Losses of Mineral Nitrogen under the Influence of Water Erosion Processes in the Wheat Cultivation on Sloping Agricultural Lands

Gergana Kuncheva, Hristo Beloev, Petar Dimitrov

Abstract: *Soil water erosion is a degradation process with a significant negative impact on the soils in the world and in Bulgaria. One of these consequences is the loss of nutrients, removed with surface water runoff and eroded soil. For the development of sustainable agriculture, preservation of soil fertility and protection of the environment from pollution, it is necessary to improve the efficiency of the use of mineral fertilizers as well as to limit water erosion processes. For this purpose, it is necessary to apply erosion control technologies for growing agricultural crops on slope arable lands. In the present study the influence of conventional and soil protection technologies in the cultivation of wheat on sloping arabale lands on the losses of mineral nitrogen under the influence of water erosion processes, is examined.*

Keywords*: loss of mineral nitrogen, water erosion, conventional technologies, soil protection technology, wheat, minimum tillage, vertical mulching.*

INTRODUCTION

Much of the soil nutrients loss is due to the action of water erosion, which directly leads to a decrease in the productivity of ecosystems. According to the studies, as a result of the action of the water erosion processes, there is a decline in the yields of the crops, between 0.1 and 0.4%. If the average annual yield reduction is 0.3% and it will be the same for the period from 2015y. to 2050y. and there are 1.53 billion hectares of arable land in the world, the loss of yields due to erosion would be equivalent to removal from harvesting of 4,5 million hectares of agricultural land annually or 150 million hectares for the period up to 2050y. (Foley et al., 2011).

In most natural ecosystems, the availability of nitrogen is a limiting factor for the productivity of ecosystems and nitrogen cycles run with minimal losses. Through the cultivation of nitrogen-fixing crops and the application of inorganic nitrogen fertilizers, people bring twice as much available nitrogen into the soil as compared to natural processes, thus significantly increase the production of biomass. However, since the efficiency of the use of mineral fertilizers is usually low and often much higher amounts (FAO, 2015) are applied than plants actually need, much of the mineral nutrients imported by fertilizing are lost. This leads to many related negative effects on the environment and human health, such as increased N_2O emissions, nitrogen fertilizer pollution, surface and ground water contamination, and food products (Galloway et al., 2008).

FAO analyzes show that global increases in nitrogen inputs in agricultural systems cannot lead to higher productivity without causing significant environmental damage (FAO, Rome, 2015).

Nutrient elements such as nitrogen, phosphorus, potassium, calcium, etc. are exported from the areas subjected to water erosion, with surface water runoff and with eroded soil (D. Piementel, N. Kounang, 1998). The study of Li Wang et al (2010) found that on the slope of 15^0, soil organic matter, available forms of nitrogen, phosphorus and potassium at the top of the slope were 74.64%, 37.92%, 55%, 86% and 51.95% in comparison with their content to its base.

In the world, 31% of land is subject to action of water erosion or it is about 1.1 billion hectares (Dobrovolsky, 2008). Annually, under its influence of water erosion, according to the Reich (2001), there are removed 130 billion tonnes of soil. Nowadays, around 430 million hectares of land have been destroyed and lost in various countries in the world by this degradation process (Dimitrov, 2016). Worldwide, soil water erosion reaches the largest dimensions in Asia, Africa and America. The annual loss of soil in India from erosion processes is 16 t/ha. Water erosion actively affects 140 mha of land, resulting in the loss of 6,000 Mt of fertile soil containing 5,5 Mt NPK(Meena N. K., 2017). Troeh (1980) estimates that in the United States the annual nutrient loss from soil in the process of water erosion, equals 20 billion $.

The many negative consequences of the action of water erosion processes require the application of erosion control measures, methods and technologies in order to preserve the soil fertility and to improve the feeding of the cultivated plants by improving the efficiency of the applied fertilizers and obtaining stable yields.

The purpose of the present study is to determine the loss of mineral nitrogen with surface water runoff and eroded soil in wheat growing by conventional and soil protection technologies, on soil calcareous chernozem, on slope of 5 ° (8.7%).

MATERIAL AND METHODS

The survey was conducted in the period 2015-2017 y. in the experimental field of Institute of soil science, agricultural technologies and plant protection "Nikola Pushkarov" - Sofia, in the village of Trastenik, Ruse, without irrigation, on medium eroded calcareous chernozem on slopping agricultural lands with inclination 5º (8.7%). Field trials with wheat were made by the block method, in four variants, in four replicates.

