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Agrochemical properties of irrigation-eroded meadow-seriozem soils of the Zerafshan River valley

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ABSTRACT

This study evaluates the factors and conditions leading to irrigation erosion during tobacco cultivation on irrigated meadow-gray soils of the Zeravshan River valley. The effects of irrigation regime, field slope, and soil structural degradation on erosion development were assessed. Quantitative losses of soil organic matter and essential nutrients were determined, with particular emphasis on nitrogen forms as the main limiting factor of soil fertility. The impact of irrigation erosion on the group and fractional composition of humus, total nitrogen content, and the distribution of mineral nitrogen forms (NH_4^+ and NO_3^-) within the soil profile was analyzed. Results showed that irrigation erosion intensifies organic matter depletion, accelerates nitrogen mineralization and leaching, and reduces the reserves of plant-available nitrogen. These processes negatively affected tobacco growth and yield. The findings demonstrate that mineral nitrogen depletion is a key consequence of irrigation erosion in meadow–gray soils. Based on the results, practical recommendations were developed to reduce erosion intensity, conserve soil nitrogen reserves, and improve nutrient-use efficiency, thereby enhancing the sustainability and productivity of tobacco cultivation under irrigated conditions.

Keywords: soil organic matter, soil degradation, irrigation erosion, Zeravshan River, humus composition, mineral nitrogen (NH_4^+, NO_3^-).

INTRODUCTION

Anthropogenic factors affecting fertility during cultivation of agricultural crops under irrigated conditions affect the quality of humus and agrochemical properties of irrigated soils of the Zeravshan River valley. Furrow irrigation, as a factor of anthropogenic impact, significantly changes the morphological and genetic properties of soils.

A scientifically based system of irrigated agriculture ensures the creation of new cultural anthropogenic soils with higher fertility and provided with good quality humus [1, 2], which depends on climatic conditions, duration and rate of irrigation, as well as the level of applied agricultural technology [3–7]. However, there is a place for the use of a primitive irrigation system on slope areas, irrigation erosion occurs, the intensity of which depends on the shape and steepness of the slope, the resistance of the soil and parent rock to the destructive action of water, as well as the applied irrigation technology [8]. In the gray soil zone, many studies have been conducted on soils subject to irrigation and recommendations have been developed to reduce erosion [9–23], which highlight the influence of erosion processes on some indicators that determine the agrochemical and physical properties of eroded soils.

A special place in recent publications is given to the study of the influence of irrigation erosion on the transformation and migration of organic matter with washed-off soil aggregates [24–26]. However, there are very few in-depth studies on the influence of irrigation erosion processes on the qualitative composition of soil organic matter, and the available information is quite contradictory.

In the soils of the Zeravshan River valley, poor in humus, the most important element of mineral nutrition of plants – nitrogen, which correlates with the humus content is in the first minimum [27], and the need of agricultural crops for it is satisfied by the introduction of nitrogen fertilizers, but the coefficient of its use by plants on irrigation-eroded soils is low due to large losses as a result of washout, which negatively affects the environment [28]. One of the ways to reduce nitrogen losses from soil and fertilizers is the use of nitrification inhibitors, which reduce nitrification activity, increase the period of nitrogen use by fertilizers and eliminate the risk of nitrate pollution of water sources [29–31].

The balance of nitrogen fertilizers, its transformation and migration in soils, the extent of biological fixation from the atmosphere and the use of nitrification inhibitors have been studied under various conditions and on various crops [32–36]. It should be noted that the effectiveness of nitrification inhibitors on irrigation-eroded meadow-gray soils, especially when cultivating row crops with furrow irrigation, has been poorly studied.

The main zone for tobacco cultivation is the slope soils of the Urgut region. They have good natural drainage, are not saline, and are also quite fertile for this zone of gray soils. However, irrigation along furrows on slopes often leads to the washout of the upper most fertile soil layer, deterioration of the agrochemical and physical properties of the soil due to the manifestation of irrigation erosion.

Increasing the fertility of sloping soils should be considered taking into account the impact of erosion processes and the introduction of methods to reduce erosion processes during irrigation. In this regard, conducting comprehensive scientific research necessary to develop methods to protect lands subject to irrigation erosion from washout, as well as studying the effect of nitrification inhibitors using the isotope 15N on the nitrogen balance and reducing its losses when growing tobacco on meadow-gray soil subject to irrigation erosion, is of great scientific and practical importance.

