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Agronomie 23 (2003) 633–641
DOI: 10.1051/agro:2003028

Original article

Drainage runoff and migration of mineral elements in organic and conventional cropping systems

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(Received 11 April 2002; accepted 16 May 2003)

Abstract – In the present investigation, organic and intensive cropping systems were compared on small autonomous drainage plots in limed Luvisoils and Cambisoils as well as non-acid Cambisoils during the period 1995–1998. In the intensive cropping system with balanced nutrient application, the yield of all crops was 38–77% higher than in the organic cropping system. Cropping intensity had no influence on mineral concentration in drainage water, which depended on geochemical soil media. The concentrations of Cl^- and NO_3^- in drainage water were, respectively, 8–22 and 24–80% higher than in the organic system. But at low N application, improvement of fertilisation efficiency increased crop yield and decreased nitrate leaching at the same time. The leached amount of solutes depended mainly upon drainage runoff, which was 6–57% lower in the intensive cropping system than in the organic one, and much less upon its concentration. From this study, organic agriculture has no essential advantage compared with intensive agriculture, considering the amount of leached elements and compounds, and secondarily, crop productivity.

intensive agriculture / organic agriculture / leaching / fertilisation / nitrate / yield

Résumé – **Drainage, ruissellement et migration des éléments minéraux dans les systèmes de culture conventionnel et biologique.** La comparaison de systèmes de cultures intensif et biologique a été conduite de 1995 à 1998 sur des petites parcelles de drainage autonomes avec des Luvisols et Cambisols chaulés ainsi que des Cambisols non acides. Avec l'agriculture intensive et une application équilibrée de fertilisants, le rendement a été de 38 à 77 % plus élevé qu'avec l'agriculture biologique. L'intensification de l'agriculture n'a pas eu d'effet sur la concentration en éléments minéraux des eaux de drainage qui dépendait surtout de la composition géochimique du sol. Les concentrations en Cl^- et NO_3^- dans l'eau de drainage des parcelles en culture traditionnelle étaient respectivement 8–22 et 24–80 % plus élevées que pour les parcelles en culture biologique. Mais avec l'application de faibles doses d'azote, l'amélioration de l'efficience de la fertilisation a permis d'augmenter le rendement des cultures et de diminuer dans le même temps le lessivage des nitrates. La quantité de solutés lessivés a dépendu surtout du drainage et du ruissellement qui était réduit de 6 à 57 % avec l'agriculture intensive comparativement à l'agriculture biologique et beaucoup moins de la concentration en solutés. D'après cette étude, l'agriculture biologique ne présente pas d'avantage essentiel comparativement à l'agriculture intensive si l'on considère la quantité d'éléments minéraux lessivés et secondairement le rendement des cultures.

agriculture intensive / agriculture biologique / lessivage / nitrate / rendement

1. INTRODUCTION

Experience of the anthropogenic impact upon the environment shows that the unforeseen negative side effects of economic activities are connected with the insufficient understanding of nature's integrity. The high standard of living of industrial society is inevitably connected with the by-products of human activity – pollution increases with population increase.

Analyses of farming practices in developed countries over the last few decades shows that intensification of agriculture generates two problems: ecological (environmental pollution) and economical (the unexpected rise in prices due to the consumption of main material resources) [36]. It is considered that 25–35% of the total yield in Lithuania can be assigned to mineral fertilisers. It is probably a very moderate estimate, as it does not evaluate the influence of fertilisers on soil productivity [34]. Many authors have stated that the productivity of organic-biological farms is rather low and the yield of main crops is less than 60% of the yield of conventional farms [6, 23, 36]. However, the energy input for a production unit is 40% less under organic farming [2, 26, 30]. Experience shows that for successful organic farming state support is necessary [36].

Communicated by Gérard Guyot (Avignon, France)

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The influence of different intensity cropping systems on water quality is considered to be very ambiguous. There are a lot of propositions that intensification of agriculture increases the migration and leaching of some elements and compounds (HCO_3^-, Ca^{2+}, SO_4^{2-}, K^+, Cl^- and NO_3^-) [7, 24]. Several authors affirm that migration of elements is slowed down by applying various organic cropping systems [6, 18, 38]. Other authors demonstrate that manure as a fertiliser increases the possibility of water pollution because mineralisation in the soil is slower and lasts for a long period [4, 5, 19]. There are opinions, too, that organic and conventional farms differ insignificantly from the point of view of nitrate leaching [17, 20]. However, it is admitted unanimously that the leaching of elements as well as the non-productive losses of nutrients significantly increase when the amounts of fertilisers exceed the needs of plants [16, 25, 33]. Some scientists from Rothamsted (Great Britain) [1] and Russia [22], unlike the authors mentioned above, show that a large proportion of nitrates get into rivers and lakes when the organic nitrogen of the soil mineralises. Therefore, it is impossible to solve the problem quickly by only reducing the amounts of nitrogen fertilisers. It may be effective only after a long period of time, while the amount of organic matter does not decrease in the soil [1, 12, 22, 38]. The investigations carried out in the former East Germany have shown that extensive agriculture significantly increased leaching of nitrates (55%) within a period of 1 year or even faster, compared with the areas of intensive agriculture [21]. Similar tendencies have been observed in Lithuania. In the years 1992–1996, agricultural production and the use of mineral fertilisers decreased while the pollution of Lithuanian rivers by nitrate nitrogen sharply increased [32]. This proposition is confirmed by the investigations carried out with isotope ^{15}N and by other methods. It was established that the amounts of nitrogen leached from mineral fertilisers made up only 2.9–3.4% of the total amount of leached nitrogen when a balanced ed fertilisation was applied. Meanwhile, the application of organic fertilisers is much more precarious in this case [3, 38]. Thus, mineral fertilisers should be considered as potential water pollutants only in exceptional circumstances. Their negative effects may appear only if fertilisation recommendations are not observed or when fundamental scientific knowledge is not adhered to [9, 13, 31].

