TECHNOLOGICAL EFFECTIVENESS OF MACHINE FOR DIGGING SEEDLINGS IN NURSERY GROWN ON VEGETATIVE ROOTSTOCKS

Ivan Rogovskii, Liudmyla Titova, Ruslan Shatrov, Oleksandr Bannyi, Oleksandr Nadtochiy
National University of Life and Environmental Sciences of Ukraine, Ukraine
rogovskii@nubip.edu.ua, ludmylkatitova@gmail.com, 72rusik@ukr.net ,
alexsandrbannyi@gmail.com , o.nad@ukr.net

Abstract. The article presents the results of experimental studies of the process of digging seedlings, which confirm the interaction of the working bodies with the soil slice and the reinforced root system of seedlings. The authors confirmed that the root system of seedlings grown on vegetative rootstocks is much more compact and has a fibrous structure, and therefore, their excavation requires less effort compared to seedlings grown on seed rootstocks. Plants are mainly planted in the first field of the fruit nursery with rows between 0.7 and 1 m that the maximum depth of excavation of biennial seedlings on clonal rootstocks is 0.30-0.35 m, and the width of the excavation soil is about 0.50 m. The results of the study showed that the energy intensity of machine technological operations was 30.8 GJ, which is more per 1 ha of land per year (permissible load of 15 GJ per 1 ha). The construction scheme and kinematic parameters of the working body of the machine are substantiated, which should consist of two elements: passive digging bracket and active shaker. The working part of the bracket should be formed by a cylinder with the radius about 0.34 m and have a width of 0.18-0.24 m, and its spatial location should provide the angle of attack about 10 degrees. The ripper must be active, namely oscillating, and the amplitude of its oscillations must increase from the minimum at the inlet of the roll to the maximum at its output. The range of changes in the amplitude and frequency of oscillations should be in the range of 0.01-0.03 m and 5.5-6.2 s^{-1}, respectively.

Keywords: plow, bracket, amplitude, frequency, productivity.

Introduction

The peculiarity of the process of digging seedlings is the interaction of working bodies with the soil slice reinforced with the root system of seedlings [1]. This interaction is based on the theory of wedge cutting, which requires consideration of conditions, factors, patterns of interaction that determine the process of minimal effort to cut a piece of soil with the root system of seedlings and their separation from each other [2]. Due to the changing trend the mass planting of high-yielding gardens in recent years with the use of vegetative [3], including dwarf [4], rootstocks has increased the volume of their cultivation in nurseries [5]. It is known that the root system of seedlings grown on vegetative rootstocks is much more compact [6], has a fibrous structure, and therefore, their excavation requires less effort compared to seedlings grown on seed rootstocks [7]. Given that the excavation of seedlings is a rather energy-intensive technological operation [8], there is an objective need to develop a specialized machine that could perform it more efficiently and at lower cost of both energy and human resources [9].

The set of technical means for the implementation of the system of basic tillage significantly determines the energy efficiency of a particular technology of growing cereals [10], its environmental and economic orientation [11]. One of the solutions in soil-saving agriculture is the introduction of parquet-type working bodies for deep loosening of the soil [12]. The original design of the paw of the tillage unit with the parquet-type working bodies has seven cutting surfaces [13]. However, [14] achieving the technological effect leaves room for finding ways to minimize energy costs.

After analyzing the existing designs of machines [15], tools and devices that are currently used for digging seedlings, presented in various sources [16], we can draw the following conclusions [17]. Obsolete and least perfect machines as a working body have a passive working body outside the tractor track in the form of a n-shaped bracket on which at the back at some angle to the horizon a ridge is fixed for loosening and partial separation of soil [18]. The choice of the research direction was made in the further improvement of the working body of the machine as the design of the digging bracket and the mechanism of actuation of the shaking mechanism [19].

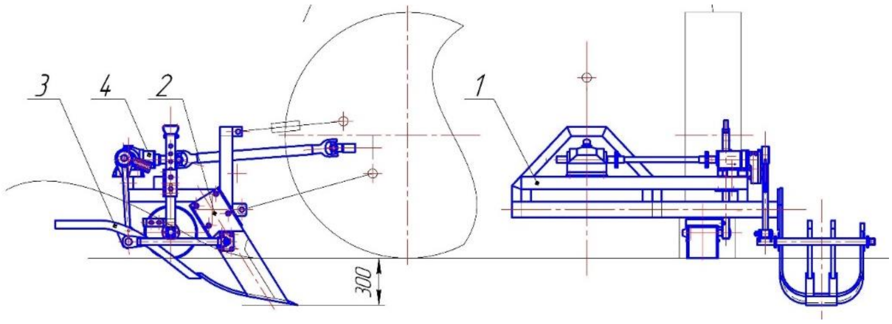
Based on the functional analysis of digging plows, it was found that the function of loosening the soil chunk with the root system of seedlings is the most important in minimizing the effort to pull dug up seedlings from the soil [20]. It was also established that in the process of loosening the soil should be separated from the root system of seedlings with the possibility of moving it to the bottom of the furrow [21]. The ripper must be active, and the effective loosening and separation of the soil from the root system of the seedling is significantly influenced by the mode of oscillations with the separation of the soil slice from the surface of the ripper, the angle of the ripper surface to the horizon [7], the distance between the shape of the ripper surface should allow the movement of the soil slice with the seedling with the lowest energy consumption for movement [16].

