Water Quality in Hydroameliorated Agricultural Areas

Ivan ŠIMUNIĆ [1(✉)]
Palma ORLOVIĆ-LEKO [2]
Tanja LIKSO [3]
Vilim FILIPOVIĆ [1]
Tatiana MINKINA [4]

Summary

Three-year investigations (2007-2009) of water quality in hydroameliorated agricultural areas were carried out at the experimental amelioration field "Jelenščak" Kutina, on hydroameliorated Gleyic Podzoluvisol. Soil was drained in four different drainpipe spacing variants (15 m, 20 m, 25 m and 30 m), set up in four replications. The areas of spacing variants were: 1425 m^2, 1900 m^2, 2375 m^2 and 2850 m^2. The same crop was grown in each research year in all variants and the same agricultural management practices were applied. Winter wheat was grown in 2007 and in 2009 and soybean in 2008. Samples of drainage water were taken at drainpipe outlets into the canal. The following parameters were determined in the samples: nitrate concentration and concentration of chlortoluron.

Based on the drainage water analysis, it was established that nitrate concentration as well as chlortoluron concentration exceeded the prescribed MAC values (10 $mg.dm^{-3}$ NO_3-N) in each year and in all variants. Nitrogen concentration in drainage water exceeded the MAC in five months (2006/07), in two months (2008) and in seven months (2008/09). Concentration of chlortoluron in drainage water exceeded the MAC (100 $ŋg.dm^{-3}$) in five months (2006/07) and in seven months (2008/09). Maximum nitrate concentration was up to 28.42 $mg.dm^{-3}$, and that of chlortoluron up to 365 $ŋg.dm^{-3}$.

Key words

hydroameliorated soil, drainage water quality, nitrate, chlortoluron

[1] University of Zagreb, Faculty of Agriculture, Department of Soil Amelioration, Svetošimunska 25, 10000 Zagreb, Croatia
✉ e-mail: simunic@agr.hr
[2] University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering, 10000 Zagreb, Croatia
[3] Meteorological and Hydrological Service of Croatia, 10000 Zagreb, Croatia
[4] Faculty of Biology and Soil Science, Department of Soil Science, Southern Federal University, Rostov-on-Don, Russia

Received: September 18, 2010 | Accepted: February 3, 2011

ACKNOWLEDGEMENTS
This work is part of the project "Effects of herbicides and fertilizers on water and soil quality in hydroameliorated areas", which is financed by the Croatian Ministry of Science, Education and Sports (Project no. 178-1782221-2037).

Introduction

Intensive use of mineral fertilizers and herbicides in conventional agricultural practices has resulted in continuous and serious environmental (soil, water, food and organisms) pollution (Jolànkai et al., 2006; Kirsch et al., 2007; Veliskovà, 2006; Šimunić et al., 2008). 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. Potential cancer risk from nitrate-N (and nitrite) in water and food has been reported (Rademaher et al., 1992 and Jasa et al., 1999). Nitrate leaching 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 and 1999; Nemeth, 2006; Josipovic et al., 2006 and Nemcic et al., 2007). Since winter wheat is the leading culture on arable areas in Croatia, herbicide products based on chlortoluron are most widely used and are most frequently found in our water resources. Recent studies have shown that due to its moderate adsorption onto soil constituents, chlortoluron is fairly mobile and leachable and can be detected in agricultural soils, lakes, streams and rivers (Denser, 2000).

The problem of nitrate and chlortoluron 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 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 and 2008), but different drainpipe spacings, along with different agricultural practices and application of mineral fertilizers and herbicides, may lead to contamination of drainage water with nitrogen pollutants (Milburn and Richards, 1994; Klacic et al., 1998; Webster et al., 1999) and chlortoluron pollutants (Šimunić et al., 2010).

The aim of the study was:

- to determine the nitrate and chlortoluron concentrations in drainage water in hydroameliorated agricultural areas under different drainpipe spacing (15 m, 20 m, 25 m and 30 m);
- to determine the nitrate and chlortoluron leaching in drainage water in hydroameliorated agricultural areas under different drainpipe spacing (15 m, 20 m, 25 m and 30 m);
- to determine statistically significant differences between the variants.

Material and methods

Three-year investigations (2007-2009) of water quality in hydroameliorated agricultural areas were carried out at the experimental amelioration field "Jelenščak" Kutina, on hydroameliorated Gleyic Podzoluvisol. Soil was drained in 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 (Figure 1).