The aim of this paper is to estimate the influence of organic and intensive cropping systems on the productivity of field crops, drainage water runoff and quality, as well as on the migration of elements in Western Lithuania.

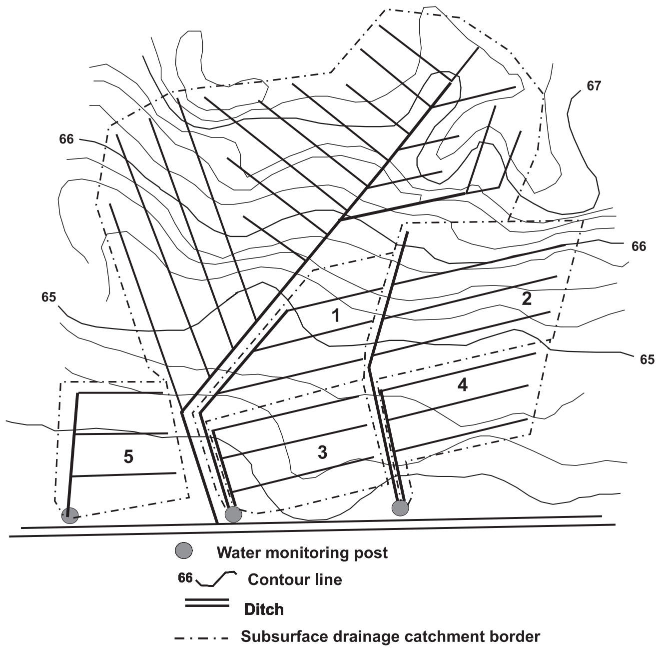

Figure 1. Map of the experimental site.

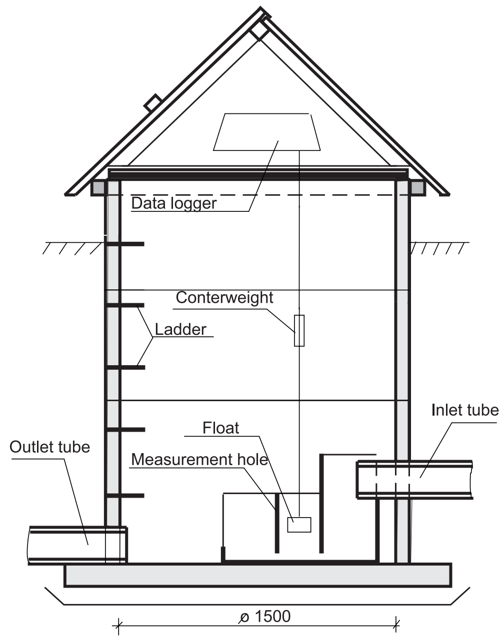

Figure 2. Drainage water monitoring post.

2. MATERIALS AND METHODS

A field experiment method on small subsurface drainage systems was used for the investigation. The experiment was established in the Lithuanian seacoast lowland, in the basin of the Minija-Skinija and in the village Samaliske. Investigations were carried out during the period of 1995–1998. The experimental site included 5 individual drainage systems with drainage water collection wells (Figs. 1 and 2).

Every drainage system consisted of three drain lines each, with 16 metres of space between the lines. Drains were connected to collectors and directed into a monitoring well. Data loggers were installed for water level measurement. Every drainage system had a different cropping system with its typical complex of agricultural measures. The experimental site included the following treatments:

1. Organic cropping system in limed Dystri-Endohypogleyic Cambisols (CMg-n-w-dy) loam, formed on sandy loam soil. No mineral fertilisers or pesticides were used. 60 t·ha^{-1} of manure was applied on fodder beet. Plot area 3358 m^2.