The purpose of these studies is to determine the technological efficiency and optimal operating parameters of the machine for digging seedlings in the nursery grown on vegetative rootstocks.

Materials and methods

The construction scheme and kinematic parameters of the working body of the machine, which should consist of two elements: passive excavation bracket and active shaker, are substantiated. The working part of the bracket should be formed by a cylinder with a radius of about 0.34 and have a width of 0.18-0.24 m, and its spatial location should provide an angle of attack of about 10°. Ripper is an active oscillator with the amplitude of its oscillations, which increases from the minimum at the inlet of the roll to the maximum at its output. The range of changes in the amplitude and frequency of oscillations should be in the range of 0.01-0.03 m and 5.5-6.2 s^{-1}, respectively. The prototype of the machine is made in a hinged version (Fig. 1).

a)



b)

Fig. 1. **Structural diagram (a) and general view (b) of the machine for digging seedlings in the nursery grown on vegetative rootstocks:** 1 – frame with a hitch; 2 – excavation bracket; 3 – separator with reduction mechanism; 4 – support wheel

The principle of operation of the machine. In the process of movement, the digging bracket cuts and lifts a piece of soil together with the plants, directing it to the separating lattice. The active lattice additionally loosens it, transforming it into a pseudo-liquid state, as a result the soil is sifted through the cracks of the lattice, exposing the roots of plants. The seedlings are then finally removed from the ground by hand, tied into bundles and loaded onto a vehicle. In the process of researching the influence of the angle of attack of the trenching bracket on the intensity of deepening and constancy of its movement in the soil, the required angle of attack of the trenching bracket was determined by changing the length of the tractor's middle drawbar. At the same time, the angle of attack varied from 5 to 20 degrees in steps of 5 degrees. The intensity of deepening of the digging bracket into the ground was estimated by the length of the distance over which the unit was moved, with the hitch in a floating position, from the beginning to the end of the process of deepening the working body. The stability of the movement of the working body in the soil was assessed visually.

Investigating the influence of the unit speed on the quality of the technological operation, the variable parameter was changed in the range of 0.5-1.5 m·s^{-1} by switching gears from the first reduced to the second increased. The quality was assessed visually by the stability of the process and the degree of separation of plant roots from the soil.

Two indicators were used to study the characteristics of change in completeness of soil separation from the frequency of lattice oscillations and soil supply to the working bodies of the machine: direct and indirect. The direct indicator – the coefficient of completeness of the separation of the *i*-th series η_i:

$$\eta_i = (m_k - m_s) \cdot m_k^{-1}, \tag{1}$$

$$m_k = \pi \cdot r_k^2 \cdot h \cdot \rho, \tag{2}$$

where m_k – estimated value of soil mass, associated with the roots of the seedling in a volume limited by a conditional cylinder with a radius equal to the average radial departure of its roots and a height equal to the depth of excavation, kg;
r_k – arithmetic mean of the radial departure of the roots, determined by measurement, m;
h – arithmetic mean of the height of the roots, which is determined by measuring the depth of excavation, m;
ρ – specific volume of soil, ρ = 1400 kg·m^{-3};
m_s – mass of soil remaining on the roots of the seedling after its removal is determined by weighing, kg.

The indirect indicator is the effort required to remove the seedling after passing the machine. It is determined using a dynamometer with a special device for capturing seedlings. The supply of soil to the working bodies was defined as:

$$q_k = \left[0.5 \cdot \pi \cdot r_k^2 + (h - r_k) \cdot b\right] \cdot V_m \cdot \rho, \tag{3}$$

where q_k – soil supply to working bodies, kg·s^{-1};
b – working width of capture of the machine, m;
V_m – working speed of the machine, m·s^{-1}.

