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LAND USE INFLUENCE ON NITROGEN LEACHING AND OPTIONS FOR POLLUTION MITIGATION

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Abstract

The investigation of land use and nitrogen leaching was performed in the Graisupis watershed (Kėdainiai region), typical of intensive land use in the Middle Lithuania region.

The investigation revealed that the largest quantities of nitrogen were leached from fields under row crops (22.4 kg ha^{-1} $year^{-1}$). Nitrogen leaching from fields under spring and winter cereals was 18.9 and 16.5 kg ha^{-1} $year^{-1}$, respectively. The lowest level of leaching was from fields under pastures (10.5 kg ha^{-1} $year^{-1}$).

Different scenarios of measures were made for the Graisupis watershed to compare nitrogen leaching reduction. In practice, the increase in percentage of areas under grasses is problematic. The analysis revealed that the fertilization rate not higher than plant need (considering plant available nutrient storage in soil) and minimized soil tillage systems are more effective for leaching reduction on a watershed scale than changes in crop structure.

Key words: land use, nitrogen, watershed, leaching mitigation.

Introduction

Protection of water bodies from pollution by main nutrients passed from agricultural fields is one of the most complicated environmental problems. The total nitrogen concentration found in the Middle Lithuania's river region under intensive agriculture is twice (Nevežis – 4.1 mgl^{-1}) as high as that under extensive agriculture in Eastern Lithuania (Sirvinta – 2.0 mgl^{-1}) /Tumas, 2001/. Land use factors such as fertilization, area of arable land and ploughing were found to have profound effects on the quantity of nutrients leached from soil /Burt, Haycock, 1993; Vinten, Smith, 1993/. Grassland, if grazed not intensively, is less prone to N leaching than arable land /Kolenbrander, 1981; Gustafson, 1987; Kutra et al., 2002/. Concentration of mineral N found by Kutra et al. (2002) was 3.5 mg l^{-1} in drainage water from the fields of perennial grasses and 11 mg l^{-1} in the drainage water from arable fields when 101 subsurface drainage systems had been investigated in the Graisupis catchment. A problem from the environmental point of view is that grain crops dominate in areas favourable for agriculture, such as the Graisupis watershed. Statistical data of crop structure in main counties of the Lithuanian Middle Plain show that 67-70 % of the total area of crops is grain crops (0). During the short period (from 2003 to 2004 year) the total area under crops increased by 1.5-9.6 % in this region.

Table 1. Share of grain crops in the total crop area in the main counties of the Lithuanian Middle Plain in 2003-2004

1 lentelė. *Javų dalis bendrame pasėlių plote pagrindinėse apskrityse Vidurio Lietuvos lygumoje 2003-2004 metais*

County *Apskritys*	Share of grain crops in the total crop area % *Javų dalis bendrame pasėlių plote %*		Increase from 2003 to 2004 % *Padidėjimas nuo 2003 iki 2004 metų %*	
	2003	2004	total crop area *visų pasėlių plotas*	grain crop area *javų plotas*
Marijampolė	68	70	1.5	4.1
Kaunas	68	69	2.2	3.2
Panevėžys	67	69	9.6	11.9
Šiauliai	68	68	5.9	6.0

New technologies and cropping systems increased grain crop yield in many farms of this region to the level of Western countries (7-9 t ha^{-1}). To increase competitiveness of farmers, they have a target to get 10-12 t ha^{-1} and higher grain crop yields. High productivity increases profitability of grain crops growing, therefore the share of grain crops in the total crop area increased from 2003 to 2004, as one can see in 0, from 3.2 % in Kaunas county to 11.9 % in Panevėžys county and can increase even more in the future.

