the total nitrogen added with fertilization and annual precipitation. Statistically significant higher maize yields were achieved in most years with the drainpipe spacing of 15 m compared to other drainpipe spacing variants.

Keywords: drainpipe spacing, drainage water, nitrate, leaching, maize

Introduction

In various soil–plant systems, pollutants may constitute a potential risk to the environment through their uptake by plants and subsequent input into the food chain, and the danger ensuing from their tendency to accumulate in vital organs of humans, animals and plants, or because of possible contamination of drinking water. The World Health Organization recommended that drinking water should contain less than 10 mg NO_3–N L^{-1} or 50 mg NO_3 L^{-1} (WHO 1998). Groundwater pollution by nitrates is an international problem (Roberts and Marsh 1987; Meybeck et al. 1989; Weisenburger 1991; Spalding and Exner 1993; Zhang et al. 1996; Lerner et al. 1999; Wakida and Lerner 2002).

Excessive nitrate concentration in water may lead to eutrophication of watercourses or stock watering places. If such water is used for human consumption, it may cause methemoglobinemia in infants and animals (Pratt and Jury 1984; Fedkiw 1991; Tyson et al. 1992; Matson et al. 1997). Potential cancer risk from nitrate-N (and nitrite) in water and

* Corresponding author; E-mail: simunic@agr.hr; Phone: +385 1 23 93 750; Fax: +385 1 23 94 099

food has been reported (Rademaher et al. 1992; Jasa et al. 1999). Leaching of nitrates from soil depends on the amount, frequency and intensity of precipitation, soil properties, crop type and crop development stage, evaporation, soil tillage practices, and nitrogen fertilization (Gausey 1991; Vidacek et al. 1996, 1999; Nadasy and Nadasy 2006; Nemeth 2006; Josipovic et al. 2006; Nemcic et al. 2007).

The problem of nitrate leaching is even more pronounced in agroecosystems of hydroameliorated fields, especially in drained soils because of changed infiltration and filtration capabilities of these soils. Total hydroameliorated areas cover 600,054 ha in Croatia, including 117,865 ha of the pipe drainage system area (Vidacek et al. 2006). Different drainpipe spacing and different nitrogen fertilization levels significantly influence soil productivity in the experimental area (Simunic et al. 2002; Mesic et al. 2007, 2008), but different drainpipe spacings along with different agricultural practices and application of mineral fertilizers may lead to contamination of drainage water with nitrogen pollutants (Milburn and Richards 1994; Klacic et al. 1998; Webster et al. 1999). The main goals of this research are to determine the quantity of nitrates leached in drainage water in four different drainpipe spacing variants, to find out the differences between the variants and to determine the maize yield in each variant in five different hydrological years and at different nitrogen fertilization rates in trial years.

Materials and Methods

Trials were carried out at the experimental amelioration field located in the Sava river valley at the altitude of 96.4 m.a.s.l. (near the place Popovaca), on soil type defined as Gleyic Podzoluvisol. The trial involved four different drainpipe spacing variants (15 m, 20 m, 25 m and 30 m), set up in four replications. All variants were combined with gravel as contact material (Ø 5–25 mm) in the drainage ditch above the pipe. Drainpipe characteristics were: length 95 m, diameter 65 mm, average slope 3‰ and average depth 1 m. Drainpipes discharged directly into open canals. Variants covered areas of 1425 m^2, 1900 m^2, 2375 m^2 and 2850 m^2, respectively. Plastic (PVC)-annular-ribbed and perforated pipes were used. Maize was grown as the trial crop and the same agricultural practices were applied in all drainpipe spacing variants during the five trial years (1991, 1993, 1996, 1999 and 2002). Sowing was done in May. The seeding density (0.7 m times 0.2 m) was about 71,000 plants/ha, species Bc 272 Eta. Crops were maintained in a conventional way, without irrigation. Harvest took place in October and harvest residues (maize stalks and straw) were ploughed in after harvesting. All measurements were taken from May to April of the following year because soybean was planted as the next crop in rotation in May. Total nitrogen fertilization was: 175 kg/ha/1991, 145 kg/ha/93, 145 kg/ha/96, 155 kg/ha/99 and 164 kg/ha/02. NPK (7:20:30) fertilizer and UREA were applied at about 120 kg N/ha at sowing. Later, at the beginning of July, KAN was applied. Topdressing was used in both cases. Meteorological data were obtained from the Meteorological Station Sisak. Drainage discharge was measured continually by means of automatic electronic gauges (limnimeters), which were set up in each variant at the drainpipe outlet into the open canal.

