AGRICULTURAL SCIENCE AND TECHNOLOGY, VOL. 16, No 1, pp 85-93, 2024
Published by Faculty of Agriculture, Trakia University, Bulgaria
ISSN 1313-8820 (print)
ISSN 1314-412X (online)
http://www.agriscitech.eu
DOI: 10.15547/ast.2024.01.010

Effect of crop rotation on nitrogen leaching with the lysimetric waters in vulnerable areas

Ts. Simeonova*, L. Nenova, M. Benkova, M. Nenov

Agricultural Academy, Institute of Soil Science, Agrotechnologies and Plant Protection "N. Poushkarov", Sofia, Bulgaria

(Manuscript received 20 March 2023; accepted for publication 19 February 2024)

Abstract. *Climate change is known to subject the functioning of agroecosystems to high levels of biotic and abiotic stress and has a significant impact on agricultural production worldwide. Crop rotation is believed to be one way of adapting agriculture to climate change compared to monoculture This study aimed to examine the maize-wheat rotation impact on soil nitrogen dynamics and leaching losses. A study has been carried out on the experimental field of Tsalapitsa, Plovdiv region on Fluvisol. In this maize-wheat rotation experiment, we compared three fertilization treatments with increasing nitrogen and phosphorus rates to a control with no fertilization. In 2020, grain maize (Zea mays L.) FAO group 310, was grown with fertilizer rates ($T_0N_0P_0$; $T_1N_{120}P_{80}$; $T_2N_{160}P_{120}$; $T_3N_{200}P_{160}$). In the period 2020/2021, wheat, (Triticum aestivum L.), was grown with the following fertilizer variants - (T_0 N_0P_0; $T_1N_{100}P_{60}$; T_2 $N_{140}P_{100}$; T_3 $N_{180}P_{140}$). The field plots were equipped with modification of Ebermayer type of lysimeters, which collect water from 100 cm depth of soil profile. The volume of lysimetric waters was calculated, the nitrogen content and its leaching were analyzed.*

The study found that the lysimetric water volume after maize cultivation was 75.95 liters per square meter, approximately 2.5 to 3 times higher than that observed after wheat cultivation. Nitrogen content varied with fertilization rates, ranging from 10.8 to 37.5 mg/L for maize and 8.73 to 23.58 mg/L for wheat. The losses of the element with drainage runoff with the first crop were – 5.6-28.5 kg.ha^{-1}, and with wheat – 1.2-6.3 kg.ha^{-1}, respectively. It was established that when cereal crops were grown the losses of nitrate nitrogen out of the root zone were significantly reduced.

Keywords: loss of nitrates, crop rotation, infiltrate, intensive agriculture

Introduction

The increasing nitrogen loading due to inorganic fertilizers used in conventional agriculture is one of the major global environmental challenges (Jurisic et al., 2014). The different forms of nitrogen in the soil depend mainly on the processes of immobilization and mineralization of organic substances (Sądej and Przekwas, 2008). Levels of plant available forms of nitrogen in the soil are usually low and they range from 1 to 5%. Applying large amounts of nitrogen fertilizers can pose environmental risks due to the complex and dynamic processes that govern nitrogen behavior in the soil.

One of the ways of nitrogen losses is its export along the soil profile and reaching to the level of shallow groundwater, eutrophication of surface waters, etc. The content and balance of chemical

*e-mail: cecka_simeonova@abv.bg

elements in soils and shallow groundwater are significantly affected by the anthropogenic load during cultivation of agricultural crops. For a better understanding of the processes, it is necessary to consider the groundwater-soil relationship as a whole, since their chemical composition begins to form passing through the soil horizon (Soldatova et al., 2019).

According to Huang et al. (2017), the understanding of the factors which control nitrate leaching processes under certain soil and climatic conditions and the different agricultural practices applied may increase knowledge for formulating targeted mitigation strategies to control nutrient exports. The applied agricultural practices such as tillage, rotations and use of catch crops can affect actual N losses (Notaris et al., 2018). Crop rotation of cover crops with winter wheat allows reduction of nitrogen leaching and the gaseous losses of ammonia (Jia et al., 2014; Huang et al., 2017; Wang et al., 2019). Crop rotation can play a major role in minimizing the potential risk of nitrate leaching into surface and groundwater by reducing soil nitrogen availability, reducing the amount of nitrogen fertilizer applied, etc. Other authors (Li et al., 2023), found that rotation also corrects soil water and nutrients distribution by crops cultivation with deep and shallow roots, and this way are enhancing yields and the fertilizer use efficiency and rainfall. Overall, the measures for conserving N, when frequently used within a crop rotation, effectively reduced NO3 concentrations in drainage water and NO3-N leaching losses, without severely affecting yield (Myrbeck and Stenberg, 2014).