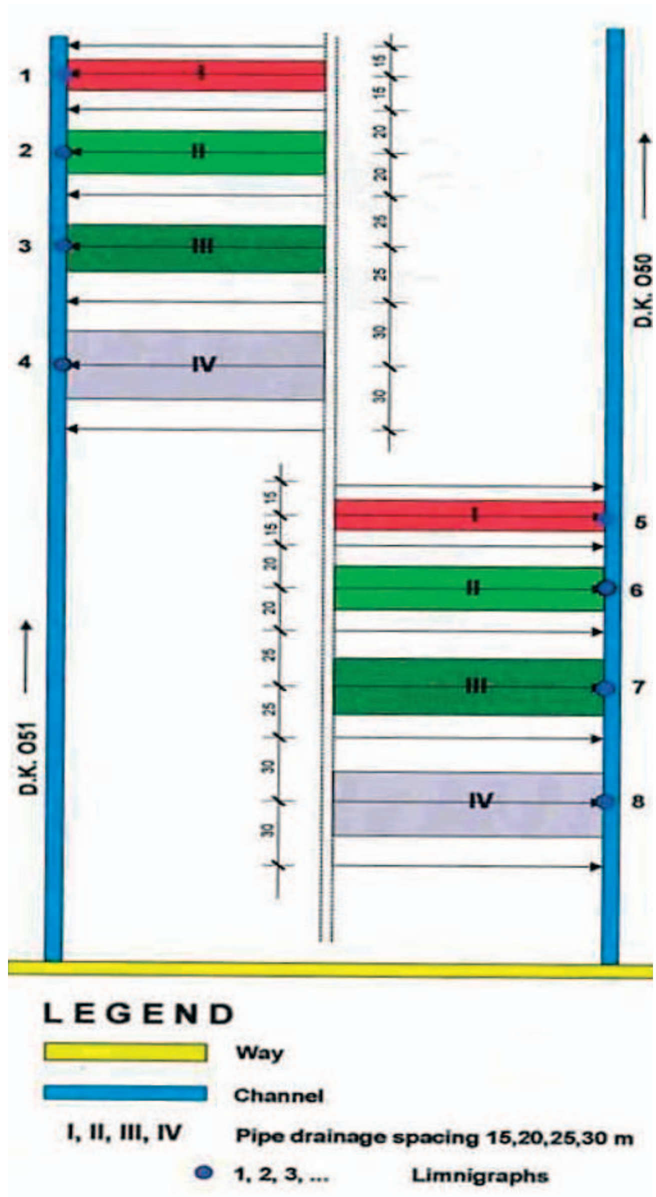

Figure 1. Experimental drainage field "Jelenscak"

Winter wheat was grown in 2007 and 2009 and soybean in 2008. The same agricultural practices were applied in all drainpipe spacing variants in each trial year. Winter wheat was sown in October 2006 and 2008 and soybean in April 2008. Total nitrogen fertilization was: 178.6 kg.ha^{-1}/2006-2007, 126.5 kg.ha^{-1}/2008 and 183.6 kg.ha^{-1}/2008-2009, added with basic fertilization and topdressing Weed control for winter wheat involved application of herbicide Dicuran forte (1.6 kg.ha^{-1}, based on active substance chlortoluron 79.25%), soon after sowing, while herbicide Frontier x 2 (1.5 kg.ha^{-1}, based on active substance P-dimetenamid) was applied to soybean soon after sowing. Crops were maintained in the conventional way, without irrigation. Winter wheat was harvested in July and soybean in October. Harvest residues (straw) were ploughed in after harvesting. Meteorological data was obtained from the Meteorological Station Sisak, which is approximately 15 km removed from the experimental field. 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. Nitrate was determined spectrophotometrically by yellow colouring of phenol disulphonic acid and chlortoluron was detected by gas chromatography (APHA-AWWA-WPCF, 1992). Total annual quantities of nitrogen and chlortoluron leached were estimated on the basis of the average monthly concentration and monthly quantity of drainage discharge. ANOVA (p=0.05) was used for determination of statistical differences between average nitrogen and chlortoluron concentrations in different drainpipe spacing variants. If significant differences were found between the tested drainage spacings, then Duncan's Multiple Range Test was applied.

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).

Yearly precipitation values are given in Table 2 and the corresponding monthly precipitation values for the whole examined period are presented in Figure 2.

