Ploughing quality and energy consumption depending on plough bodies type

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Abstract. Experimental determination of ploughing quality and energy consumption carried out on loamy soils most common for the arable lands in European part of Russia. The field tests done for three standard types of mouldboard body surfaces: cultural, semi-helicoidal (cylindroid) and helicoidal. Results shows that bodies with cylindroid mouldboard surface had better soil crumbling against cultural (digger) body surfaces. Helicoidal bodies supplied better quality of soil layer turnover than cultural and semi-helicoidal ones. Designed plough construction allowed change ploughshares installation angles relative to the furrow line from 25 to 55º. Optimal ploughshares angle to the furrow line obtained 45...50º. The traction resistance force of the plough equipped with helicoidal bodies was measured 6...8% lower than cultural and 3...4% lower than cylindroid ones at tractor speed 2.5...3.0 m s⁻¹.

1. Introduction

Mouldboard ploughs are still important tillage implements for modern technologies of field crops cultivation. Plough efficiency measured in terms of draft or input energy [1]. Plough performance and fuel consumption mainly depends on the physical properties of the soil and ploughshare-mouldboard geometric parameters [2]. Ploughing is one of the most energy consuming field operation [3]. Optimization in plough design necessitates minimization of the input energy. It estimated that tillage accounts for about a half of the energy used in crop production [4]. The most common theoretical methods for determining the forces acting on the plough working bodies are methods of soil mechanics [5, 6]. Modern methods of determination acting forces in tillage based on finite [7, 8, 9] and discrete elements [10] methods for studying soil deformation. Many researches carried out in order to reduce the developed resistance and to increase ploughing efficiency by optimising the shape of plough bodies [11, 12]. Reduced traction resistance of mouldboard plough also increases durability and resource of ploughshares [13, 14] and though reduce the cost of spare parts [15].

Currently, at Russian market offered ploughs with bodies of three shapes of mouldboard surfaces: cylindroid (cultural and semi-helicoidal) and helicoidal [16]. Agricultural producers need recommendations to justify the choice of the type and geometric shape of plough bodies for different soil conditions [17].

It is advisable to compare plough bodies performance indicators by experimental methods [18, 19, 20]. The main linear and angular parameters of the geometry of the main types of plough bodies shown in figure 1. According to the currently generally accepted classification, the basis of the plough-mouldboard surface is an oblique dihedral wedge with three initial parameters: crumbling angle $\alpha_0$, $\beta_0$ and $\gamma_0$. The most common three types of mouldboard bodies: cultural and semi-helicoidal (digger) body surfaces: cylindroid (cultural and semi-helicoidal) and helicoidal [16]. Agricultural producers need recommendations to justify the choice of the type and geometric shape of plough bodies for different soil conditions [17].

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shift angle $\gamma_0$, and turnover angle $\beta_0$ of the soil layer. Cylindroid bodies (including cultural and semi-helicoideal surfaces) formed when a rectilinear horizontal shape lines (generatrix) moves along a guide curve located in a plane perpendicular to the ploughshare blade, with a given regularity of change angle $\gamma$ in height. Helicoidal bodies formed when the angle $\beta$ changed in the transverse-vertical plane.

The study aim was experimental determination how mouldboard plough bodies surfaces geometric parameters influence on the agrotechnical and energy parameters of ploughing in certain soil conditions.

2. Methods

The field tests carried out in Shchyokinsky District (Tula region), in Zakharovsky District (Ryazan region) and on experimental station of Timiryazev State Agrarian University (Moscow region) on middle loamy soils with the following characteristics: hardness 2.7...4.1 MPa, average humidity 20...25%, post-harvest crop residues of potatoes, barley and corn.

Plough bodies with composite overhead reversible ploughshares used for in the field experiments. Optimal geometric parameters of such ploughshares substantiated in previous research [15]. The bar-pointed share ledge was 40 mm, sharpening angle of cutting edge was $7...8^\circ$.

All tests carried out on MTZ-82 tractors with mounted 3-furrow PLN-3-35 ploughs equipped with different body sets available on local market. It were serial cultural (digger) PLE-21.411 bodies, semi-helicoideal PLN-01.000 bodies and helicoideal RZZ-4-01 bodies. Plough speed varied in range 1.4...2.8 m∙s$^{-1}$, the field length was at least 250 m. The setting depth of ploughing was 22 cm in all experiments.

Main ploughing quality indicators measured during the tests: soil crumbling, soil layer turnover, incorporation degree of plant residues. Soil crumbling determined by samples taken at four points in the field (two in the direction of the unit's movement, two in the opposite direction). Samples of ploughed soil sieved through a set of
sieves with holes diameters corresponding to the sizes of fractions (less than 10, 10...20, 20...30, 30...40, 40...50, more than 50 mm).

Soil crumbling depended on the physical and mechanical properties of the soil (mechanical composition, hardness and moisture), as well as the shape of the plough bodies mouldboard surfaces. The ploughshares angle of installation to the furrow line also has a significant impact. The best crumbling quality obtained on lighter soils with less physical clay. As the content of clay particles rises in soil, the size of the clods increased.

The angle $\gamma_0$ of the installation of the ploughshare blade relative to the furrow line (see figure 1) were changed by unscrewing the middle bolt securing the plough body to the frame and placing additional washers on one of the two remaining bolts. When setting the washers under the first bolt, the angle between the blade of the working body and the wall of the groove decreased, and under the third bolt increased.

