The Influence of Irrigation on Nitrates Movement in Soil and Risk of Subsoil Contamination

Katarína NOVÁKOVÁ and Dušan NÁGEL

Soil Science and Soil Conservation Research Institute, Bratislava, Slovakia

Abstract: This paper presents the results of the nitrates movement monitoring under the conditions of field experiment, with different fertilisation doses applications, with and without irrigation and, for different crops. The experiments were conducted at the Experimental Station of the Hydromeliorácie, State Entp., at Most pri Bratislave site, south Slovakia. The soil at the site is mainly clay loam with a high retention capacity and a relatively low hydraulic conductivity. The results of the nitrates measurements in the soil profile during the vegetation period and those of lysimetric water analysis have shown that the movements of nitrates in irrigated and non-irrigated fields differed significanty during the early stages of the vegetation period, but at the end of this period the differences between the irrigated/non-irrigated and fertilised/non-fertilised soils were small, probably due to an increased uptake of water and nutrients during the vegetation period at the irrigated field. Properly applied irrigation was not the reason for nitrates penetration below the root zone under the soil and meteorological conditions of Most pri Bratislave site.

Keywords: nitrates; fertilisation; irrigation; subsurface water; groundwater protection; field experiment

Irrigation as one of the methods of soil water regime improvement is applied during the seasons with precipitation deficits; fertilisation is needed in fields with a low content of nutrients. It is necessary to optimise the inputs to the soil to assure high yields but also to prevent the groundwater resources pollution by the movement of solutes below the root zone.

Slovak Republic as a member of the European Union implemented widely accepted directives focused on the environmental protection. One of them is Nitrate Directive 676/1991 EC, relating to the prevention of water pollution through agricultural activity producing nitrates. The importance of the prevention of subsurface water pollution is accentuated by the fact that approx. 83% of potable water throughout Slovakia is pumped from the groundwater, the most important source of water being the renewable groundwater resources of the Žitný ostrov (southern Slovakia) whose soils are intensively used for agriculture (Bielek 1998).

Nitrates as a components of fertilisers are highly soluble, easy oxidate NH_4^+ to an anion NO_3^- which moves with the soil water. This is the reason why it is necessary to know the hydrophysical characteristics of the soil to describe the soil water and solutes movements and their eventual penetration to subsoil and groundwater (Nováková 2003a, b). The risk of nitrates penetration to subsoil can appear during heavy rains or/and during a massive irrigation with the following precipitation. The risk of such a movement is increased under the conditions of a highly conductive subsoil (like gravel layers in the Žitný ostrov area) and a high

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level of groundwater. Washing-out of nitrates by runoff is also possible during heavy rains on soils nearly saturated with water during spring periods (Fecenko & Ložek 2000). Then, the soil is not covered by vegetation and nitrate ions are not adsorbed. Nitrates are not specifically adsorbed in soil and therefore are easily leached to subsoil (Bízik 1989; Píš & Nováková 2002; Vidaček *et al.* 2002; Nissen & Wander 2003; Zhu *et al.* 2003; Daudén *et al.* 2004; Decau *et al.* 2004; Schnebelen *et al.* 2004; Hansen *et al.* 2007). For proposing the irrigation and fertilisation schedule, the soil hydraulic properties are important, mainly soil hydraulic conductivity, which is correlated to its texture; preferential ways in soils are of special importance, because they allow the transport of solutes to the subsoil at high rates. (Beven & Germann 1982; Nováková 2002). In general, it can be stated that a dangerous leaching of solutes takes place in the areas of highly conductive soils with high levels of groundwater (2–3 m below the soil surface) and during the periods with heavy precipitations, when soil is not covered by crops.

The aim of this paper was to evaluate the influence of irrigation on the penetration of nitrates into subsoil (and groundwater) at different levels of fertilisation and irrigation under the conditions of soils typical for the Žitný ostrov area, which is an important source of groundwater.