METHODOLOGY

In order to study the agrochemical parameters of irrigation-eroded soils of the Zeravshan River valley, expeditionary research was conducted. Irrigation-eroded meadow-gray soils of the foothill zone of the Samarkand region were studied. Using soil and agrochemical maps, land use plans and direct soil examination, the types, subtypes and the degree of erosion were determined.

Fifteen reference sections were laid in the most typical places. In order to study the tendency of changes in agrochemical parameters down the soil profile, soil samples were taken from different soil horizons for analysis. The samples were dried in a dark place.

In fresh samples, ammonium nitrogen was determined using Nessler's reagent, nitrate nitrogen by the Grandval-Lyaju method. In dried samples, the granulometric composition was determined according to Kachinsky [37], mobile phosphorus and exchangeable potassium by the Machigin method [38]. The humus content was determined by the Tyurin method as modified by Nikitin and Simakov, the fractional and group composition of humus by the Tyurin method as modified by Ponomareva and Plotnikova [37], and the gross content of NPK in one soil sample by the method of Maltseva and Gritsenko.

To establish the content of soil nitrogen available to plants, in addition to determining the sum of nitrate and exchangeable ammonium nitrogen, we supplemented this information with the determination of alkaline-hydrolyzable nitrogen according to Kornfield [38], which makes it possible to establish the nearest reserve of mineral nitrogen for carbonate soils.

On the upper part of the slopes of the meadow-gray soil massifs, on which full-size (plot area 200 m^2) field experiments with tobacco were carried out, small-plot field experiments with the same crop were laid out. Nitrogen was applied against the background of RK in the form of urea enriched with 15N – 23–25%. Labeled urea was applied manually, trying to simulate the application of nitrogen fertilizers in field conditions as much as possible, into the lateral parts of the ridge to a depth of 10–15 and 20–25 cm. Plots measuring 120 × 100 cm were placed in 1 tier across the slope, with the long side across the furrows. Thus, 2 rows of tobacco were fertilized only with labeled urea. The experiments were repeated 4 times, the variants with labeled nitrogen were laid down in 2 replicates. Total nitrogen was determined by the Ginzburg method [38]. The isotopic composition of nitrogen was determined on a mass spectrometer. The yield was determined using the method of using accounting plots on each plot, and then recalculated per hectare. In parallel, the efficiency of mineral fertilizers was calculated using the difference method [38]. The data were processed by the method of dispersion analysis in accordance with the methodology described in [39]. In all experiments (in the corresponding variants), the nitrification inhibitor 1-carbamail-3(5)-methylpyrazole (KMP) was used at a dose of 3 kg/ha. To control the possible entry of washed-off labeled nitrogen from fertilizers into plants located on the slope below the experimental plots, plant samples were taken, the total nitrogen content and its isotopic composition were determined. Samples were taken after the third watering (the second after the introduction of labeled nitrogen) and when recording the yield from every 2 subsequent meters of rows, starting from the second meter from the lower edge of the plot. 5 plants were selected from each two-meter plot. During the first period (1 month after the introduction of fertilizers), traces of labeled nitrogen were detected up to 9–11 m below the variant without a nitrification inhibitor and up to 3–5 m when a nitrification inhibitor was introduced. During harvesting, traces of labeled nitrogen from fertilizers were detected only in plants located 1–3 m below the plots of variants without a nitrification inhibitor.

RESULTS AND DISCUSSION

The studies have established that erosion processes lead to a significant change in the humus content of the soil. Thus, the humus content in the meadow-gray soil on the washed-out part is 1.0% and in the washed-out part 1.6% (Table 1). If on the washed-out meadow-gray soil its content at a depth of 0–30 cm is from 0.8±0.2 to 1.0±0.2, then on the washed-out parts of the slope it is 1.5 times more 1.0±0.2–1.7±0.2% (Table 1).

The studies have shown that on the washed-out part of the slope there is a sharp decrease in the humus content towards the lower soil horizons, and on the washed-out ones the distribution of humus along the soil profile is more uniform. It should be noted that the composition of humus is fulvate-humate, with a medium degree of humification, with a relatively low content of hydrolyzable substances (59.8–63.0% in meadow-gray soil) and a relatively high content of non-hydrolyzable residue, and as a result of irrigation erosion, the amount of hydrolyzable substances decreases by 3.2–4.5% (Table 1).

It is known that humus of the best quality usually has a large amount of humic acids. In the soils studied by us, on both parts of the slope there is more fulvic acids (Table 2). The content of humic acids is higher on washed varieties. In general, meadow-gray soils contain 27.5–29.9% of humic acids from the total humus content.