The purpose of the research was to study the influence of maize-wheat crop rotation on the behavior, content and losses of nitrogen outside the root zone.

Material and methods

A study was carried out on the experimental field of Tsalapitsa, Plovdiv region (42°10.8’ N, 24°32.5’ E) on the area of a long-term experiment (started in 1995, Stoicheva et al., 2008), where maize and wheat were grown, as part of a field crop rotation. In 2020, grain maize (*Zea mays* L.), FAO group 310, was grown with fertilizer rates ($T_0N_0P_0$; $T_1N_{120}P_{80}$; $T_2N_{160}P_{120}$; $T_3N_{200}P_{160}$). In the period 2020/2021, wheat (*Triticum aestivum* L.), was grown with the following fertilizer variants - (T_0 N_0P_0; T_1 $N_{100}P_{60}$; T_2 $N_{140}P_{100}$; T_3 $N_{180}P_{140}$) kg.ha^{-1}. Nitrogen fertilizer (ammonium nitrate) was applied to both crops - 2/3 of the rate before sowing and 1/3 for feeding in the spring. Phosphorous fertilizer (as triple superphosphate) was applied before planting, during the previous autumn for each of the experimental years. Potassium fertilizer was not applied. Fertilization rates depend on the nutrient content of the soil and the type of crop grown. The scheme of the experiment is in accordance with installed Ebermeyer type lysimeter devices (Stoichev, 1974) at a depth of 0-100 cm from the soil surface, in three replications under each variant. A randomized block design was used, each experimental plot was 100.8 m^2. The climate in the area has hot and dry summers and mild winters (Levichanska, 1991). The area was characterized by average annual rainfall of 444 mm in 2020 and 601 mm in 2021. The average annual air temperature is 12.5-12.8°C. All necessary agro-technical measures for the cultivated crops were maintained.

The investigated soil is alluvial-meadow. It is classified as Fluvisol according to the World Reference Base for Soil Resources – WRB (IUSS Working Group WRB, 2015). The soil profile has coarse texture, low water holding capacity and conditions for fast water movement downward the profile. The arable horizon is characterized by slightly acid soil reaction pH $_{H20}$ = 6.0, low total nitrogen content (0.052%), low cation exchange capacity (up to 23.11%) in the plough layer (Table 1). Base saturation is about 74%. The agrochemical characteristics of the alluvial meadow soil are: mineral N content - 21.25 mg. kg^{-1}, available P and K - 7.50 and 10.20 mg 100 g^{-1}, respectively, for the layer 0-30 cm. The chemical composition of every registered precipitation was analysed. To assess the effect of agricultural activities on the content and leaching of nitrates and other chemical elements, lysimetric water analysis was used. Lysimetric water samples were taken several times a year depending on the amount of infiltrate from the plastic containers (5.0 L) installed at the bottom outlet of each lysimeter.

The pH values and chemical composition of precipitation and lysimetric waters were analysed. The pH values (potentiometrically by Arinushkina, 1970) and the nitrate nitrogen content (spectrophotometer "Spectroquant Pharo 100) in the waters were studied. Depending on the volume and concentration of chemical elements in the lysimeter waters, the export of nitrogen below one-meter soil layer was calculated. The pH (H_2O) values were determined potentiometrically in a soil:water ratio 1:2.5. The agrochemical parameters of the soil were analyzed by the following methods: nitrogen (N) – by the method of Bremner (1965), available phosphorus and potassium (P and K) – by the oxalate-lactate method of Ivanov (1984). Cation exchange capacity (CEC) was assessed as sum of titratable acidity (pH 8.2) and extractable Ca, by saturation with K malate at pH 8.2 (Ganev and Arsova 1980).

