Simulation of agricultural landscape catenas based on the analysis of hydrodynamic characteristics of the underlying surfaces of slope lands

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Abstract. The agricultural landscape of slope lands is characterized by ecological instability and to ensure its equilibrium state a system of agronomic, melioration and environmental measures is carried out. Assessing the state of slope agricultural landscapes, it is necessary to take into account slope parameters, contour sizes, hydrological regime, types and varieties of soils, erosion processes, economic conditions, location, etc. Monitoring the above parameters will allow to detect hidden impacts or changes and restore the stability of the agricultural ecosystem early, for example, to maintain the hydrodynamic characteristics of the underlying surface for a certain period. Comprehensive research including methods of mathematical simulation and analysis carried out on the agricultural landscape catena is most effective. One of the fundamental scientific problems to be solved in this is to study and construct agricultural landscape catenas using the analysis of hydrodynamic characteristics of soil and vegetation cover of slope lands. It has been established that for compensatory melioration measures and engineering melioration systems planned on agricultural landscapes of slope lands, the following water flow rates occur: from 0.022 to 1.5 m/s for phytomelioration measures when slopes are rather steep; from 0.138 m/s for agricultural melioration measures at a slope of 0.08; and for traditional tillage rates exceed the critical ones and reach 0.8 m/s. According to the nomogram for determining the velocity diagram on a particular catchment slope, it is possible to assess and control anti-erosion melioration measures, revealing the actual speed regime of water flow in problem areas, and, therefore, it is possible to prevent erosion processes and preserve soil fertility on meliorated slope lands early.

1. Introduction
The agricultural landscape of slope lands is a natural-territorial complex, the natural vegetation on its vast area has been replaced by agrocoenoses. Since it is characterized by environmental instability, a system of agronomic, melioration and environmental measures is carried out to ensure its equilibrium state. The ability of an ecosystem to return to the previous stable equilibrium state after being temporarily subjected to natural or anthropogenic factors testifies its stability. Assessing the state of slope agricultural landscapes, it is necessary to consider slope parameters, contour sizes, hydrological regime, types and varieties of soils, erosion processes, economic conditions, location etc. It is obvious that along with the parameters responsible for the stability of agricultural ecosystems, crop yield is of utmost importance. Crop yield reduction, for example, because of soil erosion or degradation, excessive moistening or drought predetermines the transition of the ecosystem to an
unstable condition. At the same time, crop productivity decrease will be the extreme and marginal state of the agricultural ecosystem due to the impact of natural and anthropogenic factors. Unless the ecosystem reaches this state, we can control manipulate the ecosystem by controlling the dynamics of a number of hydrophysical and erosive parameters of the agricultural landscape catena, including the level of soil fertility. Monitoring the above parameters will allow to detect hidden impacts or changes and restore the stability of the agricultural ecosystem early, for example, to maintain the hydrodynamic characteristics of the underlying surface for a certain period. Thus, it is not reasonable to consider the stability of the agricultural ecosystem taking into account one or two negative factors as in many mathematical models. Comprehensive research including methods of mathematical simulation and analysis carried out on the agricultural landscape catena is most effective. It is difficult to determine the zones and areas on catena, which are subject to significant negative impacts as well as their time and space boundaries and dimensions. No concepts of these problems have been fully investigated yet.

One of the fundamental scientific problems to be solved in this is to study and construct agricultural landscape catenas using the analysis of hydrodynamic characteristics of soil and vegetation cover of slope lands. To identify the hydrodynamic characteristics of the soil and vegetation we need measuring data to assess the water balance on sloping agricultural landscape, as well as a number of soil and vegetation cover parameters. Besides we need earth remote sensing information. It is known that the value of the components of the developed and modified equation of water flow motion for the studied agricultural landscape catena is determined by experimentally measured hydrophysical and erosive parameters, as well as their dynamics in time and space.

The relevance and practical significance of the research is justified by the absence of scientifically grounded approaches to describe and construct the agricultural landscape catenas for the development of anti-erosive methods and technical means on sloping agricultural landscapes to prevent water erosion processes or decrease their intensity in crop production on slope lands.