According to the analyses of total annual precipitation values and total drainage discharge values for different drainpipe spacings (Figure 3), differences are noticeable in the amount of precipitation and in the quantity of drainage discharge both between the tested drainpipe spacings and between the trial years. Differences in the quantity of drainage discharge between drainpipe spacings in a particular year are smaller than the differences between years. Differences in the quantity of drainage discharge between drainpipe spacings are ascribed to the characteristics of drainage systems (Šimunić, 1995) while differences in the quantity of drainage discharge between years could be caused by the distribution and amount of precipitation in the vegetation and out-of-vegetation periods (Figure 2). Thus, in the year with the least precipitation (2007) the highest drainage discharge was determined at all drainpipe spacings and vice versa, in the year with the highest total precipitation (2009) the lowest drainage discharge was detected at all drainpipe spacings. Fluctuation of

Table 2. Annual precipitation (mm), main meteorological station Sisak

Year	Total precipitation (mm)
2006*	139.6
2007	899.1
2008	949.8
2009	960.2

*Precipitation from October to December

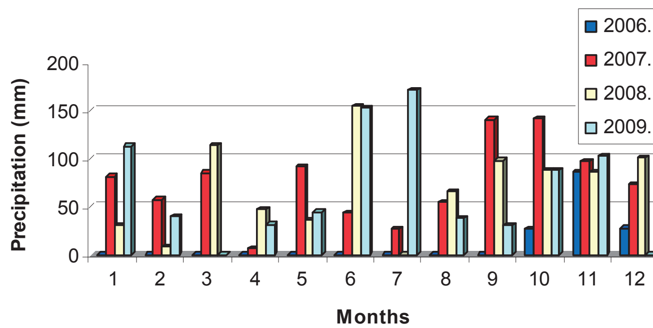

Figure 2. Monthly precipitation values (mm)

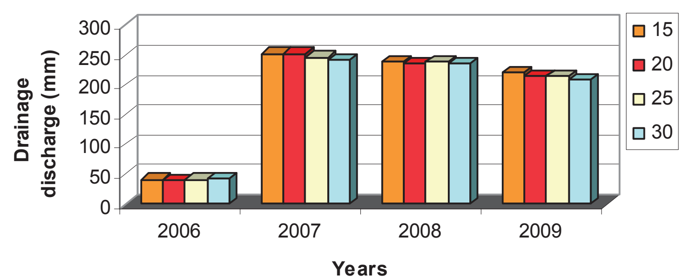

Figure 3. Quantities of drainage discharge (mm) for different drainpipe spacing

drainage discharge during the investigation period is presented in Figure 5 on the example of drainpipe spacing of 15 m; similar dynamics were observed for other drainpipe spacings. There is a strong correlation between total precipitation and total drainage discharge at each drainpipe spacing (Figure 4) and the coefficient of correlation (r) changed from 0.974 (for drainpipe spacing of 20 m) up to 0.980 (for drainpipe spacing of 25 m).

On the basis of drainage discharge and nitrate and chlortoluron concentrations, the extent of their leaching was calculated.

Table 1. Mayor characteristics of Gleyic Podzoluvisol

Profile	Depth (cm)	Content of particles (%)		Porosity (%)	Capacity (%)		Bulk density (kg/dm³)	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			

