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Results of experimental investigations of a flexible active harrow with loosening teeth

V. Bulgakov[1], H. Kaletnik[2], I. Goncharuk[2], S. Ivanovs[3] and M. Usenko[4]

[1]National University of Life and Environmental Sciences of Ukraine, Heroiv Obrony 15, UA03041 Kyiv, Ukraine
[2]Vinnytsia National Agrarian University, Soniachna street 3, UA21008 Vinnytsia, Ukraine
[3]Latvia University of Life Sciences and Technologies, Liela street 2, LV-3001 Jelgava, Latvia
[4]Lutsk National Technical University, Lvivska street 75, UA43018 Lutsk, Volyn region, Ukraine
[*]Correspondence: semjons@apollo.lv

Abstract. Soil tillage processes significantly affect the growth of cultivated plants; therefore, improvement of various designs and combinations of ploughs is still an actual practical and scientific task. This paper presents investigations of the design of a soil tillage machine consisting of three plough bodies equipped from the lateral side with a module with a flexible active harrow driven by a support wheel. The technological process of tillage by this machine is carried out in such a way that the module of the flexible active harrow is installed at a certain depth of soil tillage. The purpose of this work is an experimental comparative investigation of the quality indicators of the work of a design of the soil tillage working body with a flexible active harrow having loosening teeth. In the process of comparative experimental investigations of the operation of ploughs with a standard flexible harrow and an experimental active harrow having loosening teeth, the soil lumpiness (characterising the quality of crumbling) and water permeability of the obtained soil structure were estimated. An experimental model of this working tool was tested under the production conditions, and it showed advantages of loosening and crumpling the soil compared to the conventional harrows. This can be explained by the fact that the harrow tines, freely mounted on the axes of its links, ensure their oscillatory movements when moving in two different planes, thereby creating conditions for more intense soil disintegration.

Key words: soil tillage, active harrow, harrow teeth, crushing, water resistance, structure.

INTRODUCTION

Despite the development of modern methods for killing weeds, mechanical tillage is the most important operation in the system of crop production (Valainis et al., 2014; Tamm et al., 2016; Milkevych et al., 2018). The first operation in the complex of cultivation operations of the agricultural crops are the main and the presowing tillage. Therefore the quality indicators of the performance of these operations determine also the quality indicators of further development of the plants.

Improvement of the technology and technical means of soil tillage applied to the soil and climatic features of regions is still an urgent task (Crittenden et al., 2015).

At present, in a number of regions, along with the combined machines for the main and the presowing tillage, ploughs with disc and with tine harrows are widely used (Alexandrjan, 1985; Bezdolny, 1996; Bulgakov et al., 2018). Such machines more intensely cultivate the soil under various working conditions. Also known are the designs of flexible harrows, which are more adapted to the field microrelief and have other advantages (Usenko et al., 2005; Adamchuk et al., 2016). Nevertheless, some authors note that combinations of ploughs with the known designs of flexible harrows still have a number of disadvantages due to the relatively low degree of crumbling on heavy soils, etc. oscillate because their teeth are not able to carry out constant oscillatory movements in the treated layer (Kanarev, 1983; Usenko et al., 2005; Segun, 2012). Therefore, a task was set to improve the design of harrows with an aim to improve the quality of treatment on heavy soils and to determine the comparative performance indicators.

The most important indicators that characterise the tillage quality of soil with harrows are the lumpiness and the water resistance of its structure (Dospehov, 1985). In the structured soil packing of the particles is loose, capillary gaps predominate inside the lumps, and between the lumps there are large, non-capillary gaps; water is quickly distributed in the aggregates, the gaps between which are filled with air. In such a soil, water and air are simultaneously present in a sufficient quantity; it is rich in nutrients, available to the plants. The agronomically valuable lumpy-granular structure gives the soil a loose structure, which facilitates seed germination and spreading of the plant roots, as well as reduces the energy costs of mechanical tillage (Dospehov, 1985; Kuht ae al., 2012; Valainis et al., 2014).

