ISSN 2083-1587; e-ISSN 2449-5999
2022,Vol. 26,No.1, pp.231-241
Agricultural Engineering
www.wir.ptir.org
DOI: 10.2478/agriceng-2022-0018

# SUBSTANTIATION OF THE RADIUS OF CURVATURE OF THE CHISEL PLOW POINT OF THE WORKING BODIES OF TILLAGE IMPLEMENTS

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ARTICLE INFO

*Article history:*
Received: October 2022
Received in the revised form: November 2022
Accepted: November 2022

ABSTRACT

Chisel plows with a chisel as a working body, loosen the soil without mixing the layers. The analysis of the conducted research concludes that the most widespread is a cylindrical surface of a chisel working body -

*Keywords:*
*chisel,*
*soil,*
*wrapping of plant remains,*
*cylindrical surface*

a chisel with a constant radius of curvature. It is theoretically established that at the radius of curvature of the bit up to 0.1 m, the soil on the surface of the bit will move chaotically, while the curvature of the bit does not affect the percentage of wrapped plant debris. As the radius of curvature increases, the force of inertia decreases, therefore, the angle of soil rise decreases. For the radius of curvature of the bit bigger than 0.5 m, the force of inertia has almost no effect on the angle of the soil rise. Without the influence of the force of inertia, the soil particles begin to move more orderly, the soil and plant debris begin to move along trajectories corresponding to the shape of the bit, which increases the coefficient of wrapping plant debris. It is established that at the radius of curvature of the bit 0.5 m and at an operating speed of 2 $m \cdot s^{-1}$ there is an orderly movement of soil on the surface of the bit, which affects the percentage of wrapping of plant remains. The use of a chisel plow point with a cylindrical surface increases the wrapping of plant remains by an average of 17%.

## Introduction

Prevention of soil erosion around the world has led to development of tillage techniques (Heuser, 2022) that do not use plowing and tools for the main tillage are equipped with flat-cut paws or chisels. Tools equipped with chisels are called chisel plows. Chisel plows, the working body of which is a chisel, loosen the soil without mixing the layers (Zabrodskyi et al., 2021). This ensures proper water-air regime of the soil while maintaining stubble on the field surface, which prevents wind erosion. Studies (Ding et al., 2017) have shown the viability of chisel plows in rice cultivation in China. The use of chisel plows in the cultivation of corn on loamy soils in the eastern United States (Hill and Stott, 2000) also has a positive effect on the preservation of soil structure. Different tillage systems (Sorensen et al., 2014) lead to different resource use and environmental impact. Simplified tillage saves direct energy consumption and the amount of necessary elements of equipment. This reduces greenhouse gas emissions. It was found that based on the crop rotation consisting of spring barley, winter barley, winter wheat, and winter rape, the total energy consumption decreased by 26% for the simplified system and by 41% for the system without tillage. The need for mineral fertilizers has been reduced by 28-33%, which helps to reduce soil mineralization by 50-60% (Domnariu et al., 2022). The paper (Yu-Hong et al., 2010) notes that compared to traditional tillage, all tillage schemes without the use of plows have improved soil quality, fertility, and physical properties. For example, the soil quality index rose to 20%. There is an increase in the yield of winter wheat and spring corn by 13%...28% and 3%...12%, respectively.

The study of various forms of chisels in order to wrap plant remains is of great interest and wide application in the world. Simultaneously with the search for rational forms of chisels, research is conducted that aims at optimizing the geometric parameters of the chisel using the methods of mathematical modelling (Ghereş, 2014; Kiktev et al., 2021). The shapes of the chisel plow struts are also being investigated (Ogbeche et al., 2018; Korchak et al., 2021). In the work (Zeng et al., 2020; Kiurchev et al., 2021) the simulation of wrapping of plant remains by different types of working bodies used on chisel tillage implements was performed. However, no conclusions have been drawn on the impact on the coefficient of wrapping on the shape of the work surface. From the analysis of the conducted research, it is concluded that the most widespread is a cylindrical surface of a chisel working body

- a chisel with a constant radius of curvature. However, the analysed works do not provide complete information on the relationship between the parameters of the bit surface and soil movement. Therefore, it is necessary to develop a simple model of soil movement on the surface of the bit to justify the parameters of the working body of the tillage implement.

