Regularities of spring runoff formation and erosion under the influence of forest and agrotechnical reclamation in the southern chernozem of the Volga region

Peter Proezdov, Dmitry Eskov, Alexander Rozanov, Sergey Sviridov
Saratov state agrarian University, Saratov, Russia
E-mail: proezdov_pn@sgau.ru

Abstract. The purpose of the study was to determine the regularities of the spring formation elements of water balance and soil erosion under the influence of a set of anti-erosion techniques based on long-term observations (1964-2020). The research object was created in 1964 on the land of the farm "Vyazovsky". The complex of anti-erosion techniques consists of two forest strips 300 m apart, reinforced with ditches. The inter-lane space was developed by crop rotations and pasture with the use of mulched crevices to combat, with silting and ice content of cracks. The dose of straw sections at a distance between the slits of 1.4 m – 4.8 t / ha. Forest belts accumulate snow by 33.3% more than open agricultural landscapes, and in low-snow winters, the effect of snow deposition increases by another 20%. Long-term studies of spring runoff on land in the steppe of the Volga upland allowed us to recommend the appropriate values of 10% probability of excess for creating soil protection complexes from erosion: moldboard ploughland – 25 mm, moldboardless ploughland– 47 mm, winter crops и grass pastures – 65 mm. The content of southern chernozem with A+B <0.5 m at the permissible level of erosion equal to 0.3 t / ha is possible when a complex of anti-erosion forest reclamation and agrotechnical techniques is introduced into the technology of crop cultivation. Regression and correlation analysis found that the spring runoff coefficient and spring soil erosion depend on the amount of water reserves in the snow and the degree of protection of land from erosion by anti-erosion techniques by 92-99%.

1. Introduction
Introduction. In the Russian Federation, the problem of soil erosion control is still rele vant: 65% of arable land, 50% of pastures, and 28% of hayfields are subject to degradation processes [1]. Forest stands serve as an ecological framework for protecting land from erosion [1-3]. Many naturalists note the positive role of the complex of forest strips, agro-reclamation and hydrotechnical techniques in maintaining agriculture at an acceptable level of erosion. Along with natural anthropogenic factors that influence the formation of surface spring runoff have a different character due to climate change [4-7]. Significant experience in studying surface runoff, including spring runoff, with the aim of further developing a set of methods for protecting soil from erosion on the Volga [8-9] and Central Russian uplands [10]. For the hydrological justification of anti-erosion techniques, the corresponding indicators of spring runoff were calculated [8-10].
2. Materials and methods

The aim of the study is to establish the regularities of the spring formation elements of water balance and erosion under the influence of a complex of anti-erosion techniques. The object of research was created in 1964 on the farm "Vyazovsky" of the Tatischevsky district of the Saratov region, located in the steppe of the Volga upland (figure 1) [8-9].

Many years of experience (1964-2020) of comprehensive soil protection from erosion allowed us to generalize the accumulated experimental material. The complex of anti-erosion techniques includes:

- Organization of the territory on a contour-reclamation basis;
- Filling of gullies with preservation of the fertile soil layer and application of organic and mineral fertilizers;
- Planting of two forest strips reinforced with ditches after 300 m;
- Application of mulched crevices between forest strips;
- Development of the inter-strip area during the first 9 years for fodder crop rotations (1964-1972);
- Application of field crop rotations (1973-2001) with the share of row crops and fallow up to 25% and pasture rotation (2002-2020).

The scheme of the experiment provided for the study of the influence of forest strips and mulch crevices on the elements of the spring water balance and soil erosion of agricultural crops, crop rotations, pastures in different water content and moisture years on the erosion-dangerous type of agricultural landscape (slope steepness 4,5°).

The research was based on the recommendations of scientists from the State Hydrological Institute [11]. Regression and correlation analysis was performed according to standard computer programs Statistika, MS Excel.

3. Results and Discussion

The effectiveness of the complex of anti-erosion measures is determined by the reliability of hydrological justification, optimal use of forest stands, agro-and hydrotechnical techniques in landscapes.