Drainage water was sampled every day during the discharge period. Nitrates were determined spectrophotometrically by yellow colouring of phenol disulphonic acid (APHA-AWWA-WPCF 1992). Total annual quantities of nitrogen leached were estimated on the basis of the average monthly concentration and monthly quantity of drainage discharge. Average nitrogen concentration and yield in the different drainpipe size variants were calculated using ANOVA ($p = 0.05$). Later, significant differences were determined using Duncan's Multiple Range Test.

Results and Discussion

According to the mechanical composition of the arable layer, the soil is silty clay, belongs to the category of porous soils having average to high capacity for water and very low air capacity as well as water permeability. Humus content is good while contents of P_2O_5 and K_2O are very low (Table 1).

Monthly precipitation values and the corresponding total values (i.e. sum of monthly precipitation values for the whole examined period) are presented in Table 2.

According to the analyses of total precipitation values, total drainage discharge values and total duration of drainage discharge for different drainpipe spacings (Table 3), differences are noticeable in the quantity and duration of drainage discharge, both between the tested drainpipe spacings in each growing season and between the trial years. Differences in the quantity of drainage discharge between drainpipe spacings in a particular year are smaller than differences between years. There is a strong correlation between total precipitation and total drainage discharge ($r = 0.79$ up to 0.85; Fig. 1) and generally in case of higher precipitation, drainage discharge is higher, and vice versa (Table 3).

The shortest duration of drainage discharge was recorded in each year at the drainpipe spacing of 15 m and the longest at drainpipe spacing of 30 m. According to Petosic et al. (1998) and Tomic et al. (2002), narrower drainpipe spacing and shorter duration of drainage discharge are more efficient.

Maximum nitrogen concentrations in drainage water from all drainpipe spacing variants during the trial period exceeded the concentration of 10 mg/L (Table 4).

Average nitrogen concentration values in four years were in all drainpipe spacing variants above the allowable concentration, except in 1999/2000. The highest nitrogen concentrations were recorded in 1991/92 and 2002/03 (Fig. 2) when higher fertilizer doses were applied (175 kg/ha and 164 kg N/ha, respectively) and higher precipitation (drainage discharge) was also recorded, especially in May and July (Table 2) after fertilization. The lowest nitrogen concentration was detected in 1999/00, when the lowest total drainage discharge of all trial years was determined, although it was not the year when the lowest fertilizer rates were applied. According to Vidacek et al. (1999), nitrate concentration in drainage water is dependent on the sampling time.

Table 1. Major properties of drained Gleyic Podzoluvisol

Profile	Depth (cm)	Content of particles (%)		Porosity (%)	Capacity (%)		Bulk density (kg/dm^3)	Permeability (m/day)	pH KCl	Humus (%)	P_2O_5	K_2O
		Silt	Clay		Water	Air					mg/100 g soil	
Ap	0–35	47	46	48	44	4	1.35	0.011	5.3	3.03	1.51	8.3
Bt,g	35–75	45	48	49	45	4		0.011	5.2			
Gso	75–115	55	39	46	42	4		0.011	7.1			

Table 2. Monthly precipitation values and the corresponding total values (mm), Meteorological Station Sisak

Year	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	Sum
1991/92	156	20	160	52	50	152	108	21	15	45	78	59	916
1993/94	44	134	30	119	90	107	165	112	50	58	37	79	1025
1996/97	71	31	90	83	190	46	135	79	44	55	26	45	895
1999/00	107	89	86	66	95	72	92	104	29	37	63	77	917
2002/03	183	56	130	99	133	73	113	54	71	21	5	30	968

Table 3. Quantities of drainage discharge (mm) and total duration of drainage discharge (days)