## The results of theoretical research

For the working body we accept a geometric model in the form of a cylindrical surface. The product of this surface corresponds to the guide curve. The guide curve is located in the vertical plane, and the generating curves are located horizontally and perpendicularly to the movement of the working body. Take the arc of a circle as a guide curve. The main parameters of such a working body will be:

– the radius of the arc of the guide curve surface – the radius of curvature;
– the angle of inclination of the tangent plane of the working surface chisel plow point (chisel) to the horizon at the starting point of the forming surface.

The equations of the guide curve in the Cartesian coordinate system will look like:

$$x = R \cdot \sin(\alpha + \alpha_0), \quad 1)$$

$$z = R \cdot \cos(\alpha + \alpha_0), \quad (2)$$

where:

$R$ – radius of curvature of the guide curve of the cylindrical surface of the bit, *m*;
$\alpha_0$ – the angle of inclination of the tangent plane (Fig. 1), equal to the angle of installation of the bit to the horizon $\alpha_0 = \alpha_P$, *degree*.
$\alpha$ – the angle of inclination of the tangent to the guide cylindrical surface to the horizon (rake angle), *deg.*

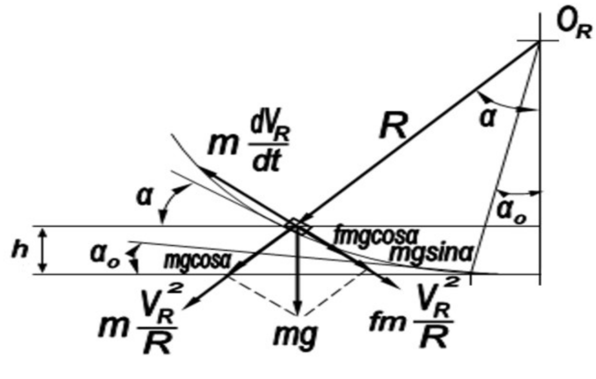



*Figure 1. The scheme of movement of soil particles on the cylindrical surface of the bit (h - soil tillage depth, other designations in the text of the article)*

The coordinates of the polar centre will be determined as follows:

$$x_{OR} = R \cdot \sin \alpha_0, \quad (3)$$

$$z_{OR} = R \cdot \cos \alpha_0, \quad (4)$$

In order to substantiate the parameters of the guide curve, consider the movement of the soil lump on the cylindrical surface of the bit according to the scheme in Fig. 1. To determine the velocity of the soil particle on the surface of the bit, depending on the angle of rotation of the radius vector R, write the differential equation of equilibrium of the soil particle:

$$m\frac{dV_R}{dt} = -f_1 \cdot Q - f_1 \cdot P \cdot \cos\alpha - P \cdot \sin\alpha, \tag{5}$$

where:
$m$ – mass of soil particles, (kg)
$V_R$ – the speed of the particle along the guide, (m·s$^{-1}$)
$t$ – time of movement of the particle on the guide, (s)
$f_1$ – coefficient of soil friction surface of the working body, (relative units)
$Q$ – centrifugal force of inertia acting on the particle, (N)
$P$ – weight of soil particles, (N);

Write the force of weight (*P*) and the force of inertia (*Q*):

$$P = mg;\ Q = m\frac{V_R^2}{R}, \tag{6}$$

where:
$g$ – acceleration of gravity, (m·s$^{-2}$)
$R$ – the radius of curvature of the guide curve, (m),

We write the equation of equilibrium of soil particles when moving on a cylindrical surface:

$$m\frac{dV_R}{dt} = -f_1 m\frac{V_R^2}{R} - f_1 mg\cos\alpha - mg\sin\alpha \tag{7}$$

When moving in a circle, the following relationships are met:

$$ds = Rd\alpha = V_R dt,\ dt = \frac{Rd\alpha}{V_K}, \tag{8}$$

where:
$ds$ – arc length of a circle, (m)

After performing the appropriate mathematical transformations and subtracting the mass of the soil lump from the equation, we arrive at the following differential equation

$$\frac{dV_R}{d\alpha} = -f_1 \cdot V_R - \frac{R \cdot g}{V_R}\left(f_1 \cdot \cos\alpha + \sin\alpha\right) \tag{9}$$

The integration of the obtained equation gives an expression for finding the tangent velocity:

$$V_R^2 = \left(-\frac{2R \cdot g \cdot \exp\left(2f_1 \cdot \alpha\right)}{4f_1^2 + 1}\left[\left(2f_1^2 - 1\right)\cos\alpha + 3f_1 \cdot \sin\alpha\right] + C\right)\exp\left(-2f_1 \cdot \alpha\right) \tag{10}$$