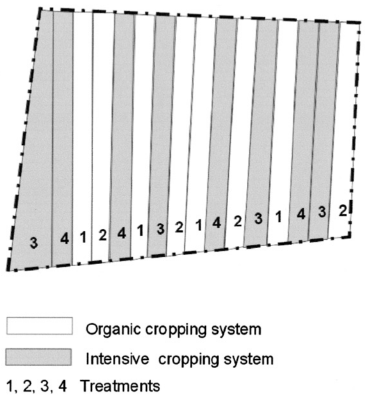

Figure 3. Plan of the crop rotation applied in the experimental site.

2. Organic cropping system in limed Bathihypogleyi-Albic Luvisols (LVa-gld-w) sandy loam on loam soil. Agricultural measures are analogous to treatment 1. Plot area 5461 m^2.
3. Intensive cropping system in limed CMg-n-w-dy loam on sandy loam soil. Mineral fertilisers were applied in order to receive a 40–50% higher yield than in treatment 1. Pesticides were applied in this treatment. Plot area 3855 m^2.
4. Intensive cropping system in limed LVa-gld-w loam on sandy loam soil. Agricultural measures were analogous to treatment 3. Plot area 4101 m^2.
5. Intensive cropping system in non-acid Endocalcari-Endohypogleyic Cambisols (CMg-n-w-can) loam on sandy loam soil. Agricultural measures were analogous to treatments 3 and 4. Plot area 3541 m^2.

ISSS-ISRIC-FAO international soil nomenclature was used for the classification of soils in this article [15].

The same crop rotation was applied during the whole study period in four replications (1- winter wheat 'Moskovskaja nizkostebelnaja'; 2- fodder beet 'Ekendorfo geltonieji'; 3- spring barley (cover crop) 'Ula' + undercrop (perennial grass) and 4- perennial grass, 1st year of usage – red clover 'Liepsna' 60% + timothy 'Gintaras II' 40%) (Fig. 3).

Before starting the trial the soil of treatments 1-4 was limed with dusty limestone, aimed at regulating the soil reaction up to pH_{KCl} 6.25. The characteristics of the parent rock and the agrochemical properties of the soil arable layer before starting the trial are listed in Table I.

The parent rock, causing soil reaction and other soil properties, lies at different depths. Carbonates are at a depth of 120–140 cm in LVa-gld-w soils (treatments 2 and 4). In treatments 1 and 3, carbonates are at a depth of 80–100 cm. The CMg-n-w-can soil of treatment 5 is very close to neutral or of neutral reaction.

Background manure fertilisation of 60 $t \cdot ha^{-1}$ from the second year of the experiment was applied in all the organic and intensive farming treatments during a four-year crop rotation. To calculate the mineral fertiliser needed for intensive crop production (to get a 40% higher yield than in the organic cropping system) a computer model developed by A. Svedas was used. The model describes the dependency of crop yield on soil characteristics such as soil texture, acidity, content of total N, humus, content of mobile P_2O_5 and K_2O etc., as well as the amount of fertilisers used. The storage of mobile P_2O_5 and K_2O in the soil was expected to achieve the limit of 150 $mg \cdot kg^{-1}$ [35]. The fertilisation of field crops within the study period is listed in Table II.

The water level in the measurement boxes was recorded weekly on a data logger. Later, it was recalculated as runoff mm/ha.

Table I. The agrochemical properties of soil arable layer.

Soil property	Treatment (cropping system)				
	Soil				
	CMg-n-w-dy		LVa-gld-w		CMg-n-w-can
	Organic	Intensive	Organic	Intensive	Intensive
pH_{KCl}	5.7	5.0	4.9	5.0	6.3
Hydrolytic acidity mg ekv $\cdot kg^{-1}$	19	14	35	36	9
Total adsorbed base mg ekv $\cdot kg^{-1}$	154	184	69	73	300
Mobile P_2O_5 $mg \cdot kg^{-1}$	108	131	98	132	212
Mobile K_2O $mg \cdot kg^{-1}$	156	155	205	227	127
Total N %	0.14	0.11	0.10	0.11	0.15
Organic C %	1.40	1.45	0.82	1.21	1.87
Beginning of carbonate seam cm	100	80	142	115	55
Mobile Ca $mg \cdot kg^{-1}$	-	-	1775	2140	-
Mg	-	-	136	158	-
S	-	-	12	11	-
Zn	-	-	1.0	1.0	-
Cu	-	-	1.9	1.8	-
Mn	-	-	89	56	-

Table II. Incorporated NPK with fertilizers kg·ha^{-1} of active matter.