To prevent monocultures in cropping systems is one of the main recommendations of the Code of Good Agricultural Practices[1]. Grain crop fertilization must be in balance with crop yield. The difficulty of the agricultural production is that plant use of nutrients is hardly predicted. Capacity of soils to keep increasing amounts of nutrient overloading, resulting from fertilization, is limited. Especially high quantities of nutrients can be left in soil, when the predicted yield is not reached, e.g. the yield of grain crops was 30-50 % lower as a result of the drought this summer (2006). Growing of winter and catch crops can be useful. In such cases, in result of coincidence of other factors, such as long-lasting rainy period or big water amounts stocked during winter, will increase water flow and nutrient leaching and contamination of water bodies.

The aim of our investigations is to evaluate agricultural impact on water quality (especially nitrogen leaching), to reveal the areas where improvement in agricultural activity would be most favourable and to propose the mitigation measures.

Materials and Methods

Description of the study object (Graisupis watershed)

Since 1994 Lithuania has been engaged in BEAROP an international project studying agricultural runoff from the countries round the Baltic sea. The Graisupis watershed was selected for the monitoring purposes in the agricultural plains region of Middle Lithuania /Bučienė et al., 2003/. The river Graisupis is the second rank tributary of the river Nevėžis. It is located in the Lithuanian Middle Plain in the central part of

[1] Ministry of Agriculture, Ministry of Environment. Code of good agricultural practices for Lithuania. Rules and recommendations. - Kėdainiai, Vilainiai, 2000

Lithuania, Kėdainiai district. The area of the Graisupis watershed is 14.2 km^2 at the river water monitoring post where water level of the river is measured continuously and water samples for chemical analysis are taken twice a week /Gaigalis et al., 2004/.