2. Materials and methods

The reason for applying various melioration measures in Morgaushskiy district environment in the Chuvash Republic was determined when the condition of the agricultural landscapes were analyzed taking into account the shape of slopes, the size of the meliorated areas and a number of other necessary parameters.

It was proposed, to determine the most efficient anti-erosion melioration measures applied on the agricultural landscapes of slopes by means of the hydrodynamic characteristic of water flowing along the slope.

Since the angle of a slope varies along the chain of facies depending on their distance from the watershed, according to the longitudinal profile of the catchment, we present the slope function as:

$$i_i = f(l_i), \quad (1)$$

where: $i_i$ - the actual grade of the studied facies at a distance $l_i$; $l_i$ - i-o.e distance from the divide line on the slope to the studied facies.

The graphs of functions for a convex slope and a concave one correspond to environment of Morgaush district of the Chuvash Republic (figure 1 and 2). The data for constructing the graph of the function for the slope are obtained according to topographic maps of sufficient scale.

The analysis of slope functions dependences presented graphically, showed that slope grade increases from 0.009 to 0.08 for a convex slope up to 1 km long, and approximating accuracy of 0.98 for the quadratic function. For a convex slope the slope grade decreases from 0.01 to 0.082 along its length for the quadratic dependence approximating the accuracy 0.99.

Then a combined graph is constructed on the bases of these slope function dependences and the hydrodynamic characteristics of the water flow moving along this slope. The combined graph is
presented as a nomogram for specifying anti-erosion melioration techniques that determine the velocity diagram on the studied catchment.

Figure 1. Slope facie of a convex profile.

The total length of the catchment is divided into a series of facies according to the classification and scheme of the types of their locations [8]:

- eluvial facies, in the form of a flattered watershed area with a little grade up to 1...2 degrees – in case of a convex slope.;
- transeluvial facies, in the form of the upper relatively steep slope sections with a grade of at least 2...3 degrees – both for convex and concave slopes;
- transaccumulative facies at the lower parts of the slopes having atterration and aggradation for concave slope.

Figure 2. Slope facies of concave profile.
Finally, we specified some facies according to their location and place at the topographic profile, exposure diversity, steepness and the shape of a slope for the studied agricultural landscape of slope lands.

Studying agricultural landscapes of slope lands by ground control apparatuses, we obtain the measurement data based on hydrophysical parameters to solve the equation of water balance as well as the equation of temporary water flow movement.

The equation of temporary water flow movement is possible to solve by graphic analytic method in the form of hydrodynamic characteristic of the water flow moving along the slope. This characteristic is put into the nomogram and is used to solve the equation (1). The solution of the equations is a velocity diagram of water flow along the length of the catchment that is formed at the low right quadrant of the nomogram taking into account the critical rates of the beginning of soil erosion.

Application of the obtained nomograms whether for a convex or concave catchments makes it possible to specify certain melioration and anti-erosion techniques at designing or to assess them when being applied. These technologies are used on the slopes depending on agricultural background and critical velocities of the watercourse moving on the underlying surface.

The analysis of the obtained nomograms shows that a convex slope requires application of anti-erosion melioration measures along the length of the catchment, whereas a concave slope requires these measures on the initial section of the agricultural landscape of slope lands.

Among the proposed melioration measures to prevent soil erosion on the agricultural landscape of slope lands the following ones can be applied [7]:

- agrotechnical – deep tillage for moisture accumulation, tilting the soil without or before ploughing, furrowing, regulation of surface runoff taking into account the microtopography (banking-up, paraploughing), etc.
- hydrotechnical – terracing of slopes, creation of special engineering facilities for water drainage (chute, ditches, earth dams), etc.