The variants of the experiments are:

5 th - wheat plots, grown by conventional technology, applied along the slope - control;

6 th - wheat plots, grown by conventional technology, applied across the slope;

7 th - wheat plots, grown by soil protection technology including the erosion control measure - surface mulching with manure, applied across the slope

8 th - wheat plots, grown under the advanced soil protection technology including erosion control measures vertical mulching with manure and direct sowing, as well as some plant protection operations to control weeds, pests and plant diseases, all operations applied across the slope.

During the research period, every year, all the technological operations carried out in variant 5 and 6 are conventional were the same, the difference between them was only in the direction of their application. In the control, they are carried out along the slope and in variant 6 in the transverse direction. In the same direction have been carried out and operations in the variant 7, as in it before sowing was carried out erosion control method surface mulching with manure (4500-5000 kg/ha), performed across the slope with fertilizer spread trailer 1 PTU – 6.

In the last 8th variant before sowing, across the slope is carried out vertically (into the soil) mulching with manure, in band scheme (distance between the slots 1,4 m and a space between the bands in the field 3 m) of a depth of 0,40 m with the that was vertically mulched with compost (3500-4000 kg/ha) with the reconstructed machine breaker-dead furrower ЩН 2-140, which consists a frame, cuttings and molehills making working bodies, as well as bunker for plant residues

The areas used for experiments were with predecessor for wheat - grain corn. In the area of the experiment, fertilization was carried out mainly with $N_{15}P_{10}K_8$ kg/da, with the total amount of the phosphorus (superphosphate) and potassium (potassium chloride) fertilizers being incorporated before sowing and the nitrogen fertilizer (ammonium nitrate) divided into two dosages, one third of it was applied before the sowing, and the other 2/3 - in the spring.

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 applied advanced soil protection technology for minimum and unconventional soil tillage for growing wheat on sloping arable lands have a significant erosion control effect due to increased soil infiltration capacity and improved soil protection effectiveness of vegetation and plant debris. This technology reflects not only the volume of surface water runoff and the amount of eroded soil, but also the loss of nutrients by water erosion.

The results obtained from the erosion studies, by years, are presented in table 1 and fig 1. It can be seen that in the variant with minimum tillage and vertical mulching with manure, the volume of surface water runoff decreases from 2.6 to 2.9 times and the eroded soil from 6.3 to 6.5 times, compared to control, variant 5, grown along the slope and this effect being maintained throughout the study period. A less erosion control effect was observed in variant 7 with application of soil protection technology using surface mulching with manure. The reduction of the surface runoff is from 1.6 to 1.8 times, and in the quantity of eroded soil it is 3.1 to 3.4 times, compared to the control. The lowest is the erosion control efficiency of the variant with conventional tillage across the slope. Here the decrease is from 1.3 to 1.5 times for the volum of water runoff, and the soil loss from 1.7 to 1.9 times, compared to the control.

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

Date	Rain l/m^2	Surface water runoff m^3/ha				Eroded soil kg/ha			
		Variant				Variant			
		5	6	7	8	5	6	7	8
26.05.15	16.0	165.985	128.000	103.794	64.483	1983.2	1181.9	640.8	315.0
10.06.15	18.0	140.584	93.895	80.643	50.344	1663.9	884.0	510.9	258.3
02.07.15	14.5	118.467	78.947	66.945	41.552	1397.9	763.9	432.7	215.7
For 2015 y.	48.5	425.036	300.842	251.384	156.379	5045.0	2829.8	1584.4	789.0
05.05.16	20.0	170.382	122.628	101.661	63.761	1925.1	1079.5	605.9	301.4
24.05.16	16.0	148.397	98.978	89.302	52.657	1598.2	926.0	491.3	247.5
06.06.16	12.0	109.924	73.577	62.193	37.687	1211.9	651.9	355.0	185.7
12.06.16	18.0	142.443	100.292	83.721	50.866	1567.1	888.2	471.7	243.6
For 2016 y.	66.0	571.146	395.475	336.877	204.971	6302.3	3545.6	1923.9	978.2
29.04.17	16.0	152.528	103.830	90.863	56.556	1578.8	878.9	495.2	246.3
06.05.17	20.2	165.626	123.319	99.604	62.284	1900.2	1062.3	598.9	300.4
27.05.17	13.0	105.934	71.915	59.808	36.979	1128.2	604.1	341.0	173.4
19.06.17	11.0	106.374	71.489	59.425	36.616	1136.1	602.9	337.3	175.2
02.07.17	32.0	169.231	128.511	103.898	65.619	2035.6	1206.2	654.2	324.3
For 2017 y.	92.2	699.693	499.064	413.398	258.54	7778.9	4354.4	2426.6	1219.6

