Study of features of differentiated soil treatment by machine-tractor units on agricultural landscapes of slope lands

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Abstract. The paper considers the features of anti-erosion contour tillage on slope lands, taking
into account the location of technological furrows at an angle to the horizontal of the slope. Obtaining
information about the terrain model is possible in different ways, including before
processing and during the processing of the soil on the slope by a machine-tractor unit. In this
case, it is necessary to calculate the angle of deviation of the soil treatment direction relative to
the slope when pro-cessing the correct areas with such machines on a complex slope. It has been
established that when technological furrows are placed in a straight line, the erosion process
develops significantly, for example, when using passive working bodies of agricultural machines
(tooth harrows, coverers) on slope lands. For processing complex slope lands, we propose to use
the active harrow as an anti-erosion tool in a machine-tractor unit. We have obtained a
mathematical model for processing complex slope lands with an active harrow as part of a
machine-tractor unit. The proposed approach can be used on slope lands with a slope of up to 15
degrees. Thus, the prerequisites for contour processing of soil on slopes by forming technological
furrows with a zero slope are justified, which excludes additional agrotechnical and
hydrotechnical anti-erosion and reclamation measures on slope lands with a slope of up to 15
degrees.

1. Introduction
Technologies for annual processing of old-arable soil of slope lands within a given land use area do not
always meet the requirements of soil protection from water erosion. The noticeable manifestation of
erosion processes is explained by insufficient consideration of many and various requirements for soil
treatment on slope lands [1, 2, 3]. In studying these processes, it is necessary for conditions to be
observed throughout the growing season of crops to prevent soil erosion, including conditions of
immediate action, that is, immediately after soil treatment.

It is known that anti-erosion agrotechnical measures are divided into general and special [4, 5, 6].
The general types include conventional tillage used on agricultural landscapes of slope lands (for
example: plowing, cultivation, harrowing, etc.). Special methods prevent washing and runoff of soil [7,
8, 9]. These include slitting, grooving, furrowing, etc.
Some difficulties arise when designing sites on complex slopes with a non-constant slope. In this case it is necessary to determine the maximum permissible deviation of the processing direction relative to the slope [10, 11, 12, 13].

To solve the difficulties that arise in processing complex slopes, it is necessary to obtain information directly about the slopes during soil treatment by machine-tractor unit and transmit it to the active working elements of the anti-erosion agricultural machine [14, 15].

Therefore, the topic of research of anti-erosion contour soil treatment with machine-tractor units on agricultural landscapes of slope lands is relevant.

The purpose of this work is development of the special methods of soil treatment to reduce erosion processes and preserve soil fertility for cultivation of agricultural crops on agricultural landscapes of slope lands.

2. Methods and materials

In agro-landscape reclamation of slope lands [1], there are three forms of slopes (figure 1):

- a simple slope characterized by a constant significant slope;
- a complex slope characterized by a variable significant slope;
- a flat surface that is typical of the flat interfluve-plain type of agricultural landscape, characterized by a slight constant or variable slope up to 0.5 degrees.

For a simple slope and flat interfluve-plain type of agricultural landscape, regardless of the variety of their types, straight-line soil treatment is possible. It involves processing along the course of the machine-tractor unit (hereinafter referred to as MTU) [1], for a complex slope – curved, as close as possible to the hypsographic line.

Taking into account that the slopes of agricultural fields have small values, it is possible to record [1]:

$$i = i_{sk} \sin \alpha,$$

where $i$ - the incline of a linear element, $i_{sk}$ - the incline of the calculated slope; $\alpha$ - the angle of deviation of the linear element relative to the slope, degrees.

In practice, when designing linear elements in agricultural fields, it is more accessible to get information from terrain maps, namely, to consider the angle of deviation of the direction of soil cultivation relative to the slope. Assuming this, the expression (1) is represented as [1]:

$$\alpha = \arcsin \frac{i}{i_{sk}}.$$

At the same time, it is known that when technological furrows are placed in a straight line, for example, when using passive working bodies (tooth harrows, coverers on slope lands), the erosion process develops significantly. The decrease in the effectiveness of this approach on complex slopes is due to the intersection of the furrows formed by the hollows. In this case, the water flow will be concentrated and redirected along micro-sloughs with the formation of washouts and possible growth of the ravine (figure 1).
To identify the dependence of the slope of the machine-tractor unit on a complex slope relative to the horizon, a formula is used to determine the angle of deviation of the direction of movement of the machine-tractor unit from the horizontal [16]

\[
\tan \gamma = \tan \alpha / \left( \arctg \frac{\tan \alpha}{\sin(\arctg \frac{\tan \alpha}{\tan \beta})} \right).
\]  

Then the angle itself will be determined by the formula

\[
\gamma = \arctg \left( \tan \alpha / \left( \arctg \frac{\tan \alpha}{\sin(\arctg \frac{\tan \alpha}{\tan \beta})} \right) \right).
\]  

where \( \alpha \) – longitudinal incline of the MTU relative to the horizontal; \( \beta \) – longitudinal slope’s incline of the MTU relative to the horizontal; \( \gamma \) – angle of deviation of the direction of movement of the machine-tractor unit from the horizontal.