Treatments	Nutrients	Years							
		1995		1996		1997		1998	
		Incorporated with							
		M	NPK	M	NPK	M	NPK	M	NPK
1. Organic	N	198.0	-	50.0	-	50.0	-	37.8	-
	P_2O_5	42.1	-	20.8	-	6.7	-	20.3	-
	K_2O	134.3	-	66.7	-	51.9	-	50.6	-
2. Organic	N	43.2	-	51.5	-	49.1	-	43.8	-
	P_2O_5	11.4	-	12.0	-	6.6	-	17.1	-
	K_2O	20.7	-	84.8	-	50.9	-	42.8	-
3. Intensive	N	47.2	71.2	56.0	103.2	59.9	75.8	31.9	61.5
	P_2O_5	12.5	15.7	13.2	32.9	8.0	-	23.4	-
	K_2O	32.4	48.5	97.3	29.0	52.3	-	58.6	-
4. Intensive	N	48.0	109.2	63.7	113.7	52.2	70.1	31.7	67.1
	P_2O_5	12.7	45.6	14.0	45.5	6.9	-	17.1	-
	K_2O	31.2	70.5	105.3	6.0	54.0	-	42.4	-
5. Intensive	N	44.9	75.9	59.9	96.4	57.9	65.3	32.2	49.4
	P_2O_5	11.9	20.5	14.1	4.2	7.8	-	17.2	-
	K_2O	31.1	136.3	99.4	70.3	60.0	-	43.5	-

M – manure, NPK – mineral fertilizers.

Samples of drainage water (1–2 litres) were taken every month. Analyses of Ca^{2+} and Mg^{2+} – were carried out by the EDTA titrimetric method, HCO_3^- – titrimetric (0.05M HCl titration), PO_4^{3-} – ammonium molybdate spectrometric, SO_4^{2-} – gravimetric using borium chloride, Cl^- – Mohr's (silver nitrate titration with chromate indicator), K^+ – by flame emission spectrometry, NO_3^- – spectrometric with phenol-4-sulfonic acid solution and B – spectrometric using azomethine-H [39]. The pH_{KCl} of soil samples was determined potentiometrically in 1M KCl, mobile P_2O_5 and K_2O – AL (method of Egnery et al.), hydrolytic acidity – in Kappen (1M sodium acetate using a weight ratio of soil to solution of 1:2.5), sum of adsorbed base – in Kappen-Hilkovic (after extraction with 0.1M HCl solution using a weight ratio of soil to solution of 1:5) total nitrogen – in Kjeldal's, and the amount of carbonate – according to the pressure – calcimeter method. The analyses of mobile Ca and Mg in an extract of buffer solution was carried out with a spectrophotometer of atomic absorption [28]. The beginning of the carbonate seam was determined with 10% HCl.

The yield was harvested mechanically and crop samples were taken from all four replications. Total N in the crop yield was determined after burning with vitriol oil, total P was determined by use of the vanadium – molybdenum method, and total K by a blaze photometer. P and K were determined from ash after burning samples in a flask of Kjeldal.

The data were processed according to the methods of mathematical statistics. Errors were calculated individually for each treatment. Methods of disperse analysis and correlation – regressions were applied [10, 11, 27]. Statistical analysis was performed using the program "Statistica for Windows 4.3" [27].

In this paper the following abbreviations are given: x – average, Sx – error of average, * and ** - connections reliable at the 95 and 99% probability levels, $LSD_{5\%}$ – limit of reliable difference at the 95% probability level, $x_{extr.}$ – extreme of function, D – coefficient of determination, and r and η - coefficient and relation of correlation, accordingly.

3. RESULTS AND DISCUSSION

3.1. Field crop yield

The application of an intensive cropping system substantially increased the yield of winter wheat (44–62%), spring barley (94–106%) and fodder beet (70–219%) (Tab. III).

The yield of perennial grasses decreased (22–25%) under the conditions of an intensive cropping system. This is related to the cover crop. The fact that the intensive cultivation of cover crops has a tendency to smother under crops and decreased productivity of perennial grass has been determined in other investigations, too [14]. The mean annual yield of metabolic energy in the intensive cropping system was 38–89% higher than in organic farms.

3.2. Drainage water runoff

The formation of drainage runoff in Lithuania mainly depends upon meteorological conditions. In the years with a higher level of precipitation (1995 and 1997 – about 850 and 1998 – 1051 mm), the drainage runoff ranged from 148 to 414 mm in different treatments and it made up 17–39% of the total amount of precipitation. However, in 1996 when the amount of precipitation was only 695 mm, the drainage runoff made up 61–141 mm or 9–20% of the total precipitation amount (Fig. 4).

Investigations have shown that the intensification of agriculture, aimed at higher crop yield, decreases drainage water

Table III. The influence of the cropping systems on the crops productivity.

