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Determination of Mineral Nitrogen Losses under the Action of Water Erosion Processes in Maize Growing on Sloping Terrains

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Abstract: *One of the main reasons for the reduction of soil productivity is water erosion, and its effect is depletion of soil layer, soil moisture holding capacity, soil organic matter, and nutrient supply. The availability of mineral nitrogen is a limiting factor for the productivity of ecosystems and unlike agricultural, in natural ecosystems, nitrogen cycles run with minimal losses. The efficiency of the use of mineral fertilizers is usually low and often much higher than plants actually need, that's why much of the mineral nutrients inserted by fertilizing are lost. The need for the development of sustainable farming systems requires soil protection from the impact of degradation processes and conservation of soil functions. For this purpose, different erosion control methods, measures and technologies are created and applied. In the present study the influence of conventional and soil protection technologies in the cultivation of maize on sloping terrains on the losses of mineral nitrogen under the influence of water erosion processes, is examined.*

Keywords*: maize, water erosion, mineral nitrogen loss, conventional technology, minimum tillage*

INTRODUCTION

The earth's surface is dominated by sloping terrains, which contributes to the occurrence of soil water erosion. Every year, as a result of its action, more than 75 Gt of the top soil layer is removed (Berhe et al., 2007). The related biogeochemical cycles of carbon (C) and nitrogen (N) are strongly affected by soil erosion as it affects their flow, storage, distribution, and residence time in the soil.

There are different ways of loss of nutrients from the soil. One is by surface removal under the action of water erosion processes, where they are taken away through surface water runoff and eroded soil to lower areas and in nearby water basins (Lal, 1991). Another way is by leaching from rain and irrigation. In dry areas in the United States, due to inefficient use or excessive application of fertilizers, after harvesting up to 90 kg ha-1 NO_3-N are leached at a depth between 1.5 and 2.5 m, below the root zone (Fuentes et al., 2003). Loss of nutrients can also occur through gaseous losses in the air, for example in alkaline soils or when organic fertilizers are applied on the soil surface, in the form of NO and NO_2, N_2 and ammonia. In a study of the impact of N-fertilizers applied on limestone sandy clay soils in the North China Plain (Cai et al., 2002), losses of nitrogen in the form of ammonia were found to be 30-39% of applied nitrogen in rice, 11-48% in maize, and about 20% in wheat (Mai Van Trinh, 2007).

Loss of nutrients leads to a number of environmental impacts. Nitrates, phosphates and other nutrients can cause eutrophication of water basins and contamination of drinking water, which creates conditions for potential health risks.

As a result of a study of the different erosion parameters of natural factors in the Republic of Bulgaria it is estimated that 62% of the territory of our country has a potential erosion risk of 10 t/ha y and for 43% of the territory the potential risk exceeds 10 t/ha y.

The consequences of the action of water erosion are of great importance for the economic life of humans, and the damage caused of it is enormous, which requires the application of a system of erosion control measures by implementation of different methods and technologies.

The purpose of this study is to examine mineral nitrogen losses in maize for grain cultivation, using conventional technologies, as well as application of soil protection, on sloping agricultural lands, on soil calcareous chernozem.

MATERIAL AND METHODS

The study was conducted in the period 2015-2017y., in the experimental field of the "Nikola Pushkarov" Institute of Soil Science, Agrotechnologies and Plant Protection - Sofia, on the territory of the village of Trastenik, Rousse district, in non-irrigated conditions, on a medium eroded calcareous chernozem, on slope 5° (8.7%).

A single factor field experiment with grain maize was conducted, using the block method, in four variants, in four replicates. The tested variants are:

13th - maize plots, grown by conventional technology, applied along the slope - control;

14 th - maize plots, grown by using conventional technology applied across the slope;

15 th - maize plots, grown by erosion control technology, including surface mulching with manure, all operations applied across the slope;

16 th - maize plots, grown by erosion control technology, including soil tillage without reversing the layer - loosening and soil protection operation vertical mulching with manure, slits with ducts forming, along with sowing and digging and furrowing along the hilling (advanced technology for minimum unconventional soil tillage) applied across the slope.

During the three year survey period, all the technological operations carried out in variant 13 and 14 were conventional and the same, the difference between them is only in the direction of their realization. In the control variant, they are applied along the slope, and in variant 14 in the transverse direction. In the same direction, the operations in variant 15 were carried out, before sowing, the erosion control method surface mulching with manure was applied (4500-5000 kg / ha), using a fertilizer trailer 1PTU-6.