The ratio of Cgc:Cfc on meadow-gray soils is 0.71–0.9, while on washed varieties this indicator is closer to one. The predominant group of hydrolyzable compounds is fulvic acids, the content of which varies slightly depending on erosion. Mobile humic acids of the first fraction in meadow-gray soils make up an insignificant part (2.2–2.8%). The largest part of humic acids is represented by the second fraction, the content of which is slightly higher on the washed part of the slope. The high content of the second fraction is due to the saturation of the soil with bases and the fixation of humic substances with calcium, which makes up 72–85% of the total content of absorbed cations. Humic acids associated with clay minerals and stable forms of sesquioxides account for 8–8.5% in meadow-gray soils, with some increase in this fraction noted in alluvial soil varieties ().

A slightly different trend is noted among fulvic acids. Thus, if fractions 1 and 3 are higher on the washed-out part than on the washed-out part, then fraction 1, on the contrary, increases in the lower washed-out part of the slope. The predominant fraction of fulvic acids (17.2–19%) is calcium-bound fraction 2.

According to our data, irrigation erosion leads to a decrease in humic acids on washed-out soil, the composition of humic substances changes towards an increase in their amount in the washed-out part, as well as an increase in the second fractions of humic and fulvic acids (Figure 1).

Along with a decrease in organic matter in the soil, irrigation erosion leads to a change in the content of gross and plant-available phosphorus compounds, so on washed-out meadow-gray soils the content of gross phosphorus in the arable (0–30 cm) layer is from 0.10±0.02 to 0.13±0.03%, on washed-out soils 0.13±0.02–0.21±0.03% (Table 1). At the same time, if at a depth of 80–100 cm in washed-out soils the amount of phosphorus sharply decreases to 0.02–0.04 ± 0.01%, then at the same depth in washed-out soils it is 0.03–0.05 ± 0.01%. The decrease in phosphorus content in the soil profile of the washed-out part of the slope is more abrupt than in the washed-out part, i.e. phosphates in the washed-out soil are evenly distributed over the soil profile. The same pattern is noted for the change in the content of mobile

Table 1. Content of humus and various forms of NPK in irrigation-eroded meadow-gray soil

Horizons, cm	Humus, %	Gross forms, %		Digestible forms, mg/kg		
		Nitrogen	Phosphorus	N	P_2O_5	K_2O
Meadow-chernozem soils (average for 15 sections)						
Washed away						
0–10	1.0±0.2	0.09±0.03	0.13±0.03	8.9±7.2	14.7±6.7	220±40
10–20	0.9±0.3	0.08±0.03	0.12±0.04	10.3±5.1	12.5±3.9	300±53
20–30	0.8±0.2	0.07±0.02	0.10±0.02	10.2±4.2	11.2±5.9	300±42
30–40	0.6±0.2	0.06±0.01	0.09±0.02	3.1±2.1	10.6±4.1	200±33
40–50	0.4±0.2	0.05±0.01	0.08±0.02	3.1±2.0	9.2±3.8	140±28
50–60	0.4±0.1	0.04±0.01	0.07±0.02	1.1±1.0	7.5±3.1	140±20
60–70	0.3±0.1	0.02±0.01	0.06±0.01	2.8±1.2	7.0±2.9	100±26
70–80	0.3±0.1	0.02±0.01	0.05±0.01	1.7±1.1	5.8±5.1	100±19
80–90	0.2±0.1	0.01±0.01	0.04±0.01	1.9±1.3	4.3±2.5	60±15
90–100	0.2±0.1	0.01±0.01	0.02±0.01	0.5±0.5	2.0±1.0	50±27
Washed						
0–10	1.7±0.2	0.14±0.04	0.21±0.03	18.3±11.3	27.0±9.4	420±80
10–20	1.6±0.3	0.12±0.04	0.20±0.02	11.8±6.3	24.0±13.2	380±43
20–30	1.0±0.2	0.10±0.02	0.13±0.02	12.4±5.8	21.0±9.3	380±67
30–40	0.9±0.2	0.08±0.02	0.13±0.03	9.8±5.0	17.4±5.1	320±34
40–50	0.7±0.2	0.06±0.01	0.11±0.04	6.8±4.3	16.0±4.8	240±60
50–60	0.6±0.1	0.05±0.01	0.10±0.02	5.8±3.9	14.0±6.2	200±38
60–70	0.5±0.2	0.04±0.01	0.10±0.01	3.9±2.0	13.0±3.8	150±24
70–80	0.3±0.2	0.03±0.01	0.08±0.01	4.5±2.0	11.2±4.1	140±36
80–90	0.2±0.1	0.02±0.01	0.05±0.01	2.2±2.0	9.4±7.8	120±20
90–100	0.2±0.1	0.02±0.01	0.03±0.01	1.6±1.5	7.6±3.1	90±25

phosphorus, which in a meter-thick layer of the washed-out part ranges from 2.0±1.0 to 14.7±6.7 mg/kg, and in the washed-out part 7.6±3.1–27.0±9.4 mg/kg (Table 1).