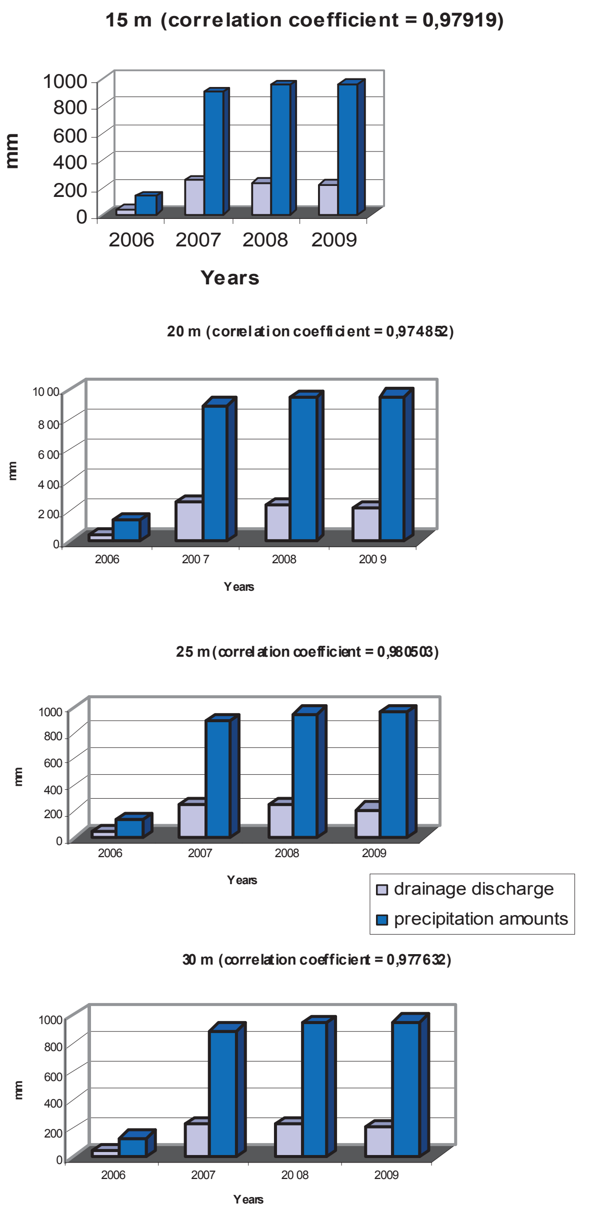

Figure 4. Correlation coefficients between precipitation (mm) and drainage discharge (mm) for drainpipe spacing: 15, 20, 25 and 30 m

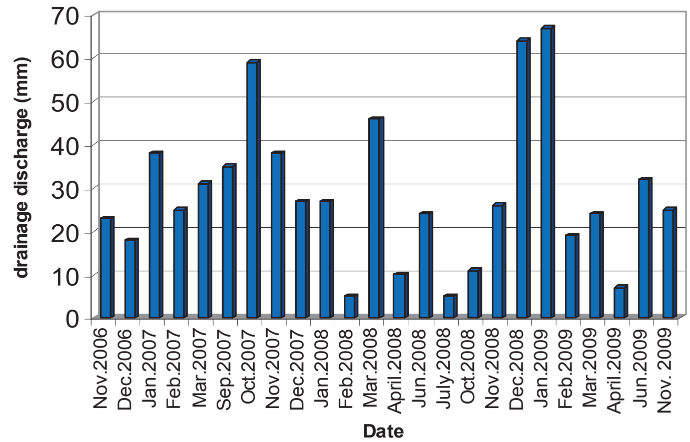

Figure 5. Fluctuation of drainage discharge (mm) for drainpipe spacing of 15 m

Nitrogen in drainage water

Average and maximum nitrogen concentrations in drainage water in all drainpipe spacings exceeded the concentration of 10 mg.dm^{-3} during the trial period (Table 3).

The lowest average nitrogen concentrations in all drainpipe spacing variants were recorded in 2006/07 and the results ranged from 11.78 mg.dm^{-3} to 12.74 mg.dm^{-3} while the highest average nitrogen concentrations in all drainpipe spacings were recorded in 2008 (from 19.42 mg.dm^{-3} to 20.67 mg.dm^{-3}). The highest maximum nitrogen concentrations in all variants were recorded in 2008 and ranged from 24.35 mg.dm^{-3} to 27.71 mg.dm^{-3} while the lowest maximum nitrogen concentrations in all drainpipe spacing variants were recorded in 2008/09, ranging from 23.12 mg.dm^{-3} to 24.59 mg.dm^{-3}. The longest drainage discharge period (October 2006-April 2008) was observed in 2006/07; this was also the longest period without crop, which probably influenced lower average nitrogen concentration in drainage water. The opposite happened in 2008 - a shorter vegetation (drainage) period (May 2008-September 2008) and intense growing (fertilization) of soybean, and very high drainage discharge in June and July.

As seen in Figure 6 for the drainpipe spacing of 15 m (similar fluctuations of nitrogen concentration were found in other drainpipe spacing variants), maximum nitrogen concentrations in drainage water in all years were detected soon after sowing and fertilization, which generally coincided with higher precipitation maxima (i.e., after higher drainage discharge). In winter

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

Drainpipe spacing (m)	01 Oct 2006 – 30 Apr 2008		01 May 2008 – 30 Sep 2008		01 Oct 2008 – 31 Aug 2009	
	Average	Max	Average	Max	Average	Max
15	12.15	28.42	20.67	26.20	13.90 a	23.12
20	12.33	28.12	19.42	24.35	13.71 a	23.18
25	12.74	27.23	19.61	27.71	12.57 b	24.59
30	11.78	27.05	20.30	26.02	12.65 b	23.53
	F (0.05)=2.78; Critical value (c)=3.49		F (0.05)=1.82; c=3.49		F (0.05)=6.37; c=3.49	