In the last 16th variant, the erosion control methods are included, such as basic soil loosening as basic soil tillage, vertical mulching with manure, forming slits with ducts, along with sowing and digging and furrowing along the hilling operation. In this case, the chisel cultivator CP-9, a specialized machine for vertical mulching, the hoeing devices mounted on the SPS-6 pneumatic sowing frame and the KOV-4.2 cultivator, and a combined (forming slits and ducts) cultivator KRN 4.2.

The area of the grain maize experiment was after wheat predecessor and was fertilized with N10P8K8 kg/da, with phosphorus (potassium phosphate) and potassium (potassium chloride) fertilizers being introduced before plowing, and all nitrogen fertilizer (ammonium nitrate) applied pre-sowing.

The erosion measurements are carried out by the stationary method and for each variant there were constructed 15m x 5m sites with an area of 75 m^2 and containers for collecting runoff. Besides the measurement of the erosion indicators (volume of surface water runoff and quantity of eroded soil), the concentration of available forms of nitrogen - ammonium and nitrate in the eroded soil and nitrate in the water runoff was measured by the Keldahl method.

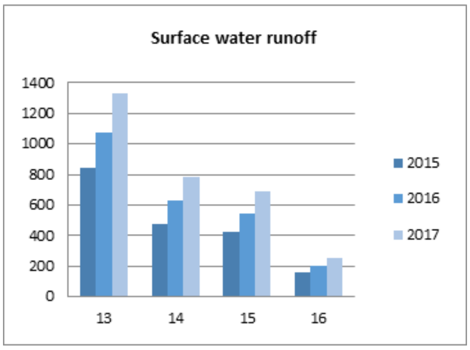
RESULTS AND DISCUSSION

The results of the erosion studies, performed for the three years period of the experiment are presented in table 1 and fig. 1. It can be seen that the values of surface water runoff and eroded soil are the lowest in variant 16, where sowing maize was cultivated applying advanced soil protection technology for minimum and unconventional soil tillage. Using this technology, surface water runoff is reduced from 5.1 to 5.5 times, and eroded soil from 22.2 to 23.1 times, compared to a control, grown along the slope. It should be noted that this effect persists throughout the study period. Lower erosion control indicators are observed in variant 15 with application of soil protection technology with surface mulching with manure. The decrease of the volume of surface water runoff is 1.9 to 2.2 times, and the amount of the eroded soil is 2.7 to 3.1 times, compared to the control variant 13.

Table 1 *Total volume of surface water runoff and amount of eroded soil 2015-2017y.*

Date	Volume of erosive rainfall l/m^2	Surface water runoff m^3/ha				Eroded soil kg/ha			
		Variant				Variant			
		13	14	15	16	13	14	15	16
26.05.15	16.0	266.426	154.983	142.614	51.378	3758.7	1501.6	1375.1	167.0
10.06.15	18.0	226.137	124.068	112.705	42.581	2879.9	1094.9	982.9	125.3
02.07.15	14.5	201.227	110.034	97.933	37.478	2517.8	939.5	843.6	109.3
21.08.15	51.0	154.224	83.797	74.407	28.856	1930.7	704.3	624.8	84.3
For 2015 y.	99.5	848.014	472.882	427.659	160.293	11087.1	4240.3	3826.4	485.9
05.05.16	20.0	265.263	159.468	140.964	52.023	3457.1	1375.7	1263.5	156.2
24.05.16	16.0	233.263	137.143	120.722	44.740	2920.0	1140.4	1050.0	129.7
06.06.16	12.0	174.737	98.073	84.217	32.601	2139.5	795.8	736.4	93.4
12.06.16	18.0	224.842	133.555	115.663	42.948	2802.0	1063.3	983.8	123.8
11.08.16	15.0	181.053	101.262	83.133	32.948	2192.2	812.8	727.1	95.4
For 2016 y.	81.0	1079.16	629.501	544.699	204.624	13510.8	5188.0	4760.8	598.5
06.05.17	20.2	255.582	149.591	133.060	50.269	3116.7	1240.6	1162.8	140.1
27.05.17	13.0	168.435	99.785	88.198	32.618	2017.7	748.2	697.6	89.0
19.06.17	11.0	170.149	95.054	85.230	31.812	2039.6	756.3	705.7	89.7
02.07.17	32.0	261.940	153.979	137.809	51.544	2960.6	1136.9	1059.6	133.4
13.08.17	18.0	220.299	129.462	114.912	41.477	2692.2	1036.7	925.9	119.2
03.09.17	42.0	256.567	153.979	134.841	50.336	2885.9	1118.3	1030.4	130.0
For 2017 y.	136.2	1332.97	781.850	694.050	258.056	15712.7	6037.0	5582.0	701.4