Constant integration is found from the initial conditions at time t = 0, when the velocity of the soil particle on the guide cylindrical surface of the bit is equal to the speed of the cultivator (cultivator) V, and the initial angle of tangent to the guide is $\alpha_0$. In this case, the constant integration is equal to:

$$C = V_0^2 \exp(2 f_1 \alpha_0) + \frac{2Rg \exp(2 f_1 \alpha_0)}{4 f_1^2 + 1}\left[\left(2 f_1^2 - 1\right)\cos\alpha_0 + 3 f_1 \sin\alpha_0\right] \quad (11)$$

In fig. 2 shows the graphs of the theoretically calculated angle of soil rise (according to equation 10) at the average coefficient of friction of the soil on the material of the working body $f$=0.55.

As can be seen from the graphs, at a radius of curvature $R$=0.1 m, the function $\alpha(V_0)$ goes up sharply. The soil on the surface of the bit will move chaotically, while the curvature of the bit does not affect the percentage of wrapped plant debris. Traction resistance also increases. This behaviour of the elevation angle function is explained by the fact that starting from the speed $V_0$=2 $m \cdot s^{-1}$, the force of inertia begins to appear, which overcomes the force of gravity of the soil layer. This is especially noticeable at $R$=0.1 $m$. As the arc radius increases, the force of inertia decreases, therefore, the angle of soil rise decreases. As the radius of the arc increases, the curvature of the dependence $\alpha(V_0)$ decreases, and for the radius of curvature $R$ = 0.5 $m$, it practically approaches the straight line. With a radius of curvature $R$=0.5 $m$ and more, the action of the force of inertia almost does not affect the angle of soil rise.

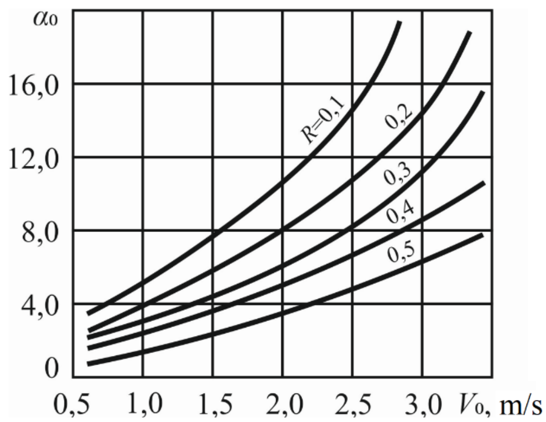



*Figure 2. Characteristics of the velocity of soil particles on the cylindrical surface of the bit depending on the radius of curvature (calculated according to equation 10)*

Without the influence of the force of inertia, soil particles begin to move more orderly, while soil and plant debris begin to move along trajectories corresponding to the shape of the bit, which in our opinion will increase the wrapping coefficient of plant debris and reduce traction resistance.

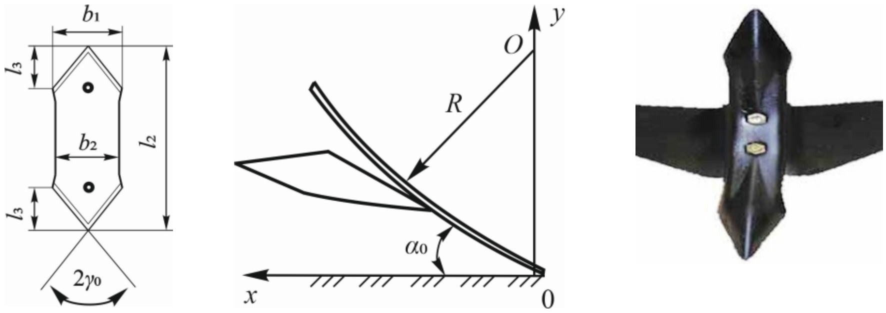
## Material and Methods

For experimental studies, the bits were made with the parameters listed in table 1. The manufacture of bits was installed on the tillage tool PSHN-2.5 (ПЩН-2,5, manufacturer Kalinivskii Repair and Mechanical Plant, Vinnitsa, Ukraine) (Fig. 4).