No significant change in the content of gross potassium in the washed-out and washed-out difference was noted, however, the amount of exchangeable potassium in the lower part of the slopes is much greater than in the upper part (Table 1).

In the sierozem zone, the main element limiting the yield is nitrogen. In places subject to irrigation erosion, nitrogen is lost as a result of washout and leaching. The nitrogen content in the arable layer of meadow-gray soils varies from 0.07 to 0.15%. As a result of irrigation erosion, its content in the arable layer of washed-out soils decreases significantly and there is some increase in the alluvial part of the slopes (Table 1).

It is known that the assimilation of nitrogen by plants is not always the same and largely depends on the properties of the soil, the ratio and presence of factors of growth and development of plants, their physiological state and biological activity of the soil. In this regard, studying the nitrogen regime of soils is quite difficult, especially in irrigated conditions.

We have found that soil ammonium nitrogen in meadow-gray soils before sowing occurs to a depth of 90 cm, most of it is concentrated in the arable and subarable layer. The content of ammonium nitrogen does not exceed 30 mg / kg on washed-out soils. On alluvial soils, its concentration is significantly higher. Thus, in the 0–30 cm layer of the washed part there were 22.0–33.0 kg/ha, and in the reclaimed part 40.5–60.1 kg/ha of NH4. Nitrate nitrogen in the washed part in early spring was 11.7–14.8 kg/ha, while in the reclaimed part it was 15.1–23.4 kg/ha (Table 3). The nitrification process in the reclaimed part of the soil is activated somewhat later than in the washed part. Nitrates are present in all genetic horizons of the soil, and in the lower horizons of the soil their concentration is significantly higher than that of ammonium nitrogen. It should be noted that in the reclaimed soils in the lower horizons the nitrate content is

Table 2. Quality of humus in the arable layer of meadow-gray soils

Soil	HA	FA	HA+FA	Humins	$\frac{C_{гк}}{C_{фк}}$
Meadow-chernozem washed away	27.5 / 9489	32.1 / 10994	59.8 / 20181	40.2 / 11785	0.71
Meadow-chernozem reclaimed	29.9 / 6309	33.1 / 15431	63.0 / 32256	37.0 / 18944	0.90

Note: *– in the numerator % of the total humus content, **– in the denominator in kg/ha.

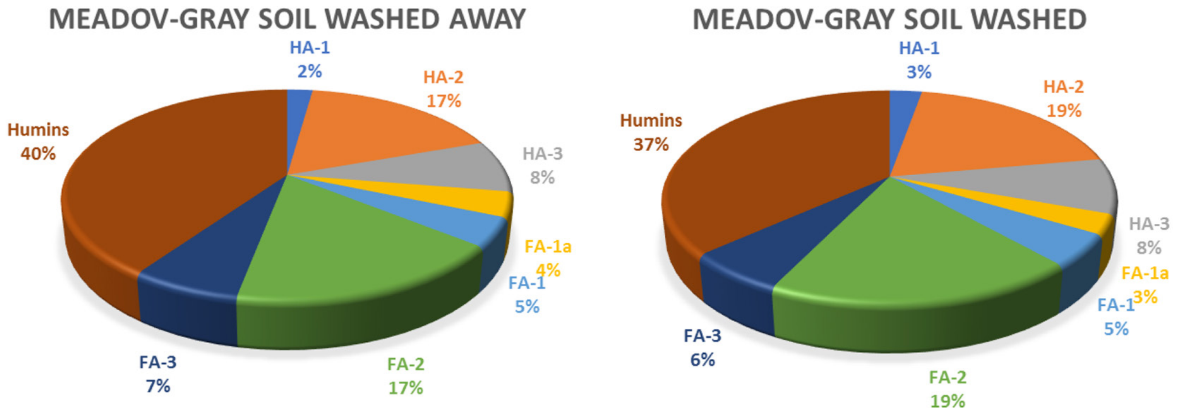

Figure 1. Fractional composition of humus in the arable layer of meadow-gray soils

2–2.5 times higher than in the same horizons of the washed soils (Table 1).