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

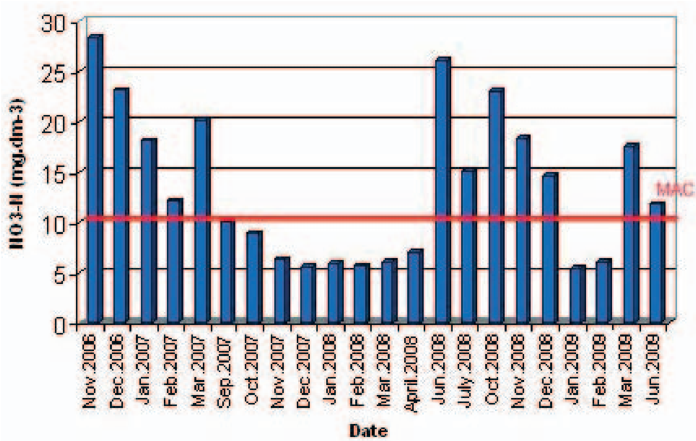

Figure 6. Fluctuation of nitrogen concentration in drainage water for drainpipe spacing of 15 m

Table 4. Nitrate leached through drainage water (kg.ha^{-1}) and percentage of nitrogen leached relative to total N added with fertilization

Drainpipe spacing (m)	01 Oct 2006 – 30 Apr 2008		0
	kg.ha^{-1}	%	kg.
15	46.41	25.98	5.
20	46.85	26.23	5.
25	47.78	26.75	5.
30	43.70	24.46	5.

Table 5. Average and maximum concentrations of chlortoluron (ŋg.dm^{-3}) in drainage water

Drainpipe spacing (m)	01 Oct 2006 – 30 Sep 2007		01 Oct 2008 – 31 Aug 2009	
	Average	Max	Average	Max
15	226	365	194	320
20	227	360	190	330
25	223	350	191	320
30	222	350	191	330
	F (0.05)=0.79; Critical value (c)=3.49		F (0.05)=0.54; (c)=3.49	

wheat production, this was in autumn (November 2006 and October 2008) and in soybean production in spring (June 2008).

Nitrogen concentration in drainage water exceeded the maximum allowable concentration (MAC) in five months (2006/07), two months (2008) and in seven months (2008/09).

In the first two years, there were no significant differences between drainpipe spacings (p=0.05); but in the last year, however, significant differences were found between the first two drainpipe spacings and the second two drainpipe spacings. Similar results for nitrogen concentrations in drainage water were obtained by Kladivko et al. (1999), 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 4), differences between trial years are evident. The lowest quantity of nitrogen leached was recorded in soybean production (vegetation period was from May 2008 to September 2008). The lowest drainage discharge (Figure 5) was recorded in the said year and the lowest nitrogen rate was applied. The extent of nitrate leaching ranged from 5.08 kg.ha^{-1} (4.01 %) to 5.99 kg.ha^{-1} (4.73 %). Higher quantity of nitrogen leached was recorded in winter wheat production in 2006/07 than in 2008/09. Similar fertilizer amounts were applied to winter wheat in both years, but higher drainage discharge was recorded in 2006/07, probably because of longer drainage discharge observation period (October 2006-April 2008) compared to 2008/09, when drainage discharge was observed from October 2008 to August 2009; this was possibly the reason for the larger quantity of nitrate leached than in 2008/2009. According to Mesic et al. (2007), the quantity of nitrogen leached is in linear correlation with the quantity of drainage discharge. The quantity of nitrogen leached in 2006/07 ranged from 43.70 kg.ha^{-1} (24.46%) to 47.78 kg.ha^{-1} (26.75%) and in 2008/09 from 30.36 kg.ha^{-1} (16.53%) to 34.75 kg.ha^{-1} (18.93%). As regards drainpipe spacing, it can be seen that the lowest quantities of nitrogen leached in all years were recorded for drainpipe spacing of 30 m, and the highest for drainpipe spacing of 15 m (2008 and 2008/09) and 25 m (2006/07), because of different functions of drainage systems (Šimunić, 1995).