The theoretical aspect of the content of southern chernozem with A+B<0.5 m at an acceptable level of erosion, depending on the formation of spring runoff and the use of a set of anti-erosion techniques, is to use an analytical and empirical method based on which multiple regressions are constructed:

$$k_v=b_0+b_1W_c+b_2h_b+b_3B_l+b_4W_cB_l+b_5h_bB_l+b_6W_c+b_7h_bB_l$$

\[ E = b_0 + b_1W_c + b_2k_b + b_3W_cB_l + b_4W_ck_b + b_5W_cB_l + b_6k_bB_l + b_7W_ck_bB_l \] (2)

Where \( k_b \) – spring runoff coefficient \((k_b = h_b / W_c)\); \( W_c \) – water reserves in the snow, mm; \( h_b \) – spring runoff, mm; \( B_l \) – the degree of protection of land from erosion by protective forest stands and agricultural practices: \( B_{l1} \) – open field (control) – 0,1; \( B_{l2} \) – mulch crevice (MC) on arable land or shrubby backstage (SB) in the pasture – 0,4; \( B_{l3} \) – forest strips (FS) on the land – 0,6; \( B_{l4} \) – FS+ MC on arable land or FS+SB in the pasture – 0,9; \( E_b \) – spring erosion, т/ha; \( b_0 \) – \( b_7 \) – multiple regression coefficients.

The soil cover of the object of study is southern crushed-stone chernozem, incompletely developed, medium loamy, medium eroded on a flask with a thickness of horizons \( A + B <0.5 \) m and a content of 3.7% humus in horizon \( A \). Of the agricultural practices, the most effective was slitting, which was used for tillage, crop rotation, pasture, in the aisles of forest strips (before closing), etc. In order to combat silting during runoff and "clogging" with ice during winter thaws, the cracks were filled with a 0.2 m straw section to a depth of 0.1 m with an elevation of 0.1 m above the surface. Consumption of mulching material at inter-slit distances of 1.4 m-4.8 t / ha. The slots were cut with a slotted-mole-maker SCHN-2-140, and with a moldboard-free (flat-cut) tillage - with a cultivator-flat-cutter — a deep ripper KPG-2-150.

Forest belts have the greatest impact on snow accumulation, regardless of the applied crop rotation, tillage, and crop cultivation technology: the increase in water reserves in snow on land was on average 18.2-33.3%, with a probability of exceeding 10% - 22.1-30.0%. Snow accumulates on an average 24.3% more on a non-tilled swell without the influence of forest strips than on plowing, and 18.7% more with the influence of plantings. Forage crop rotations have an advantage in water reserves in snow over field ones by 15.6%, while forest belts increase snow accumulation by 6.9%, respectively (table 1). Studies have shown that in low-snow winters, forest stands accumulate more snow by 15-20% than in multi-snow ones, which affects the formation of spring surface runoff [9].

The largest spring runoff is formed on pasture (27 mm), winter crops (23 mm), smaller on spring-free swell (16 mm), on perennial grasses (11 mm) and on plowing (7 mm). The runoff coefficient, as well as the amount of runoff, tends to change depending on the technology of growing crops, the type of crop rotation, and the anti-erosion techniques used. On average, the runoff coefficient is higher in the spring-free swell than in the winter ploughing by 80.0%, the gap in the swell reduces this value by 66.7% and the forest strips equalize the value of the runoff coefficients to 0.03 (table 1). Indicators of surface spring runoff with a probability of exceeding 10% based on long-term studies are proposed for creating a set of anti-erosion techniques: dump-25 mm, dump-free-47 mm, winter crops and pasture grasses-65 mm (table 1).

Spring soil erosion without the use of anti-erosion techniques exceeds the permissible value equal to the southern chernozem on the flask with \( A+B<0.5 \) m 0.3 t / ha [9], depending on the tillage of the soil and land by 2.7-3.4 times. Acceptable sizes of spring erosion are achieved when applied to soil treatment, crop rotation and pasture of mulched crevice and forest strips. Cultivation of perennial grasses in crop rotations allows you to keep the soil during the spring flood at an acceptable level of erosion. The turbidity of spring runoff tends to decrease with the introduction of soil protection techniques from erosion (table 1).

The regression and correlation analysis of the spring runoff coefficient (1) and soil erosion (2) dependences on natural and anthropogenic factors showed a complex multidimensional relationship. The response surfaces for the proposed regression models (1,2) cannot be represented on the plane, so they are represented as separate three-dimensional sections (figure 2-5). The graphs are based on long-term studies of spring elements of water balance and soil erosion (tables 1 and 2). The coefficient of spring runoff by 98-99% depends on the water reserves in the snow, the amount of runoff, and the degree of protection of land by forest stands and agricultural techniques. Spring soil erosion by 92-94% is determined by snow deposition, runoff coefficient, and land protection techniques.
Table 1. Elements of the water balance and erosion of spring floods with a probability of exceeding 10% and 50% on land and crop rotations under the influence of anti-erosion techniques (1964-2020).