Table 1. Characteristics of the studied Fluvisol*

Horizons	Depth, cm	pH_{H2O}	Organic C, %	Total N, %	C:N	$CaCO_3$, %	Cation exchange capacity, $cmol.kg^{-1}$	Particle size, mm 0.05- 0.001 %	< 0.001 %	<0.01 %
Alluvial-meadow soil - Eutric Fluvisol (WRBSR)										
A_{arable}	0-35	6.0	0.70	0.052	7.8	0.00	7.92	33	13	32
A_2	35-60	6.4	0.55	0.050	6.4	0.00	18.18	32	33	35
A_3C_1	60-87	6.5	0.42	0.042	5.8	0.00	22.77	37	36	40
C_2	87-118	6.5	0.38	0.030	7.5	0.00	23.11	47	27	-

*(Stoichev, 1997)

Results and discussion

The concentration of nitrates, the depth and the rate of leaching of nitrate nitrogen are determined by the specific soil and climatic factors, the ways of land use in a certain area as well as from the interactions between them (Huang, 2017). It is known that the cultivation technology of different crops and its influence on the agroecosystem has a determining role on the soil water characteristics in the one-meter layer. This is the zone of active root activity, whose water and air regime determines both the conditions for the development of cultivated plants and the formation of infiltration runoff. It is a potential transporter of nitrogen and other nutrients to groundwaters. Alluvial-meadow soil has a specific soil water and air regime, which is less favorable than zonal soils. With them, for example, with about twice the amount of precipitation, the water-holding capacity can be filled and a drainage runoff can be formed under the one-meter soil layer.

Volume of lysimeter waters

The amounts of chemical elements exported with the lysimeter waters are directly dependent on the infiltrated amounts of water, which are determined by the soil water characteristics and by the water regime created by rainfall and irrigation water. The studied soil is characterized by significant spatial heterogeneity and great variety in the arrangement of alluvial materials throughout the profile. The greatest percentage of infiltrated water relative to the total amount of incoming water for this soil occurs when the input of large amounts of precipitation coincides with the applied irrigations. The increase in precipitation in 2021 to 601 mm, approximately 1.5 times the amount in 2020, suggests a potential for increased leaching and nutrient transport, particularly given the soil's characteristics (Table 2). Precipitation during the studied periods was irregularly distributed, both monthly and seasonally, but there was a spring and autumn maximum, better expressed in 2021, when winter wheat was grown. Then there was a very large variation (Coefficient of Variation, CV) of 81%, while in 2020 the coefficient of variation was lower - 55%.

Table 2. Precipitation (mm) for the study period (2020-2021), compared with a long-term period (1961 - 1990)*

Year	Months											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
2020	6.0	43.5	58.5	88.3	41.3	49.8	31.8	8.0	_	62.0	_	55.0
2021	87.0	31.0	27.0	76.0	44.0	42.0	_	28.0	16.0	165.0	9.0	76.0
1961-1990	40.5	32.0	41.0	43.6	59.9	48.2	45.7	33.3	28.8	30.3	45.6	43.1

*(Popova and Pepeira, 2011)

According to some authors (Owens et al., 2000), climatic conditions in certain years can have a significant influence on nitrogen leaching, even more significant than the applied agricultural techniques. The significant precipitation in the spring and snowmelt can be the cause of movement of nutrients and nitrogen out of the soil profile. Summer drought limits transpiration and nutrient uptake by plants and accumulated nitrogen is leached, especially on soils with a light mechanical composition, low water holding capacity and high water permeability like the studied soil. When the amount of precipitation increases by about 100 mm, the depth of leaching of nitrates increases by about 3 times, and their concentration by more than 2 times. A negative impact on the content and transformations of nitrogen in the soil is exerted by both drought and torrential local precipitation.

From the results obtained (Figure 1), it was established that the volume of lysimeter waters obtained from the different fertilization options under the one-meter soil layer in 2020, when growing maize, was within the limits of 53.21-75.95 l.m^2. The winter wheat amount varied from 13.5 to 32.7 l.m^2, which was 2 to 4 times less than the obtained in 2020.

