Research of the soil plowing technology on slope lands with a circular profilograph

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Abstract. A number of indicators estimates the quality of tillage during field operations. Thus the assessment takes time that is not always reasonable. To control the quality of tillage on slope agricultural landscapes we propose a newly developed technical means for profiling the day soil surface. A specific feature of the technical means is an automated circular scanning with a rangefinder. The scanning radius of the day soil surface can be variable or constant. Processing of the obtained data array is performed in a semi-automatic mode. Thus, we can get full information about the impact of agricultural machine on the soil, i.e. to assess the lumpiness, plowing, furrow depth, straightness of plowing and other measurements within a short time span. Simultaneously the assessment of slope is performed when the machine is moving along and across the slope. The way the machine impacts the soil, shows if soil conditions, adjustments, timing of work and other conditions have been specified correctly. Thus, due to the rapid comprehensive assessment of the impact on the soil, the proposed approach makes it possible to adapt the operating modes to the various soil properties on slope agricultural landscapes in the shortest time possible.

1. Introduction

The quality of field operations depends on the technical condition of the tillage and sowing machines, their accurate adjustment, the quality of previous soil tillage, soil conditions, the timing of work and so on. Violation of agro-technical requirements for tillage results in deterioration of the growth conditions and development of cultivated plants; reduction in yields; fertilizers effectiveness and chemical plant protection products; decrease in the effectiveness of land reclamation and fertility. Besides, it can make soil erosion possible. Therefore, constant control of the quality of field operations, in particular, the quality of specific tillage techniques should be organized. The quality of soil tillage is a set of indicators that demonstrate if soil conditions after its tillage meet the agro-technical requirements (GOST 16265-89 Agriculture. Terms and Definitions).

The main indicators of the quality of tillage include the depth of plowing and its uniformity [1], the coefficient of plowing, lumpiness and ridgeness of the arable land surface, straightness of plowing (deviation from straightness) [2,3]. The slope of the field plot is also taken into account. To measure the degree of soil crumbling during plowing, the coefficient of plowing, i.e. the ratio of the depth of the loose plowed soil layer to the depth of plowing measured in the furrow is used.

There is a device for controlling the micro-relief of a plot that consists of a coordinate rail, two pins with height-adjustable grooves, a level gauge, a movable carriage with a mirror that can be turned to fix
the angle of inclination to the direction of the laser beam [4]. It also has a laser distance sensor with a built-in level gauge to set the coordinate bar in a horizontal plane by adjusting the height with the grooves of the pins. To control the micro-relief of the field plot, the two pins with height-adjustable grooves are put into the soil in the transverse direction before the test machine passes the plot [5]. A movable carriage with a mirror and a laser distance sensor are mounted on the coordinate rail. The built-in level gauge of a laser distance sensor is used to set the coordinate rail in a horizontal plane by adjusting the height with the grooves of the pins [6,7]. Moving the carriage, we can turn the attached mirror and fix the angle of inclination towards the laser beam along the coordinate rail. We can also measure the distances up to the back side of the mirror and the total distances to the mirror and to the soil surface. The results of measurements are stored in the memory of the laser distance sensor and then transferred to a personal computer for the appropriate statistical processing [8]. The main drawback of the method is that installation of the pins with a built-in level gauge takes too much time. Besides, the method determines only the transverse profile of the micro-relief of the plot relative to the test machine passage [9].

There is also a device for determining the quality of tillage, which contains a coordinate rail with a laser distance sensors fixed on it, a hinge with a gyroscope, which is rigidly fixed to the frame of the tillage machine. The device also has an on-board computer and a navigator installed in the cab of the tractor that works in combination with the tillage machine. Thus, the tractor and the tillage machine make an integrated unit [10]. The device attached to the frame of the tillage machine by a bracket moves along with this unit, being constantly above the tilled soil. Laser distance sensors continuously measure the distance between the coordinate rail and the soil irregularities formed by the working parts of the tillage machine when it moves and sends the results of measurement to the on-board computer [11,12]. The computer receives real-time information about the current coordinates of the unit from the laser distance sensors and the navigator and then using special programs builds a digital characteristic of irregularities for each coordinate point of the tilled area [13]. The program interprets the received data in 3-D format and presents it as a digitized field profile with marked coordinates of areas that do not meet the agro-technical quality requirements established by GOST. A specific feature of this method is that it determines only the longitudinal profiling of the micro-relief of the plot relative to the tillage machine passage in dynamics, but the transverse profiling is determined by-point at a distance of 5 cm. Besides, due to dusty particles produces during tillage on the path of the laser beam directed and reflected from the day soil surface there is an increased information noise causing accuracy reduction of the obtained data.

2. Materials and methods

The method will be implemented using a technical means for profiling the day soil surface. It consists of a base 1, a holder 2, a movable arm 3, a laser distance sensor 4, a rangefinder 5 and an encoder – an angle sensor 6 (figure 1). This device is connected via a USB cable to a laptop (not shown in the diagram).