ANOVA Surface water runoff: HSD[0.05]=420.41; HSD[0.01]=574.7; *1 vs 2 P<0.05; 1 vs 3 P<0.05; 13 vs 16 P<0.01; 14 vs 15 NS; 14vs16 P<0.05; 15 vs 16 NS;* ***ANOVA Eroded soil: HSD[0.05]=3453.12; HSD[0.01]=4720.44;*** *13 vs 14 P<0.01; 13 vs 15 P<0.01; 13 vs 16 P<0.01; 14 vs15 NS; 14 vs 16 P<0.05; 15vs16 P<0.05*



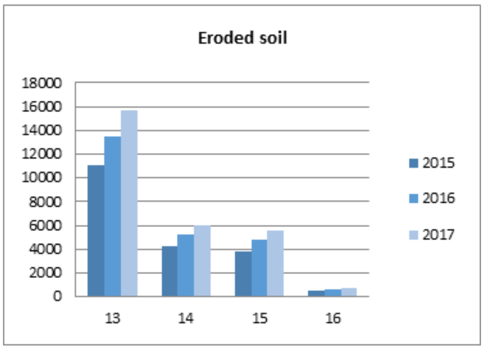


Fig. 1 Erosion control efficiency of the applied technologies for soil tillage, maize experiment, for the period 2015-2017 y.

Table 2 *Mineral nitrogen soil content (N-NH_4 (mg/kg), N-NO_3 (mg/kg)), by variants, 2015 – 2017y.*

Year	Before sowing				Maximum growth stage				After harvesting			
	Variant				Variant				Variant			
	13	14	15	16	13	14	15	16	13	14	15	16
2015 y.	61.58	68.81	71.00	97.14	27.32	27.80	48.30	66.18	23.03	23.08	39.68	49.36
2016y.	69.49	68.70	105.9	74.19	37.45	36.80	40.89	76.20	33.43	33.68	69.39	79.57
2017 y.	35.11	35.02	55.44	58.56	29.15	36.77	60.57	49.57	26.43	29.31	40.38	56.74

ANOVA; p=0.002182; HSD[.05]=23.04; HSD[.01]=28.66; *13 vs 14 nonsignificant; 13 vs 15 nonsignificant;13 vs 16 P<.01 14 vs 15 nonsignificant;14 vs 16 P<.01;15 vs 16 nonsignificant*

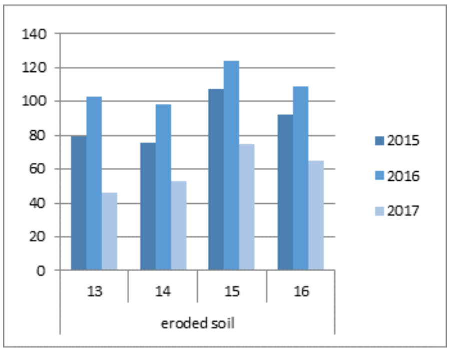
The agrochemical indicators of the soil at different phases of the development of the crop, for the three years of research are presented in Table 2. Before sowing, ammonia and nitrate nitrogen are the highest in variant with surface mulching with manure and in variant with minimum tillage and vertical mulching, due to the nitrogen intake with the mulching material, compared to conventional technologies applied along the slope and across the slope. This tendency remains in the other phases of the development of maize.

Along with that, the levels of nutrients in the surface water runoff and in the eroded soil are determined. The results obtained from the studies show that the mineral nitrogen forms in the 13th variant are the lowest, with conventional tillage, applied along the slope, which is most exposed to the action of water erosion and has the highest soil losses and volume of surface water runoff.