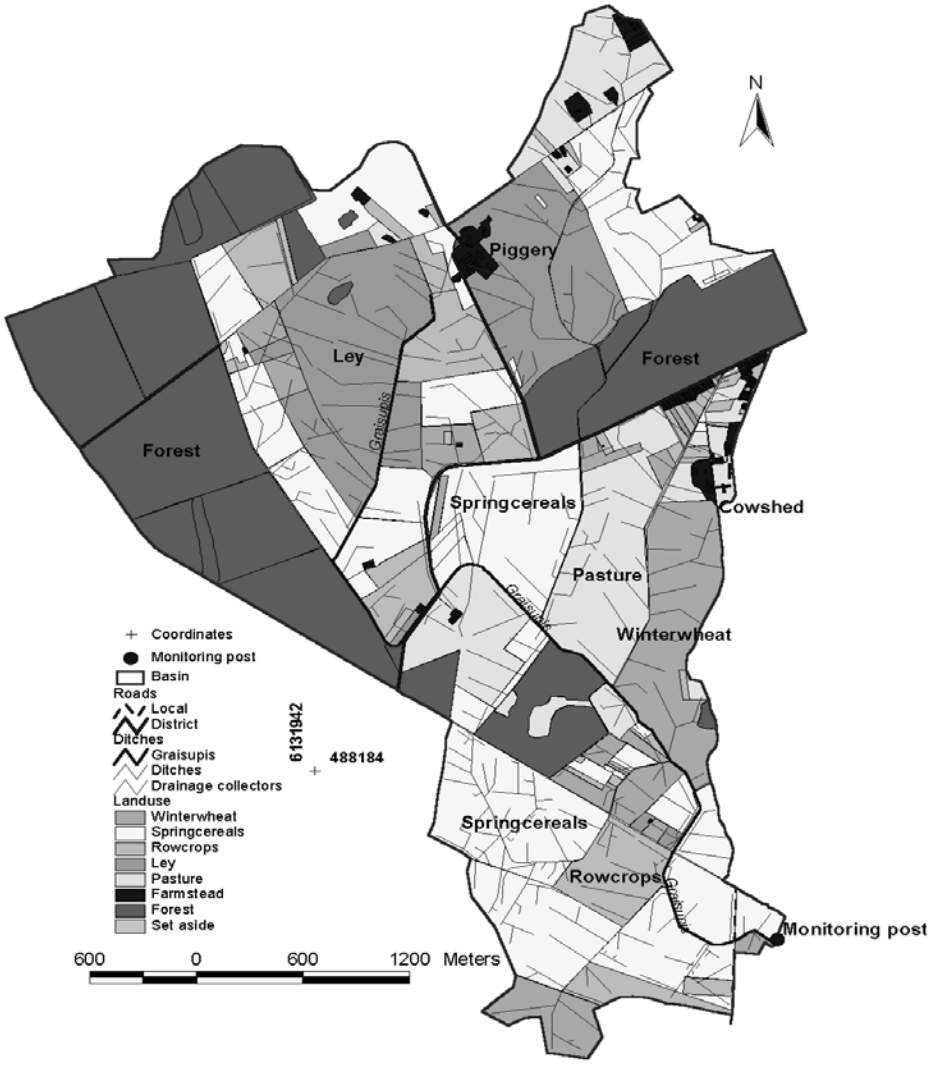

Figure 1. Land use in the Graisupis watershed
1 paveikslas. *Žemėnauda Graisupio baseine*

The Graisupis watershed lies on a Silurian limestone bedrock. Soils are mainly Endocalcari-Endohypogleyic Cambisols with light loam and sandy loam textures. The landscape is flat, 60-70 m above the sea level.

Soil in the Graisupis watershed is saturated with phosphorus and rather poor in potassium. The average mineral N content was found to be 0.65 mg 100 g of soil^{-1} when 12 fields of various crops had been investigated. Fertile soils and flat land surface gives good opportunities for the intensive agricultural production. All agricultural land in the watershed is drained by subsurface drainage. The main part of the watershed is occupied by arable land (54 %) and some by grassland (15 %). Forests cover 29 % of the watershed area (Figure 1).

N leaching coefficients

Nitrogen concentrations for winter crops, spring crops, row crops and pasture in 2000-2005 were obtained by measuring the concentrations in about 50 drainage systems in spring annually in the Graisupis demonstration watershed. Mean concentration for each group of crops was calculated according to the crops grown on the drained fields (standard errors for the mean concentrations are presented in the table). Every year the crops grown on most of the fields of the Graisupis watershed were registered. Total nitrogen (N) in the water was determined by photometric method using phenoldisulphoacid and potassium peroxodisulphate after oxidation[2]. Hypothesis that the concentrations for the crop groups are equal was tested by Student's t-test assuming that variances are equal. Error probability was calculated in order to reject the hypothesis. Microsoft Office Excel programme (two-sample t-test assuming equal variances) was used for the statistical analysis. Nitrogen leaching coefficients (kg N ha^{-1} year^{-1}) for each crop group was calculated using the mean concentrations and mean annual water discharge measured at the Graisupis water monitoring post.

Pollution mitigation measures

Farming practices on the farms of the Graisupis watershed were analysed from the environmental point of view. Measures for mitigation of the nutrient leaching were proposed and their positive and negative environmental and economic effects were pointed out. The nitrogen leaching coefficients for different crop groups were used to calculate reduction in leaching if one crop was substituted by another crop. Results from our earlier investigations /Kutra et al., 1996; Kutra, Račkauskaitė, 2001; Aksomaitienė et al., 2002; Kutra, Aksomaitienė, 2003; Baigys et al., 2006/ were used to evaluate leaching reduction for the mitigation measures other than the changes in crop rotation. Effectiveness of each measure for the watershed was calculated according to the reduction of leaching for a watershed area unit and to the area of the watershed where the proposed mitigation measure should be applied.

Results and discussion

Mean nitrogen concentration in the drainage water from the fields occupied by pasture was the lowest among all the fields and comprised 6.1 mg l^{-1} on the average in

[2] Lietuvos Respublikos Aplinkos Ministerija. Unifikuoti nuotekų ir paviršinių vandenų kokybės tyrimų metodai. - Vilnius, 1994.