The method works as follows. To control the quality of agricultural landscapes tillage during field operations we use a technical means with a rangefinder for circular profiling of the day soil surface with a vertical accuracy of up to 1 mm. The rangefinder is installed in the furrow that separates the tilled and untilled areas formed after the passage of the machine and tractor unit. It provides a measurement range of up to 150 meters. Circular profiling is performed upon the surfaces of untilled area, the furrow and the tilled area.
Figure 1. Scheme of implementation of the method for quality control of agricultural landscapes tillage in the field operation (side view).

On the basis of the obtained data the relation between the distance from the sensor to the day soil surface and the angle of rotation of the encoder (in the form of the Cartesian coordinate system scan) and the depth of plowing and its uniformity are determined. When processing data by the moving average method, the value of the lumpiness and ridgeness of the arable land surface is determined. According to the obtained regression equations the lines of the greatest slope on the tilled and untilled field areas are:

\[ z = k_H y + b_H ; \]  
\[ z = k_O y + b_O , \]  

where \( x \) - the longitudinal coordinate, m; \( y \) - the transverse coordinate, m; \( z \) - the vertical coordinate i.e. the height of the irregularities of the soil surface, m; \( k_O \) and \( k_H \) - the angular coefficients of the regression equation for the soil surface of the tilled and untilled field areas; \( b_O \) and \( b_H \) - absolute terms of regression equations for the day soil surface of the tilled and untilled field areas;

The slope of the day soil surface \( \alpha \) of the field plot is calculated by the expressions:

\[ \alpha_H = \arctg \ k_H = \arctg \left( \frac{z - b_H}{y} \right) ; \]  
\[ \alpha_O = \arctg \ k_O = \arctg \left( \frac{z - b_O}{y} \right) ; \]  

\[ \alpha = \frac{\alpha_H + \alpha_O}{2} , \]

where \( \alpha_O \) and \( \alpha_H \) - the slopes of the day soil surface of the tilled and untilled field areas, deg.; \( \alpha \) - the slope of the day soil surface of the field plot, deg.
The coefficient of plowing is determined by the expression:

\[ v = \frac{b_n - b_{nl}}{h}; \]  

(6)

where \( h \) – the depth of plowing – the distance from the surface of the untilled field to the depth of penetration of the working parts of machines into the soil, m (figure 1).

The rangefinder mounted over the furrow wall at a distance from the profiler 2 measures the straightness (deviation from straightness) of plowing by determining the angle of deviation along the length of furrow according to the formula:

\[ D = R \sin \gamma_0, \]  

(7)

where \( D \) - the distance from the profiler holder to the furrow wall in the horizontal plane, m; \( R \) - the radius of profiling along the circle, m; \( \gamma_0 \) - the angle at which the data jump determined by the furrow wall during circular profiling occurred, deg. (figure 2);
data jump determined by the furrow wall at a given distance occurred (figure 3), allows calculating the deviation from the straightness of plowing by the expression

\[ \Delta = \sin \gamma II , \]

where \( \Delta \) - the deviation from the straightness of plowing, \%; \( \gamma II \) - the angle when the data jump determined by the furrow wall at a given distance of the length of furrow occurred, m.

3. Results and discussion

Field studies were carried out on various agricultural backgrounds of slope lands with a slope of up to 6 degrees, especially after under-winter ploughing. For the open furrow of arable land on the slope formed by the MTZ-82 and PLN-3-35 machines we determined the agro-technical indicators of soil plowing quality in the field according to the data presented in figure 3.

Figure 4 shows the data in the Cartesian coordinate system obtained by the experiment.

Figure 3. The obtained data on plowed soil surface in polar coordinates: rotation angle and distance to the soil.

Figure 4. The obtained data on plowed soil surface in Cartesian coordinates: * - actual; * - adjusted for the slope.

The analysis of the obtained data (figure 4, blue line), shows that the maximum values of the depth of tillage can be seen at 102.1 and 286.3 degrees according to scanning. Using the measured values we
calculated the agro-technical indicators: the depth of the furrow is 259 ... 275 mm, the slope along the movement (along the open furrow) is 0.6...0.7 degrees, the side slope is 3.8...3.9 degrees, the coefficient of plowing is 1.4...1.5, the straightness of plowing (deviation from the straightness per 100 m of length of furrow) is 100 mm. Processing the data to determine the plowing coefficient it is necessary to take into account the slope of the slope lands (see figure 4, red line). The slope adjustment is made on the basis of the same data as for the untilled soil surface plot. After specifying the slope before tillage, its values are subtracted from those of the tilled soil slope thus, determining the elevation of the soil surface. The values are introduced into the formula (6) and calculated.

4. Conclusions
A method for controlling the quality of tillage on agricultural landscapes in the field operation is implemented by a technical means for circular profiling of the day soil surface with a high-accuracy rangefinder mounted on it. The main agro-technical indicators of plowing on the slope are determined. The way the machine impacts the soil shows if soil conditions, adjustments, timing of work and other conditions have been specified correctly. Thus, the application of this method ensures high accuracy of the obtained data. Comprehensive assessment of the impact on soil is carried out rather fast, which allows adapting the operating modes to various soil properties on slope agricultural landscapes in the shortest time possible.

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