Drainpipe spacing (m)	Year	Precipitation (mm)	Drainage discharge		Duration of drainage discharge (days)
			mm	% of precipitation	
15	1991/92	916	228	24.9	134
20			219	23.9	136
25			213	23.3	139
30			229	25.0	141
15	1993/94	1025	266	26.0	167
20			271	26.4	170
25			268	26.1	177
30			277	27.0	182
15	1996/97	895	198	22.1	140
20			198	22.1	146
25			203	22.7	153
30			199	22.2	157
15	1999/00	917	174	19.0	124
20			175	19.1	126
25			166	18.1	129
30			171	18.6	129
15	2002/03	968	273	28.2	143
20			270	27.9	151
25			277	28.6	153
30			285	29.4	165

Table 4. Average and maximum concentration of nitrogen ($mg.dm^{-3}$) in drainage water

Spacing variants (m)	1991/92		1993/94		1996/97		1999/00		2002/03	
	Aver.	Max	Aver.	Max	Aver.	Max	Aver.	Max	Aver.	Max
15	16.25 a	32.82	12.90 a	29.15	10.21 a	20.05	9.51 a	18.15	17.37 b	34.32
20	15.95 b	30.93	12.22 b	29.03	10.36 a	20.81	8.99 a	19.24	17.70 ab	33.19
25	15.67 b	31.67	12.88 a	29.13	10.58 a	20.34	9.54 a	20.21	17.81 a	34.71
30	15.26 c	30.63	11.95 c	29.07	10.51 a	19.91	9.47 a	18.43	17.82 a	33.58

Values marked by the same letter are not significantly different according to Duncan's test ($p = 0.01$)

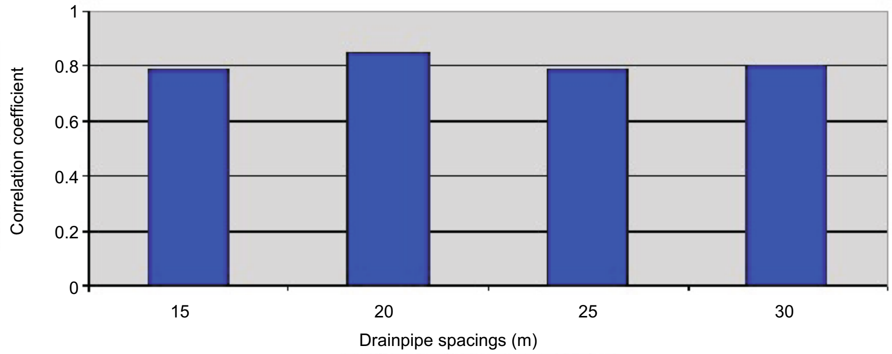

Figure 1. Correlation between precipitation and drainage discharge

As observed in Figure 2 for drainpipe spacing of 15 m, maximum nitrogen concentrations in drainage water in all years were detected in spring, soon after sowing and top-dressing, which generally coincided with precipitation maxima (i.e. after higher drainage discharge), except in 1996/97, when the highest drainage discharge occurred in September. Similar fluctuations of nitrogen concentration were observed in other drainpipe spacing variants.

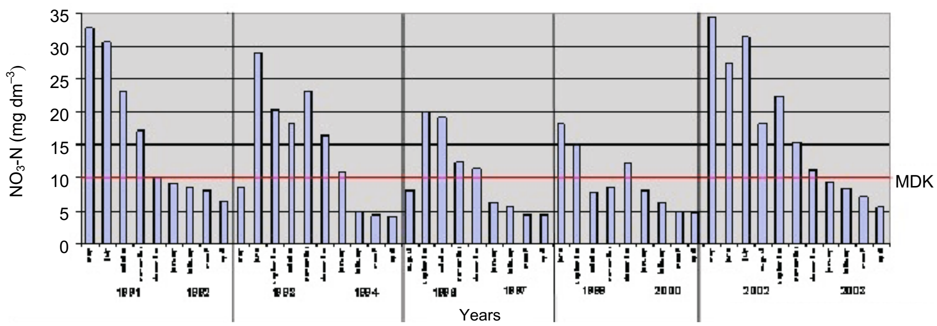

Figure 2. Fluctuation of nitrogen concentration in drainage water

In the years 1991/92, 1993/94 and 2002/03 there were significant differences between drainpipe spacings ($p = 0.05$). Nitrogen concentration in drainage water exceeded the MAC in four (1996/97) to seven months (1993/94) (Fig. 2). Similar results for nitrogen concentrations in drainage water were obtained by Kladivko et al. (1991), Rossi et al. (1991), Simunic et al. (2002) and Bensa et al. (2007).