2000-2005 in the Graisupis watershed (0). The mean concentration from winter cereals, spring cereals and row crops was 9.6, 11.0 and 13.0 mg l^{-1} respectively. Student's t-test showed the probability that the mean concentrations of different crop groups are equal is less than 30 % (the probability that mean N concentration from pasture is equal to other crops is only 8 %).

Table 2. N mean concentration (± standard error) and leaching coefficients for each crop group in 2000-2005
2 lentelė. Vidutinė N koncentracija ir išplovimo koeficientai kiekvienai pasėlių grupei 2000-2005 metais

Crop group *Pasėlių grupės*	Concentration mg l^{-1} *Koncentracija mg l^{-1}*	Leaching kg ha^{-1} $year^{-1}$ *Išplovimas kg ha^{-1} per metus*
Pasture / *Ganyklos*	6.1±1.3	10.5
Winter cereals / *Žieminiai javai*	9.6±2.0	16.5
Spring cereals / *Vasariniai javai*	11.0±1.5	18.9
Row crops / *Kaupiamieji*	13.0±1.9	22.4

Nitrogen leaching coefficient was 10.5 kg ha^{-1} $year^{-1}$ for the pastures and other perennial grass fields of the Graisupis watershed (0). Nitrogen leaching for winter and spring cereals was 16.5 and 18.9 kg ha^{-1} $year^{-1}$. The highest leaching observed for the row crops (sugar beets mainly) comprised 22.4 kg ha^{-1} $year^{-1}$ for the period of 2000 to 2005 on the average.

Nitrogen concentration in the river Graisupis was lower than its concentration contained in the drainage water from the arable land fields. Mean flow-weighted concentration measured in the Graisupis river at water monitoring post was 7.5 mg l^{-1} in 2000-2005. Mean annual nitrogen runoff of the watershed was 12.8 kg ha^{-1}.

Crop structure on the main farms of the Graisupis watershed is given in 0. As we stated in the introduction part of this manuscript, farmers seeking to improve their economy in farming practice often use such cropping systems that are hardly approved from the environmental point of view. On some farms cereals or sugar beets occupy more than 2/3 of all the crop area (0).

The amount of commercial nitrogen fertilizers is often not balanced with the need of crops. Calculations done according to the LAI methodology show that seeking grain crop yield above 6-7 t ha^{-1} is not environmentally sound and exceeds nutrient storage capacities in the soil. Changes in farming practices in the Graisupis watershed should be implemented in near future seeking to prevent the increase of water pollution.

The EU policy for the development of agriculture in the member states promotes suitable measures to improve farming practices, which helps to solve environmental problems. In many cases environmentally sound measures can help to decrease total income and profitability of farmers, but production after the implementation of the recommended measures will become more stable and less vulnerable to extreme natural conditions as well as economic problems.

Table 3. Crop structure in the Graisupis watershed and on each farm in 2005
3 lentelė. *Pasėlių struktūra Graisupio baseine ir kiekviename ūkyje 2005 metais*

Farm No. *Ūkio Nr.*	Crop share % *Pasėlių dalis %*							
	Spring cereals *Vasariniai javai*	Winter cereals *Žieminiai javai*	Sugar beet *Cukriniai runkeliai*	Maize *Kukurūzai*	Vegetables *Daržovės*	Pasture *Ganyklos*	Clover *Dobilai*	Fallow land *Pūdymas*
1	33.6	3.7	1.7	11	0.1	38.5	10.5	1.0
2	31.2	43.7	2.2	-	0.2	11.5	-	-
3	64.2	10.2	25.6	-	-	-	-	-
4	49.5	13.5	15.4	-	-	19.4	2.2	-
5	100	-	-	-	-	-	-	-
6	-	100	-	-	-	-	-	-
7	-	-	100	-	-	-	-	-
8	23.3	-	-	-	16.7	36.7	23.3	-
Graisupis watershed *Graisupio baseinas*	45.8	12.1	12.0	2.8	1.2	20.6	5.2	0.2

In 0 we present some measures that, we find, are more promising and applicable for use in the Graisupis watershed and similar territories of high agricultural productivity.