The purpose of this work is a comparative experimental investigation of the quality indicators of the operation of a new design of a tillage working tool with a flexible active harrow having loosening teeth.

MATERIALS AND METHODS

As a result of the preliminary investigations and design developments (Adamchuk et al., 2016), an experimental plough was made, equipped with a flexible active harrow having loosening teeth for minimal soil tillage (Fig. 1).

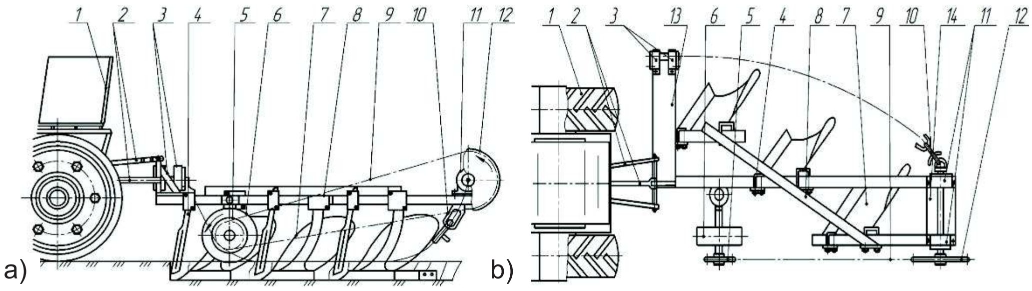


Figure 1. A plough, equipped with a flexible harrow driven by a support wheel (a – a side view; b – a top view): 1 – the aggregating tractor; 2 – the hitch mechanism of the tractor; 3 – the frontal support of the flexible harrow; 4 – the knives; 5 – the driving sprocket; 6 – the supporting wheel; 7 – the plough bodies; 8 – the main beam; 9 – the driving chain; 10 – a chain of the flexible harrow with the loosening teeth; 11 – the rear chain support; 12 – the driven sprocket; 13 – the frontal part of the frame; 14 – the rear part of the frame.

The design of a separate flexible harrow module with the loosening teeth is shown schematically in Fig. 2. It consists of links 1 of the chain, a pair of the basic working teeth 2, and a pair of additional teeth 3, both the basic pair of teeth and the additional pair being fixed to the sleeve 4 installed with the possibility of angular deviations and freely mounted on the axle 5, but the free ends of the axle 5 are connected by means of fastening elements 6 to the link 1 of the chain; the sleeve 4 is equipped with a fastening element 7 that is used depending on the type of the soil and its humidity.

The technological process of soil tillage by means of a flexible harrow, equipped with a three-body plough, is carried out as follows. The tractor 1 is aggregated with a plough having the plough bodies 7 installed at a predetermined depth of the basic tillage. The supporting wheel 6 moves along the untilled soil surface. The flexible harrow in the form of a chain with modules 10 moves on the side and behind the plough bodies 7 at a certain depth.

In addition, rotation from the support wheel 6 is transmitted to its modules with the loosening teeth (the torque is transmitted through the driving sprocket 5, the driven chain 9 and the driven sprocket 12 to the chain of the flexible harrow 10).Thus the chain of the flexible harrow 10 is forcibly continuously rotated, and, as a result, it crushes and loosens the solid soil masses remaining after the basic tillage by the plough bodies 7. The efficiency of the loosening teeth 2 and 3 (Fig. 2) is especially evident when working in heavy and excessively wet soils. Besides this, an additional pair of teeth 3 (Fig. 2) self-cleans the chain of the flexible harrow 10 from the adhered soil and plant residues. In case this plough is applied in light and dry soils, the additional pair of teeth 3 may not be used. In this case, the additional pair of teeth 3 is rigidly fixed inside the links of the chain 1 by means of the fastening elements 7.