Table 3 *Avarage content of N-NH_4 (mg/kg), N-NO_3 (mg/kg), in the eroded soil, N-NO_3 (mg/l), in the surface water runoff, 2015-2017y.*

Year	Eroded soil				Surface water runoff			
	Variant				Variant			
	13	14	15	16	13	14	15	16
For 2015y.	79.74	75.81	107.43	92.40	11.29	11.21	12.20	8.88
For 2016y.	102.87	98.49	123.92	108.17	8.49	8.56	13.91	6.19
For 2017y.	46.29	52.58	75.20	64.75	12.03	12.49	14.78	11.61
Avarage 2015-2017y.	60.87	58.10	77.12	88.44	10.60	10.75	13.63	8.89

ANOVA; NS



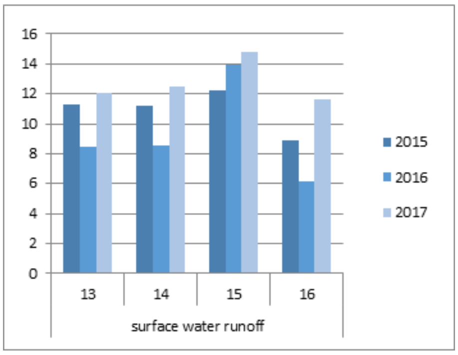


Fig. 2 Avarage content of N-NH_4 (mg/kg), N-NO_3 (mg/kg), in the eroded soil, N-NO_3 (mg/l), in the surface water runoff, 2015-2017y.

From the analysis of the experiments with maize for grain, it can be concluded that the application of manure in soil protection practices leads to an increase in the concentration of available forms of nitrogen in the eroded soil and in the surface water runoff as a result of the increased amount of these elements in the surface soil layer. The results of the analysis are presented in table. 3 and fig.1.

On the basis of the results for the volume of surface water runoff and the amount of eroded soil as well as the mineral nitrogen concentration in them, the losses of this chemical element, obtained during erosive rainfalls, during the studied period were calculated. The data on the losses occurring both with the surface water runoff and the exported soil are presented in table. 4 and fig.3. For maize growing on sloping terrain, using conventional technology, mineral nitrogen losses are 12.46 kg/ha active substance, average over the three-year study period. Using conventional technology across the slope, the loss of mineral nitrogen from water erosion is 7.08 kg/ha active substance. The mineral nitrogen loss on average for the three-year period of the experiments with the surface application of manure is 8.32 kg/ha. The lowest nitrogen losses are in the variant with application of the advanced technology for minimum and unconventional soil tillage, with the average annual loss for the studied period of 1.96 kg/ha.

Table 4 *Losses of available of nitrogen N ($N\text{-}NO_3^-$ + $N\text{-}NH_4^+$) with eroded soil and surface water runoff (kg/ha),at erosive rainfalls 2015-2017 y.*

Date	Rainfall l/m^2	Eroded soil, ($N\text{-}NO_3^-$ + $N\text{-}NH_4^+$), kg/ha				Surface water runoff $N\text{-}NO_3^-$, kg/ha				Total losses of mineral nitrogen, kg/ha			
		Variant				Variant				Variant			
		13	14	15	16	13	14	15	16	13	14	15	16
26.05.15	16.0	0.347	0.124	0.142	0.014	2.632	1.398	1.462	0.388	2.979	1.513	1.476	0.402
10.06.15	18.0	0.462	0.168	0.192	0.027	3.177	1.740	1.952	0.553	3.639	1.908	2.144	0.58
02.07.15	14.5	0.111	0.039	0.056	0.006	2.487	1.430	1.828	0.323	2.598	1.469	1.884	0.329
21.08.15	51.0	0.104	0.038	0.070	0.007	1.369	0.735	0.933	0.182	1.473	0.773	1.003	0.189
Total for 2015y.	99.5	1.025	0.368	0.459	0.053	9.666	5.673	6.634	1.500	10.691	6.041	7.093	1.553
05.05.16	20.0	0.482	0.163	0.198	0.020	2.090	1.275	1.735	0.363	2.579	1.438	1.933	0.383
24.05.16	16.0	0.276	0.112	0.129	0.014	2.076	1.235	1.692	0.353	2.352	1.347	1.821	0.367
06.06.16	12.0	0.194	0.076	0.098	0.010	1.363	0.770	1.503	0.149	1.557	0.846	1.601	0.159
12.06.16	18.0	0.339	0.112	0.115	0.012	2.012	1.197	1.594	0.268	2.351	1.309	1.709	0.28
11.08.16	15.0	0.172	0.061	0.065	0.009	1.611	0.910	0.963	0.174	1.783	0.971	1.028	0.183
Total for 2016y.	81.0	1.464	0.525	0.606	0.066	9.15	5.38	7.49	1.31	10.614	5.905	8.096	1.376
06.05.17	20.2	0.193	0.085	0.095	0.009	3.348	2.097	2.230	0.796	3.541	2.182	2.325	0.805
27.05.17	13.0	0.106	0.040	0.059	0.007	2.419	1.455	1.647	0.281	2.525	1.495	1.706	0.288
19.06.17	11.0	0.117	0.024	0.047	0.005	2.687	1.522	1.554	0.464	2.804	1.546	1.601	0.469
02.07.17	32.0	0.098	0.059	0.073	0.007	2.292	1.318	1.506	0.479	2.39	1.377	1.579	0.486
13.08.17	18.0	0.119	0.051	0.074	0.008	3.481	2.061	2.095	0.646	3.6	2.112	2.169	0.654
03.09.17	42.0	0.083	0.044	0.070	0.009	1.121	0.898	0.786	0.289	1.204	2.942	0.856	0.298
Total for 2017y.	136.2	0.716	0.304	0.419	0.045	15.347	9.352	9.818	2.955	16.063	9.656	10.237	3.00
Avarage for three years		1.06	0.40	0.49	0.05	11.38	6.68	7.83	1.90	12.46	7.08	8.32	1.96