ANOVA; Surface water runoff*: p<.0001;HSD[.05]=21.62; HSD[.01]=26.67; 5 vs 6 P<.01;5 vs 7 P<.01; 5 vs 8 P<.01; 6 vs 7 nonsignificant; 6 vs 8 P<.01; 7 vs 8 P<.01;* ***Eroded soil*** *p<.0001; HSD[.05]=223.02; HSD[.01]=275.14; 5 vs 6 P<.01; 5vs7 P<.01; 5 vs 8 P<.01; 6 vs 7 P<.01; 6 vs 8 P<.01; 7 vs 8 P<.05*

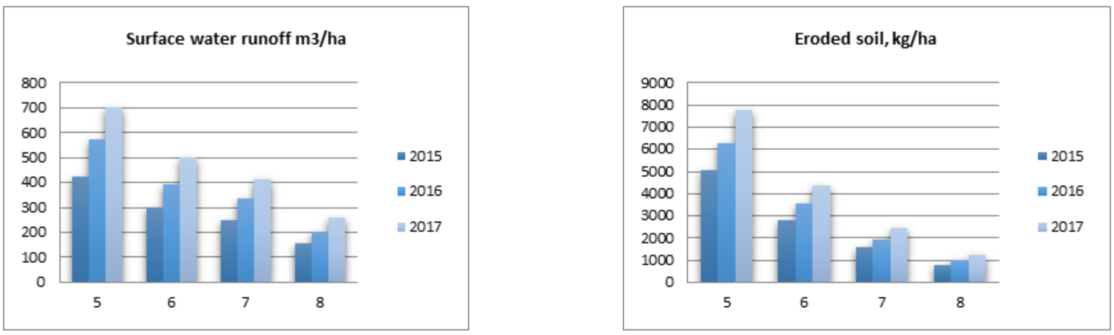


Fig. 1 Volume of surface water runoff (m^3/ha) and amount of eroded soil (kg/ha) 2015-2017 y.

Table 2 *Mineral nitrogen soil content (N-NH$_4$ (mg/kg), N-NO3 (mg/kg)), by variants, 2015 – 2017y.*

Year	Before sowing				Maximum growt stage				After harvesting			
	Variant				Variant				Variant			
	5	6	7	8	5	6	7	8	5	6	7	8
2015 y.	59.56	58.23	68.44	85.42	63.29	66.30	85.87	106.74	15.35	16.55	17.84	29.34
2016y.	35.00	37.09	69.18	67.94	29.67	30.70	51.27	71.06	19.20	19.80	25.52	28.71
2017 y.	32.25	32.87	51.27	69.30	37.88	36.08	53.98	89.07	31.29	27.54	45.93	53.25

ANOVA: 1 vs 4, p=0.008479

The mineral nitrogen content (N-NH$_4$ (mg/kg), N-NO$_3$ (mg/kg)) of the soil at different stages of the development of the crop, for the three years of research are presented in table 2. The highest levels of soluble mineral forms of nitrogen are observed in the variants with minimum soil tillage with vertical mulching with manure and in the variant with surface mulching with manure. As can be seen from the data, the input of a material with high nitrogen content significantly influences the agrochemical content of soil in variant 7 and variant 8.

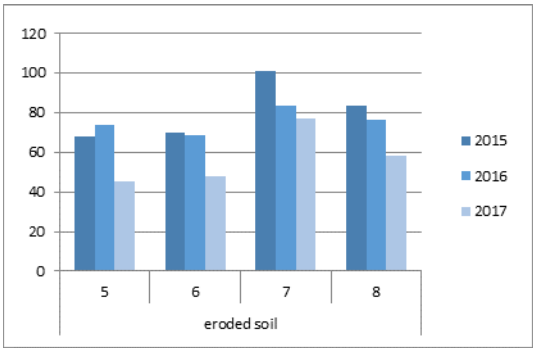
From samples taken from the collected runoffs, by variants, the concentrations of the mineral nitrogen forms in the surface water flow and in the eroded soil were measured. Average concentrations by years are shown in Table 3.

There is higher concentration of mineral nitrogen forms in variants with organic fertilizer applications (variants 7 and 8). This is most strongly observed in the variant with application of surface mulching. The concentration of mineral nitrogen in the eroded soil as well as in the surface water runoff, are affected by the stock at the moment of the erosive rainfalls as well as by the applied manure and the way of its deposition.

