Impact of the error of circular control methods on assessing the quality of anti-erosion soil tillage on slope lands

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Abstract. The scientific article considers the impact of the error of circular control methods on assessing the quality of anti-erosion soil tillage on slope lands. The applied control methods are implemented in scientifically based designs of technical control facilities that can provide high measuring accuracy of the parameters, when profiling the soil surface for different slopes of the agricultural landscape of slope lands. It was found that the device error along the measurement path is negligible, since it is theoretically possible to set the scanning angle of 60 or more degrees, while the radial error is restrained, which does not allow setting such limits of angles even when the device arm length is 0.5 m. On the bases of the results of analytical studies, we obtained a graph of changes of the surface width being measured after the passage of the working part, depending on the scanning angle when the mechanism vibrates. The analysis of the graph allows us to conclude that in order to scan the underlying surface in case the working part width of the anti-erosion machine is known or can be predicted within the acceptable error values, it is necessary to change the radius of the scanned circle by changing the arm length. For example, when working part width is less than 0.5 meters, you can use any circle radii. If the width of soil tillage from 0.5 meters to 1 meter, the circle radius should be more than 0.7 m and the scanning angle should be less than 50 degrees. When the width of the working part of more than 1 meter the circle radius should be about 3 meters that slightly complicates the design of the device since the diameter reaches almost 6 meters.

1. Introduction
Assessing the quality of anti-erosion technologies carried out in agriculture, the fulfillment of the requirements for soil tillage of slope lands are taken into account, using various instrumental methods [1]. Currently non-contact methods are becoming more and more popular, due to their low labor intensity, the cost of conducting research and the minimum equipment cost. In addition, they do not damage the surface being studied, which is often a decisive factor for the customer when choosing an examination method. However, using non-destructive methods, the organizations performing the survey often do not consider the error, taking the obtained data as reliable. Non-contact control devices are most often used in the survey of various technologies in environmental engineering. In measuring every known parameter, an error can occur, which can significantly overestimate or underestimate the quality of the performed operation in further calculations. Accordingly, it may result...
in overestimating the reliability of anti-erosion measures or extra financial expenses for their improvement [2, 3].

Each method has an error that largely depends on the conditions of measurement and the device used for research. Conducting the research, we have to deal with various agricultural backgrounds [4, 5].

In this paper, we will discuss the impact of the error of circular non-contact control methods on assessing the quality of anti-erosion soil tillage on slope lands.

Conducting the research, we reviewed domestic literature and foreign scientific articles, on properties and application of control methods for assessing the quality of anti-erosion soil tillage technologies. They include the pin meter method, or profilometry, stereo photography, the shadow method, laser scanning, and the chain and acoustic scattering method [1].

The design of the pin meter or profilograph is simple. It consists of probes that are arranged in a row and can move down to the surface of the soil. The position of the probe may be recorded electronically or in the form of photographs. Then the records are converted into digital form [1]. The main drawback of this method is the potentially destructive effect of the pins that prevents further measurements. Its main advantage is simplicity and ease of operation in the field.

Thus, the literature allows us to assess the design and possible errors in determining the parameters of the impact of circular error control methods for assessing the quality of anti-erosion soil tillage on sloping lands. The purpose of the work presented is to resolve the problem resulted from the lack of data on the direct impact of the error on the quality of anti-erosion soil tillage [3]. This work should demonstrate the impact of the error of non-contact circular control methods on assessing the quality of anti-erosion soil tillage and consider the efficiency of using these methods in certain cases.

2. Materials and methods

A principle diagram and a general view of the field non-contact profilograph are given in works [6, 7]. The device consists of a massive base with legs for fixing on the soil surface. On the base there is a rod mounted by means of a bearing. At the lower end of the rod there is an encoder – angle sensor – and a movable arm fixed perpendicularly at its upper end. There is a counterweight at one end of the movable arm and a laser position sensor installed by means of a rod at the other end. It allows moving the laser sensor vertically. At the upper end of the rod there is an electronic signal processing unit which is connected to the laptop via a USB cable. A level is also attached to the rod.

The device operates as follows. First the profilograph is leveled vertically in all directions by moving the arm around the circle. The angle and position sensors are powered from the laptop. The "RF 605+encoder" computer program is run on the laptop. Then the arm is slowly rotated around the base. Performing one revolution, the laser position sensor scans the soil surface and transmits the data to the electronic signal processing unit. The principle of operation of the laser sensor is based on the method of determining the distance with a laser. The laser beam lights a point on the surface of the soil the distance is to which is to be measured. Scattered reflection from the soil surface point is taken by a CCD ruler. The electronic signal block determines the length to the soil surface by the location of the focused spot on the CCD ruler.

In order to determine the error of the device, we consider the calculation diagram in figure 1. Assume the device scans along an arc of the circle with radius $R$, the arc being bounded by the distance $\Delta l$. To calculate the method error according to the difference of the arc and chord lengths and to the value $h$ - distance in the radial direction from the point A to point B, considering the design of the device, we carry out analytical work.

To determine the length of the chord, we use the well-known equation

$$l_x = 2R \sin \frac{\gamma}{2};$$

(1)
where \( R \) - the radius of the circumscribed circle, \( m \), \( \gamma \) is the scanning angle when the mechanism vibrates, deg.