In meadow-serozem soil, the total content of gross nitrogen in the soil profile is directly dependent on the amount of humus. The C:N ratio remains high at 5.8–7.1. A smaller portion of the total nitrogen is in mineral form, and at the beginning of the growing season, the concentration of ammonium nitrogen is significantly lower than nitrate nitrogen. This is due to the lower soil temperature, i.e., the lower activity of the nitrification process during this period, and, naturally, the leaching of nitrates in winter. The content of alkaline-hydrolyzable nitrogen on reclaimed meadow sierozems is higher than on washed-out ones, while the potential for increasing nitrogen available to plants is significant (Table 3).

Hardly hydrolyzable and non-hydrolyzable fractions of nitrogen in meadow-gray soil on reclaimed areas are higher than on washed-out areas.

Determination of factors that increase the efficiency of nitrogen fertilizers when used together with a nitrification inhibitor for tobacco on irrigation-eroded meadow-gray soils and an explanation for the sharp increase in the use of nitrogen fertilizers by these crops (determined by the difference method) when a nitrification inhibitor is added is possible only in experiments using nitrogen-15.

The scheme of small-plot experiments with nitrogen-15 is fragments of more complete schemes of field experiments. The crop yields in the corresponding variants of small-plot and full-size field experiments turned out to be very close (Figure 2). The coefficient of fertilizer nitrogen use by tobacco plants, determined by the isotope method, was slightly lower and amounted to 32.5% in the variant without a nitrification inhibitor, and 46.6% with the inhibitor applied. The use of a nitrification inhibitor increased the use of fertilizer nitrogen by the aboveground mass from 27.1 to 38.8%, the fixation of fertilizer nitrogen in the soil increased from 21.4 to 29.3%, while losses with solid runoff and discharge water decreased from 10.3 to 4.5%.

Losses of fertilizer nitrogen due to leaching from the half-meter soil layer and volatilization decreased with the application of a nitrification inhibitor from 35.8 to 19.6%.

After harvesting, 26.8% of the nitrogen applied remained with the tobacco roots in the half-meter layer and was fixed in the soil in the variant without a nitrification inhibitor, and 37.1% with the inhibitor applied. The amount removed from this soil layer with the above-ground mass of plants alienated from the field and losses due to washout, volatilization and leaching in these variants was 73.2 and 62.9%, respectively.

Table 3. Content of various nitrogen fractions in meadow-chernozem soil

Depth, cm	C/N	N total, kg/ha	$N\text{-}NH_4$ kg/ha, % of gross	$N\text{-}NO_3$ kg/ha, % of gross	$N\text{-}NH_4$+$N\text{-}NO_3$ кг/га, % к gross	Alkaline hydrolyzable, kg/ha, % of gross
Washed away						
0–10	6.8	1188	33/2.8	11.7/1.0	44.7/3.8	128/10.7
10–20	6.5	1128	28/2.5	14.5/1.3	42.5/3.8	109/9.7
20–30	6.5	1015	22/2.1	14.8/1.6	36.8/3.7	89/8.7
30–40	6.5	822	16.4/2.0	4.2/0.5	20.6/2.5	65.6/8.0
40–50	5.8	705	8.4/2.0	4.4/0.6	12.8/1.8	53/7.5
50–60	5.8	512	6/1.2	2.8/0.6	8.8/1.8	35.8/7.0
60–70	5.8	262	4/1.6	3.7/1.4	7.7/3.0	20.4/7.8
70–80	-	274	3/10.5	2.4/0.9	5.4/1.4	19/6.9
80–90	-	144	2/1.5	2.7/1.9	4.7/3.4	11/7.6
90–100	-	148	-	0.7/0.5	0.7/0.5	8/5.4
Washed						
0–10	7.1	1792	44.8/2.5	23.4/1.3	68.2/3.8	187.4/10.4
10–20	7.1	1536	60.1/3.9	15.1/1.0	65.2/4.9	168/10.9
20–30	6.4	1320	40.5/3.1	16.4/1.2	46.9/4.3	129/9.8
30–40	6.4	1120	24/2.1	13.7/1.2	37.7/3.3	92/8.2
40–50	6.4	810	15/1.8	9.2/1.1	24.2/2.9	70/8.6
50–60	5.8	630	/1.9	8.3/1.3	20.3/3.2	52/8.2
60–70	-	399	6.0/1.5	7.2/1.8	13.2/3.3	23/5.8
70–80	-	402	4.5/0.2	6.1/1.5	10.6/2.7	25.6/0.4
80–90	-	405	1.5/0.4	3.0/0.8	4.5/1.2	16.5/4.1
90–100	-	130	-	2.1/1.6	2.1/1.6	10/7.6

