Nitrate-Nitrogen Content in Soil and Lysimeter Water under Different Nitrogen Fertilization Levels in Crop Production

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Summary

Production of biomass for energy, food or biomaterials requires certain agricultural practices. The increasing nitrogen loading due to inorganic fertilizers used in conventional agriculture is one of the major global environmental challenges. This research was conducted in central part of Croatia near Park of nature Lonjsko polje, on experimental field which was established 17 years ago in order to determine influence of mineral nitrogen fertilization on nitrate leaching. The soil type of trial site is drained distric Stagnosols and four different nitrogen fertilization levels are taken into consideration: 1. N_0+P+K, 2. N_{100}+P+K, 3. N_{200}+P+K, 4. N_{300}+P+K (kg N ha^{-1}). Water samples were taken in periods with lysimeters discharge. Soil sampling (0-0.25 m) was carried out four times in the investigated period from June 2007 to June 2008 during the vegetation of maize and winter wheat. Research results indicate that the soil NO_3-N content significantly varied (27.3 kg ha^{-1} to 338.2 kg ha^{-1}) depending on the treatment and sampling time. Compare to the winter sampling time (November 2007 and February 2008) significantly higher content of soil NO_3-N was determined in the summer sampling (June 2007 and June 2008). Regarding to the water samples, results revealed that the total nitrate-nitrogen losses were in the range from 5.97 kg NO_3-N ha^{-1} to 112.3 kg NO_3-N ha^{-1}. Lysimeter discharge varied in dependence on precipitation and crop type. Total amounts of precipitation during the investigation were 652.5 mm and 34.6 % of them were recorded in lysimeters. Average NO_3 -N concentration in lysimeter water varied from 2.4 mg L^{-1} (0 kg N ha^{-1}) up to 54.5 mg L^{-1} (300 kg N ha^{-1}).

Key words

soil; water; nitrogen fertilization; nitrate leaching; maize; winter wheat

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Introduction

Biomass is defined as mass of live or dead organic matter. Above-ground biomass implies all living biomass above the soil including stem, stump, branches, bark, seeds and foliage (FAO, 2009). In the case of conventional agriculture high levels of biomass production need to be balanced against the potentially damaging impacts of some crop management techniques. Key criteria to assess the environmental sustainability of agricultural systems are the performance regarding soil quality (organic matter content, water retention capacity), water use (overuse of water bodies, water quality), biodiversity, nitrate leaching, pesticide and herbicide load (Muller, 2006). In terms of biomass production for food it is evident that the increasing human population (due to its need for food) increased cereal grain production from 877 Tg in 1962 to 2494 Tg in 2009 (FAOSTAT, 2011). Brown (1999) emphasizes that in 35-y period (1965-1999) 40% of the large annual increase in crop production is attributed to the increase in use of nitrogen (N) fertilizers. According to FAOSTAT database in 40-y period N fertilizer consumption increased for 140.4 Tg.

Excessive uses of N fertilizers leads to environmental pollution. Regarding the air pollution, the nitrous oxides (N_2Os) affect global climate change and its contribution from nitrogen and carbon management systems are of great significance. Mesić et al. (2006) calculated that agricultural soil management activities such as fertilizer application and other cropping practices were the largest source of Croatian N_2O emissions, accounting for 70 percent of the total emission. Romanovskaya et al. (2001) reported that 30% of N_2O emissions in Russia are related to the consumption of N fertilizers. Khalil et al. (2001) concluded that N_2O fluxes varied with the forms and amount of applied N fertilizer. In terms of water contamination, the "Nitrates Directive" (Council Directive 91/676/EC) is intended to reduce water contamination caused by nitrates from agricultural sources. Based on that directive throughout Europe new environmental lows are being implemented to limit N fertilization on arable land. According to some authors from Croatia average nitrate-nitrogen (NO_3-N) concentrations in drainage and lysimeters waters were in the range from to 1.9 mg L^{-1} up to 319.0 mg L^{-1} due to different nitrogen fertilization levels, amount of precipitation and time of fertilizer application [15.0-25.8 mg L^{-1} (Mesic et al. 2012); 17.5-319.0 mg L^{-1} (Zovko et al. 2008); 1.9-231.3 mg L^{-1} (Bensa et al. 2008); 16.7-25.9 mg L^{-1} (Čoga et al. 2003)]. Thus, more and more attention has been given to the study on accumulation of soil nitrate-nitrogen in farmland ecosystems (Bai et al. 2011; Lu et al. 2008; Zgorelec et al. 2007; Yin et al. 2007; Oikeh et al. 2003).