Some measures, such as increased area under perennial grasses (Scenario A), are very effective from the environmental point of view, but are not economically feasible for the territories of high productivity such as the Graisupis watershed. In our opinion, the most rational solution is when perennial grasses occupy 1/5 of the total area, or 1 field for a 5-field rotation.

The possibility to reduce the area of grain crops (Scenario A) is limited. Grains are in great demand for food industry; they are the main feed for poultry and pork production. Besides, the demand for grain fodder increases when animal production becomes more intensive. Substitution of grain crops by rape does not lead to big reduction in leaching, but it is favourable from an environmental point of view as rape is more often used for organic fuel production.

Balanced fertilization as a mitigation measure is proposed for Scenario B according to the results of our earlier investigations /Kutra et al., 1996; Kutra, Račkauskaitė, 2001; Aksomaitienė et al., 2002; Kutra, Aksomaitienė, 2003/. Misbalanced use of P and K fertilizers is one of the factors leading to increased nutrients surplus in soil. According to Aksomaitienė et al. (2003), leaching of nitrogen (y) depends on N content in the soil (x_1) and on fertilization (x_2) by the following relationships: $y = 0.26x_1+3.4$ ($R^2 = 0.68$), $y = 14.57-0.061x_2+0.00058x_2^2$ ($R^2 = 0.74$). Effectiveness of nutrient leaching for this scenario is approximated to 10%.

Table 4. Measures for mitigation of nutrient leaching in the Graisupis watershed and their effect

4 lentelė. *Išplovimą mažinančios priemonės Graisupio baseine ir jų poveikis*

Mitigation measures *Taršą mažinančios priemonės*	Reduction in leaching % *Išplovimo sumažėjimas %*	Applied area ha *Pritaikymo teritorija ha*	Effect on the river % *Poveikis upei %*	Positive and negative environmental and economic effects *Teigiamas ir neigiamas aplinkosauginis bei ekonominis poveikis*
1	2	3	4	5
Scenario A. Environmentally sound crop rotations on plant production farms. 4 years' programme *A scenarijus. Pažangios aplinkosauginės sėjomainos augalininkystės ūkiuose. 4 metų programa*				
Change of ¼ of sugar beets to rape *¼ cukrinių runkelių pakeitimas rapsais*	20	40	0.6	**Positive**: can be supported by country energetic programs, decrease in nutrient leaching and expenses for crop cultivation. **Negative**: lower income from production, decrease variation of crops. ***Teigiamas****: gali būti remiama sprendžiant šalies energetikos programą, sumažėja maisto medžia-gų išsiplovimas ir augalų auginimo sąnaudos.* ***Neigiamas****: už produkciją gaunama mažiau pajamų, mažėja augalų įvairovė.*
Change of ¼ of grain crops to rape *¼ javų pakeitimas rapsais*	10	140	1.0	**Positive**: can be supported by country energetic programs, higher income, and improved crop rotation and soil nutrient use. **Negative**: expenses for new equipments and technologies. ***Teigiamas****: gali būti remiama, sprendžiant šalies ener-getikos programą, gaunama daugiau pajamų, pagerėja pasėlių rotacija ir maisto medžiagų panaudojimas.* ***Neigiamas****: išlaidos naujiems mechanizmams įsigyti ir technologijai įsavinti.*
Perennial grasses in 1/5 of total crop area *Daugiametės žolės 1/5 pasėlių teritorijos*	50	80	2.8	**Positive**: large decrease in nutrient leaching. Improved soil structure and humus balance. **Negative**: lower income. Expenses for new equipment and technologies. ***Teigiamas****: žymiai sumažėja maisto medžiagų išsiplovi-mas, pagerėja dirvožemio struktūra ir humuso balansas.* ***Neigiamas****: mažiau pajamų. Išlaidos žolių derliaus dorojimo technikai įsigyti ir technologijoms įsavinti.*
	Total of scenario A *Iš viso pagal A scenarijų*		4.4	
Scenario B. Balanced fertilization. 3 years' programme *B scenarijus. Subalansuotas tręšimas. 3 metų programa*				
Analysis of plant available P and K in 1/3 of fields *P ir K tyrimai 1/3 laukų*	10	300	2.1	**Positive**: decrease of leaching and soil overloading by nutrients when results of analysis are used for fertilization planning. **Negative**: expenses for analysis. ***Teigiamas****: sumažėja išsiplovimo ir maisto medžiagų pertekliaus dirvožemyje tikimybė, kai tręšimo normos nustatomos pagal tyrimų rezultatus.* ***Neigiamas****: išlaidos analizėms.*