| Cultures, Crop rotation. | Anti-erosion techniques (slope steepness 4.50°) | Snow reserves, mm | Spring runoff, mm / | Spring erosion *, t/ha / Turbidity, g/l |
|-------------------------|------------------------------------------------|------------------|----------------------|----------------------------------------|
| Pasture. | | 10% | 50% | 10% | 50% | 10% | 50% |
| Fodder crop rotation (1964-1972) | | | | | | |
| Without mulched crevice (MC) and forest strips (FS) – (Control) | | | | | | |
| Moldboard ploughland (3 years) | MC | 125 | 70 | 25/0.20 | 7/0.10 | 3.80/15.2 | 1.03/14.7 |
| | FS | 159 | 91 | 13/0.08 | 3/0.03 | 1.52/11.7 | 0.37/12.3 |
| | FS +MC | 157 | 88 | 9/0.06 | 2/0.02 | 0.95/10.6 | 0.23/11.5 |
| | Control | 149 | 99 | 31/0.21 | 11/0.11 | 0.25/0.8 | 0.07/0.6 |
| Herbs of the 2nd and 3rd years (6 years) | MC | 150 | 97 | 19/0.13 | 10/0.10 | 0.18/0.9 | 0.06/0.6 |
| | FS | 182 | 117 | 12/0.06 | 7/0.04 | 1.11/1.2 | 0.03/0.6 |
| | FS +MC | 182 | 118 | 9/0.05 | 5/0.04 | 0.64/21.3 | 0.37/12.3 |
| | Control | 141 | 89 | 29/0.21 | 9/0.10 | 1.43/4.9 | 0.39/4.3 |
| Fodder crop rotation. 9 years. 100% herbs; (1964-1972) | MC | 143 | 88 | 17/0.12 | 6/0.07 | 0.91/5.4 | 0.25/4.2 |
| | FS | 174 | 108 | 12/0.07 | 5/0.04 | 0.61/5.1 | 0.16/3.2 |
| | FS +MC | 174 | 108 | 9/0.05 | 4/0.03 | 0.39/4.3 | 0.11/2.8 |
| Moldboard ploughland (16 years): 15 years for spring; 1 year under steam | FS +MC | 157 | 88 | 9/0.06 | 2/0.02 | 0.95/10.6 | 0.23/11.5 |
| | Control | 145 | 87 | 47/0.32 | 16/0.18 | 1.95/4.1 | 0.90/5.6 |
| | M**S | 151 | 92 | 19/0.13 | 6/0.06 | 1.22/6.4 | 0.48/8.0 |
| | FS | 179 | 108 | 10/0.06 | 3/0.03 | 0.78/7.8 | 0.29/9.7 |
| Field crop rotation (1973-2001) | FS +M**S | 177 | 109 | 11/0.06 | 7/0.06 | 0.54/4.9 | 0.11/1.6 |
| Moldboardless ploughland (8 years: 4 years under steam. 4 years for spring crops) | MC | 143 | 82 | 33/0.23 | 16/0.20 | 1.45/4.4 | 0.38/2.4 |
| | FS | 179 | 108 | 11/0.11 | 6/0.06 | 1.25/7.4 | 0.48/8.0 |
| | FS +MC | 177 | 109 | 19/0.11 | 7/0.06 | 0.54/4.9 | 0.11/1.6 |
| | Control | 133 | 77 | 38/0.28 | 12/0.16 | 3.16/8.3 | 0.95/7.9 |
| Winter crops (5 years) | MC | 137 | 79 | 22/0.16 | 8/0.10 | 1.90/8.6 | 0.55/6.9 |
| | FS | 168 | 99 | 17/0.10 | 6/0.06 | 1.25/7.4 | 0.32/5.3 |
| | FS +MC | 166 | 97 | 11/0.07 | 4/0.04 | 0.75/6.8 | 0.20/5.0 |
| | Control | 135 | 80 | 36/0.27 | 11/0.14 | 2.75/7.6 | 0.82/7.4 |
| Field crop rotation 29 years (1973-2001) | MC | 138 | 81 | 27/0.20 | 8/0.10 | 1.66/6.1 | 0.48/6.0 |
| | FS | 169 | 101 | 16/0.09 | 6/0.06 | 1.09/6.8 | 0.28/4.7 |
| | FS +MC | 168 | 100 | 10/0.06 | 4/0.04 | 0.66/6.6 | 0.18/4.5 |
| Average for crop rotations for 38 years (1964-2001) | FS +MC | 171 | 100 | 12/0.07 | 5/0.05 | 0.46/8.8 | 0.13/2.6 |
| Pasture rotation (2002-2020) | (Control) | 136 | 77 | 67/0.49 | 27/0.35 | 2.27/3.4 | 0.85/3.1 |
| Pasture rotation for 19 years (2002-2020) | MC | 137 | 78 | 35/0.26 | 19/0.24 | 1.19/3.4 | 0.33/1.7 |
| | FS | 175 | 100 | 23/0.13 | 10/0.10 | 0.44/1.9 | 0.08/0.8 |
| | FS +MC | 179 | 104 | 15/0.08 | 8/0.08 | 0.07/0.5 | 0.02/0.2 |
| Average for crop rotations and pasture rotation for 57 years (1964-2020) | MC | 138 | 80 | 29/0.21 | 12/0.15 | 1.50/5.2 | 0.43/3.6 |
| | FS | 171 | 101 | 18/0.11 | 7/0.07 | 0.87/4.8 | 0.21/3.0 |
| | FS +MC | 171 | 100 | 12/0.07 | 5/0.05 | 0.46/3.8 | 0.13/2.6 |