Treatments	Average yield of main production $Mg \cdot ha^{-1}$ (1995–1998)				Average yield of
	Winter wheat (15%)	Spring barley (15%)	Perennial grasses (dry matter)	Fodder beet (dry matter)	metabolic energy $GJ \cdot ha^{-1}$
1. Organic	2.82	2.17	4.50	2.07	36.9
3. Intensive	4.57	4.47	3.38	6.62	69.9
$LSD_{5\%}$	0.64	0.58	0.84	0.94	10.5
2. Organic	2.90	2.12	4.52	3.15	45.3
4. Intensive	4.17	4.12	3.52	5.34	62.6
$LSD_{5\%}$	0.83	0.61	1.09	1.27	13.0
5. Intensive	4.73	3.94	3.24	5.51	63.7

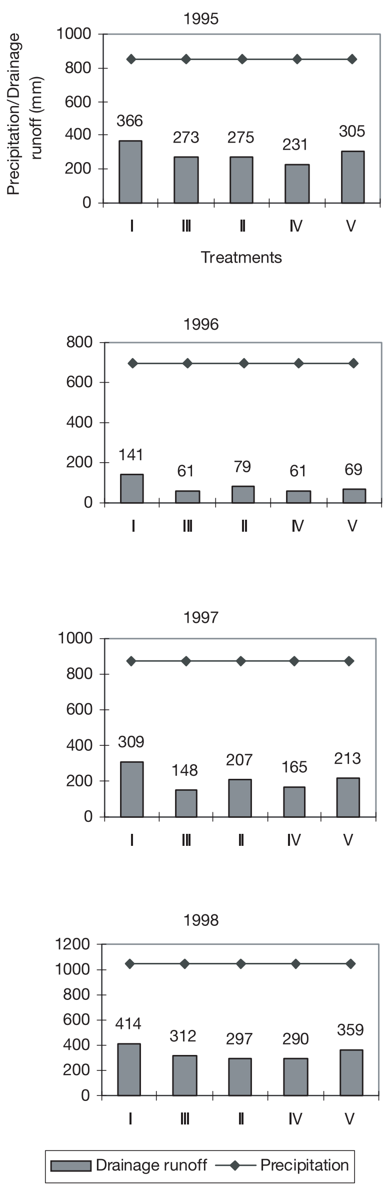

Figure 4. The amount of precipitation and drainage water runoff at the experimental site.

runoff at the same time. The application of an intensive cropping system in different years decreased drainage runoff from 6 to 57% in comparison with the application of an organic one. An exponential relation was determined between field crops' NPK fertilisation (manure + mineral fertilisers) (x_1) $kg \cdot ha^{-1}$ active matter as well as mean field crops' yield (x_2) $GJ \cdot ha^{-1}$ and the annual drainage water runoff (y) mm.

$y = 408.22e^{-0.0039x1}$; $r = 0.57$; $r_{5\%} = 0.46$; $D = 33\%$; $y = 450.85e^{-0.0244x2}$; $r = 0.64$; $r_{5\%} = 0.46$; $D = 41\%$.

With an increase in fertilisation and crop yield, the drainage water runoff decreases.

3.3. Chemical composition of drainage water

The concentration of elements and compounds in drainage water was defined, taking into account geochemical soil media and fertilisation intensity (Tab. IV).

The concentrations of Ca^{2+}, HCO_3^- and SO_4^{2-} in water depends on the genetic type of soil and increases in the following sequence: LVa-gld-w→ CMg-n-w-dy→ CMg-n-w-can. LVa-gld-w soil, containing smaller amounts of adsorbed base and humus, predetermined that Ca^{2+} and HCO_3^- concentrations in the drainage water were smaller and reached 170–175 and 147–173 $mg \cdot l^{-1}$, respectively. When the soil turns into a CMg-n-w-dy type these concentrations increase up to 17–18 and 41–67%. The highest one was recorded in non-acid CMg-n-w-can soil. An exponential relation between carbonate content in soil cm (x) and Ca^{2+} concentration in drainage water $mg \cdot l^{-1}$ was found.

$y = 314.24e^{-0.0046x}$; $r = 0.73^{**}$; $D = 53\%$.

Statements that higher mineral fertilisation, especially nitric fertilisation, induces Ca^{2+} migration and its leaching from the soil, are frequent in the literature [8]. In the present investigations, the intensity of agriculture had no influence on Ca^{2+} concentration in drainage water. SO_4^{2-} ion concentration in the water of LVa-gld-w soil was 136–145 $mg \cdot l^{-1}$, while in the other soil types investigated it was 15% higher. This is related to sulphur metabolism, because nitrification and suphofication processes occur in soil simultaneously [22]. The concentration of K^+ in water changes in a different sequence. The highest one was recorded in poor LVa-gld-w soils. The concentrations of Cl^- in drainage water depend on fertilisation. Under the intensive cropping system the concentration of Cl^- in drainage water increased by 8–22, compared with the organic cropping system.

Table IV. The average annual concentration of ions in drainage water ($mg \cdot l^{-1}$).