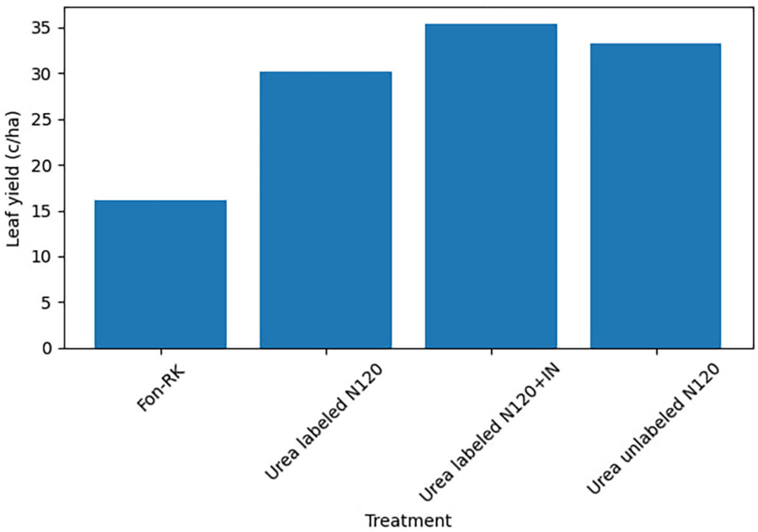

Figure 2. Nitrogen balance of labeled urea in a small-plot experiment with tobacco. The denominator is the use of nitrogen by the above-ground mass of plants. The numerator is the use of nitrogen by the entire vegetative mass of plants

The use of nitrification inhibitors had a positive effect not only on the use of fertilizer nitrogen by tobacco plants, but also on the share of soil and fertilizer nitrogen in the total amount of nitrogen supplied to plants. Thus, the share of fertilizer nitrogen in the total nitrogen removal by plants with the application of a nitrification inhibitor increased from 41.8 to 50.9%, and the share of soil nitrogen decreased from 58.2 to 49.1%.

CONCLUSIONS

Based on the study of irrigation-eroded meadow-gray soils of the Urgut district, the following conclusions can be made:

- Irrigation water mostly washes away fine silty, organic-matter-rich soil particles. Due to this, the thickness of the humus horizon increases on the washed part of the slope. On the washed part of the slope, a sharp decrease in the humus content is observed towards the lower soil horizons, and on the washed ones, the distribution of humus along the soil profile is more uniform.
- Erosion processes lead to a decrease in the content of the sum of $N\text{-}NO_3 + NH_4$ and alkaline-hydrolyzable nitrogen in the arable and, partially, subarable horizons of washed soils. At the same time, its amount increases on washed varieties.

The use of a nitrification inhibitor on tobacco plantations on washed meadow-gray soils contributed to a more rational use of soil nitrogen reserves, significantly reduced the washout of fertilizer nitrogen. The latter is especially important, since tobacco plantations in the Urgut region are located on fairly steep slopes. The use of a nitrification inhibitor against the background of a single application of the entire dose of urea affected individual items of the nitrogen balance of fertilizers: it increased fixation in the soil from 21–30% to 29–34%, and losses with solid runoff and discharge water decreased by 2 times in experiments from 12 to 5%, the amount of losses due to volatilization and leaching from a half-meter soil layer decreased from 36–39% to 11–20%.