According to the analyses of total annual quantity of nitrogen leached through drainage water (Table 5), there are differences both between the tested drainpipe spacings in each year and between trial years. Differences between drainpipe spacings in the quantity of nitrogen leached in a particular year are smaller, but there are greater differences between years. Lower nitrogen leaching was recorded in all drainpipe spacing variants in the periods 1996/97 and 1999/00, when the quantity of drainage discharge was the lowest and

Table 5. Quantity of nitrogen leached through drainage water (kg.ha^{-1}) and percentage of nitrogen leached relative to the total N added with fertilization

Spacing	1991/92		1993/94		1996/97		1999/00		2002/03	
variants (m)	kg.ha^{-1}	%	kg.ha^{-1}	%	kg.ha^{-1}	%	kg.ha^{-1}	%	kg.ha^{-1}	%
15	35.7	20.4	34.4	23.7	20.3	14.0	16.6	10.7	47.2	28.7
20	30.7	17.5	33.2	22.9	20.6	14.2	15.8	10.2	48.4	29.5
25	33.9	19.4	34.6	23.9	21.5	14.8	15.9	10.3	49.4	30.1
30	34.9	19.9	33.2	22.9	21.0	14.5	16.2	10.5	50.8	31.0

Table 6. Duncan's Multiple Range Test of the mean values of maize yields (t/ha) in dependence on drainpipe spacing

Drainpipe	Dry maize grain yield (t.ha^{-1})									
spacing (m)	1991		1993		1996		1999		2002	
15	8.80	a	6.43	a	5.82	a	6.23	a	6.62	a
20	8.13	b	6.35	a	5.34	b	6.16	a	6.44	a
25	7.86	c	5.58	b	4.92	c	5.77	b	6.12	b
30	7.17	d	5.21	c	4.35	d	5.62	b	5.87	b

Values marked by the same letter are not significantly different according to Duncan's test (p = 0.01).

lower nitrogen rates were applied than in 1992/93 and 2002/03. Higher leaching occurred in the years 1991/92, 1993/94 and 2002/03 (either larger amount of nitrogen added with fertilization or higher drainage discharge).

According to Mesic et al. (2007), the quantity of nitrogen leached is in linear correlation with the quantity of drainage discharge. These results (Table 5) are in accord with the results obtained by Skaggs and Gilliam (1985) and Klacic et al. (1998). Different quantities of leached nitrogen are influenced by climate conditions. The total amount and distribution of precipitation (drainage discharge), crops grown, their development stages, as well as by the quantity of fertilizers applied and the time of their application. In this case, if there is higher amount of precipitation in spring when maize needs less nitrogen and less water for its development, then it results in higher nitrate leaching. If other crops (wheat or alfalfa) were grown, nitrate leaching would probably be different because of different root depth, different growth, etc.

The mean values of maize yield, in dependence on the drainpipe spacing variant, are presented in Table 6.

Maize yields varied both between different drainpipe spacings and between trial years. Generally, in all trial years the highest yield were achieved with the drainpipe spacing of 15 m, and the lowest yields were achieved with the drainpipe spacing of 30 m. This may be due to the very low soil permeability (Table 1) and longer stagnation of surplus water in soil. According to Tomic et al. (2007) and Mesic et al. (2008), the efficiency of a particular drainage system has an influence on yields.

The highest yields in all variants were achieved in 1991, when the highest fertilizer rate was applied (175 kg N/ha) and the lowest yield in all variants was obtained in 1996, when the lowest fertilizer rate was applied (145 kg/ha). Further, with the same agrotechnical practices and the same hybrid, the quantity of fertilizer applied affected the yields in all variants on this hydroameliorated soil. Although with smaller differences in fertilizers added their influence on higher yield, were not detected, like in 1993 and 1999, but yield could be influenced by other factors such as fluctuation and amount of yearly precipitation, date of topdressing, etc.