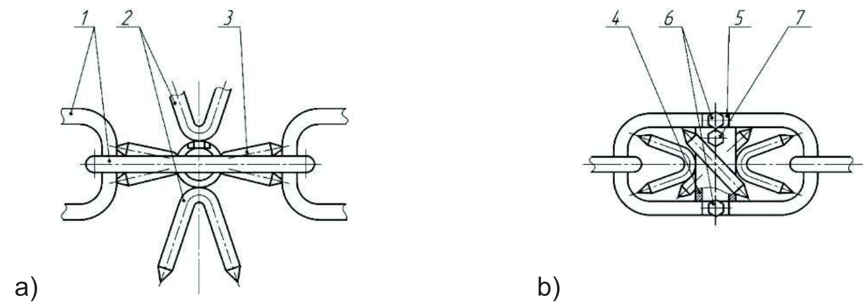


Figure 2. A flexible harrow module with the loosening teeth (a – a side view; b – a top view): 1 – links of the chain; 2 – the basic loosening teeth; 3 – the additional teeth; 4 – a rotary sleeve; 5 – the axle; 6 – fastening elements of the basic teeth; 7 – fastening elements of the additional teeth.

In the process of comparative experimental investigations of the operation of ploughs with a standard flexible harrow BP-3 and an experimental active harrow having loosening teeth, the soil lumpiness (characterising the quality of crumbling) and water permeability of the obtained soil structure were estimated (Bezdolny, 1995; Adamchuk et al., 2016). The research was conducted in the soil tillage zone by harrows in layers to the depth of up to 9–10 cm with the measurement of indicators on three backgrounds of the soil moisture (W): 18%, 22% and 25%.

The research was carried out using standard methods of the field experiments and processing of their results on the PC (Dospehov, 1985, Alexandrjan, 1985; Adamchuk et al., 2016). Lumpiness or the percentage of the agronomically valuable fraction 0.25–10 mm characterises the crushing degree of the soil by the working bodies, and its condition for growing plants.

Water resistance of the lumps, not flooded out for 10 minutes, is taken as 100%. The stability of the aggregates against the destructive action of water (g, %) is determined by the formula:

$$g = \frac{(P_1K_1 + P_2K_2 + \cdots + P_{10}K_{10})}{A}\,100\% \qquad (1)$$

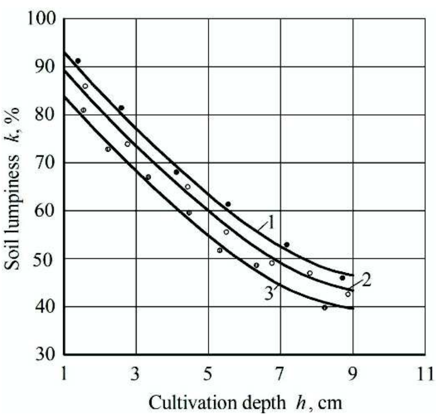
where $P_1, P_2, \dots P_{10}$ – the number of aggregates disintegrated in the respective minute; $K_1, K_2, \dots K_{10}$ – correction factors for the respective minutes; A – total number of aggregates taken for analysis.

Within 10 minutes, with an interval of 1 min, completely disintegrated aggregates are counted. Since disintegration of the aggregates in water occurs at different time, then, to characterise the water resistance degree of the structure, the Kachinsky correction factor is introduced into the calculations, which is (%) for every minute: for the 1st, 5; 2nd – 15; 3rd – 25; 4th – 35; 5th – 45; 6th – 55; 7th – 65; 8^{th} – 75; 9th – 85; 10th – 95.