REFERENCES

1. Khashimov F.Kh., Tashkenbaev O.N., Kubayeva M.T. (2024). The importance of humus in the fertility of irrigated gray-earth soils and the effectiveness of mineral fertilizers. *Innovations in Sustainable Agricultural Systems, 1*, 170–176, https://doi.org/10.1007/978-3-031-70673-8_19
2. Khashimov F.Kh., Tashkenbaev O.N., Kubaeva M.T. (2024). The influence of irrigation on the humus state and fertility of meadow soils in the desert zone of the Zerafshan Valley. *Problems of Agrochemistry and Ecology,* 2, 24–29. https://doi.org/10.26178/AE.2024.43.87.006
3. Emde D., Hannam K.D., Most I., Nelson L.M., Jones M.D. (2021). Soil organic carbon in irrigated agricultural systems: a metaanalysis. *Glob. Change Biol, 27*, 3898–3910. https://doi.org/10.1111/gcb.15680
4. Nunez A., Schipanski M. (2023). Changes in soil organic matter after conversion from irrigated to dryland cropping systems. *Agric., Ecosyst. Environ. 347*, 108392 https://doi.org/10.1016/j.agee.2023.108392
5. MaGill B.M., Hamilton S.K., Millar N., Robertson G.Ph. (2018). The greenhouse gas cost of agricultural intensification with groundwater irrigation in a Midwest U.S. row cropping system. *Glob. Change Biol. 24*, 5948–5960.
6. Khashimov F.Kh., Tashkenbaev O.N., Kubayeva M.T., Abdyeva G.M. (2022). Influence of anthropogenic impact on the group composition of humus in irrigated soils of the Zarafshan valley. *European Journal of Agricultural and Rural Education (EJARE) 3*(5). https://www.scholarzest.com
7. Khashimov F., Tashkenbayev O., Khayitov M. (2021). The interdependens of the humus state and the productivity of individual crop on irrigated soils. *Conference Proceedings: Global food forum*. 31–39 p. Gussak V.B. Some observations on soil erosion in the boundary layer using microphotography. Soil Science, 1948, 7, 453–457.
8. Khashimov F.Kh. (2018). The state and ways of increasing the fertility of soils of the Zarafshan Valley. Monograph. *Samarkand*, 241.
9. Gussak V.B., Makhsudov H.M. (1963). Irrigation erosion on typical sierozem and issues of combating it. *Proceedings of the Institute of Soil Science, 3*, Tashkent, pp. 111–121.
10. Gussak V.B. et al. (1967). *Study of the influence of irrigation technology on irrigation erosion*. In the book: Questions of hydraulic engineering. Issue 31. Tashkent, pp. 43–63.
11. Gussak V.B., Makhsudov H.M. (1969). *Erosion control in the irrigated agriculture zone.* In the book: Problems of using land and water resources of the Uzbek SSR. Tashkent, pp. 59-63
12. Protasov P.V., Mailibaev S.S. (1966). Methods of increasing the fertility of eroded soils. *Cotton growing*, 5, 8.
13. Kambarov B.F. (1994). *Anti-erosion and water-saving equipment and technology for irrigation of lands in the foothill zone of Uzbekistan*. Abstract for the degree of Doctor of Technical Sciences, Tashkent, 39 p.
14. Yakutilov M.R. (1982). *Reclamation of lands subject to gully erosion in the new irrigation zone*. In the collection: Complex agrotechnical and reclamation measures to increase the fertility of soils in Tajikistan. Dushanbe, pp. 16–18.