These results (Table 4) 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 several factors such as: 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 (growing the test crops), higher amounts of precipitation in autumn or spring when crops need less nitrogen and less water for development result in higher nitrate leaching; thus the solution might be to grow other crops (e.g., alfalfa), for which nitrate leaching would probably be lower because of their different root depth, different growth, etc.

Chlortoluron in drainage water

Average and maximum chlortoluron concentrations in drainage water in all drainpipe spacing variants during the trial period exceeded the concentration of 100 ŋg.dm^{-3} (Table 5).

The lowest average chlortoluron concentration in all drainpipe spacing variants were recorded in 2008/09 and the results ranged from 190 ŋg.dm^{-3} to 194 ŋg.dm^{-3} and the highest average chlortoluron concentration for all drainpipe spacings was recorded in 2006/07, ranging from 222 ŋg.dm^{-3} to 227 ŋg.dm^{-3}. The highest maximum chlortoluron concentration in all variants was also recorded in 2006/07. The results ranged from 350 ŋg.dm^{-3} to 365 ŋg.dm^{-3} and the lowest maximum chlortoluron concentration at all drainpipe spacings was recorded in 2008/09 and ranged from 320 ŋg.dm^{-3} to 330 ŋg.dm^{-3}. In 2006/07, the total drainage discharge was higher than in 2008/09 (Figure 3), which probably influenced the higher average and maximum concentration of chlortoluron in drainage water.

As seen in Figure 7 for drainpipe spacing of 15 m (similar fluctuations of chlortoluron concentration were found for other drainpipe spacing), maximum concentrations of chlortoluron in drainage water in both years (2006 and 2008) were detected

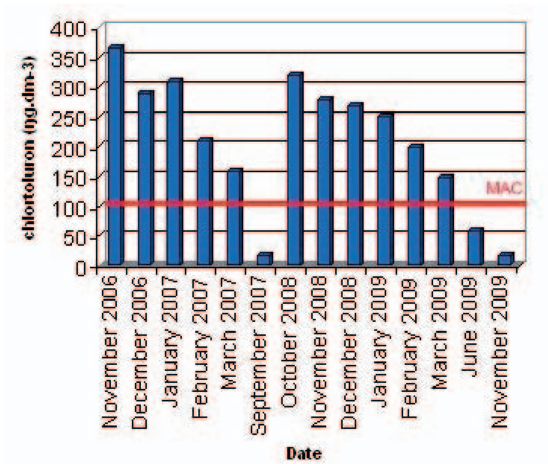

Figure 7. Fluctuation of chlortoluron concentration in drainage water for drainpipe spacing of 15 m

Table 6. Extent of chlortoluron leached through drainage water (kg.ha^{-1}) and percentage of chlortoluron leached relative to total N added

Drainpipe spacing (m)	01 Oct 2006 – 30 Sep 2007		01 Oct 2008 – 30 Nov 2009	
	kg.ha^{-1}	%	kg.ha^{-1}	%
15	0.384	30.28	0.534	42.11
20	0.384	30.28	0.509	40.14
25	0.372	29.34	0.518	40.85
30	0.366	28.86	0.502	39.59

soon after winter wheat sowing and herbicide application, respectively (November 2006 and October 2008), which generally coincided with higher precipitation maxima (i.e., after higher drainage discharge). Concentrations of chlortoluron decreased in both years with later drainage discharge. The results on contamination of drainage water with chlortoluron are in agreement with the results of Accinelli et al. (2002). These authors point to the fact that the quantity of pesticides leached in these parts is strongly influenced by the distribution of precipitation (drainage discharge), time of herbicide application, their quantities added, and the phenological stage of winter wheat. Similar results for chlortoluron concentrations in drainage water for drainpipe spacings were obtained by Sraka et al. (2007) and Simunic et al. (2010).

Chlortoluron concentration in drainage water exceeded the MAC in five months (2006/07) and in seven months (2008/09). In all trial years, there were no significant differences in chlortoluron concentrations between drainpipe spacings ($p=0.05$).

Larger quantity of total chlortoluron leached was recorded in 2008/09 than in 2006/07 possibly because of longer period of drainage discharge and very high total drainage discharge, especially in December and January. Chlortoluron losses ranged from 0.366 (28.86%) to 0.384 (30.28%) in 2006/07 and from 39.59% to 42.11% in 2008/09 (Table 6).

Conclusion

The results point to the following conclusions:

Very high coefficients of correlation between annual precipitation and drainage discharge were calculated for each drainpipe spacing in all trial years and ranged from 0.974 (for drainpipe spacing of 20 m) up to 0.980 (for drainpipe spacing of 25 m).