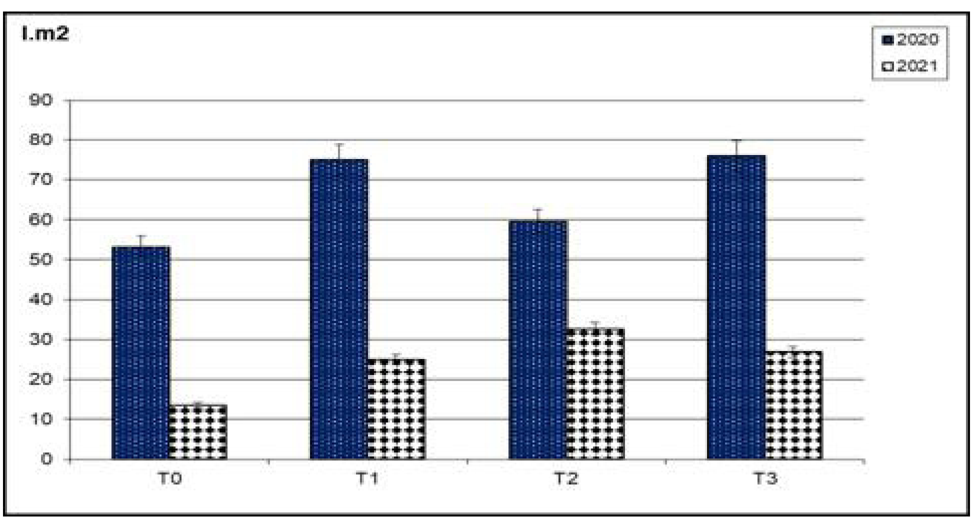

Figure 1. Volumes of lysimeter waters (l.m^2), when growing maize in 2020 and winter wheat in 2021, Tsalapitsa, Plovdiv Region

It was established that the resulting (Figure 2) amounts of leachate from the total amount of incoming water for 2020 were from 8 to 11%, which was close to the averages typical for this soil (between 7 and 13-14%). In 2021, the quantities were significantly lower, between 2 and 5%, due to the fact that no irrigation was applied to the cultivated crop (wheat).

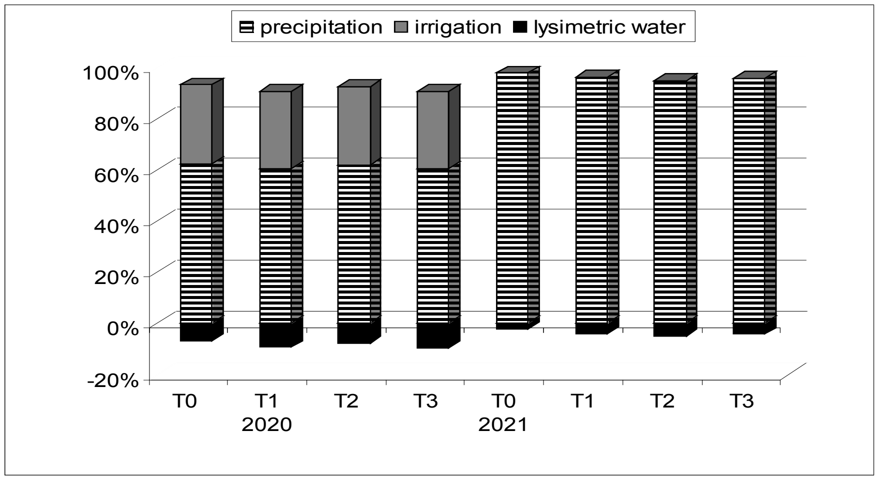

Figure 2. Amount of lysimeter waters draining the one-meter soil layer during the study period

Content of mineral nitrogen in the soil when growing both crops

The significant variation of mineral nitrogen content in time and space in the alluvial-meadow soil is explained by the fact that it is the result of two dynamic and complex processes - the mineralization of organic matter and mobilization of mineral nitrogen in organic forms. For this reason, the amount of mineral nitrogen in the soil profile is determined by its content at the time of the measurements, i.e. input with precipitation, irrigation water, seeds, fertilizers, free and symbiotic fixation and output with plants, gaseous losses and leaching. In this soil type it is very important and special attention should be paid to land use and the intensity of loading with organic and mineral fertilizers. According to Pasley et al. (2021), the processes that determine the state of nitrogen in the soil after the application of nitrogen fertilizers are not well studied, due to the cumulative effect of the influence of soil organic matter, residual nitrogen in the soil, nitrogen in plant residues, etc. According to the same authors, soils have a defined buffer between fertilization rates and nitrogen leaching along the soil profile, however, within a given field and season there is a threshold rate of N („limitation point“) above which the risk of contamination increases significantly. That is why it is important to determine how soil type, climate, and cropping systems affect the relationship between the fertilizer rate and leaching of nitrogen.