Table 3 *Average content of N-NH$_4$ (mg/kg), N-NO$_3$ (mg/kg), in the eroded soil, N-NO3 (mg/l), in the surface water runoff, 2015-2017y.*

Year	Eroded soil				Surface water runoff			
	Variant				Variant			
	5	6	7	8	5	6	7	8
For 2015y.	68.11	69.92	101.24	83.92	11.65	13.25	22.67	12.58
For 2016y.	73.63	68.93	83.31	76.57	10.84	11.07	16.56	11.56
For 2017y.	45.02	47.88	77.31	58.06	9.93	10.49	15.76	10.04
Avarage 2015-2017y.	62.25	62.24	87.29	72.85	10.81	11.60	18.33	11.39

***ANOVA: Eroded soil p**= 1.00;* **Surface water runoff *p**= 1.00*



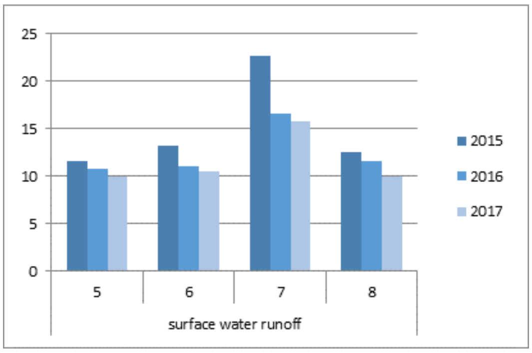


Fig. 2 Average content of N-NH$_4$ (mg/kg), N-NO$_3$ (mg/kg), in the eroded soil, N-NO$_3$ (mg/l), in the surface water runoff, 2015-2017y.

Based on the data for amount of eroded soil, volume of surface water runoff and the concentration of mineral nitrogen forms, nitrogen losses by erosive rainfalls, occurring during the vegetation of the crop, were calculated. Losses of ammonium and nitrate nitrogen with surface water runoff and eroded soil were lower in variant 8 compared to conventional technology, applied along the slope - control, with 2,66 times average over the three-years study period. In variant 7, despite the reduction of surface water runoff and the amount of eroded soil, the concentrations of available nitrogen forms in them are high, so the reported losses are similar to variant 5, despite the proven erosion control effect. This is due to the surface application of manure.

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

Date	Rainfall l/m²	Eroded soil, (N-NO_3^- + N- NH_4^+), kg/ha				Surface water runoff N-NO_3^-, kg/ha				Total losses of mineral nitrogen, kg/ha			
		Variant				Variant				Variant			
		5	6	7	8	5	6	7	8	5	6	7	8
26.05.15	16.0	0.129	0.085	0.076	0.029	1.934	1.696	2.594	0.773	2.062	1.780	2.67	0.802
10.06.15	18.0	0.104	0.052	0.045	0.019	1.683	1.224	1.612	0.679	1.742	1.296	1.657	0.698
02.07.15	14.5	0.107	0.060	0.042	0.019	1.380	1.046	1.540	0.508	1.487	1.104	1.582	0.526
Total for 2015y.		0.340	0.197	0.163	0.067	4.997	3.966	5.698	1.967	5.291	4.18	5.861	2.033
05.05.16	20.0	0.146	0.079	0.048	0.024	2.711	1.962	2.134	1.112	2.857	2.041	2.183	1.136
24.05.16	16.0	0.125	0.053	0.036	0.014	1.730	1.194	1.615	0.620	1.858	1.247	1.651	0.634
06.06.16	12.0	0.067	0.042	0.028	0.013	0.856	0.592	0.755	0.297	0.923	0.634	0.783	0.310
12.06.16	18.0	0.134	0.071	0.048	0.025	1.139	0.819	1.256	0.464	1.273	0.890	1.304	0.489
Total for 2016y.		0.464	0.245	0.160	0.075	6.191	4.377	5.578	2.370	6.655	4.621	5.739	2.445
29.04.17	16.0	0.066	0.038	0.051	0.021	1.98	1.375	2.87	0.857	2.046	1.413	2.921	0.878
06.05.17	20.2	0.083	0.061	0.041	0.016	0.848	0.644	0.569	0.286	0.931	0.705	0.610	0.302
27.05.17	13.0	0.067	0.036	0.021	0.008	0.760	0.519	0.445	0.234	0.827	0.555	0.466	0.242
19.06.17	11.0	0.045	0.022	0.020	0.008	1.196	0.818	0.713	0.338	1.241	0.840	0.733	0.346
02.07.17	32.0	0.083	0.053	0.063	0.019	2.216	1.964	2.290	0.976	2.300	2.017	2.353	0.995
Total for 2017y.		0.344	0.21	0.196	0.072	6.95	5.233	6.517	2.596	7.300	5.44	6.704	2.668
Avarage for three years		0.385	0.217	0.170	0.07	6.031	4.532	5.931	2.311	6.415	4.749	6.101	2.382