The lowest average nitrogen concentration for all drainpipe spacings was recorded in 2006/07 and the results ranged from 11.78 mg.dm^{-3} to 12.74 mg.dm^{-3} while the highest average nitrogen concentration at all drainpipe spacings was recorded in 2008 with results from 19.42 mg.dm^{-3} to 20.67 mg.dm^{-3}.

The highest maximum nitrogen concentration for all drainpipe spacings was recorded in 2008 and the results ranged from 24.35 mg.dm^{-3} to 27.71 mg.dm^{-3} while the lowest maximum nitrogen concentration at all drainpipe spacings was recorded in 2008/09 with the results from 23.12 mg.dm^{-3} to 24.59 mg.dm^{-3}.

Average and maximum concentrations of nitrogen in drainage water exceeded the MAC (10 mg.dm^{-3}) in five months (2006/07), in two months (2008) and in seven months (2008/09) in all drainpipe spacing variants.

ANOVA ($p=0.05$) showed that there were no statistically significant differences in nitrate concentration between drainpipe spacings in 2006/2007 and 2008, but there were statistically significant differences between drainpipe spacings in 2008/2009.

The lowest quantity of nitrogen leached was recorded in soybean production in 2008. The extent of nitrate leached ranged from 5.08 kg.ha^{-1} (4.01%) to 5.99 kg.ha^{-1} (4.73%). The highest quantity of nitrogen leached was recorded in winter wheat production in 2006/07 when the values ranged from 43.70 kg.ha^{-1} (24.46%) to 47.78 kg.ha^{-1} (26.75%).

The lowest average chlortoluron concentration at all drainpipe spacings was recorded in 2008/09 and the results ranged from 190 ηg.dm^{-3} to 194 ηg.dm^{-3} while the highest average chlortoluron concentration at all drainpipe spacings was recorded in 2006/07 with the results from 222 ηg.dm^{-3} to 227 ηg.dm^{-3}.

The highest maximum chlortoluron concentration in all variants was recorded in 2006/07 and the results ranged from 350 ηg.dm^{-3} to 365 ηg.dm^{-3} while the lowest maximum chlortoluron concentration at all drainpipe spacings was recorded in 2008/09 with the results from 320 ηg.dm^{-3} to 330 ηg.dm^{-3}.

Average and maximum concentrations of chlortoluron in drainage water exceeded the MAC (100 ηg.dm^{-3}) in five months of 2006/2007, and in seven months of 2008/2009 in all drainpipe spacing variants.

ANOVA ($p=0.05$) showed that there were no statistically significant differences in chlortoluron concentrations between drainpipe spacings in the trial years.

Chlortoluron losses ranged from 0.366 (28.86%) to 0.384 (30.28%) in 2006/07 and from 39.59% to 42.11% in 2008/09.

Quantity of nitrate and chlortoluron leached depended on the total drainage discharge and its concentration in drainage water.

References

Accineli C., Vicari A., Rossi P., Catizone P. (2002). Losses of atrazine, metolachlor, prosulfuron and triasulfuron in subsurface drain water. Agronomie 22: 399-411

APHA-AWWA-WPCF. (1992). Standard methods for the examination of water and wastewater. Washington, DC 20005: 156-157

Bensa A., Vidaček Ž., Čoga L., Sraka M., Vrhovec D. (2007). Influences of pipe drainage and fertilization on nitrate leaching. Cereal Research Communications 35 (2):237-240

Denser J.W. (2000). Toxicity of mixtures of pesticides in aquatic systems. Pest Management Science **56**: 516–520

Gausey N.R. (1991). Nitrate leaching to subsurface drains as affected by drain spacing and changes in crop production system. Journal of Environmental Quality 20 (1):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

Jolánkai M., Szentpétery Z., Hegedűs Z. (2006). Pesticide residue discharge dynamics in wheat grain. Cereal Research Communications 34 (1): 505-508

Josipović M., Kovačević V., Šostarić J., Plavšić H., Liovic J. (2006). Influences of irrigation and fertilization on soybean properties and nitrogen leaching. Cereal Research Communications 34 (1):513-516

Kirsch J., Horváth E., Vágvölgyi C., Tanács L. (2007). Mobility of herbicides and fungicides in soil and their effects on soil microorganisms. Cereal Research Communications 35 (1): 673-676

