Surface flow of melted snow water on the central Russian upland

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Abstract. In areas with a pronounced relief, water erosion causes great harm to agriculture and other sectors of the national economy. It leads to the destruction of the soil cover, a reduction in the area of arable land, a decrease in fertility, the removal of erosion products into floodplains, the siltation of ponds and rivers and the destruction of the road network. The scientific goal was to identify the influence of the main natural factors (snow reserves, freezing and soil moisture) on the formation of the spring melt water runoff on the plow. To study the questions raised, the water-balance method was used with the use of runoff sites. Observations showed that the formation of the melt water runoff depended on the depth of soil freezing. With shallow soil freezing up to 50 cm, there was no runoff. All the melt water was absorbed by the soil. As a result of 30 years of research (1991-2020), it was found that the average annual runoff on the plow was very weak - 3.8 mm on the scale of Surmach, the runoff coefficient is 0.05, shallow soil freezing - 19-28 cm, duration of snow melting - 16 days.

1. Introduction
For reliable soil protection from water erosion, it is necessary to apply a set of anti-erosion measures, which includes: anti-erosion organization of the territory, forest reclamation, agrotechnical, meadow reclamation and hydrotechnical measures [1, 2, 3, 4].

The basis for the implementation of these measures aimed at protecting the soil from washout and erosion is the anti-erosion organization of the territory. It includes land classification, crop rotation system. Agrotechnical methods of cultivation of any agricultural crops in our conditions should contain soil-protective elements that prevent the flow of melt and storm water and help to protect the soil from destruction. Protection should be carried out not only in areas prone to flushing, but also in fields where there is no flushing, but runoff is formed [5, 6]. The generalization of long-term research materials showed that the arsenal of agrotechnical anti-erosion methods is large, but their effectiveness is low. The most effective of these is deep winter plowing. Effective retention of melt water on the
plow is achieved by creating a deep arable layer rich in organic matter by introducing large doses of organic fertilizers and reducing the number of treatments due to the cultivation of perennial grasses.

2. Materials and methods
Field experiments were carried out at the Novosilskaya Zonal Agroforestry Experimental Station in 1991-2020. The soil in the experimental plots is gray forest, washed away. Every year, drainage plots with a size of 20 × 100 m were created on the plowing fields. Snow deposition, freezing and soil moisture, melt water runoff, and soil thawing were studied on them. Before the spring snowmelt, the snow height was measured at runoff sites using two snow-measuring runs every 2-4 m in 3-5 times. Snow density was determined with a weight snow gauge at each runoff site at 6 points in 2-fold repetition. The depth of soil freezing was determined by the presence of ice crystals during drilling. The thermostat-weight method was used to determine soil moisture. Soil samples for moisture were taken from the following depths: 0-3, 10, 20, 30, 40, 50, 75-100 cm. Runoff measurements at the thresholds of weirs with a triangular cut were carried out with a ruler with millimeter divisions every hour [7, 8]. Observations of soil thawing were carried out using a metal rod in the upper, middle, and lower parts of the runoff plots in 5 replicates. The study studied the regularities of the influence of natural and anthropogenic factors on the indicators of the runoff of thawed waves on the plow [9].

3. Results and discussion
Water erosion is a big problem for agriculture. For the successful protection of soils from washout and erosion, it is necessary to understand the patterns of erosion-hydrological processes. Barabanov previously found that the relationship between the runoff layer and the duration of snow melting is very weak. This is explained by the fact that the period of snow melting at the Novosilskaya Zonal Agroforestry Experimental Station is long (10-27 days) and even its minimum duration (10 days) is enough for the topsoil (0-30 cm) to be moistened to the lowest and even full moisture capacity. The depth of freezing affects the formation of runoff, which is confirmed by our research. If, before the snowmelt, the soil is thawed or frozen up to 50 cm, then the spring runoff is not formed or is weak, regardless of soil moisture, snow reserves and the duration of snow melting. When the depth of soil freezing is more than 50 cm, the runoff of melt water is formed depending on the level of moisture (ice content) of the soil and snow reserves.

On the basis of generalization and analysis of long-term data characterizing the relationship between the layer of melt water runoff from the plow and compacted arable land with natural factors, the law of limiting factors of melt water runoff was discovered earlier [2]. The essence of the law is that at a certain (limiting) value of one of the factors (freezing depth, soil moisture and snow reserves), runoff is not formed regardless of the level of others. If the soil is thawed or frozen to a depth of no more than 50 cm, runoff is not formed, regardless of the level of soil moisture and the amount of snow reserves. An increase in the depth of soil freezing above the limiting level has practically no effect on the amount of runoff, i.e. at any depth of soil freezing above the limiting one, the runoff is formed the same. In this case, soil moisture and water reserves in the snow have a decisive influence on it. When the upper (0-50 cm) layer is moistened to a level of 120-130 mm, runoff is also not formed, regardless of the depth of soil freezing and the amount of water in the snow, i.e. the limiting factor is soil moisture.