Ions	Treatment (cropping system)						
	Soil						
	CMg-n-w-dy			LVa-gld-w			CMg-n-w-can
	1. Organic	3. Intensive	$LSD_{5\%}$	2. Organic	4. Intensive	$LSD_{5\%}$	5. Intensive
Ca^{2+}	204	200	39	170	175	54	246
Mg^{2+}	24	21	25	19	17	9	14
SO_4^{2-}	167	156	154	145	136	147	157
NO_3^-	37	46	15	35	63	33	34
K^+	1.1	1.0	0.2	1.9	2.6	1.1	1.0
PO_4^{3-}	0.06	0.07	0.06	0.06	0.05	0.05	0.07
Cl^-	27	33	11	26	28	8	36
HCO_3^-	244	245	105	173	147	84	285
B	-	-	-	0.11	0.09	0.06	-
Zn	-	-	-	0.11	0.09	0.14	-
Cu	-	-	-	0.003	0.003	0.003	-
Mn	-	-	-	0.005	0.005	0.009	-
Total mineral content	704	702	194	570	569	181	773

Nitrogen is not only the main life force of today's agriculture, but also the main environmental pollutant. Therefore, the relationship of nitrate concentration in drainage water with the productivity of the agricultural ecosystem and the factors predetermining it are discussed in a broader context. The average nitrate concentration in drainage water was rather high (34–63 $mg \cdot l^{-1}$) and was mostly predetermined by fertilisation. Application of intensive cropping systems increased the nitrogen concentration by 25% and 81% to values of 46 and 63 $mg \cdot l^{-1}$ in CMg-n-w-dy soil and LVa-gld-w soil respectively compared with organic systems. In the state of Iowa, in the USA, it was determined that the concentration of NO_3^- in drainage water did not exceed the 10 $mg \cdot l^{-1}$ N (50 $mg \cdot l^{-1}$ NO_3^-) maximum contamination level for drinking water when low rates of fertilisers were applied [16]. According to the present investigations, this concentration exceeded the permitted limit for drinking water by 26% only in poor LVa-gld-w soil under the conditions of an intensive cropping system. Thorough correlation – regression analysis of annual data NO_3^- concentrations shows that nitrate leaching depend on mineral fertilisation efficiency (Fig. 5).

Together with the increased nitrogen fertilisation the concentration of NO_3^- in drainage water changes in parabola ($y = a–bx+cx^2$) regularity. When nitrogen fertilisation increases up to 53 $kg \cdot ha^{-1}$, this concentration decreases. A further increase in fertilisation increases this concentration. However, nitrate concentration decreases in drainage water only at a rather low N application level (up to 53 $kg \cdot ha^{-1}$). With a more abundant N fertilisation, this concentration increases. Such changes in nitrate concentrations under the influence of fertilisation are related to the fertilisation efficiency for crops and the yield. The dependence of average field crop metabolic energy yield ($GJ \cdot ha^{-1}$) (y) upon nitrogen fertilisation $kg \cdot ha^{-1}$ active matter (x) can be expressed by the following regression equation:

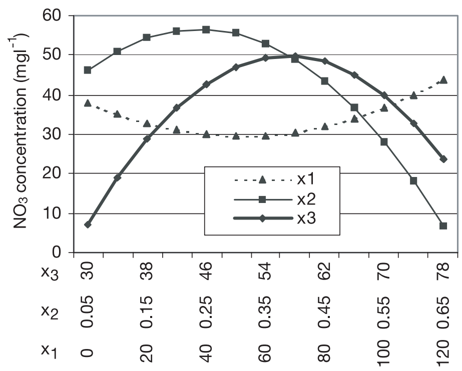

Figure 5. The relationship between nitrate concentration in drainage water, fertilisation, fertilisation efficiency and yield: 1 (x_1) N fertilisation $kg \cdot ha^{-1}$ active matter, 2 (x_2) NPK fertilisation efficiency $GJ \cdot ha^{-1}$ yield per 1 kg NPK, 3 (x_3) yield $GJ \cdot ha^{-1}$.
(1) – $y = 234.04 – 1.985x_1 + 0.0061x_1^2$; $\eta = 0.78^{**}$; D = 61%; $x_{ekstr} = 162$
(2) – $y = 54.372 + 2.785x_2 – 0.0577x_2^2$; $\eta = 0.77^{**}$; D = 59%; $x_{ekstr} = 24.1$
(3) – $y = 284.9 – 9.228x_3 – 0.085x_3^2$; $\eta = 0.76^{**}$; D = 58%; $x_{ekstr} = 54.3$.

$y = –43.001 + 0.6908x – 0.00484x^2$; $\eta = 0.90^{**}$; D = 81%; $x_{extr.} = 71$.

Thus, crop yield increases at a nitrogen fertilisation rate of 71 $kg \cdot ha^{-1}$ active matter. Crop yield higher than 57 $GJ \cdot ha^{-1}$ already decreases nitrate concentration in drainage water. When fertilization efficiency increases, the consumption of fertilisers is better, and herewith any possibility of nitrogen migration in water is reduced. The conformities observed lead us to believe that rational and effective fertilisation not only

Table V. The leached amounts of elements and compounds ($kg \cdot ha^{-1} \pm Sx$).