Tractor speed with a plough was determined using a Trimble® GPS navigator. The pulling resistance of the plough measured using a tensometric elements installed between the three-point hitch of the tractor and the plough. The signals from the strain gauges recorded using data acquisition system from National Instruments® installed on the tractor. The error in measuring tractor speed and plough resistance forces was less than 3...4%.

3. Results and Discussion

All tested serial bodies ensured plough quality requirements adopted in Russia [6]. Better quality of soil layer turnover and sealing of plant residues provided by helicoidal bodies: plant residues sealed to a depth of 15...17 cm from the soil surface.

The influence of the blade sharpness and the overhang of the share point on the penetration capacity and power characteristics of the plough justified in previous researches [13]. To determine the effect of inclination in the horizontal plane of the share-mouldboard surface, cylindrical plough bodies installed at angles $\gamma_0 = 30, 35, 38, 40, 42, 45, 50, 55^\circ$ relative to the furrow line.

When the angle $\gamma_0$ is less than 35° in the ploughed soil, the number of clods more than 50 mm in size increased by 10...20% (figure 2).

At $\gamma_0 = 40…42^\circ$ the average value of the clod diameter was 20…50 mm, which corresponded to the best crumbling quality. An increase in the angle $\gamma_0$ over 45° (in the experiments 50° and 55°) increased the degree of soil crumbling. At the same time, there was a transition from tear-off chips to shear chips while cutting soil layer, which caused an increasing plough traction resistance.

An excessive crumbling of the upper soil layer (a significant predominance of a fraction size less than 0...10 mm) can lead to increased soil compaction during autumn post-harvest ploughing and, accordingly, a deterioration of air and water regimes in the winter-spring period, which negatively affects the yield and leads to soil erosion. Thus, for the most common in central Russia loamy soils for semi-helicoidal mouldboard, the best soil crumbling obtained with angles of installation of the share blades to the furrow line $\gamma_0 = 40…42^\circ$.

When ploughing with cultural bodies on loamy soil, good crumbling obtained, but sealing of plant residues worse compared to helicoidal bodies.

In the soil conditions under which the tests carried out, the turnover of the soil layer was better at the helicoidal bodies. However, the size of the soil fragments increased and the quality of soil crumbling decreased.
Ploughing with cultural bodies obtained not sufficient turnover of cohesive soil layers, but satisfactory loosening took place. Cultural bodies gave good quality of ploughing only on cultivated old arable soils with a hardness less than 3.0 MPa.

The plough traction resistance (the horizontal component of the resistance forces) with different types of bodies determined depending on the ploughing depth, the angles of inclination of the share to the bottom and the wall of the furrow, the depth of ploughing, the speed of the unit movement, as well as the geometric parameters of the plough body. An example in figure 3 shows how measured plough traction resistance on loamy soil with hardness 3.1 MPa depends on speed. The coefficient of determination $R^2$ for this experimental data ranges from 0.75 to 0.85.

Plough quality indicators, including soil crumbling, soil layer turnover, the degree of sealing of plant residues, make it possible to draw conclusions regarding the preference for using one or another type of plough bodies.

Better soil crumbling, as expected, observed for bodies with cylindroid (cultural and semi-helicoidal) surfaces. During tests, the maximum diameter of clods at a loamy soil with hardness of 3.1 MPa did not exceed 30...50 mm. However, when the soil layer turned over, incomplete sealing of plant residues observed.

The best plough quality indicators obtained with cultural and semi-helicoidal bodies: the crumbling of loam was good, and the soil layer turnover was quite complete. At the same time, in terms of traction characteristics, semi-helicoidal bodies had some advantages.

The helicoidal bodies had the best indicators of soil layer turnover and the degree of sealing of plant residues, but the soil crumbling left much to be desired: on heavy loamy soil, the amount of clods with a diameter of more than 100 mm sometimes exceeded 10% allowed by agrotechnical requirements.

Based on the tests carried out, on loamy soils of medium texture, the most common in the central zone of Russia, we recommend use ploughs equipped with semi-helicoidal bodies.

**Figure 2.** Soil crumbling results for plough bodies

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4. Conclusions
Comparison of performance of the serial plough with cultural, semi-helicoidal and helicoidal bodies showed that the better quality on loamy soils usually provided by semi-helicoidal bodies. With rise in the soil content of clay particles, an increase in clods average size occurs when ploughing with any bodies.

On loamy soils, with an increase in the angle of installation of the ploughshare-mouldboard surface to the furrow line, the size of soil fragments decreases with the transition from breakaway shavings to shear shavings, which causes an increase in the traction resistance of the plough. For typical in central Russia loamy soils ploughing with semi-helicoidal bodies, we recommend the angle of the share blades installation to the furrow line 40…42°.

The traction resistance of the plough is less by 6...8% when using helicoidal bodies compared to cultural (digger) ones and less by 3...4% compared to semi-helicoidal bodies at ploughing speeds 2.5…3.0 m/s. This result explained by a less soil pressure on the ploughshare-mouldboard helicoidal surfaces compared to cylindroid surfaces.

On medium loamy soils with hardness near 3.0 MPa at humidity 20...22% the best ratio of quality indicators and energy costs ensured by using ploughs equipped with semi-helicoidal bodies.

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