Table 4 continued
4 lentelės tęsinys

1	2	3	4	5
Use of organic fertilizers for 1/5 of total crop area *Organinės trąšos 1/5 teritorijos*	10	200	1.4	**Positive**: improved humus balance and soil structure. Increase in fertilization effectiveness and decrease in leaching. **Negative**: expenses for manure handling, compost making and spreading. ***Teigiamas**: humuso balanso ir dirvožemio struktūros pagerėjimas. Tręšimo efektyvumo padidėjimas ir maisto medžiagų išsiplovimo sumažėjimas.* ***Neigiamas**: didelės mėšlo saugaus laikymo ir naudojimo bei komposto gamybos sąnaudos.*
	Total of scenario B *Iš viso pagal B scenarijų*		3.5	
	Scenario C. Minimized and late autumn soil tillage *C scenarijus. Minimalus ir vėlyvas rudeninis dirbimas*			
Minimized soil tillage *Minimalus dirbimas*	30	365	7.7	**Positive**: lower expenses for soil tillage, decreased humus mineralization, decreased leaching. **Negative**: investment in new machinery. Lower yield. Increased use of herbicides. ***Teigiamas**: mažesnės žemės dirbimo sąnaudos, humuso mineralizacijos ir maisto medžiagų išsiplovimo sumažėjimas.* ***Neigiamas**: investicijos ir kitos išlaidos naujai technikai įsigyti bei technologijoms įsisavinti. Mažesnis derlius. Herbicidų naudojimo didėjimas.*
Late autumn soil ploughing *Vėlyvas rudeninis arimas*	30	365	7.7	**Positive**: decreased nutrients leaching. Improved planning and organisation of field work. **Negative**: worse weather and soil conditions for ploughing and short daytime. ***Teigiamas**: maisto medžiagų išsiplovimo sumažėjimas. Darbų planavimo ir organizavimo sąlygų, visapusiškiau panaudojant turimas mechanines priemones, pagerėjimas.* ***Neigiamas**: darbo sąlygų pablogėjimas sutrumpėjus dienai ir padidėjus dirvožemio drėgmei.*
	Total of scenario C *Iš viso pagal C scenarijų*		15.4	
	Scenario D. Catch crops *D scenarijus. Tarpiniai augalai*			
Catch crops after harvesting of grain crops *Tarpiniai augalai nuėmus javus*	30	570	12	**Positive**: decreased nutrient leaching. **Negative**: expenses for seeds. Leaching increase when catch crops organic matter is decayed. ***Teigiamas**: maisto medžiagų išsiplovimo sumažėjimas.* ***Neigiamas**: išlaidos sėkloms. Maisto medžiagų išsiplovimo padidėjimas susikaupusioms organinėms medžiagoms mineralizuojantis vėlesniais metais.*
	Total of scenario D *Iš viso pagal D scenarijų*		12	
	Total of all measures *Iš viso, įgyvendinus visas priemones*		35.3	

Saving energy resources and reducing labour expenses, the measures such as minimized soil tillage (Scenario C) become more popular. Moreover, our investigations show that it leads to reduced nutrient leaching. As a result of 5-year rotation experiment, nitrogen leaching from fields of conventional tillage was 148 kg ha^{-1}; the leaching from fields of minimized tillage (using a disc cultivator) was 103 kg ha^{-1}; and when ploughing by a mouldboard plough was performed late autumn (before freezing in November) the leaching was 98 kg ha^{-1}. Approximated leaching decrease was 30 % /Baigys et al., 2006/.