Klačić, Ž., Petošić, D., Čoga L. (1998). Nitrogen Leaching in Different Pipe Drainage Distances. Agriculturae Conspectus Scientificus 63 (4):331-338

Kladivko E.J., Frankenberger J.R., Jaynes D.B., Meek D.W., Jenkinson B.J., Lerner D.N., Yang Y., Barrett M.H., Tellam J.H. (1999). Loading of non-agricultural nitrogen in urban groundwater. In: Impacts of urban growth on surface and groundwater quality (Proceedings of IUGG99 Symposium HS5, Birmingham, July 1999). IAHS publ., no. 259, Ellis, J.B. (Ed.), IAHS Press, Wallingford, 117-123

Mesić M., Bašić F., Kisić I., Butorac A., Gašpar I. (2007). Influence of mineral nitrogen fertilization on corn grain yield and nitrogen leaching. Cereal Research Communications 35 (2):773-776

Mesić M., Šimunić I., Bašić F., Vuković I., Jurišić A. (2008). Soil type influence on drainage discharge and yields of soybean. Cereal Research Communications 36 (Part 2 Suppl S):1207-1210

Milburn P., Richards J.E. (1994). Nitrate concentration of the subsurface drainage water from a corn field in southern New Brunswick. Canadian Agricultural Engineering 36 (2):69-78

Nemčić Jurec J., Mesić M., Bašić F., Kisić I., Zgorelec Ž. (2007). Nitrate concentration in drinking water from wells at three different locations in Northwest Croatia. Cereal Research Communication 35 (2):533-536

Nemeth T. (2006). Nitrogen in the soil-plant system nitrogen balances. Cereal Research Communications 34 (1):61-64

Rademaher J.J., Young T.B., Kanarek M.S. (1992). Gastric cancer mortality and nitrate levels in Wisconsin drinking water. Arch. Environ. Health **47** (4):292–294

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 (1-2): 1-10

Skaggs R., Gilliam J.W. (1985). Effect of drainage system design and operation on nitrate transport. Transaction of the ASAE 24:929-934

Sraka M., Vidaček Ž., Šmit Z., Bensa A., Vrhovec D. (2007). Herbicides in the soil and waters of river Drava catchment area. Cereal Research Communications 35 (2): 1089-1092

Šimunić I. (1995). Reguliranje suvišnih voda tla kombiniranom detaljnom odvodnjom u Lonjskom polju (summary in english). Agriculturae Conspectus Scientificus 60 (3-4):279-305

Šimunić I., Tomić F., Mesić, M., Kolak I. (2002). Nitrogen leaching from Hydroameliorated Soil. Die Bodenkultur 53 (2):73-83

Šimunić I., Sraka M., Husnjak S., Tomić F., Barić K. (2008). Influence of drainpipe on atrazine leaching. Cereal Research Communications, 36, (Suppl.). 1143-1146.

Šimunić I., Sraka M., Likso T., Filipović V., Beljan S. (2010). Influence of hydroameliorated soil on chlortoluron leaching and yield of winter wheat. Novenyterm, 59 (Suppl.3): 251-254

Velisková Y. (2006). Problem of water pollution and ways of solution. Cereal Research Communications 34, 1: 101-103

Vidaček Ž., Bogunović M., Sraka M., Husnjak S. (1996). Water discharges and nitrates from some soils of the Sava river valley. 6. Gumpensteiner Lysimetertagung "Lysimeter in Dienste des Grundwassershutzes". BAL, Gumpenstein, pp. 111-115

Vidaček Ž., Sraka M., Čoga L., Mihalić A. (1999). Nitrates, heavy metals and herbicides in soil and water of Karasica-Vučica catchment area. Agriculturae Conspectus Scientificus 64 (2):143-150

Vidaček Ž., Bogunović M., Husnjak S., Sraka M., Bensa A. (2006). Hydropedological map of the Republic of Croatia. World Congress of Soil Science Frontiers of Soil Science Technology and the Information Age, Abstracts p. 228.

Webster C., Poulton P.R., Goulding K.W.T. (1999). Nitrogen leaching from winter cereals grown as part of a 5-yearly-arable rotation. European Journal of Agronomy 10: 99-109

Regulation on amendments to the Regulation on water classification in Croatia (Official Gazette, 2008, No. 47)

The Rulebook on Health Criteria for Drinking Water in Croatia (Official Gazette, 2008, No. 137

acs76_08