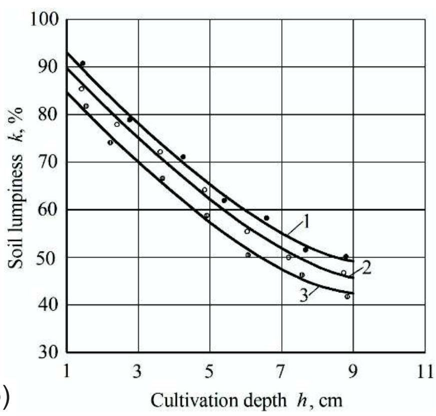
RESULTS AND DISCUSSION

It has been established by our previous investigations and the data of other researchers that on the soils of the steppe zone of Ukraine the optimum percentage of the soil loosening quality on slopes with a steepness of up to 12° should be 45...50%, with the initial soil lumpiness before starting work (after tillage by the plough bodies) – 30...35% (Adamchuk et al., 2016).

The results of the experimental research of the soil crumbling quality using a plough with standard flexible harrows BP-3 and experimental active flexible harrows are respectively reflected in Fig. 3 and Fig. 4.



a)



b)

Figure 3. Dependence of the soil lumpiness k upon the depth of its tillage h at various soil humidities W while working with a standard flexible harrow: 1 – W = 18%; 2 – W = 22%; 3 – W = 25%.

Figure 4. The value of the soil lumpiness k depending on the depth of its tillage h at different soil humidities W while working with an experimental flexible harrow: 1 – W = 18%; 2 – W = 22%; 3 – W = 25%.

As it is evident from the graphs, when the depth of tillage is increased, the degree of crumbling of the soil decreases. Increased humidity also reduces the degree of crumbling of the soil. However, when using standard flexible harrows, the soil lumpiness within the required limits (40...45%) is ensured only at a depth of 4...6 cm. At other depths the value of the loosening quality differs from the required (optimal) agrotechnical requirements.

The value of indicators (Fig. 3) of statistical data processing for soil crushing in the experiments with standard flexible harrows was:

for $W = 18\%$: $\bar{k} = 64.4\%$, $\sigma = \pm\ 1.4\%$, $V = 2.17\%$,

for $W = 22\%$: $\bar{k} = 61.3\%$, $\sigma = \pm\ 1.7\%$, $V = 2.77\%$,

for $W = 25\%$: $\bar{k} = 60.2\%$, $\sigma = \pm\ 1.2\%$, $V = 2.00\%$.

Where $\bar{k}$ – the average value of the indicator; σ – standard deviation; V – the coefficient of variation;

The value of indicators (Fig. 4) of statistical data processing for soil crushing in the experiments using a flexible harrow with the loosening teeth was:

for $W = 18\%$ – $\bar{k} = 69.2\%$, $\sigma = \pm\ 1.9\%$, $V = 2.75\%$,

for $W = 22\%$ – $\bar{k} = 67.5\%$, $\sigma = \pm\ 1.7\%$, $V = 2.52\%$,

for $W = 25\%$ – $\bar{k} = 63.7\%$, $\sigma = \pm\ 1.4\%$, $V = 2.2\%$.

As the curves of the graph show, the soil lumpiness within the required limits 40...45% – is ensured by an experimental harrow at the required tillage depth of 8…9 cm.

At other depths the quality of loosening changes (as the tillage depth increases, the quality of loosening decreases), and its values differ from the optimal ones.

The presence and degree of the erosion processes, especially on slopes, determines the water resistance of the soil structure. Compliance of this indicator with the agrotechnical rules allows avoiding or significant reduction of the negative effect of the water and wind erosion upon the soil.

For the conditions of the Ukrainian chernozem an important agronomic characteristic of the soil is the water resistance of its structure, i.e. the formation of solid, water non-eroded particles. Such a structure is formed as a result of the fastening of the mechanical elements by organomineral colloids that are irreversibly coagulated. Soils with a water-resistant structure have a water-air regime that is favourable for the development of plants, good mechanical properties, and so on. Soils that do not have a water-resistant structure quickly flood out, become impermeable to water and air, and, while drying, they crack into large blocks.

The graphs show the dependences of the water resistance of the soil structure tilled by a plough aggregate with a standard (Fig. 5) and an experimental active flexible harrow (Fig. 6).