The effectiveness of catch crops (Scenario D) to decrease nitrogen leaching has been investigated in Sweden for many years /Stenberg, 1988/. Our investigations /Baigys et al., 2006/ revealed that on the average during the first year of undersown annual ryegrass (*Lolium multiflorum*) nitrogen leaching decreased by 23 % (from 21.6 kg N ha^{-1} to 18.1 kg N ha^{-1}), and during the second year the effectiveness increased and it was 38 % (from 28 kg N ha^{-1} to 11.2 kg N ha^{-1}). Approximate effectiveness was 30 %.

Total reduction in nitrogen leaching could reach 35.3 % (0) if all the proposed measures were applied in the watershed, i.e. mean annual nitrogen runoff would decrease from 12.8 to 8.3 kg ha^{-1}. A similar study performed in Sweden showed that nitrogen leaching could be reduced by between 34 and 54 % for separate catchments if the following measures were applied: applying manure in spring instead of autumn; postponing ploughing-in of ley and green fallow in autumn; undersowing a catch crop in cereals and oilseeds; and increasing the area of catch crops by substituting winter cereals and winter oilseeds with corresponding spring crops /Kyllmar et al., 2005/.

The effectiveness of the proposed mitigation measures should be elaborated further as they had been investigated on a plot level only. When the measures have been applied in at least a few watersheds, the estimations will be further improved.

Conclusions

A 6-year mean nitrogen concentration in the drainage water draining pasture was 6.1 mg l^{-1}. Corresponding concentration for winter cereals, spring cereals and row crops was 9.6, 11.0 and 13.0 mg l^{-1}.

The scheme of measures for nutrient leaching mitigation was prepared by analysing nutrient leaching patterns and farming practices in the Graisupis watershed and summarising the results of crop rotation environmental impact. According to the scheme, nitrogen leaching in a watershed could be reduced by 35 %, i. e. by 4.5 kg ha^{-1}.

The scheme is of great value for planning farming activities under conditions of intensive agricultural production when environmental impact is concerned. The described effect on water quality allows assessing the effectiveness of the measures on a watershed scale.

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ŽEMĖNAUDOS POVEIKIS AZOTO IŠPLOVIMUI IR TARŠOS MAŽINIMO GALIMYBĖS

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Santrauka

Dirvos dirbimo ir naudojimo ir azoto išplovimo tyrimas atliktas Graisupio upelio baseine (Kėdainių r.), kuris intensyviu žemės naudojimu yra būdingas Vidurio Lietuvos regionui.

Tyrimas parodė, kad daugiausia azoto išplaunama iš kaupiamųjų augalų laukų (22,4 kg ha^{-1} per metus). Azoto išplovimas iš laukų, kur auginami vasariniai ir žieminiai javai, buvo atitinkamai 18,9 ir 16,59,6 kg ha^{-1}. Mažiausias azoto išplovimas nustatytas iš ganyklų (10,5 kg ha^{-1}).

Graisupio baseinui buvo paruošti keli priemonių scenarijai siekiant nustatyti, kaip sumažinti azoto išplovimą. Praktikoje žolių santykinių plotų padidinimas yra problemiškas. Atlikta analizė atskleidė, kad tręšimas, neviršijantis augalų poreikio, ir supaprastintas žemės dirbimas efektyviau sumažina azoto išplovimą negu pasėlių struktūros keitimas.

Reikšminiai žodžiai: žemėnauda, azotas, baseinas, išplovimo mažinimas.