One way to avoid N surplus is to apply precise management strategies. Spatial analysis of NO_3-N content and site-specific crop management based upon spatial variation of NO_3-N content can maximize crop production and minimized environmental impacts of N fertilization (Abu and Malgwi, 2011). Jurisic et al. (2013) determined that the long term N fertilization effected on the variability of NO_3-N content within a square meter (CVs were from 31.3% to 58.9%). They reported that contour N maps may provide useful information for variable-rate nitrogen management, better understanding nitrogen uptake by plant and plant nutrition in general. Also, their results indicate that grid sample is more accurate and representative than random sampling for accurate nitrogen fertilizer recommendations.

Objectives of this study are to: (1) determine load of NO_3-N content in soil and NO_3-N concentrations in lysimeters water regarding the different nitrogen fertilization levels; (2) quantify the effect of nitrogen application rates on NO_3-N losses via lysimeter outflow.

Material and methods

Research was conducted on experimental field within hydroameliorated cropland located in Western Pannonian subregion of Croatia (45°33´N, 16°31´E) near Park of nature Lonjsko polje. The soil type of trial site is drained distric Stagnosol. Terrain is flat with average altitude 97.2 m. The experiment had 10 treatments with different nitrogen fertilization levels, whence quantities of phosphorus (P) and potassium (K) were constant for all treatments (120 kg P ha^{-1} and 180 kg K ha^{-1}). Only four treatments were taken into consideration in this investigation: 1. N_0+P+K, 2. N_{100}+P+K, 3. N_{200}+P+K, 4. N_{300}+P+K (kg N ha^{-1}). Parcel dimension is conditioned by distance between drain pipes. Each treatment area includes two drain pipes. Dimension of each trial treatment is 30 x 130 m including blank space, and 26 x 26 m for replication parcel. Fertilization and seeding practice is implemented on total area of each treatment.

During the vegetation of maize and winter wheat soil sampling was carried out four times:

15 June 2007 – maize vegetation (V3 growth stage); 06 November 2007 – out of vegetation; 22 February 2008 – winter wheat vegetation (24 according the Zodaks scale – tillering); 26 June 2008 – winter wheat vegetation (90 according the Zodaks scale – ripening). Samples were taken in four (4) replication from surface soil layer (0-0.25 m). On each treatment one zero-tension pan lysimeter is installed at the depth of 80 cm. Water samples were taken on a daily basis in periods with lysimeters discharge (eight times in investigated period: 07 October 2007, 31 October 2007, 22 November 2007; 02 December 2007; 08 December 2007, 10 January 2008, 23 March 2008 and 08 June 2008).

NO_3-N content in wet soil samples was extracted in ultra pure water in 1:10 (w/v) ratio according to ÖNORM L 1092 norm. After the extraction, samples were centrifuged, filtrated (disposable syringe filter; Chromafil Xtra PET; pore size 0.45 μm; filter size 25mm; N free) and NO_3-N content is detected by suppressed conductivity on Doinex ICS-1000 system with an analytical column [Ion Pac AS 17 (4x250 mm), Dionex]. Results were calculated upon soil dry matter and expressed in kg NO_3-N ha^{-1} as product of nitrate concentration, soil layer density (1.54 tm^{-3}) and layer height (0-0.25 m). NO_3-N content in lysimeters water was determined by ion chromatography method (HRN EN ISO 10304-1:1998).

Statistical analyses of differences in soil nitrate-nitrogen content according to fertilization treatments for each sampling time and across sampling dates for each treatment were computed by analysis of variance (ANOVA) (SAS 9.1, SAS Institute Inc., USA). The significance test was performed at probability level of $P < 0.05$. Differences among treatment means and sampling dates means were separated using Fisher's least significant difference procedure.

Results and discussion

The investigation area has a temperate continental climate, with 10.7°C annual mean temperature. The annual average rainfall for 25-y period is 865 mm (Table 1). Compared to average period (1965-1990) investigation period was drier (about 161 mm less of precipitation) and warmer (for 2.0 °C).