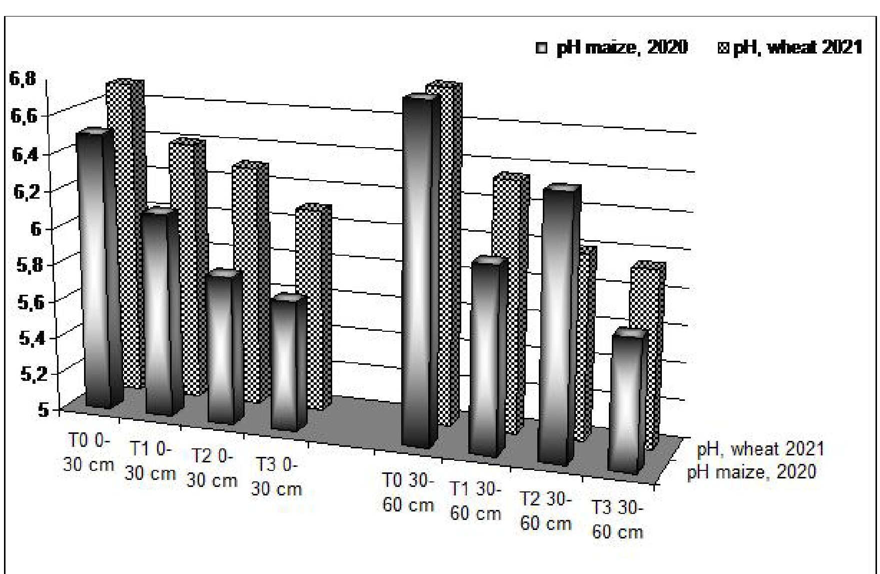

Figure 3. Soil pH values during the study period 2020-2021, Tsalapitsa, Plovdiv Region

It can be seen from Figure 3 that the pH values for the 0-30 layer were lower after growing maize (average 6.0+/-0.4) compared to wheat (6.4+/-0.3), while for the 30-60 soil layer equalization of the pH values was observed for both crops (6.2+/-0.5 and 6.3+/-0.4).

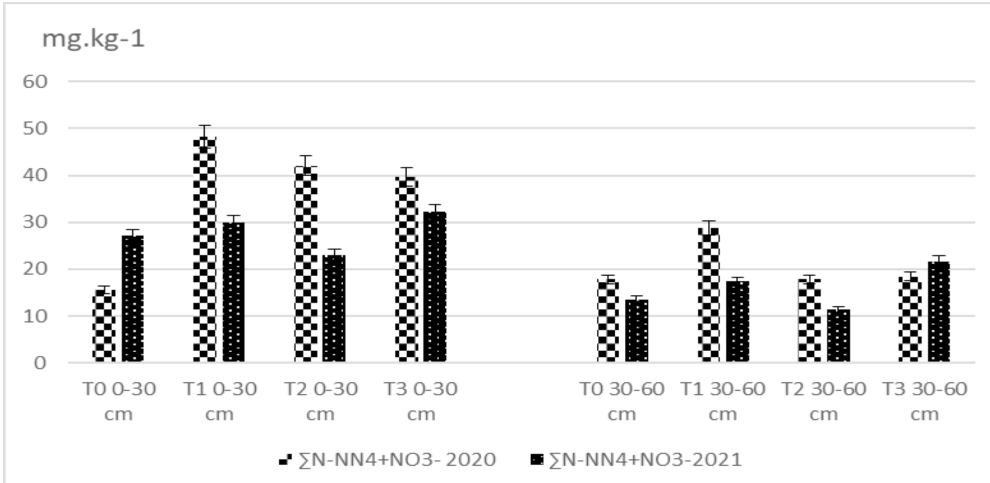

Figure 4. Mineral nitrogen content (mg.kg^{-1}) after growing maize in 2020 and wheat in 2021