The value of indicators (Fig. 5) of the statistical data processing for the water resistance of the obtained soil structure in the experiments using standard flexible harrows was:

for $W = 18\%$ – $\bar{g} = 20.4\%$, $\sigma = \pm\ 0.4\%$, $V = 1.96\%$,

for $W = 22\%$ – $\bar{g} = 20.1\%$, $\sigma = \pm\ 0.4\%$, $V = 1.99\%$,

for $W = 25\%$ – $\bar{g} = 19.8\%$, $\sigma = \pm\ 0.35\%$, $V = 1.78\%$.

Fig. 6 shows graphs of the water resistance of the soil structure tilled by a plough aggregate with an experimental flexible harrow.

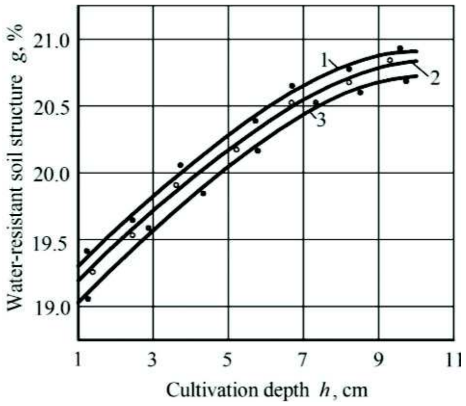


Figure 5. Dependence of the water resistance of the soil structure upon the tillage depth *h* at various soil moistures *W* when operating with a standard flexible harrow: 1 – *W* = 18%; 2 – *W* = 22%; 3 – *W* = 25%.

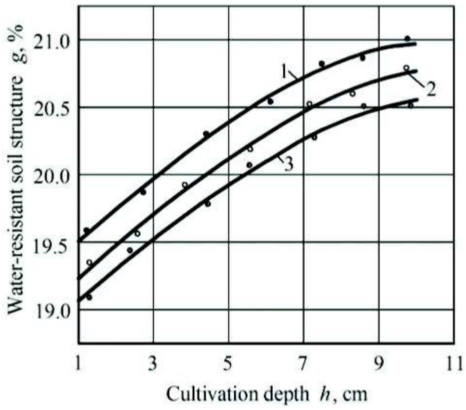


Figure 6. Dependence of the water resistance of the soil structure *g* upon the tillage depth *h* at various soil moistures *W* when working with the experimental active flexible harrow: 1 – *W* = 18%; 2 – *W* = 22%; 3 – *W* = 25%.

The value of indicators (Fig. 6) of the statistical processing of data for the water resistance of the obtained soil structure in experiments using an experimental flexible harrow was:

for $W = 18\%$ - $\overline{g} = 21.3\%$, $\sigma = \pm 1.1\%$, $V = 5.16\%$,

for $W = 22\%$ - $\overline{g} = 20.7\%$, $\sigma = \pm 0.9\%$, $V = 4.35\%$,

for $W = 25\%$ - $\overline{g} = 20.1\%$, $\sigma = \pm 0.8\%$, $V = 3.98\%$.

As the curves of the graph show, the water resistance of the soil structure within the required limits – 20...22% is provided by the experimental harrow working at the required depth of 9…10 cm. At other depths the value of this indicator changes (as the tillage depth increases, it increases), but its value somewhat differs from the required one by the agrotechnical rules. However, the experimental harrow provides an optimum value of the water resistance index of the soil structure in wider ranges than with the standard harrow.

CONCLUSIONS

The use of flexible active harrows on heavy soils in combination with a plough driven by the plough copying wheel, provides constant oscillating movements of the teeth in two planes, which intensively destroys large clumps and creates a more optimal soil structure. In contrast to the standard flexible harrow, the use of a flexible active harrow with the plough, 1.5 times (up to 9–10 cm) improves the soil layer with optimal lumpiness and a wider range of optimum soil water resistance.

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