Table 1. Total precipitations and mean temperatures in sampling years

	Average 1965-1990	2007	2008
Sum, mm	865	749	659
T, °C	10.7	12.8	12.6

Monthly precipitation and air temperature values, along with 25-y average values for investigation period from June 2007 to June 2008 are shown more detailed in Figures 1 and 2.

Precipitations were in the range from 1.8 mm in February 2008 to 140.8 mm in September 2007. The coldest month during the investigation was December 2007 (0.4 °C) and the warmest was July 2007 (23.4 °C).

Figure 3 overviews a comparison of mean values of NO_3- N content in soil samples between nitrogen treatments for sampling dates. Bars signed by different letters in same sampling date were significant at P<0.05 according Fisher's LSD test. Fertilization levels significantly increased NO_3-N content. The highest significant differences were obtained between treatment without nitrogen fertilization and treatment with 300 kg N ha^{-1}. NO_3-N content varied between 27.3 kg ha^{-1} and 338.2 kg ha^{-1} depending on the treatment and sampling time. Similar findings were reported in studies around the world: America (Nance and Karlen, 2007), Europe (Kristensen and Thorup Kristensen, 2007; Németh and Kádár, 1999), Asia (Guo et al. 2001) and Africa (Ikerra et al. 1999).

Net nitrogen mineralization is governed by rainfall, soil moisture, and temperature (Maithani et al. 1998). In order to determine influence of sampling season obtained data were compared across the sampling dates for each treatment (Figure 4). Bars marked by same latter are not significantly different according Fisher's LSD test. It is evident that on all three fertilization treatments (100, 200, 300 kg N ha^{-1}) the highest significant differences were recorded in June 2007 when mean monthly temperature was 22.5 °C. These findings can partly by explain by the fact that temperature has a marked effect on ammonification and nitrification. According to Beck (1983) nitrification attains its optimum at 26 °C. Also, excessive soil moisture inhibits the nitrification process (Sabay, 1969). In June 2007 total monthly precipitations were 28.2 mm (Figure 1) which also attributed to the significantly highest nitrate-nitrogen content in June 2007. On treatment with 300 kg N ha^{-1} significantly lower content of nitrate-nitrogen was observed in November 2007 and February 2008 compared to the nitrate-nitrogen content in summer 2007 and 2008. Fang et al. (2006) explained that nitrogen leaching and its accumulation in deeper soil layers during the rainfall season resulted with significantly lower NO_3-N content in top soil layer (0-0.20 m).

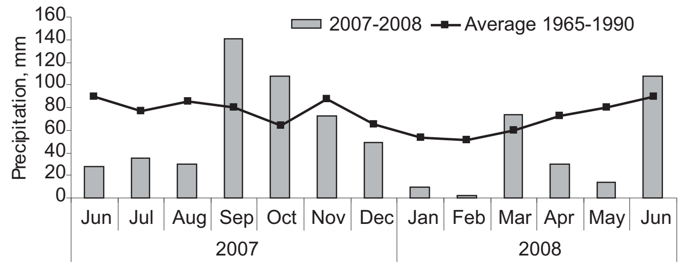

Figure 1. Monthly precipitation (mm), Meteorological Station Sisak

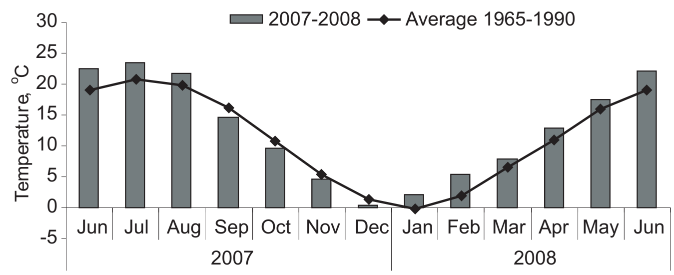

Figure 2. Monthly mean air temperatures, Meteorological Station Sisak

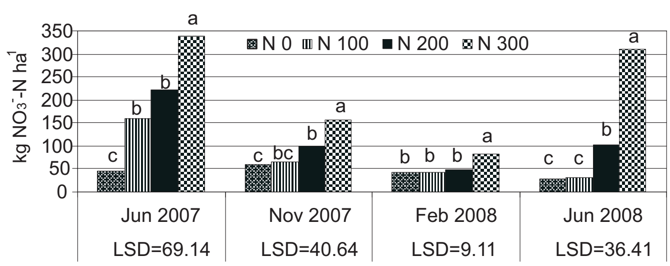

Figure 3. Mean nitrate-nitrogen content in soil samples per treatments for sampling dates