**Figure 1.** Calculation diagram for determining the device error.

It is possible to determine the length of an arc on a chord \( l_A \) using the expression

\[
I_A = \frac{\pi R \gamma}{180}.
\]  

Considering the equations (1) and (2), we can determine the error of the method according the difference of arc and chord lengths by the expression

\[
\kappa = \left( \frac{I_A}{l_A} - 1 \right) \times 100\% = \left( \frac{\pi \gamma}{360 \sin \frac{\gamma}{2}} - 1 \right) \times 100\%.
\]  

According to the resulting equation we make a graph (figure 2).

The distance in the radial direction from point A to point B will allow determining the error of the device in \( \% \) by the expression

\[
h = R(1 - \cos \frac{\gamma}{2}).
\]  

According to the obtained expression, we analyze the change of the radial error of the device depending on the scanning angle and the circle radius when the mechanism vibrates (reciprocating movements of the laser along the arc) (figure 3).

3. Results and discussion
The authors in [1, 8] point out that effective methods and technical control facilities allowing to obtain reliable data about the changes of main underlying surface parameters when using anti-erosion
technologies and mechanical equipment were developed to determine the intensity of soil erosion processes on agricultural landscapes of slope lands. Using the profilograph we studied a field plot, located on a steep slope, after fall soil tillage by BDM-3x4П disc cutter and obtained the following data: the average slope was 0.06 or 3.44°, roughness - 3.54 mm, waviness of the surface soil - 7.94 cm, the direction of the main soil tillage - angle of deviation from the technological grooves of the direction of the slope made 93.6°.

\[ y = 1E-05x^2 - 8E-05x + 0.0005 \]
\[ R^2 = 0.9999 \]

**Figure 2.** Graph of the device error change along the path depending on the scanning angle when the mechanism vibrates.

\[ h = 2E-05x^2 + 7E-05x - 0.0005 \]
\[ h = 4E-05x^2 + 5E-05x - 0.0002 \]
\[ h = 0.0001x^2 + 9E-06x \]
\[ h = 6E-05x^2 + 2E-05x \]

**Figure 3.** Graph of radial error changes of the device depending on the scanning angle when the mechanism vibrates:
- arm length of 3 meters;
- arm length of 1.5 meters;
The developed control methods are implemented in scientifically based designs of technical control facilities that can provide high measuring accuracy of parameters when profiling the soil surface for various slopes of agricultural landscape of slope lands (with an error of up to 1% for non-contact and up to 3% for contact methods) [6, 7]. This accuracy is provided by the laser sensor of the device however the accuracy of the non-contact device is not taken into account.

Comparing the figures 2 and 3, you can see that the error of the device along the path is negligible, since it is theoretically possible to set the scanning angle of 60 or more degrees. However, these values are restrained by a radial error, which does not allow setting such angle limits even with the arm length of 0.5 m.

In anti-erosion tillage of the soil by different working parts of agricultural and reclamation machines, surface shapes of various widths are formed [9, 10, 11], so we present a graph of the change of the measured surface width after the passage of a working part, depending on the scanning angle when the mechanism vibrates (reciprocating laser movements along the arc) in figure 4.

Figure 4. Graph of changes of the measured width of the micro waterway depending on the scanning angle when the mechanism vibrates:

- arm length of 3 meters;
- arm length of 1.5 meters;
- arm length of 1 meter;
- arm length 0.5 meters.
--- critical error curve, up to 6 %.

The analysis of the graph allows us to conclude that in order to scan the underlying surface in case the working part width of the anti-erosion machine is known or can be predicted within the acceptable error values, it is necessary to change the radius of the scanned circle by changing the arm length [12]. For example, when working part width is less than 0.5 meters, you can use any circle radii. If the width of soil tillage - from 0.5 meters to 1 meter, the circle radius should be more than 0.7 m and the scanning angle should be less than 50 degrees. When the width of the working part of more than 1
meter the circle radius should be about 3 meters that slightly complicates the design of the device since the diameter reaches almost 6 meters.

4. Conclusions
The article demonstrates that circular control methods are used to assess engineering reclamation systems as well as reclamation and erosion control measures performed during soil tillage on agricultural landscapes of slope lands.

I was found that the device error along the measurement path is negligible, since it is theoretically possible to set the scanning angle of 60 or more degrees, while the radial error is restrained, which does not allow setting such limits of angles even when the device arm length is 0.5 m.

On the bases of the results of analytical studies, we obtained a graph of changes of the surface width being measured after the passage of the working part, depending on the scanning angle when the mechanism vibrates.

The analysis of the graph allows us to conclude that in order to scan the underlying surface in case the working part width of the anti-erosion machine is known or can be predicted within the acceptable error values, it is necessary to change the radius of the scanned circle by changing the arm length. For example, when working part width is less than 0.5 meters, you can use any circle radii. If the width of soil tillage - from 0.5 meters to 1 meter, the circle radius should be more than 0.7 m and the scanning angle should be less than 50 degrees. When the width of the working part of more than 1 meter, the circle radius should be about 3 meters that slightly complicates the design of the device since the diameter reaches almost 6 meters.

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