Ions	Treatment (cropping system)						
	Soil						
	CMg-n-w-dy			LVa-gld-w			CMg-n-w-can
	Organic	Intensive	$LSD_{5\%}$	Organic	Intensive	$LSD_{5\%}$	Intensive
Ca^{2+}	629±43.2	410±25.1	100	367±24.3	316±36.9	88	607±22.9
Mg^{2+}	73±17.0	35±14.5	45	37±6.2	29±5.5	17	29±13.7
SO_4^{2-}	554±177.5	349±153.1	166	342±62.9	280±130.0	289	419±158.9
NO_3^-	101±15.2	83±15.4	43	63±19.5	101±34.0	78	69±23.4
K^+	3.4±0.54	2.2±.0.46	1.4	4.3±0.77	4.7±0.89	2.4	25.7±0.47
PO_4^{3-}	0.16±0.009	0.15±0.025	0.05	0.11±0.025	0.08±0.03	0.08	0.16±0.007
Cl^-	79±8.2	63±7.4	22	54±3.5	49±5.9	14	85±12.2
HCO_3^-	750±170.7	505±82.5	379	386±44.8	280±81.5	186	664±93.2

ensures high field crop productivity but also reduces unproductive nitrogen losses. At the same time, it decreases the possibilities of environment and water pollution. The increase of nitrate concentration in drainage water (24–80%) observed under the conditions of intensive cropping system is connected with the insufficient efficiency of fertilisation or inefficiency of other agricultural interventions which do not allow plants to absorb nitrogen to the maximum.

The cropping systems and different soil genetic types investigated had no great influence on the concentration of Mg^{2+}; PO_4^{3-} in drainage water. Total mineral content in drainage water does not depend on cropping intensity and is defined by geochemical soil media. The smallest was in LVa-gld-w soil (569–570 $mg \cdot l^{-1}$). In CMg-n-w-dy soil it increased by 23%. The highest one was in CMg-n-w-can soil (773 $mg \cdot l^{-1}$).

3.4. The leaching of elements and compounds

The amounts of ions leached by drainage were essentially determined by drainage water runoff volume and geochemical soil media as well as by cropping intensity (Tab. V).

The correlation – regression analysis revealed that the total amount of leached elements is influenced much more by drainage runoff volume rather than by total mineral content in the unit of volume. Variation in NO_3^- leaching (z_1) is similarly predetermined by the drainage runoff (y), and NO_3^- concentration in water (x).

$z_1 = 10.87 + 0.27x + 0.045y - 0.002x^2 + 0.001xy - 0.00001y^2$; $R = 0.92^{**}$; $r_{concentration} = 0.91$; D = 82%; $r_{runoff} = 0.89$; D = 79%.

Thus, the amount of nitrates leached shows a very sensitive response to all natural and anthropogenic factors. The application of an intensive cropping system, which ensured a higher crop yield, decreased drainage water runoff and the leaching amount of elements and compounds at the same time.

Under the conditions of an intensive cropping system the average annual leaching of Ca^{2+} (14–35%), Mg^{2+} (22–52%), HCO_3^- (27–33%) and SO_4^{2-} (18–37%) decreased. In all cases, the smallest amounts of these elements and compounds were leached in poor LVa-gld-w soil. Cl^-, K^+, PO_4^{3-} leaching data shows similar results. The application of an intensive cropping system decreased the annual leached amount of Cl^- by 9–20% in different years. Leached amounts of K^+ and PO_4^{3-} were comparatively small, and varied between 2.2–4.3 and 0.08–0.16 $kg \cdot ha^{-1}$. Other authors obtained similar results, too. Where the crop yield was bigger due to fertilisation, it decreased the amount of infiltration water, and the leaching of elements and compounds decreased as well [38]. Thorough correlation – regression analysis of the data shows that increasing fertilisation $kg \cdot ha^{-1}$ (x_1) together with the increase in crop yield $GJ \cdot ha^{-1}$ (x_2), reduces the leaching of all compounds $t \cdot ha^{-1}$ (y). This relation can be described by a y = a + b/x regression equation.

$y = 1.51 + 0.00022/x_1$; $r = 0.71^{**}$; D = 50%; $y = 1.846 + 217.049/x_2$; $r = 0.77^{**}$; D = 59%.

The amount of nitrates leached fluctuated widely in different years (34–211 $kg \cdot ha^{-1}$). Therefore, observations over a limited time span can be misleading. In order to reveal the regularities of leaching relations with agroecosystem productivity, a particular analysis of the investigation data was carried out (Fig. 6).