ANOVA; P<.0001, HSD[.05]=0.51; HSD[.01]=0.63, *13 vs 14 P<.01;13 vs 15 P<.01;13 vs 16 P<.01;14 vs 15 nonsignificant;13 vs 16 P<.01;15 vs 16 P<.01*

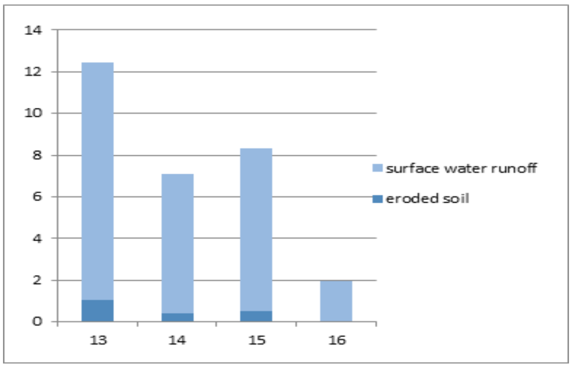


Fig. 1 Losses of available of nitrogen N ($N\text{-}NO_3^-$ + $N\text{-}NH_4^+$) with eroded soil and surface water runoff (kg/ha),at erosive rainfalls 2012-2015 y.

As can be seen from the presented tables, the losses of mineral nitrogen from water erosion occur mainly with the surface water runoff in the different variants for growing of the studied agricultural crop. The major part of the nitrogen is exported in the form of nitrate ions. In the sloping arable lands with application of conventional technology, 91.33% of nitrogen losses occur with surface water runoff and 8.67% - with eroded soil. In variant 14, nitrogen losses with surface water runoff are 94.35% of total mineral nitrogen losses. In variant 15, with the water flow, 94.11% of the losses of mineral nitrogen occur, and in case of variant 16 - 96.94%.

CONCLUSION

1. The lowest values of the erosion indicators, the amount of eroded soil and the surface water runoff in the experiments carried out as well as the highest losses of mineral nitrogen are observed with the application of the advanced technology for minimum and unconventional soil tillage with vertical mulching with manure, when growing corn on

inclined terrains. In its implementation, the surface water flow is reduced from 5.1 to 5.5 times, and the eroded soil decreases from 22.2 to 23.1 times, compared to the control grown conventionally along the slope.

2. Almost all mineral nitrogen losses occur with surface water runoff (between 91-97%) and a little part with eroded soil. With the application of soil protection technologies (variants 15 and 16), mineral nitrogen losses are in higher degree occur with the water flow (94-97%), compared to those, using conventional (91-94%).

3. The lowest nitrogen losses occur in variant 16 with unconventional soil tillage technologies with 10.50 kg/ha lower than the control grown by conventional technology, applied along the slope. In variant 15, despite the reduction of surface water runoff and the amount of eroded soil, the concentrations of available nitrogen forms in them are high, therefore the reported losses are only 4.13 kg/ha lower than those of variant 13, although the erosion control effect is significantly higher. This is due to the surface application of manure.

4. Soil-protection technology for minimum and unconventional soil tillage using manure as a mulching material for growing maize on sloping terrains, has a significant erosion control effect, reduces surface water runoff and soil loss, increases water retention and increases the efficiency of used mineral and organic fertilizers. This leads to an improved feeding and development of the cultivated agricultural crop and thus to higher productivity.

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