This paper shows that there were significant differences in drainage water contamination with nitrates among the tested drainpipe spacings in the years 1991/92, 1993/94 and 2002/03 ($p = 0.05$), but in years 1996/97 and 1999/00 there were no significant differences. Nitrate levels in drainage water exceeded the MAC in all drainpipe spacings in four (1996/97) to seven months (1993/94). The highest nitrate leaching (2002/03) concurred with the highest drainage discharge. The highest maize yields in all trial years were achieved with the drainpipe spacing of 15 m, and therefore this variant should have priority in the agroecological conditions of the central Sava valley and should be managed pursuant to the requirements of sustainable agriculture.

Acknowledgements

This research was initiated and supported by the Ministry of Science and Technology of the Republic of Croatia (Project, No. 178131-Systems of Water-Soil-Plant Management) and the Water Management Agency "Hrvatske vode", Croatia.

References

APHA-AWWA-WPCF. 1992. Standard Methods for the Examination of Water and Wastewater. Washington, DC, USA, pp. 156–157.

Bensa, A., Vidacek, Z., Coga, L., Sraka, M., Vrhovec, D. 2007. Influences of pipe drainage and fertilization on nitrate leaching. Cereal Res. Commun. **35**:237–240.

Fedkiw, J. 1991. Nitrate Occurrence in U.S. Waters (and Related Questions). U.S. Department of Agriculture, Working Group on Water Quality, Washington, DC, 35 pp.

Gausey, N.R. 1991. Nitrate leaching to subsurface drains as affected by drain spacing and changes in crop production system. J. Environ. Quality **20**:264–270.

Jasa, P., Skipton, S., Varner, D., Hay, D. 1999. Drinking Water: NO_3–N. NebGuide. Published by Cooperative Extension Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln, Lincoln, NE, USA.

Jackson, M.L. 1958. Soil Chemical Analysis. Madison, WI, USA, 498 pp.

Josipovic, M., Kovacevic, V., Sostaric, J., Plavsic, H., Liovic, J. 2006. Influences of irrigation and fertilization on soybean properties and nitrogen leaching. Cereal Res. Commun. **34**:513–516.

Klacic, Z., Petosic, D., Coga, L. 1998. Nitrogen leaching in different pipe drainage distances. Agriculturae Conspectus Scientificus **63**:331–338.

Kladivko, E.J., Frankenberger, J.R., Jaynes, D.B., Meek, D.W., Jenkinson, B.J., Gausey, N.R. 1991. Nitrate leaching to subsurface drains as affected by drain spacing and changes in crop production system. J. Environ. Quality **20**:264–270.

Lerner, D.N., Yang, Y., Barrett, M.H., Tellam, J.H. 1999. Loading of non-agricultural nitrogen in urban groundwater. In: Ellis, J.B. (ed.), Impacts of Urban Growth on Surface and Groundwater Quality (Proc. of IUGG99 Symposium HS5, Birmingham, July 1999). IAHS Publ., no. 259. IAHS Press, Wallingford, UK, pp. 117–123.

Matson, P.A., Parton, W.J., Power, A.G., Swift, M.J. 1997. Agricultural intensification and ecosystem properties. Science **277**:504–509.

Mesic, M., Basic, F., Kisic, I., Butorac, A., Gaspar, I. 2007. Influence of mineral nitrogen fertilization on corn grain yield and nitrogen leaching. Cereal Res. Commun. **35**:773–776.

Mesic, M., Simunic, I., Basic, F., Vukovic, I., Jurisic, A. 2008. Soil type influence on drainage discharge and yields of soybean. Cereal Res. Commun. **36**(Suppl 5, Part II):1207–1210.

Meybeck, M., Chapman, D., Helman, P. 1989. Global Freshwater Quality: A First Assessment, Global Environment Monitoring System. WHO and UNEP. Blackwell Ltd., New York, USA.

Milburn, P., Richards, J.E. 1994. Nitrate concentration of the subsurface drainage water from a corn field in southern New Brunswick. Canad. Agricult. Engineering **36**:69–78.

Nadasy, E., Nadasy, M. 2006. Some harmful or useful environmental effects of nitrogen fertilisers. Cereal Res. Commun. **34**:49–52.

Nemcic, J.J., Mesic, M., Basic, F., Kisic, I., Zgorelec, Z. 2007. Nitrate concentration in drinking water from wells at three different locations in Northwest Croatia. Cereal Res. Commun. **35**:533–536.