The results obtained during the autumn of 2020 for the content of mineral nitrogen after maize cultivation (Figure 4) show that the differences in the surface layer (0-30 cm) are very well expressed and range between 15.55-48.38 mg.kg^{-1} depending on the studied fertilizer rate, while the differences in soil depth are relatively smaller. Equalization of the mineral nitrogen content for the 30-60 cm layer in the T_2 and T_3 variants was observed. From the data on the content of mineral nitrogen after growing wheat in the autumn of 2021, a higher content of mineral nitrogen was found for the surface layer - 0-30 cm (from 27.07 to 32.06 mg.kg^{-1}) compared to the 30-60 cm soil layer where values ranged between 13.6-21.7 mg.kg^{-1} depending on the fertilization rates. Blesh and Drinkwate (2013) reported that intensively cultivated areas under various agricultural practices contributed disproportionately to nitrate loading. However, creating conditions that produce high maize yields can reduce excess nitrogen in soils. In their research, Wang et al. (2019) found that the application of appropriate practices (changing the rates and timing of fertilizer application, the volume of irrigation, nitrification inhibitors, etc.), can reduce the nitrogen content in the soil to a certain extent without affecting the yields of the cultivated crops. It is known that monoculture cultivation can lead to constantly lower yields and to the accumulation of nitrates due to the lower efficiency of nitrogen use.

Nitrogen content and leaching with lysimeter waters in maize (2020) and wheat (2021) cultivation

Lysimeters are widely used to quantify nitrate leaching in situ because they can directly quantify the nitrate concentration and volume of water flow, reflecting the actual situation of field management accurately (Bakhsh et al., 2005).

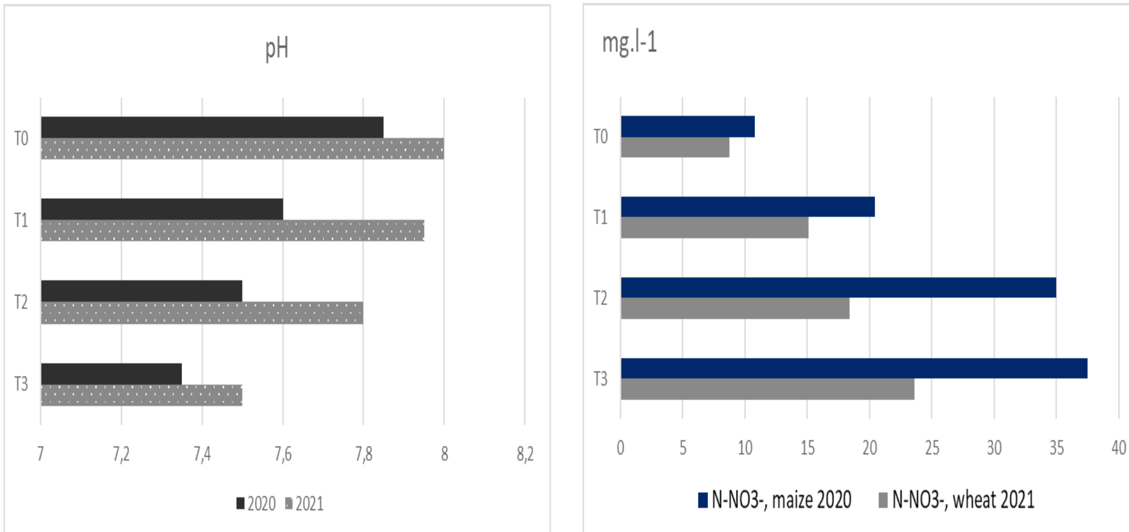

Figure 5. pH values and nitrate nitrogen content (mg.l^{-1}) in the lysimetric waters during the cultivation of maize 2020 and wheat 2021

The pH values in lysimetric waters with maize cultivation ranged from 7.35 to 7.85, while the pH values during wheat cultivation were slightly higher, ranging from 7.5 to 8. It was found that the content of nitrate nitrogen in the lysimeter waters (Figure 5) varied within certain limits depending on the fertilization rates. When growing maize in 2020 in the drainage, the nitrogen content was 10.8 mg.l^{-1} from T_0 variant up to 37.5 mg.l^{-1} for the maximum fertilized rate T_3 ($N_{200}P_{160}$). It should be noted that during wheat cultivation, the concentration of nitrate nitrogen in the lysimeter waters varied from 8.73 mg.l^{-1} in the variant without fertilization, to 23.58 mg.l^{-1} T_3 ($N_{180}P_{140}$). The nitrogen content in the solutions and lysimeter waters is directly dependent on the fertilization rate, which is also confirmed by the high correlation coefficient (R^2=0.91-0.98) in both cultivated crops. Based on the volumes and nitrogen content in the lysimeter waters, their leaching below the one-meter soil layer was calculated. After summarizing the results, it was found that the losses with the water obtained during the maize cultivation varied from 5.6 to 28.5 kg.ha^{-1} depending on the fertilization rates (Table 3). When growing wheat, leaching with lysimeter waters was about 3.5-4.5 times lower depending on the applied fertilization rates and varied within narrow limits of 1.2-6.3 kg.ha^{-1}. It was found that wheat cultivation resulted in an average decrease of 25% in the export of nitrate nitrogen compared to maize. Similar studies by Jurisic et al. (2014) and Zhang et al. (2015) also found higher nitrogen content and leaching with lysimeter waters after growing maize compared to winter wheat. Lapierre et al. (2022) also reported a strong reduction in nitrate export from fields if they were sown with cover crops of different cereal mixtures. Tonitto et al. (2006) found that using crop rotations with winter cover crops resulted in about 40% less nitrate leaching. Pasley et al. (2021) reported that rotating maize with soybean offered a greater environmental buffer against the impact of overfertilization on NO3-N leaching than continuous maize cultivation does.