Earlier it was found [2] that the soil is capable of absorbing and retaining a certain amount of water (the maximum in the frozen state can reach the value of the total moisture capacity of the upper layer). Moisture deficiency (the difference between the total moisture capacity and the actual moisture content) determines the amount of water absorption. The runoff layer depends on the moisture deficit in the soil and snow reserves before snow melting.

Over the long-term observation period, the prevailing hydrometeorological conditions of the winter period with weak soil freezing and other factors determined the absorption of all melt water into the soil for 23 years (Table 1). Water absorption ranged from 40 to 151 mm. In 1994, the largest spring runoff was formed - 37 mm with a runoff coefficient of 0.31, soil freezing of 75 cm.
| Years | Runoff, mm | Water supply, mm | The depth of soil freezing, cm | Duration of snow melting, days | Precipitation during the period of snow melting, mm | Runoff coefficient | Water absorption, mm |
|-------|------------|------------------|-------------------------------|-------------------------------|-----------------------------------------------|-------------------|---------------------|
| 1991  | 34         | 172              | 58                            | 10                            | 17                                            | 0.05              | 71                  |
| 1992  | 0          | 169              | 54                            | 0-17                          | 14                                            | 16                | 0                   |
| 1993  | 17         | 139              | 40                            | 45-83                         | 10                                            | 22                | 0.22                |
| 1994  | 37         | 263              | 119                           | 75                            | 12                                            | 17                | 0.31                |
| 1995  | 0          | 228              | 107                           | 25                            | 21                                            | 10                | 0                   |
| 1996  | 29         | 166              | 73                            | 70-80                         | 16                                            | 8                 | 0.40                |
| 1997  | 1          | 227              | 56                            | 38-53, in places thawed       | 2                                             | 5                 | 0.02                |
| 1998  | 0          | 188              | 48                            | 18-20                         | 18                                            | 12                | 0                   |
| 1999  | 0          | 166              | 144                           | 20-25, in places thawed       | 11                                            | 7                 | 0                   |
| 2000  | 0          | 209              | 57                            | 7-25                          | 12                                            | 0                 | 0                   |
| 2001  | 0          | 198              | 81                            | 0-5                           | 12                                            | 21                | 0                   |
| 2002  | 0          | 184              | 81                            | 8-10                          | 10                                            | 40                | 0                   |
| 2003  | 26         | 212              | 97                            | 41-70                         | 13                                            | 25                | 0.25                |
| 2004  | 0          | 189              | 58                            | 10-18                         | 6                                             | 14                | 0                   |
| 2005  | 0          | 203              | 71                            | 5-12                          | 12                                            | 14                | 0                   |
| 2006  | 0          | 212              | 109                           | 0-3                           | 5                                             | 21                | 0                   |
| 2007  | 0          | 225              | 51                            | 0                             | 13                                            | 30                | 0                   |
| 2008  | 0          | 208              | 67                            | 20-31                         | 8                                             | 14                | 0                   |
| 2009  | 0          | 202              | 105                           | 12-25                         | 21                                            | 33                | 0                   |
| 2010  | 0          | 262              | 89                            | 30-40                         | 15                                            | 22                | 0                   |
| 2011  | 0          | 156              | 119                           | thawed                        | 15                                            | 14                | 0                   |
| 2012  | 0          | 168              | 61                            | 18-40                         | 18                                            | 25                | 0                   |
| 2013  | 0          | 171              | 108                           | 0-15                          | 12                                            | 18                | 0                   |

Table 1. Slope runoff of melt water and water absorption on the plow.
4. Conclusion

Long-term studies (1991-2020) established the influence of the main natural factors on the slope spring runoff. It depends on the depth of soil freezing, snow storage and soil moisture before spring snow melting. With shallow soil freezing, there is no runoff of melt water, and when freezing deeper than 50 cm, spring runoff is formed.

The prevailing hydrometeorological conditions of the winter period for 30 years (shallow freezing of the soil before snow melting and its weak moisture in some years) caused the total water absorption of melt water into the soil (40-151 mm) for 23 years and no runoff was formed during these years.

The system of measures to protect soil from erosion should be based on knowledge of the regularities of erosion-hydrological processes under the influence of natural and anthropogenic factors. The analysis of long-term studies of the regularities of the formation of surface melt water...
runoff over a 30-year period made it possible to establish the leading natural factors, influencing which it is possible to control the erosion-hydrological process.

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