Nemeth, T. 2006. Nitrogen in the soil-plant system nitrogen balances. Cereal Res. Commun. **34**:61–64.

Petosic, D., Dolanjski, D., Husnjak S. 1998. Functionality of pipe drainage at the trial field Oborovo in the Sava River Valley. Agriculturae Conspectus Scientificus **63**:353–360.

Pratt, P., Jury, W.A. 1984. Pollution of the unsaturated zone with nitrate. Ecol. Stud. **47**:52–67.

Rademaher, J.J., Young, T.B., Kanarek, M.S. 1992. Gastric cancer mortality and nitrate levels in Wisconsin drinking water. Arch. Environ. Health **47**:292–294.

Roberts, G., Marsh, T. 1987. The effects of agricultural practices on the nitrate concentrations in the surface water domestic supply sources of Western Europe. IAHS **164**:365–380.

Rossi, N., Ciavatta, C., Antisari, L.V. 1991. Seasonal pattern of nitrate losses from cultivated soil with subsurface drainage. Water, Air and Soil Pollution **60**:1–10.
Simunic, I., Tomic, F., Mesic, M., Kolak, I. 2002. Nitrogen leaching from hydroameliorated soil. Die Bodenkultur **53**:73–83.
Skaggs, R., Gilliam, J.W. 1985. Effect of drainage system design and operation on nitrate transport. Transaction of the ASAE **24**:929–934.
Spalding, R.F., Exner, M.E. 1993. Occurrence of nitrate in groundwater – A review. J. Environ. Qual. **22**:392–402.
Tomic, F., Simunic, I., Petosic, D., Romic, D., Satovic, Z. 2002. Effect of drainpipe spacing on the yield of field crops grown on hydroameliorated soil. Agriculturae Conspectus Scientificus **67**:101–105.
Tomic, F., Kricka, T., Simunic, I., Petosic, D., Voca, N., Jukic, Z. 2007. Effect of drainage systems on the water release rate in the process of drying corn grain. Irrigation and Drainage **56**:107–113.
Tóth, B., Makó, A., Rajkai, K., Marth, P. 2006. Study of the estimation possibilities of soil hydraulic conductivity. Cereal Res. Commun. **34**:327–330.
Tyson, A., Dixon, M.L., Segars, W. 1992. Your Drinking Water: Nitrates. Ext. Publ. 819–5, Univ. of Georgia, Athens, GA, USA.
Vidacek, Z., Bogunovic, M., Sraka, M., Husnjak, S. 1996. Water discharges and nitrates from some soils of the Sava river valley. In: 6. Gumpensteiner Lysimetertagung "Lysimeter in Dienste des Grundwassershutzes". BAL, Gumpenstein, Austria, pp. 111–115.
Vidacek, Z., Sraka, M., Coga, L., Mihalic, A. 1999. Nitrates, heavy metals and herbicides in soil and water of Karasica-Vucica catchment area. Agriculturae Conspectus Scientificus **64**:143–150.
Vidacek, Z., Bogunovic, M., Husnjak, S., Sraka, M., Bensa, A. 2006. Hydropedological map of the Republic of Croatia. In: World Congress of Soil Science Frontiers of Soil Science Technology and the Information Age, Abstracts, p. 228.
Wakida, F.T., Lerner, D.N. 2002. Nitrate leaching from construction sites to groundwater in the Nottingham, UK, urban area. Water Sci. Technol. **45**:243–248.
Webster, C., Poulton, P.R., Goulding, K.W.T. 1999. Nitrogen leaching from winter cereals grown as part of a 5-yearly-arable rotation. Eur. J. Agron. **10**:99–109.
Weisenburger, D.D. 1991. Potential health consequences of ground-water contamination by nitrate in Nebraska. In: Bogardi, I., Kuzelka, R.D. (eds), Nitrate Contamination-exposure, Consequence, and Control. NATO ASI Serial G. Ecological Sciences, vol. 30. Springer-Verlag, Berlin, Germany, pp. 309–315.
WHO, 1998. Guidelines for Drinking-water Quality. 2nd Edn. World Health Organization. Geneva, Switzerland.
Zhang, W.I., Tian, Z.X., Zhang, N., Li, X.Q. 1996. Nitrate pollution of groundwater in northern China. Agric. Ecosyst. Environ. **59**:223–231.