The prototype of the machine was aggregated with a tractor PMZ-8082 class 14 kN. The working speed ranged V_m from 0.5 to 1.5 m·s^{-1}, with soil supply q_k 230, 340, and 450 kg·s^{-1}, crank speed n_p was 7.5, 9.0 and 10.5 s^{-1}. The research used the method of mathematical planning, a three-level plan of the second order for two factors: the supply of soil and the frequency of oscillations of the lattice. The effort to pull the seedlings was measured after digging them with a digging plow. To do this, a rope with a loop was attached to the seedling trunk above the root neck, which was attached to the dynamometer hook DPU-0.02-2 with a measurement accuracy of 0.1 N. The amount of force was measured by gradually moving the dynamometer along the seedling trunk with visual fixation of the maximum. The total number of seedlings to measure the pulling force was 30, i.e. 10 seedlings in three replicates.

Results and discussion

During the statistical processing of the obtained results, it was found that the optimal angle of attack of the trench bracket should be considered to be 12 ± 0.1 degrees. It is in this period of the spatial position of the bracket that the sufficient intensity of its deepening and acceptable constancy of movement in the soil are ensured. With the increase of the unit speed from 0.5 m·s^{-1} to 1.5 m·s^{-1}, the quality of the technological operation deteriorated. The intensity of the quality change was insignificant in the range of 0.5-1.0 m·s^{-1}. Further increase in the speed of movement led to a significant deterioration in the quality of soil separation, especially on clay, heavy soils. In addition, with increasing the operating speed from 0.5 m·s^{-1} to 1.5 m·s^{-1}, increases the traction resistance of the working body from 12.3 kN to 16.8 kN. To determine the effect of the amount of soil supply on the working parts of the machine and the frequency of oscillations of the lattice on the completeness of the separation of soil from the roots of seedlings, two series of experiments were conducted.

The first series was performed in a nursery on medium loam with a moisture content of 15-17% and a hardness of 1.5-1.8 mPa. Based on the experimental data and in accordance with the methodology of experiments, we determined the dependence of the coefficient of completeness of soil separation associated with the roots of seedlings, the soil supply and the frequency of oscillations of the lattice in the form of:

$$\eta_1 = 0.788 + 1.854 \cdot 10^{-2} \cdot n_p + 1.354 \cdot 10^{-4} \cdot q_k - 7.804 \cdot 10^{-4} \cdot n_p^2 + 1.063 \cdot 10^{-5} \cdot n_p \cdot q_k^2 . \qquad (4)$$

Statistics of processing the experimental data of expression (4) – polynomial of the second degree, probability level $P = 0.95$, $t_\alpha = 2.013$, the regression coefficient is linearized + 0.788, coefficient of multiple determination $D = 0.968$, coefficient of multiple correlation 0.918, standard deviation of the estimate of 0.040, F Fisher's criterion 82.616, the coefficient D is significant with a probability of 0.9997. The dependence (4) is graphically represented in Fig. 2. It can be seen that changing the frequency of lattice oscillations from 7.5 s^{-1} to 10.5 s^{-1} does not lead to a significant increase in the completeness of soil separation. At $q_k = 200$ kg·s^{-1} this change is from 0.9 to 0.92, and at $q_k = 400$ kg·s^{-1} from 0.865 to 0.890. At the same time, there is a tendency η_1 to decrease with increasing soil supply. Thus, at $n_p = 9.0$ s^{-1}, the increase in soil supply from 200 kg·s^{-1} to 400 kg·s^{-1}, i.e. twice, leads to a decrease in the coefficient η_1 from 0.91 to 0.88.

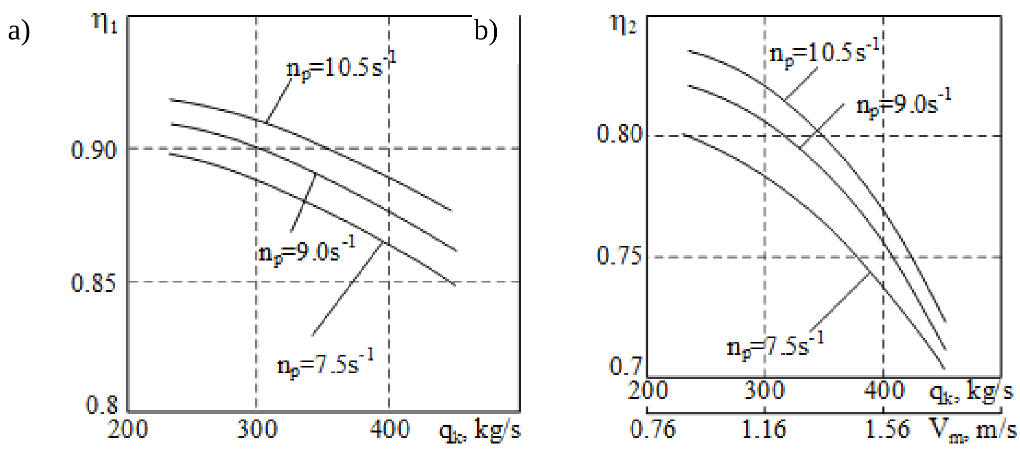


Fig. 2. **Dependence of coefficient of completeness of soil separation on its supply and the frequency of oscillations of lattice:** a – average loam; b – clay