15. Mailibaev S.S. (1965). Mineral fertilizers on eroded soils. *Cotton growing,* 8, 16.
16. 16. Makhsudov Kh.M. (1959). Effect of irrigation erosion on some properties of typical sierozems. *Uzbek biological journal, C 3*, 74–79.
17. Makhsudov Kh.M. (1963). *Irrigation erosion on typical sierozem and principles of its control.* Abstract for the degree of candidate of agricultural sciences, Tashkent, 24 p.
18. Makhsudov Kh.M. Eroded sierozems and ways to increase their productivity. Tashkent, Fan, 1981, 157 p.
19. Makhsudov Kh.M. (1984). *Eroded soils of the arid zone, increasing their fertility and protection from erosion.* Abstract for the degree of Doctor of Biological Sciences. Moscow, 48.
20. Khamdamov H.H., Khashimov F.H., Muminov K.M., (1985). Erosion as a barrier. *Agriculture of Uzbekistan,* 5, Tashkent, p. 49.
21. Khamdamov H.H., Khashimov F.H., Muminov K.M., (1987). *Productivity of eroded soils in the tobacco-growing zone of the Samarkand region*. Works, reports of VASKhNIL. Moscow, 1, 27
22. Khamdamov H.H., Khashimov F.H., Muminov K.M., (1987). *How to increase the fertility of eroded soils.* Tashkent. Mekhnat, 160 p.
23. Khamdamov H.H., Khashimov K.M., (1988). Reduce erosion losses. Agriculture of Uzbekistan, 2, 47–49.
24. Núñez A., Schipanski M. (2023). Changes in soil organic matter after conversion from irrigated to dryland cropping systems. *Agriculture, Ecosystems & Environment 347*, https://doi.org/10.1016/j.agee.2023.108392
25. Núñez A., Cotrufo M.F., Schipanski M. (2022). Irrigation effects on the formation of soil organic matter from aboveground plant litter inputs in semiarid agricultural systems. *Geoderma. 416*, https://doi.org/10.1016/j.geoderma.2022. 115804
26. Jakab, G., Szabó, J., Szalai, Z., Mészáros, E., Madarász, B., Centeri, C., Szabó, B., Németh, T., Sipos, P. (2016). Changes in organic carbon concentration and organic matter compound of erosion-delivered soil aggregates. *Environmental Earth Sciences, 75*(144), https://doi.org/10.1007/s12665-015-5052-9
27. Xashimov F.X., Tashkenbayev O.N., Axadova Ch.F. (2023). Zarafshon vodiysining turli anthropogen hududlari tuproqlarida azotning umumiy va harakatchan shakllarini o'rganish. Theoretical and practical foundations of introducing smart agriculture in Uzbekistan, *International Scientific and Practical Conference*, *SamTSAU Conference, 4*(1), 1172–1181.
28. Zavalin A.A., Sokolov O.A., Shmyreva N.Ya. (2021). Development of agrochemical research with the isotope 15N in Russia. *Plodorodie 3*, 56–62, https://doi.org/10.25680/S19948603.2021.120.10
29. Karydogianni S., Darawsheh M.K., Kakabouki I., Zisi Ch., Folina A.E., Roussis I., Tselia Z., Bilalis D. (2020). Effect of nitrogen fertilizations, with and without inhibitors, on cotton growth and fiber quality. *Agronomy Research 18*(2), 432–449, https://doi.org/10.15159/AR.20.148
30. Cui, L., Li D., Wu, Z., Xue, Y., Xiao, F., Zhang, L., Song, Y., Li, Y., Zheng, Y., Zhang, J., Cui, Y. (2021). Effects of nitrification inhibitors on soil nitrification and ammonia volatilization in three soils with different pH. *Agronomy 11*(8), 1674; https://doi.org/10.3390/agronomy11081674
31. Maher H., Moussadek R., Zouahri A., Douaik A., Amenzou N.E., Benmansour M., Iaaich H., Dakak H., El Mouridi Z., Bellaouchou A., Ghanimi A. (2023). Nitrogen use efficiency using the 15N dilution technique for wheat yield under conservation agriculture and nitrogen fertilizer. *Nitrogen 4*(4), 369–381. https://doi.org/10.3390/nitrogen4040026
32. Scheer, C., Rütting, T. (2023). Use of 15N tracers to study nitrogen flows in agro-ecosystems: transformation, losses and plant uptake. *Nutr Cycl Agroecosyst 125*, 89–93. https://doi.org/10.1007/s10705-023-10269-x
33. Salazar, O., Diaz, R., Nario, A., Videla, X., Alonso-Ayuso, M., Quemada, M. (2021). Nitrogen Fertilizer efficiency determined by the 15N dilution technique in maize followed or not by a cover crop in Mediterranean Chile. *Agriculture 11*, 721.
34. Khashimov F.Kh., Tashkenbaev O.N., Umurzakov A.A. (2024). The effectiveness nitrogen balance urea cotton using nitrification inhibitor washed typical sierozems. *BIO Web of Conferences 149*, 01046. Genetic Resources 2024, https://doi.org/10.1051/bioconf/202414901046
35. Abagandura, G.O., Park, D., Bridges, W.C., Brown, K. (2021). Soil surfactants applied with 15N labeled urea increases bermudagrass uptake of nitrogen and reduces nitrogen leaching. *J. Plant Nutr. Soil Sci. 184*, 378–387, https://doi.org/10.1002/jpln.201900162
36. Ingraffia, R., Lo Porto, A., Ruisi, P., Amato, G., Giambalvo, D., Frenda, A.S. (2023). Conventional tillage versus no-tillage: Nitrogen use efficiency component analysis of contrasting durum wheat genotypes grown in a Mediterranean environment. *Field Crops Res. 296*, https://doi.org/10.1016/j.fcr.2023.108904
37. Yagodin B. A. et al. (1987). Agrochemistry Workshop [edited by B. A. Yagodin]. – Moscow: Agropromizdat, 511.
38. Dospekhov B. A. (1985). Methodology of field experiment (with the basics of statistical processing of research results). Moscow: Agropromizdat, 351.