MATERIALS AND METHODS

The measurements were performed at the Experimental Station of the Hydromeliorácie, State Entp., at Most pri Bratislave site, south Slovakia, during the vegetation periods of 2004–2006. The experimental field represents, by its soil properties, a significant part of the irrigated West Slovakia Lowland, with relatively small precipitation total during the vegetation period (Table 1), with soil water deficit for crops with a long vegetation period. The site is situated in the upper (western) part of the Žitný ostrov, at 133 m a.s.l. The climate of the site is warm, with average annual daily temperature 9.7°C, however, during the vegetation period (April–September) it is 16.2°C. The average number of tropical days during the season is 16 (those whose average daily temperature is above 30°C), and average daily air humidity is 74%. The soil can be characterised as Chernozem with pH = 7.6. The soil texture data are given in Table 2. Some physical properties of the soil are shown in Table 3; they can be classified as favourable for the water retention. Carbonate sediments are continuously changing to sand and gravel layers at the depth of 1.10–1.35 m below the soil surface. Humus content in the plowing layer is 2.56% (according to Tjurin). The content of nutrients in the soil is medium up to good. The contents of easily accessible phosphorus and potassium are 60 mg/kg and 90–120 mg/kg, respectively (Mehlich III). This soil belongs to the most fertile in Slovakia.

The groundwater level oscillates between the depths of 6–8 m below the soil surface, therefore the crops under non-irrigated conditions are supplied by precipitations only. The average annual precipitation total is 550 (1901–1980) mm, during the vegetation period (April–September) it is 305 mm, and during the winter period (October–March) it is 245 mm. Heavy rains occur during summer storms. Monthly totals of precipitation during the vegetation periods of 2004–2006 and long-time averages are given in Table 1. Spring barley was grown in 2004, winter wheat in 2005, and sugar beet in 2006. The field experiments were conducted with two different variants of fertilisation (Table 4) and irrigation regime (Table 5).

Table 1. Precipitations (in mm) during the seasons 2004–2006, Most pri Bratislave site, southern Slovakia

Month	2004	2005	2006	Long time average
IV.	34.6	49.4	62.4	39
V.	50.0	29.0	111.4	55
VI.	89.8	28.9	58.0	59
VII.	31.7	109.3	17.0	61
VIII.	56.1	129.2	132.0	51
IX.	39.8	38.3	15.2	40

Table 2. Soil texture; expressesed in percentages of textural classes

Depth (m)	< 0.002 mm	< 0.01 mm	0.01–0.05 mm	0.05–0.1 mm	0.1–2 mm	Textural class
0.3	19.84	51.80	35.88	10.31	2.01	clay loam
0.6	22.73	50.92	33.77	14.02	1.28	clay loam
1.0	15.26	32.08	41.70	24.57	1.65	loam
1.5	11.29	22.22	46.04	29.67	2.07	sandy loam

Table 3. Soil physical properties

Depth (m)	ρ_s (kg/m^3)	ρ_d (kg/m^3)	θ_{fc} (vol.%)	P (vol.%)	θ_v (vol.%)
0.3	2 720	1 160	33.62	57.28	11.33
0.6	2 760	1 390	35.14	49.48	12.77
1.0	2 770	1 380	35.00	50.18	5.43
1.5	2 780	1 400	39.06	49.76	5.78

ρ_s – soil specific density; ρ_d – soil bulk density; θ_{fc} – field capacity, P – porosity, θ_v – wilting point

Table 4. Doses of NO_3^- fertilisers applied

Year/plant	Application time	Variant	Dose of N (kg/ha)
2004 Spring barley	Autumn 2003	2	45
		3	67.5
2005 Winter wheat	Autumn 2004	2	30
		3	45
	Spring 2005	2	30
		3	45
2006 Sugar beet	Spring 2006	2	90
		3	135

The soil water content was measured regularly once per week during the vegetation period, to identify the soil water movement below the root zone.

The movement of the solute was measured in the field in 3 variants during the vegetation period (Table 6):

Variant 1, non-fertilised,

Variant 2, fertilisation with basic doses,

Variant 3, fertilisation with increased doses,

The increased doses of fertilisers were 1.5 times higher than the basic ones (see Table 4). All the three variants were both irrigated and non-irrigated (Table 5).

The content of nitrates was measured in the soil samples taken from different depths for variants 1, 2, and 3 from both irrigated and non-irrigated soil. NO_3^- content was measured in moist soil in the solute extracted with 1% K_2SO_4 using the equipment Skalar San Plus System. The soil was sampled three times per vegetation period: before the growing period, during maximum vegetation stage, and after the harvest; the irrigation was applied according to the plant needs.