Table 1.
*The main parameters of the bit (Fig. 3)*

| Name of parameters | Values of parameters of a cylindrical surface of a bit |
|---|---|
| Surface guide curve and its location | The arc of a circle located in the vertical plane |
| The main parameter of the bit surface is the radius of the arc of the circle, (m) | 0.5 |
| The angle of the front $2\gamma_0$, $^0$ | 65 |
| The width of the front $b_1$, (mm) | 75 |
| Chisel plow point width $b_2$, (mm) | 65 |
| Chisel plow point length $l_2$, (mm) | 465 |

Technological parameters of flat-cutting paws are given in table 2, the general view of the working body and the scheme of the structure of the tillage working body (paws with a chisel plow point) in fig. 3.



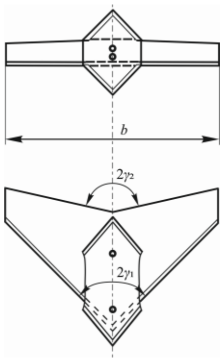

**a** **b** **c**

*Figure 3. Scheme of the chisel plow point: a – front view: b – guide curve-circle arc; c – general view of the tillage working body complete with flat-cutting paw.*

Table 2.
*The main parameters of the paws, tillage implements mounted on the base tool PSHN-2.5*

| Width Capture B, (mm) | Loosening angle $\alpha$, (deg.) | Front corner of the blade $2\gamma_1$, (deg.) | Rear corner of the blade $2\gamma_2$, (deg) | Blade sharpening angle $i$, (deg.) |
|---|---|---|---|---|
| 440 | 4…15 | 65 | 120 | 10 |

Repetition of experiments and removal of all planned agronomic and energy indicators in the field was carried out in accordance with standard methods (Behera et al., 2021, Kukharets et al., 2018, Korchak et al., 2021). All studies were performed in the speed range 1.4… 3.16 $m \cdot s^{-1}$ in triplicate.



**a** **b**

*Figure 4. Tools for experimental research: a – general view of the basic tool PSHN-2,5: b – diagram of the structure of the tillage working body*

Studies of the work of the experimental tillage working body for tillage less tillage were carried out in conditions typical of shallow (8…16 *sm*) tillage in the cultivation of oilseeds and cereals: agrofon – winter wheat stubble, crop residues 365 $g{\cdot}m^{-2}$, type – chernozem, the relief is smooth, the micro-relief is levelled. The average relative humidity was 19.2% and the soil hardness was 5.67 $N{\cdot}sm^{-2}$.

## Results and Discussion

The results of experimental studies have established the effect of the working speed of the tillage implement on the percentage of wrapping of plant remains. The data characterizing the wrapping of plant remains depending on the working speed are obtained. In table 3 shows the percentage of wrapping of plant remains depending on the speed.

Table 3.
*The percentage of wrapping of plant remains* $k_Z$ *,(%)*

| Speed of movement ($m{\cdot}s^{-1}$) | Basic tools PSHN-2,5 without chisels plow point | Basic tool PSHN-2,5 with the chisels plow point executed on an arc of a circle |
|---|---|---|
| 1.4 | 13.0 | 26.4 |
| 2.0 | 15.7 | 32.6 |
| 3.16 | 17.8 | 36.8 |

From table 3 it is obvious that the installation of chisels plow point increases the percentage of wrapped plant remains. Thus, at the speed of 2 $m{\cdot}s^{-1}$ the percentage of wrapping of plant remains for paws without chisels is 16%, and for paws with chisels made in an arc of a circle 33%. At an operating speed of 3 m·s$^{-1}$, the wrapping of plant remains is 18% for paws without bits and 37%. for chisels plow point with a cylindrical surface. In fig. 5 shows sections of the field after the passage of tillage implements.

a b

*Figure 5. Wrapping of plant remains (grain stubble) with PSN-2,5 tools: a – with cylindrical chisels plow point; b – without chisels plow point*

As a result of the analysis of the performed experimental research, the empirical equation of communication between the percentage of wrapping of plant remains $k_Z$, speed V and the presence of a bit was found (table 4 shows the values of the parameters included in the equation):

$$k_Z = kV + b \tag{12}$$

where:
$V$ – speed of movement of the gun, (m·s$^{-1}$)

Table 4.
*Parameters of the regression equation for wrapping plant remains*

| No. | Type and brand of tool | Regression equation parameters (in 12) | | Correlation coefficient |
|---|---|---|---|---|
| | | $k$ | $b$ | r |
| 1 | Basic tools PSHN-2.5 without chisels plow point | 2.44 | 9.78 | 0.9 |
| 2 | Basic tools PSHN-2.5 with chisels plow point | 4.0 | 21.56 | 0.96 |