Application of anti-erosion melioration measures is determined by the velocity diagram that is formed in the lower right quadrant of the nomogram, taking into account the critical velocities of the water flow [5, 7, 9]. As a rule, soil erosion occurs on transeluvial facies, where the water rates begin to exceed the limits for the underlying surfaces: 0.15...0.3 m/s depending on the soil type and agricultural background. The flow erosive velocity and the main parameters of the underlying surface of the agricultural background on the studied catchment are determined by means of the developed control devices [3, 6]

3. Results and discussion
To determine of water flow velocity on the underlying surface we carried out field experimental studies in the Morgauisky district in autumn 2019. The main parameters of the underlying surface were measured and calculated by the developed methods and control devices [1, 2, 4]. The following parameters were determined for different agricultural backgrounds: coefficient of hydraulic roughness, PES and waviness of the underlying surface [3, 10].

The equation of temporary water flow movement shows the balance between the actual grade and the sum of the grades of hydraulic losses during water flow movement on the underlying surface, in a simplified form without any dimentions [7]:

\[ i = i_\phi + i_\psi + i_\delta + i_\gamma + i_j. \]  

(2)

where: \(i\) - the actual facie grade; \(i_\phi\) – the grade of the hydraulic friction losses; \(i_\psi\) – the grade of the hydraulic losses on the underlying erosion surface slope; \(i_\delta\) – the grade of hydraulic losses to pass
through plants; $i_r$ – the grade of the hydraulic losses to overcome the waviness of the surface; $i_j$ – the grade of hydraulic losses to overcome the inertia of the water flow.

**Figure 3.** Experimental studies to determine the potential of soil erosion resistance in the field.

On the bases of results presented in figure 4, we construct hydrodynamic characteristics of a water flow for various agricultural backgrounds. The equation of the temporary water flow motion (2) was applied

To compare of hydrodynamic characteristics of the water flow moving on various agricultural backgrounds, we present the data of N. N. Bobrovitskaya's research in table 1. She studied the process of slope runoff movement on the catchment area [6].

**Table 1.** Results of field studies for melt water presented by N. N. Bobrovitskaya [6].

| Measurement sections | Exposition | Grade | Speed Of the stream, cm/s | Depth of the stream, cm | Agricultural background          |
|----------------------|------------|-------|---------------------------|--------------------------|---------------------------------|
| 1                    | S          | 0,027 | 6,08                      | 0,85                     | Winter plowing with harrowing    |
| 2                    | S          | 0,05  | 50                        | 3                        |                                  |
| 3                    | S          | 0,075 | 81,3                      | 5,1                      |                                  |
| 4                    | S-E        | 0,183 | 5                         | 1,3                      | Perennial grass sainfoin         |
| 5                    | W          | 0,115 | 2,2                       | 0,03                     |                                  |
| 6                    | S-E        | 0,08  | 13,8                      | 1                        | Winter crops                    |

The figure 4 shows both hydrodynamic characteristics obtained by our research (winter stubble and winter crops) and the data on Winter plowing with harrowing and perennial grass sainfoin obtained by N. N. Bobrovitskaya that are marked by dots.

Due to the fact that the agricultural backgrounds in the form of perennial grass sainfoin was not available, since such a feed crop is not found the Chuvash Republic, the data were obtained for perennial grass alfalfa.

**4. Conclusions**

In this article, it has been established that for compensatory melioration measures and engineering melioration systems planned on agricultural landscapes of slope lands, the following water flow rates occur: from 0.022 to 1.5 m/s for phytomelioration measures when slopes are rather steep; from 0.138 m/s for agricultural melioration measures at a slope of 0.08; and for traditional tillage rates exceed the critical ones and reach 0.8 m/s.

According to the nomogram for determining the velocity diagram on a particular catchment slope, it is possible to assess and control anti-erosion melioration measures, revealing the actual speed
regime of water flow in problem areas, and, therefore, it is possible to prevent erosion processes and preserve soil fertility on meliorated slope lands early.

Figure 4. Hydrodynamic characteristics of the water flow moving along different agricultural backgrounds at the catchment, constructed according to our experimental data and research by N. N. Bobrovitskaya [6].

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