Flat lysimeters (horizontally oriented plastic vessels) were installed at the depth 0.6 m dur-

Table 5. Irrigation doses applied

Year/plant	Application time	Irrigation dose (mm)
2004 Spring barley	17. 6. 2004	15
	19. 6. 2004	20
2005 Winter wheat	21. 6. 2005	24
	26. 6. 2005	15
2006 Sugar beet	21. 6. 2006	20
	11. 7. 2006	40

Table 6. Nitrates distribution in the soil profile, expressed in mg/kg of N-NO_3^-

Variant	Depth (m)	N-NO_3^-						
		23. 3. 2004	26. 5. 2004	18. 8. 2004	11. 5. 2005	8. 6. 2006	1. 8. 2006	18.10. 2006
Irrigated field								
1	0–0.3	8.21	5.19	4.36	1.56	7.84	3.60	3.37
	0.3–0.6	6.29	5.78	3.44	< 1	6.32	2.96	2.32
	0.6–0.9	2.02	9.07	1.46	< 1	3.03	< 1	< 1
2	0–0.3	10.60	3.58	5.81	1.53	11.00	2.88	4.94
	0.3–0.6	11.60	4.79	2.97	2.80	9.61	3.57	3.81
	0.6–0.9	7.21	5.36	< 1	< 1	11.35	4.36	< 1
3	0–0.3	24.80	5.96	11.50	2.14	11.72	4.18	4.05
	0.3–0.6	15.40	6.46	4.02	1.3	12.59	4.63	3.68
	0.6–0.9	14.00	8.95	7.01	< 1	12.85	3.16	5.14
Non-irrigated field								
1	0–0.3	4.81	2.59	3.63	< 1	9.56	4.32	3.73
	0.3–0.6	2.40	1.92	2.48	< 1	7.35	2.54	3.15
	0.6–0.9	2.29	3.17	1.75	< 1	< 1	1.22	< 1
2	0–0.3	13.80	2.94	6.21	6.04	7.67	4.46	3.07
	0.3–0.6	9.76	4.65	2.03	3.20	3.95	4.15	2.58
	0.6–0.9	6.67	10.50	2.94	< 1	6.42	2.10	2.05
3	0–0.3	26.10	5.48	11.30	17.40	12.08	14.05	3.60
	0.3–0.6	24.30	8.36	10.10	8.32	10.41	8.64	2.97
	0.6–0.9	17.80	19.50	11.30	1.41	8.58	9.36	1.91

ing the years 2004–2006. Nitrates content in the solute was evaluated by the same method as in the soil samples.

RESULTS AND DISCUSSION

The distribution of nitrates in three upper soil layers (0–0.3, 0.3–0.6, and 0.6–0.9 m below the soil surface), for three stages of plant ontogenesis, three different variants of fertilisation and for both irrigated and non-irrigated soils can be seen in Table 6. The content of nitrates decreased with the depth even in irrigated conditions, which indicates the uptake of nutrients by plants rather than their movement to the subsoil. The seasonal courses of nitrates content in the upper 0.9 m soil layer during two seasons and with all three variants can be seen in Figure 1. Significant differences can be seen in nitrate contents for irrigated and non-irrigated variants during the vegetation periods of the 2006 season, when irrigation was applied before the second soil sampling. During the season 2004, the irrigation could influence only the nitrate content in the last sampling. Because of the application of relatively low doses of water (approx. one tenth of the precipitation total during the vegetation period), the irrigation did not influence the nitrates movement significantly. The nitrates contents in the soil during the two first samplings in both variants (irrigated and nonirrigated) developed in identical conditions, the differences were probably due to the spatial variability of the soil properties; the courses of nitrates content were nearly parallel. The crops extracted nitrates from the soil in both variants, thus the nitrates content in the fertilised soils was comparable to that in the non-fertilised soil at the end of the vegetation periods. There occurred differences during the seasons; in the low-precipitation season 2004, higher nitrates concentration was preserved during