The analysis of Equation 12 shows that there is a relationship between the speed of the working body and the percentage of wrapping of plant residues. At low speeds up to 1.4 m·s$^{-1}$, the soil moves chaotically on the surface of the bit and the wings of the paws, i.e., a wave is formed that mixes both plant debris and soil, while the curvature of the bit does not affect the percentage of wrapped debris. As the speed increases, the soil and plant debris begin to move, more orderly, while the soil and plant debris begin to move along trajectories corresponding to the curvature of the bit. The close relationship between velocity and percentage of wrapped residues is indicated by a large correlation coefficient, which is about one between the rate and per-centage of wrapped residues.

A chisel plow point fully provides agrotechnical requirements for the burying of fertilizers, plant residues, herbicides, weed seeds, etc in comparison to existing tillage implements and that allows to improve soil quality indicators (Raiesi and Kabiri, 2016; Pires et al., 2017). Studies (Igoni and Jumbo, 2019) have shown that chisel tillage tools loosen the soil well. Studies (Piskier, 2017) have shown significant reductions in fuel consumption (up to 2%) compared to plowing. In addition, the duration of the technological process is reduced by up to 30% compared to traditional cultivation. The paper notes an increase of up to 7% in winter wheat yield under the use of shelfless and strip tillage.

## Conclusions

1. It is theoretically established that at the radius of curvature of the bit up to 0.1 m the soil on the surface of the bit will move chaotically, while the curvature of the bit does not affect the percentage of wrapped plant debris. Traction resistance also increases. This can be explained by the fact that starting from the speed of 2 $m \cdot s^{-1}$, the force of inertia is intense, which is more important than the force of gravity acting on the boards (layer) of soil. As the radius of curvature increases, the force of inertia decreases, therefore, the angle of soil rise decreases. For the radius of curvature of more than 0.5 m, the force of inertia has almost no effect on the angle of soil rise. Without the influence of inertia, soil particles begin to move more orderly, while soil and plant debris begin to move along trajectories corresponding to the shape of the bit, which in our opinion increases the coefficient of wrapping of plant remains and reduces traction resistance.
2. It is established that at the radius of curvature of the bit 0.5 m and at the working speed of 2 $m \cdot s^{-1}$ there is an orderly movement of soil on the surface of the bit, which affects the percentage of earned crop residues.
3. Experimental studies have shown a stable relationship between the percentage of earned balances and the speed of the working body. Moreover, with increasing speed (up to 2 m/s) the percentage of earned plant residues increases.
4. The use of a chisel plow point with a cylindrical surface increases the stocking of crop residues by an average of 17% and reduces traction resistance by 3-5%.

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## UZASADNIENIE PROMIENIA KRZYWIZNY REDLICZKI KULTYWATORA W ELEMENTACH ROBOCZYCH MASZYN UPRAWOWYCH

**Streszczenie.** Kultywatory, których elementem roboczym jest dłuto, rozluźniają glebę poprzez zmieszanie jej warstw. Przeprowadzona analiza wskazuje na to, że najbardziej rozpowszechniona jest cylindryczna powierzchnia elementu roboczego dłuta – dłuto o stałym promieniu krzywizny. Teoretycznie, przy promieniu krzywizny elementu o długości do 0.1 m, gleba na powierzchni elementu porusza się chaotycznie, podczas gdy krzywizna elementu nie wpływa na procent owiniętych resztek roślin. Wraz ze wzrostem promienia krzywizny, spada siła bezwładności. Zatem, kąt uniesienia gleby maleje. Dla promienia krzywizny element dłuższego niż 0.5 m, siła bezwładności nie wpływa na kąt uniesienia gleby. Bez wpływu siły bezwładności, cząsteczki gleby zaczynają poruszać się w porządku, ziemia i resztki roślin zaczynają poruszać się wzdłuż trajektorii odpowiadającej kształtowi elementu, co zwiększa współczynnik owinięcia resztek roślin. Użycie redliczek kultywatora o cylindrycznym kształcie zwiększa owinięcie resztek roślin o średnio 17%.

**Słowa kluczowe:** dłuto, gleba, owinięcie resztek roślin, powierzchnia cylindryczna