Technological effectiveness of formation of planting furrow by working body of passive type of orchard planting machine

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Abstract. The article presents the results of experimental studies of technological effectiveness of formation of planting furrow by working body of passive type of orchard planting machine. The authors adhered to working hypothesis that to reduce energy consumption and increase the reliability of orchard planting machine in various operating conditions, possibly due to passive type of working body, which provides undercutting the soil layer and raises it to formation of planting furrow, and after placing the seedling in it, it encloses it as before area without additional significant movement or rotation. The article presents the results of study of number of roots hooks of two-year-old apple seedlings when trying to place their root system in interval between the opener model extensions. The authors presented the models of schemes of interaction between plant stems and blade of main blade and optimized the parameters of working surface of barrel blade. The authors established the dependence of additional averaged soil resistance coefficient on planting depth. The article investigates the dependence of resistance force of working body of orchard planting machine on planting depth and soil type. The authors presented the results of technological effectiveness of prototype of working body of orchard planting machine during experimental research and production tests.

1. Introduction
The technological effectiveness of process of orchard planting seedlings provides for the following stages [1]. Seedlings for planting are placed on the site on both sides of the machine [2]. There are 2-3 operators on special seats [3], depending on the speed of the tractor [4], which perform the following functions. One operator directly lowers the seedlings into the furrow [5], the other two alternately feed the first seedlings directly into the hands [6], taking (removing) the seedlings from the site of the machine. In the course of movement of the unit after installation of a sapling in a furrow by means of two dumps (wrappers) there is a backfill of a furrow [7]. The rear wheels compact the soil in the rhizome area [8]. The planting area can be pre-marked with lines with small furrows for even placement of seedlings [9].

The mechanization of production processes in horticulture is an innovative reserve for increasing labour productivity and profitability of fruit production [10]. The specialized machines created in recent years allow to increase the level of mechanization of technological operations on cultivation of fruit crops [11]. A review of literature sources [12] shows that the existing working bodies of orchard planting machine of active and passive type do not fully meet the quality criteria, namely: to be easy to manufacture, reliable, undemanding to the soil and energy efficient [13]. Thus, wedge-shaped passive organs, pushing the soil during the technological operation in both directions, form a landing gap [14].
This method requires significant energy costs [15], because, firstly, its application requires preliminary deep ploughing [16], which leads to significant additional costs, and secondly, compacting, the soil has a significant resistance to the motor unit [17]. Active milling-type bodies are no less energy-intensive, moreover difficult to manufacture [18], and therefore are characterized by a high initial cost and also require significant operating costs [19].

The aim of research is to reduce energy consumption and increase the reliability of the orchard planting machine in different conditions of its operation by developing a passive working body of advanced design, designed to form a planting furrow.

2. Materials and methods

According to the working hypothesis, all these requirements can be met by a passive type body, which, unlike a wedge-shaped opener, does not spread the soil, and pruning the layer, raises it to form a planting furrow, and after placing the seedling in it moving or rotating.

According to agricultural requirements, the depth of the planting furrow should be 0.20–0.35 m, and the width should ensure the free location of the root system of the seedling. To determine the optimal value of the last of these parameters, the process of entering and placing the root system of biennial apple seedlings grown on vegetative rootstocks in the interval between the opener extensions, the distance between which varied from 0.10 to 0.20 m step 0.02 m. The number of root hooks at their edges was recorded.

In accordance with the hypothesis of the advantages of the working body in terms of energy savings, a model and a prototype of the working surface of the opener were developed and manufactured. It consists of two cylindrical surfaces located at an angle of 40°. This arrangement provides the required bevel angle of the blade $\gamma$ (figure 1a); the development was based on the mandatory condition of its self-cleaning from the fibrous stems of plants. The condition for sliding the plant stem along the blade of drill coulter point was $\gamma<90^\circ-\varphi$.

It is known that the angle of friction of the plant stem on the blade of the tillage body $\varphi\leq45^\circ$, therefore: $\gamma<90^\circ-45^\circ=45^\circ$. It is known that the adhesion of soil to the working surface of the blade prevents weeds from sliding on it, so the bevel angle $\gamma$ was reduced to 40°. The working surface of drill coulter point was built in accordance with the set goal – to minimize energy consumption during the operation, choosing the most optimal angle of crushing the soil.

Studies have shown that the most optimal variant of the working surface is a cylinder with a certain radius of curvature of the surface $R$ and the initial angle of crumb $\beta$ (figure 1b).

To create favourable conditions for plant survival and development of their root system, as well as to prune the soil layer to ensure the effect of its opening and the formation of the landing gap, the blades of the cylinders are elongated and they act as wings for the size of the opener by $a$ (figure 1b).