Table 3. Nitrate nitrogen leaching (kg.ha-1) with the lysimetric waters during the study period 2020-2021

Variants	N-NO3-, maize, 2020	N-NO3-, wheat, 2021
T0	5.6	1.2
T1	15.3	3.8
T2	20.8	6.0
T3	28.5	6.3

Conclusion

After maize cultivation, the volume of lysimetric waters reached 75.95 l.m^2, while the drainage was about 2.5-3 times lower after wheat. The nitrogen content varied with fertilization rates, ranging from

10.8 to 37.5 mg/L for maize and from 8.73 to 23.58 mg/L for wheat. The losses of the element with drainage runoff with the first crop were 5.6-28.5 $kg.ha^{-1}$, and with wheat – 1.2-6.3 $kg.ha^{-1}$, respectively. It was established that when growing cereal crops, the losses of nitrate nitrogen out of the root zone were significantly reduced. The assumption is made that the rotation of maize and wheat is an appropriate technological solution that ensures maximum incorporation of nitrogen into the biological nutrient cycle and prevents the accumulation of residual nitrogen in the soil profile.

References

Arinushkina EV, 1970. Guidelines of chemical analysis of soil. Publishing house MGU, Moskow, p. 487 (Ru).

Bakhsh A, Kanwar RS and Karlen DL, 2005. Effects of liquid swine manure applications on NO3-N leaching losses to subsurface drainage water from loamy soils in Iowa. Agriculture, Ecosystems & Environment, 109, 118-128. https://doi.org/10.1016/j.agee.2005.01.018

Blesh J and Drinkwate LE, 2013. The impact of nitrogen source and crop rotation on nitrogen mass balances in the Mississippi River Basin. Ecological Application: a publication of the Ecological Society of America 23, 1017-1035. https://doi.org/10.1890/12-0132.1

Bremner JM, 1965. Inorganic forms of nitrogen. In: C. A. Black et al., (eds.) Methods of soil analyses. Part 2: Chemical and microbiological properties, № 9, Agronomy, American Society of Agronomy Inc. Madison, Wisconsin, USA, p. 1179-123

Ganev S and Arsova A, 1980. Methods for determining the strongly acidic and the slightly acidic cation exchange in soil. Soil Science and Agrochemistry, 15, 22-33 (Bg).

Huang T, Ju X and Yang H, 2017. Nitrate leaching in a winter wheat-summer maize rotation on a calcareous soil as affected by nitrogen and straw management. Scientific Report, 7, 42247. https://doi.org/10.1038/srep42247

Ivanov P, 1984. New acetate-lactate method for determination of available forms of P and K in soil. Soil Science and Agrochemistry, 4, 88-98 (Bg).

Jia X, Shao L, Liu P, Zhao B, Gu L, Dong Sh, Bing SH, Zhang J and Zhao B, 2014. Effect of different nitrogen and irrigation treatments on yield and nitrate leaching of summer maize (*Zea mays* L.) under lysimeter conditions. Agricultural Water Management, Elsevier, 137 (C), 92-103. DOI: 10.1016/j.agwat.2014.02.010

Jurisic A, Zgorelec Ž, Šestak I, Mesic M and Mikos V, 2014. Nitrate-nitrogen content in soil and lysimeter water under different nitrogen fertilization levels in crop production. Agriculturae Conspectus Scientificus, 79, 45-50. https://acs.agr.hr/acs/index.php/acs/article/view/858

Lapierre J, Machado PVF, Debruyn Z, Brown SE, Jordan S, Berg A, Biswas A, Henry HAL and Wagner-Riddle C, 2022. Cover crop mixtures: A powerful strategy to reduce post-harvest surplus of soil nitrate and leaching. Agriculture, Ecosystems and Environment, 325, 107750. doi:10.1016/j.agee. 2021.107750

Levichanska E, 1991. Climate of Bulgaria. Publishing House of Bulgarian Academy of Science, Sofia, p. 449 (Bg).