ANOVA *P=0.003584;HSD[.05]=2.63; HSD[.01]=3.6, 5 vs 6 nonsignificant, 5 vs 7 nonsignificant, 5 vs 8 P<.01, 6 vs 7 nonsignificant, 6 vs 8 P<.05, 7 vs 8 P<.01*

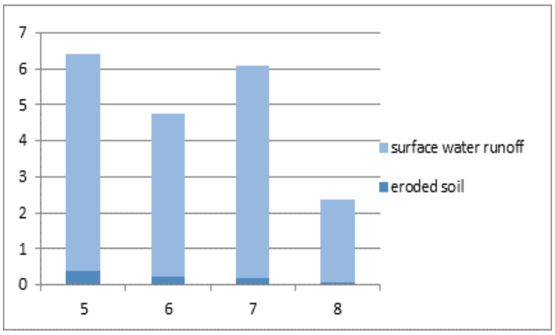


Fig. 3 Losses of available of nitrogen N (N-NO_3^- + N- NH_4^+) with eroded soil and surface water runoff (kg/ha), at erosive rainfalls 2015-2017 y.

As can be seen from the tables (tables 3 and 4), the losses of mineral nitrogen from water erosion occur mainly with the surface water runoff in the different variants of the experiment. The major part of the nitrogen is loss in the form of nitrate ions. In the control variant, wheat grown along slope with application of conventional technology, 93.77% of nitrogen losses occur with surface water runoff and 6.23% with eroded soil. In variant 6, surface water runoff losses are 95.43% of total mineral nitrogen losses. In variant 7, with the water flow, 97.21% of the losses of mineral nitrogen occur, and in case of variant 8 - 97.0% . In Fig. 3 are shown loss of available forms of N (N-NO_3^- + N- NH_4^+) with eroded soil and surface water runoff (kg / ha), on average for the three years of study (2015-2017y.).

The loss of mineral nitrogen in the growing wheat on carbonate chernozem on sloping terrains by conventional technology (variant 5) resulted in a mineral nitrogen loss of 6,42 kg/ha of active substance, averaged over the three years period of study. This as well as the lower water retention capacity, the higher compaction resulting from the erosion processes, influences the development of the cultivated crop. In the variant with conventional tillage, applied across the slope (variant 6), the average annual nitrogen loss is 4.75 kg/ha. In the variant with surface mulching with manure, the nitrate nitrogen concentration in the surface water runoff is the highest and overall losses are high, irrespective of the erosion control effect and improved agrochemical content of the soil. The lowest is the loss of mineral nitrogen using advanced technology for minimum and unconventional tillage for growing wheat on slope arable lands (variant 8). With this variant, the losses are 2.38 kg/ha. In the variant with surface mulching, mineral nitrogen losses are similar to control losses due to the surface application of the manure. However, in this variant, the erosion control effect has been proven and the agrochemical indicators of the soil are improved.

CONCLUSIONS

1. The highest amount of eroded soil and volume surface water runoff, as well as the highest mineral nitrogen losses, are observed in sowings with applying conventional technologies for growing wheat on slope arable lands, along the slope. Using the advanced technology for minimum and unconventional soil tillage, surface water runoff decreases 1.6 to 1.8 times and the amount of eroded soil decreases from 6.3 to 6.5, compared to the control variant.

2. Almost all mineral nitrogen losses (94-97%) occur with surface water runoff and only 3-6 % are loss with eroded soil and are in nitrate form. In variants 7 and 8, and this percentage is higher in variants 7 and 8, with application of soil protection technologies, than in conventionally grown.

3. Mineral nitrogen losses when growing wheat on sloping terrains with the application of advanced technology for minimum and unconventional soil tillage using manure, such as mulch, are reduced with 4.04 kg/ha active substance.

4. In application of technology with surface mulching with manure, nitrogen losses are almost the same as in the control variant due to the surface application of this organic material, although the erosion indicators in the implementation of this soil protection technology are significantly reduced.

5. The applied erosion control technologies reduce surface water runoff and thus improve water retention as well as the efficiency of applied mineral nitrogen and organic fertilizers. This leads to higher soil productivity and improved crop feeding and development on sloping terrains, with calcareous chernozem.

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