The main indicator of the tillage tool is its traction resistance. It is known that this indicator is influenced by many factors, among them: the geometric parameters of the working surfaces of the tool,
the physical and mechanical properties of the soil, the speed of interaction with it, the depth and width of cultivation, etc. [3]. Given such a number of factors, their change over time and unpredictability, especially in relation to physical and mechanical properties, it is theoretically impossible to describe the process of interaction of all forces and resistance factors [2, 4]. With this in mind, we will try to determine the expected traction resistance of the opener $R_x$, without going into the details of this complex process.

Based on the similarity of interaction with the soil of the developed drill coulter point opener and ploughshare, as well as taking into account the similarity of their working surfaces, we apply the well-known rational formula of Academician V. P. Goryachkin:

$$R_x = f \times P + k \times a \times b \times n + \varepsilon \times a \times b \times n \times V^2,$$

where $(f \times P)$, $(k \times a \times b \times n)$ and $(\varepsilon \times a \times b \times n \times V^2)$ – traction supports associated, respectively, with the drawing of the working body in the open furrow, the deformation of the soil and the provision of raised and deformed soil kinetic energy.

3. Results and discussion

In figure 2 illustrates the dependence of root hooks on their edges on the distance between them. Increasing the distance from 0.16 m does not significantly affect the number of such cases. In view of this, as well as taking into account the direct dependence of the growth of the resistance of the opener on increasing its width, as the optimal parameter of the distance between the extensions of the opener, and hence the width of the landing gap of 0.16 m.

![Figure 2. The number of hooking’s of roots of two-year-old apple seedlings when trying to place their root system in area between the extensions of opener model.](image)

It is necessary to consider some features of working bodies of orchard planting machine. Thus, in contrast to the plough body, its opener constantly works in the mode of laying the first furrow, in which the traction resistance increases by 2–3 times. In addition, the depth of its cutting is about 0.30 m, which in most cases exceeds the depth of tillage in previous years, and this leads to an increase in the expected resistance by 1.5–2.0 times. Taking into account these factors, it is necessary to increase the second component of the above formula by an additional factor $\mu$. In our case, it was found that depending on the planting depth (0.15–0.35 m) and the condition and type of soil, this coefficient can take values from 1.0 to 6.0 (figure 3). As a result, the horizontal component of soil resistance $R_x$ when planting to a depth of 0.30 m will be:

$$R_x = f \times P + \mu \times k \times a \times b \times n,$$

where $f$ – coefficient of friction of the body of drill coulter point with soil, $f$=0.5; $P$ – gravity of the working body, $P$=8.0 kN, $k$ – coefficient that characterizes the ability of the soil layer to resist deformation, $k=35.5$ kN/m$^2$; $a, b$ – respectively the depth and width of the layer of soil to be cultivated, $a=0.30, b=0.18$ m; $n$ – number of working bodies, $n=1$. 


Based on the results, the orchard planting machine can be aggregated with a tractor class 1.4, in contrast to the known orchard planting machine Spaperri MPS-1. Its aggregation is provided with class 3 tractors. The figure 4 illustrates the dependence of the resistance of the working body of the orchard planting machine on the depth of planting and soil type.

As a result, we get:

$$R_x = 0.5 \times 8.0 \text{kN} + 4 \times 35.5 \text{kN/m}^2 \times 0.3m \times 0.18m = 11.7 \text{kN}.$$  \hspace{1cm} (3)

Taking into account the calculations, a prototype of such a body was developed and manufactured (figure 5).
Preliminary tests have shown its stable operation at all depths in the range of 0.15–0.35 m, and everywhere it is successfully aggregated with the tractor Belarus 82.1 (class 1.4), even on fallow lands after pre-surface treatment with disc tools.

The conducted researches confirmed the correctness of the working hypothesis accepted at the beginning of researches about possibility of essential reduction of the energy consumption necessary for performance of the technological operation connected with formation of a landing furrow by means of simple in manufacturing [20] and reliable in operation working body of passive type [21], spreads the soil [22], and pruning the layer [23], raises it to the formation of a planting furrow [24], and after placing the seedling in it lays it in the previous place without additional significant movement or rotation [25].

4. Conclusion

Hooks of roots of two-year-old apple-tree saplings are absent at placement of their root system in an interval between extensions of model of an opener at width of a landing crack in the size of 0.30 m.

The optimum option for the working surface of blade of drill coulter point is a cylinder, which protrudes the wings beyond the dimensions of the opener, which provides a minimum horizontal component of soil resistance \( R \), during planting and is 11.7 kN when performing the operation to a depth of 0.30 m.

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