Note: Perennial grasses of the 1st year under spring crops in the forage crop rotation (3 years), spring crops and pairs in the field rotation (24 years) are subject to storm erosion; * erosion permissible - 0.3 t/ha; ** Slots from the stands KPG-2-150.
Table 2. Elements of water balance and erosion of spring floods in crop rotations and pasture under anti-erosion techniques (on average for 1964-2020).

| Crop rotation. Pasture | Anti-erosion techniques (slope steepness 4.50°) | The degree of protection of land from erosion | Water balance elements, mm | Runoff coefficient | Erosion* spring, t/ha | Runoff turbidity, g/l |
|------------------------|-----------------------------------------------|---------------------------------------------|--------------------------|-------------------|---------------------|---------------------|
|                        | Without mulched crevice (MC) and forest strips (FS) | 0.1 | 89 | 9 | 0.10 | 0.39 | 4.3 |
| Fodder crop rotation. 9 years old, 100% - herbs (1964-1972) | MC | 0.4 | 88 | 6 | 0.07 | 0.25 | 4.2 |
|                        | FS | 0.6 | 108 | 5 | 0.04 | 0.16 | 3.2 |
|                        | FS + MC | 0.9 | 108 | 4 | 0.03 | 0.11 | 2.8 |
|                        | Control | 0.1 | 77 | 12 | 0.16 | 0.95 | 7.9 |
| Field crop rotation. 29 years old (1973-2001) | MC | 0.4 | 79 | 8 | 0.10 | 0.55 | 6.9 |
|                        | FS | 0.6 | 99 | 6 | 0.06 | 0.32 | 5.3 |
|                        | FS +MC | 0.9 | 99 | 4 | 0.04 | 0.20 | 5.0 |
|                        | Control | 0.1 | 77 | 27 | 0.35 | 0.85 | 3.1 |
| Pasture rotation 19 years (2002-2020) | MC | 0.4 | 78 | 19 | 0.24 | 0.33 | 1.7 |
|                        | FS | 0.6 | 100 | 10 | 0.10 | 0.08 | 0.8 |
|                        | FS +MC | 0.9 | 104 | 8 | 0.08 | 0.02 | 0.2 |
|                        | Control | 0.1 | 79 | 16 | 0.20 | 0.83 | 5.2 |
| Average for crop rotations and pasture | MC | 0.4 | 80 | 12 | 0.15 | 0.43 | 3.6 |
|                        | FS | 0.6 | 101 | 7 | 0.07 | 0.21 | 3.0 |
|                        | FS + MC | 0.9 | 100 | 5 | 0.05 | 0.13 | 2.6 |

Note: * Erosion permissible - 0.3 t/ha.

Figure 2. Dependence of the spring runoff coefficient on snow storage and the degree of protection of lands by anti-erosion methods.

Figure 3. Dependence of the spring runoff coefficient on the degree of protection of lands by anti-erosion methods.
4. Conclusion
Of the complex of anti-erosion techniques, forest belts have the greatest impact on the elements of water balance and soil erosion during spring floods. Under the influence of protective plantings, the increase in snow on land is up to 33.3%, with a greater increase typical for snow-covered winters. The spring runoff coefficient is increased by ditch-free cultivation compared to traditional plowing with a reservoir turnover of up to 80%, but ditch-free cultivation technology allows the soil to be kept at an acceptable level of erosion. Studies of spring surface runoff for 57 years allowed us to recommend the corresponding values of 10% probability of exceeding when creating anti-erosion objects: winter crops and pasture-65 mm; dump – 25 mm; non – dump-47 mm.

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