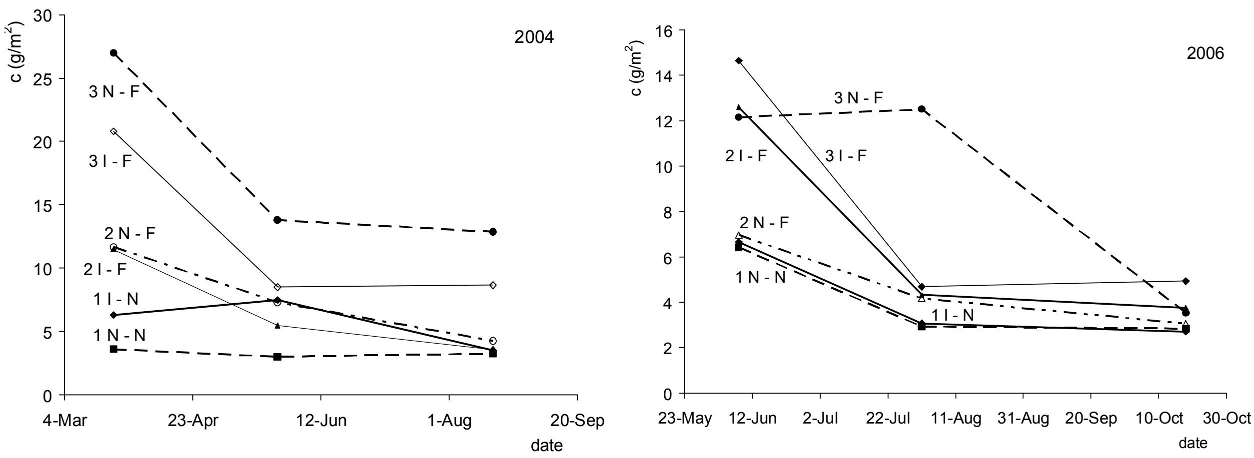

Figure 1. Seasonal courses of N-NO_3^- content in the upper 0.9 m soil layer estimated by soil sample analysis expressed in g/m^2 of soil surface under different combination of fertilisation and irrigation for Most pri Bratislave site, south Slovakia and for two seasons: 2004 (spring barley) and 2006 (sugar beet); variants details are given in Tables 4 and 5 (the first label number in Figures means variant, the second one I – irrigated, N – non-irrigated variants, the third is F – fertilised and N – non-fertilised variants)

the vegetation period, but in the season 2006 with higher precipitations during August, the allowed uptake of water and nitrates by plants resulted in the decrease of their content in the soil profile, as found by Logsden *et al.* (2002).

To interprete the results of the measurements properly, it is necessary to mention different intervals of the vegetation periods presented in Figure 1. The figures show close courses of nitrates contents during the corresponding time intervals for both irrigated and non-irigated variants, so the penetration of the dissolved nitrates below the root zone and then to groundwater due to the irrigation application was not probable during the crops vegetation period. Nitrates content with 3N-F variant at the second sampling could be the result of fluctuations or errors in the measurements. As shown by Gaines and Gaines (1994), the soil texture significantly influences the nitrates retention and leaching. A low retention capacity and a high hydraulic conductivity of sandy soil are favourable for nitrate leaching, but loamy soil (like that in this study) has a high retention and a medium conductivity. Thus, all findings at the experimental site indicate a low probability of an increased nitrates movement to the subsoil during the vegetation period under the fertilising and irrigation regime under study. An increased risk of nutrients (and particulary nitrates) movement below the soil root zone in conditions like those at the experimental site can be expected for increased fertilisers doses (variant 3) during winter periods when soil is wet enough, and after heavy rains, if fertilisation is performed in the late autumn or early spring times. Cover crops can eliminate this risk (Logsden *et al.* 2002). Generalisation of these findings is difficult, because deep penetration of nitrates during the vegetation period depends rather on precipitations than on irrigation, because a proper application of the irrigation dose (during the dry period) should prevent the deep water movement as its sum is usually much smaller than the precipitation total.

CONCLUSION

The nitrates movements in the rooting zone of the soil performed at the experimental site Most pri Bratislave (southern Slovakia) with clay loamy soil under different combinations of fertilisation and irrigation demonstrated a low risk of nitrates penetration below the root zone due to irrigation during the vegetation period. Nitrates contents in the rooting zone of soil were found close with the irrigated and non-irrigated variants at the end of the vegetation periods 2004, 2005, and 2006, with crops of spring barley, winter wheat, and sugar beet. Shown was also a significant nitrates content decrease during the early stages of the vegetation period with both the irrigated and non-irrigated variants for all crops grown, probably due to the nitrates uptake by plants.

A potential risk of nitrates leaching exists during heavy rains when soil is not covered by crops, i.e during winters and in early spring times, therefore it is recommended to fertilise with nitrates early in the autumn and in the spring just before sowing. It is advisable to divide the nitrates fertilisation doses. These findings are valid for the soils with the hydraulic properties closely resembling those at the experimental site. Properly applied irrigation does not increase the risk of nitrates leaching because of their high rate of uptake by plant canopy.

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Corresponding author:

RNDr. Katarína Nováková, CSc., Výskumný ústav pôdoznalectva a ochrany pôdy, Gagarinova 10, 827 13 Bratislava, Slovakia

tel.: + 421 249 105 090, e-mail: k.novakova@vupop.sk