The nitrate leaching, yield and nitrogen balance depend on NPK fertilisation (manure + mineral fertilisers) in parabola conformity. Together with the increase in fertilisation to 162 $kg \cdot ha^{-1}$ and with the increase of yield up to 54.3 $GJ \cdot ha^{-1}$, the leaching of nitrate decreases. Further increase in the fertilisation rate increases nitrate leaching. The data analysis shows that the maximum mean yield of all crops was obtained at the average NPK fertilisation rate of 142 $kg \cdot ha^{-1}$. Further increase in fertilisation causes unproductive losses of fertilisers. This is clearly illustrated by the dependence of the nitrate leaching amount upon the efficiency of fertilisation (see Fig. 6). An increase in the fertilisation efficiency (even from 24%) ensures a higher yield and lower nitrate leaching, compared with an unfertilised treatment. A small positive nitrogen balance (+6.7 $kg \cdot ha^{-1}$) ensures the smallest nitrate leaching. Thus, the data from these investigations do not allow us to consider the organic cropping system as a more friendly to environment than intensive one.

Investigations carried out in other countries show similar results. It was determined that increasing crop yield reduces

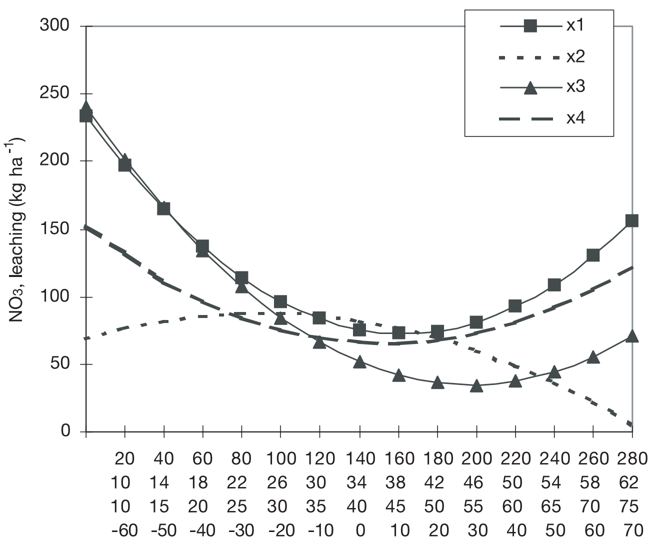

Figure 6. The relationship between nitrate losses, fertilisation, fertilisation efficiency, yield and N balance: 1 (x_1) NPK fertilisation (manure + mineral fertilisers) kg·ha^{-1} active matter, 2 (x_2) NPK fertilisation efficiency (additional yield %), 3 (x_3) yield GJ·ha^{-1}, 4 (x_4) N balance kg·ha^{-1}.

nitrate leaching. However, rather abundant but inefficient fertilisation slightly increases the yield, while the leaching losses of nitrogen disproportionately increase [16, 29, 37]. In all cases the application of manure increases nitrogen losses (depending on rates – 15–35%) [37].

4. CONCLUSIONS

The investigations of manure fertilised organic cropping systems (without mineral fertilisers or pesticides) and intensive cropping systems with application of mineral fertilisers and manure as well as using pesticides carried out in CMg-n-w-dy and LVa-gld-w soils in a four field crop rotation enable us to make the following conclusions.

Organic agriculture has no essential advantages compared with the intensive one in terms of nitrate leaching and is secondary in terms of crop productivity. The increase in yield due to cropping intensity accounts for 38–76%.

Intensification of agriculture and higher crop yield influences other components of the agroecosytem.

- The application of an intensive cropping system decreased drainage water runoff from 6–23 to 23–57% in different years.
- Cropping intensity has no influence on Ca^{2+}, Mg^{2+}, K^+, PO_4^{3-}, HCO_3^-, SO_4^{2-} concentration in drainage water and on total mineral content in water.
- The concentrations of Ca^{2+}, SO_4^{2-} and HCO_3^- in drainage water and their total mineral content in water depend upon the genetic soil type, and increase in this sequence: LVa-gld-w→ CMg-n-w-dy→ CMg-n-w-can.
- Under the intensive cropping system conditions the concentration of NO_3^- increased by 24–80, Cl^- 8–22% to 46–63 and 28–33 mg·l^{-1} respectively.
- The concentration of NO_3^- in drainage water depends on nitrogen fertilisation as well as crop yield and changes in parabola conformity. Rational N application and high fertilisation efficiency decreases this concentration.
- The leached amounts of elements and compounds mainly depend upon drainage runoff intensity and much less on its concentration in water. Under high efficiency of the intensive cropping system less Ca^{2+}, Mg^{2+}, SO_4^{2}, Cl^- and HCO_3^- are leached. Moderate NPK fertilisation (manure + mineral fertilisers) and high fertilisation efficiency reduce the amount of nitrates leached.

According to our investigations the intensive cropping system should not be considered as a more polluting than organic one. The results of our investigations lead us to believe that the fertilisation recommendations in Lithuania estimate the migration of biogens insufficiently. In order to reduce non-point source pollution, the aim should be to reach the maximum efficiency of fertilisers at high yield.

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