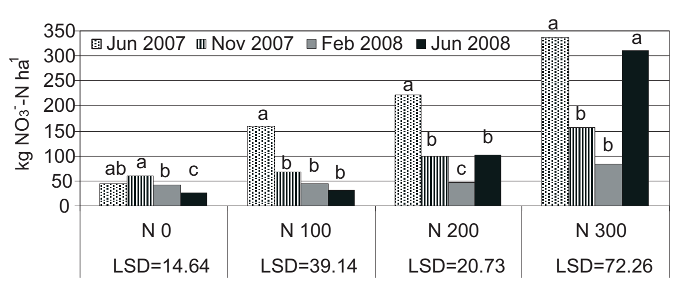

Figure 4. Mean nitrate-nitrogen content in soil samples across the sampling dates for each treatment

Regarding the water samples, from June 2007 to June 2008 eight (8) discharge events were recorded. In table 2 listed precipitations for each sampling date are sum of daily amounts which were recorded between two discharged periods. Between 31 May and 07 October (first discharge in this investigation) total daily amounts were 272.8 mm (Table 2). The lowest precipita-

Table 2. Precipitations (mm) and quantities of lysimeters discharge (L) during investigation

	07 Oct	31 Oct	22 Nov	02 Dec	08 Dec	10 Jan	23 Mar	08 Jun	Sum
Precipitations, mm	272.8	69.9	48.5	26.5	24.3	2.9	62.9	144.7	652.5
Treatment				Lysimeters discharge (L)					Sum
N 0	18.0	14.0	18.0	15.0	15.0	7.0	18.0	17.0	122.0
N 100	17.0	18.0	21.0	18.0	17.0	6.0	23.0	20.0	140.0
N 200	15.0	16.0	17.0	15.0	16.0	7.0	15.0	8.0	109.0
N 300	7.0	17.0	19.0	17.0	15.0	1.0	12.0	7.0	95.0
Average	14.3	16.3	18.8	16.3	15.8	5.3	17.0	13.0	116.5

tions (2.9) were registered in period from 08 December and 10 January. Differences are noticeable in the quantity of lysimeters discharge between treatments (95.0 L in treatment with 300 kg N ha^{-1} to 140 L in treatment with 100 kg N ha^{-1}) probably because the experimental trail was hydro ameliorated. Šimunić et al. (2011) reported that nitrate leaching is more pronounced in hydroameliorated fields, especially in drained soils because the soil infiltration and filtration capabilities are changed. It is possible that among the investigation area (4 ha) infiltration is different which influenced on quantity of lysimeters discharge between treatments. These findings were not affected by plant density. According to Mesić et al. (2009) significant differences (P<0.05) were not observed between winter wheat density on treatment with 100 kg N ha^{-1} (409 plants m^{-2}) and treatment with 300 kg N ha^{-1} (405 plants m^{-2}).

To protect human health, world and national health organizations have established drinking water standards, limiting NO_3-N concentration to a maximum of 10 mg NO_3-N L^{-1} or 50 mg NO_3^- L^{-1} (WHO, 1998), the same as current EC regulations specify (EU Nitrate Directive 91/676/ EEC). Nitrate-nitrogen concentrations in lysimeters water under fertilization exceeded the concentrations of 10 mg NO_3-N L^{-1} (Figure 5). Average NO_3-N values from 07 October to 08 June in nitrogen treatments varied from 19.8 mg L^{-1} to 54.4 mg L^{-1}. The lowest concentration (7.12 mg L^{-1}) was determinate in treatment with 100 kg N ha^{-1} (08 June 2008) and the highest (73.0 mg L^{-1}) in treatment with 300 kg N ha^{-1} (31 October 2007). NO_3-N concentrations in control treatment (0 kg N ha^{-1}) were not above maximum contaminant levels (10 mg NO_3-N L^{-1}; WHO, 1998) and they were in range from 1.20 mg L^{-1} to 5.43 mg L^{-1}. These results are in accord with Arnsson and Bergström (2001). They reported that the rapid increase in NO_3-N concentrations in lysimeters water was strongly influenced by N applications and soil type (differences were detected between clay and sandy soils). Šimunić et al. (2011) also recorded exceeded NO_3-N concentrations (> 10 mg NO_3-N L^{-1}) in drainage water (10 mg NO_3-N L^{-1} to 35 mg NO_3-N L^{-1}) due to different drainpipe spacing, climate condition and sampling time.