Li H, Zhang Y, Sun Y, Liu P, Zhang Qi, Wang X, Wang R and Li J, 2023. Long-term effects of optimized fertilization, tillage and crop rotation on soil fertility, crop yield and economic profit on the Loess Plateau. European Journal of Agronomy, 143, 126731. https://doi.org/10.1016/j.eja.2022.126731

Myrbeck Å and Stenberg M, 2014. Changes in N leaching and crop production as a result of measures to reduce N losses to water in a 6-yr crop rotation. Soil Use and Management, 30, 219-230. https://doi.org/10.1111/sum.12118

Notaris De Chiara, Rasmussen J, Sørensen P and Olesen JE, 2018. Nitrogen leaching: A crop rotation perspective on the effect of N surplus, field management and use of catch crop. Agriculture, Ecosystems and Environment, 255, 1-11. https://doi.org/10.1016/j.agee.2017.12.009

Owens LB, Malone RW, Shipitalo MJ, Edwards WM and Bonta JV, 2000. Lysimeter Study of Nitrate Leaching from a Corn-Soybean Rotation. Journal of Environmental Quality, 29, 467-474, https://doi.org/10.2134/jeq2000.00472425002900020015x

Pasley H, Nichols V, Castellano M, Baum M, Kladivko E, Helmers M and Archontoulis S, 2021. Rotating maize reduces the risk and rate of nitrate leaching. Environmental Research Letters, 16, 6. DOI 10.1088/1748-9326/abef8f

Popova Z and Pereira L , 2011. Modelling for maize irrigation scheduling using long term experimental data from Plovdiv region, Bulgaria. Agricultural Water Management, Elsevier, 98, 675-683, https://doi.org/10.1016/j.agwat.2010.11.009

Sądej W and Przekwas K, 2008. Fluctuations of nitrogen levels in soil profile under conditions of a long-term fertilization experiment. Plant, Soil and Environment, 54, 197-203, https://www.agriculturejournals.cz/pdfs/pse/2008/05/03.pdf

Soldatova E, Dong Y, Li J and Sun Z, 2019. Nitrogen behavior in the shallow groundwater–soil system within agricultural landscapes. E3S Web of Conferences, 98, 01046 WRI-16, https://doi.org/10.1051/e3sconf/20199801046

Stoichev D, 1974. A device to obtain lysimetric water. Soil Science and Agrochemistry, 5, 13-18 (Bg).

Stoichev D, 1997. Some ecological aspects of the anthropogenic loading on the soils. Thesis for DSc, Sofia, Bulgaria (Bg).

Stoicheva D, Kercheva M, Koleva V, Alexandrova P and Simeonova Ts, 2008. Good agricultural practices for protecting groundwater from nitrate pollution as a result of agricultural activity, Sofia, p. 32, ISBN: 978-954-749-078-9, (Bg).

Tonitto C, David MB and Drinkwater LE, 2006. Replacing bare fallows with cover crops in fertilizer-intensive cropping systems: a meta-analysis of crop yield and N dynamics. Agriculture, Ecosystems & Environment, 112, 58-72. https://doi.org/10.1016/j.agee.2005.07.003

Wang D, Guo L, Zheng L, Zhang Y, Yang R, Li M, Ma F, Zhang X and Li Y, 2019. Effects of nitrogen fertilizer and water management practices on nitrogen leaching from a typical open field used for vegetable planting in northern China. Agricultural Water Management, 213, 913-921. https://doi.org/10.1016/j.agwat.2018.12.015

IUSS Working Group WRB, 2015 World Reference Base for Soil Resources 2014, Update 2015. IUSS Working Group International Soil Classification System for Naming Soils and Creating Legends for Soil Maps. World Soil Resources Reports No. 106. FAO, Rome.

Zhang X, Davidson E, Mauzerall DL, Searchinger TD, Dumas P and Shen Ye, 2015. Managing nitrogen for sustainable development. Nature, 528, 51-59. https://doi.org/10.1038/nature1574