For processing complex slope lands, we suggest using an active harrow as an anti-erosion tool in a machine-tractor unit. The angle of deviation of the actual speed vector of the tooth can be determined by the expression:
\[ tg\gamma = \frac{V_H}{V_M} \]  

(5)

where \( \gamma \) – angle of deviation of the vector of the actual speed of the screw turn from the vector of the longitudinal movement of the machine-tractor unit (MTU), degrees; \( V_a \) – the transverse speed of the tooth, equal to the speed of the machine-tractor unit, m/s; \( V_n \) – transverse speed of tooth movement, m/s.

Taking into account equation (5) and the calculations given in [17], we obtain the angle of deviation of the vector of the actual speed of the tooth of the active harrow:

\[ \gamma = \arctg \left( \frac{z \cdot d_\theta \cdot \sin \left( \frac{180}{z} \right) \cdot n}{V_M} \right) \]  

(6)

where \( z \) – number of teeth of the leading sprocket; \( d_\theta \) – pitch diameter of the drive sprocket, mm; \( n \) – frequency of rotation of the leading sprockets, sec\(^{-1}\).

Equate expressions (4) and (6)

\[ \frac{z \cdot d_\theta \cdot \sin \left( \frac{180}{z} \right) \cdot n}{V_M} = tg\alpha / \left( \arctg \frac{tg\alpha}{\sin \left( \arctg \frac{tg\alpha}{tg\beta} \right)} \right) \]  

(7)

Thus, we have obtained a mathematical model for processing complex slope lands with an active harrow as part of a machine-tractor unit. On the one hand, the parameters of a complex slope are defined, on the other hand, the parameters of an active harrow are set.

3. Results and discussion

Field studies were conducted on the obtained expressions. The dependences of the horizontal deviation from the longitudinal axis of the tractor under the specified conditions are obtained, taking into account the slope’s incline (figure 2).

![Figure 2](image_url). The installation of sensors on the tractor and conducting field research.
The dependences of the horizontal deviation from the longitudinal axis of the tractor in degrees under specified conditions are presented, taking into account the longitudinal and transverse incline of the slope (figure 3).

It is known that on agricultural landscapes slopes are no more than 12 degrees [18, 19]. In field studies, the longitudinal and transverse slopes of the tractor frames relative to the horizontal lines were established. Their value varied from -15 to +12 degrees. As a result of setting these angle’s values, it was found that the deviation of the direction of the tractor’s movement from the horizontal changes from -88 deg. up to 89 deg.

![Figure 3](image.png)

Figure 3. The dependence of the horizontal deviation from the longitudinal axis of the tractor in degrees at the specified inclines of the slope.

According to the identified dependencies, it is possible to determine the design capabilities of the machine-tractor unit to overcome the inclines of the underlying surface by the position of the wheels relative to the horizontal plane. Next, you can calculate the deviation’s angle of the direction of the machine-tractor’s unit movement (the longitudinal axis of the tractor) from the horizontal slope.

It should be noted from the graphs in figure 3 that for small incline’s values (0 ... 2 degrees), the value of the deviation of the direction of the machine-tractor’s unit movement from the horizontal changes significantly and quickly achieves 70...80 degrees when changing the transverse angle. At large inclines (6 ... 10 degrees), this change is not so significant and achieves values of 40...60 degrees. In any case, these values of deviation play a significant role in the formation of water flow on the slope. The results obtained are prerequisites for further studies [20].

4. Conclusion

Thus, the paper considers the features of soil treatment on slope lands and the possibility of implementing anti-erosion contour treatment, taking into account the location of technological furrows at an angle to the horizontal slope. It is established that when technological furrows are placed in a straight line, for example, when using passive working bodies of agricultural machines (tooth harrows, coverers) on slope lands, the erosion process develops significantly. For processing complex slope lands, we propose to use the active harrow as an anti-erosion tool in a machine-tractor unit. A mathematical model of processing complex slope lands with an active harrow as part of a machine-tractor unit is obtained. By implementing it, we can obtain contour soil treatment with a zero incline of technological furrows, which excludes additional agrotechnical and hydrotechnical anti-erosion and reclamation measures on slope lands with an incline of up to 15 degrees.
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