NO_3-N losses through leaching during the investigation period are shown in Table 3. NO_3-N losses through leaching increased with increasing N inputs and sum of loses varied from 5.97 kg ha^{-1} (0 kg N ha^{-1}) to 112.3 kg ha^{-1} (300 kg N ha^{-1}) (Table 3). Results indicate that in period from 7 October 2007 to 10 January 2008 sum of average nitrogen losses was 51.3 kg ha^{-1}. During that period maize harvesting was at the beginning of October (05 Oct 2007), basic fertilization for winter wheat, seeding of winter wheat in November (11-13 Nov 2007) and up to 10 January 2007 winter wheat was in tillering growth stage.

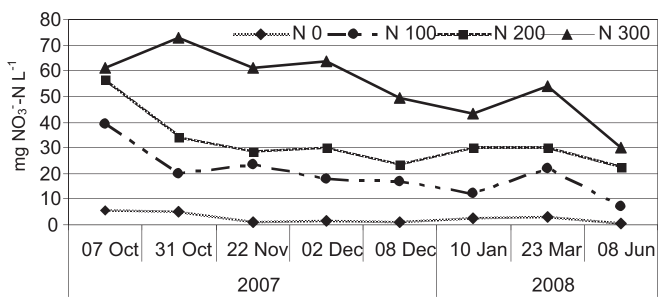

Figure 5. Nitrate-nitrogen concentrations in lysimeter outflow per treatments and sampling dates

In period from 23 March to 08 June 2008 (second and third N topdressing in 09 April 2008) when winter wheat was in steam extension and ripening growth stage sum of average nitrogen losses was 10.3 kg ha^{-1} (Table 3). It is evident that winter wheat in those two growing stages consumes more nitrates from soil and consequently less nitrate-nitrogen was presented in lysimeter outflow. These results are in accord with Mesić et al. (2012) reports. Results suggest that nitrate-nitrogen losses were in cor-

Table 3. Losses of NO_3^- -N with lysimeters water per treatments and sampling period

Treatment	kg NO_3-N ha^{-1}								
	07 Oct	31 Oct	22 Nov	02 Dec	08 Dec	10 Jan	23 Mar	08 Jun	Sum
N 0	1.96	1.38	0.42	0.39	0.36	0.33	1.01	0.12	5.97
N 100	13.28	7.24	9.79	6.43	5.71	1.49	10.10	2.85	56.90
N 200	16.89	10.99	9.65	8.98	7.48	4.23	9.08	3.62	70.92
N 300	12.60	24.82	23.27	21.64	14.80	0.87	12.91	1.35	112.26
Average	11.18	11.11	10.78	9.36	7.09	1.73	8.27	1.98	61.51

relation with applied nitrogen fertilization doses and varied from 6.3 kg ha^{-1} to 28.4 kg ha^{-1}. Mesić et al. (2007) also conclude that sustainable mineral fertilizer rate for maize ranges between 150 and 200 kg ha^{-1} of mineral nitrogen. Additional amounts of nitrogen can cause increase in yield and in grain nitrogen content, but with stronger adverse effects on water quality. Zgorelec et al. (2007) reported significantly higher losses of NO_3-N in periods of crop absence then in crop presence. In maize vegetation periods nitrogen losses range was 1.81 to 16.02 kg ha^{-1}, while in crop absence from 8.46 to 57.65 kg ha^{-1} depending on N application rates, amount of precipitations and outlet from drainpipe.

Conclusions

Research results indicate that the soil NO_3^--N content significantly varied (27.3 kg ha^{-1} to 338.2 kg ha^{-1}) depending on the treatment and sampling time. This NO_3-N loads permanently retained within the system and regarding the nitrate-nitrogen content in the soil-water system it is necessary to investigate nitrate-nitrogen transfer from soil to groundwater. This study shows that high rates of N fertilizer in the production of maize and winter wheat have resulted in excessive NO_3-N leaching, with concentrations in lysimeter water frequently exceeding the maximum allowable level of 10 mg/L of nitrate nitrogen for drinking water. NO_3-N losses through lysimeter outflow were influenced by quantity and time of fertilizers applications, but also by climate conditions, crops grown and their development stages.

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