Analysis of the obtained function (4) was performed by constructing two-dimensional sections at fixed values $\eta_1 = 0.85$; 0.875 and 0.90 (Fig. 2). The obtained isolines show the relationship between n_P and q_k , and also mean that the same value can be obtained at different values η_1 of the combination of these factors. Thus, $\eta_1 = 0.875$ will remain with increasing feed from 200 kg·s^{-1} to 400 kg·s^{-1}, if it increases np from 6 s^{-1} to 9 s^{-1}. Thus, on dry, average mechanical composition of the soil, the frequency of lattice oscillations does not significantly affect the completeness of the separation of the soil at a constant speed of the machine.

The second series of experiments was performed on heavy clay soil at a humidity of 19-22% and a hardness of 1.7-2.3 mPa, which shows the properties of stickiness and plasticity. On clay soil, the dependence of the completeness of separation of the soil from its supply and the frequency of oscillations of the lattice is defined as:

$$\eta_2 = 0.591 + 2.839 \cdot 10^{-2} \cdot n_p + 5.878 \cdot 10^{-4} \cdot q_k - 7.369 \cdot 10^{-4} \cdot n_p^2 - 1.507 \cdot 10^{-5} \cdot n_p \cdot q_k - -1.378 \cdot 10^{-6} \cdot q_k^2 . \qquad (5)$$

Statistics of processing the experimental data of expression (5) – polynomial of the second degree, probability level $P = 0.95$, $t_\alpha = 2.013$, the regression coefficient is linearized + 0.591, coefficient of multiple determination $D = 0.976$, coefficient of multiple correlation 0.931, standard deviation of the estimate of 0.612, F Fisher's criterion 49.279, the coefficient D is significant with a probability of 0.9995. Graphic representation of this dependence (5) in Fig. 3 shows that with increasing soil supply to the working bodies and decreasing the frequency of oscillations of the lattice there is a decrease in the coefficient. If when feeding q_k = 230 kg·s^{-1} (at $V_m = 0.88$ m·s^{-1}) and frequency $n_p = 9.0$ s^{-1} $\eta_1 = 0.82$, then when increasing the feed to q_k = 450 kg·s^{-1} (at $V_m = 1.71$ m·s^{-1}) $\eta_1 = 0.71$.

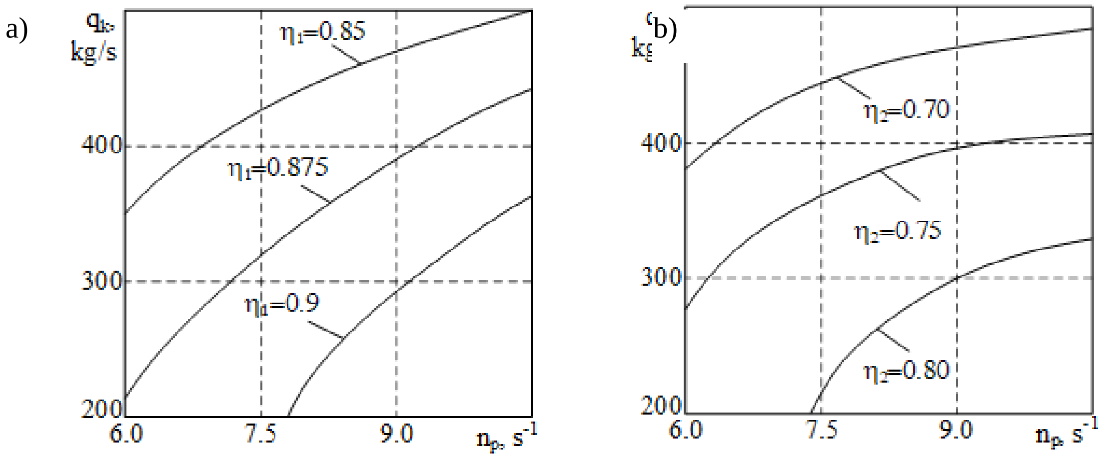


Fig. 3. **Isolines of two-dimensional sections at fixed values of completeness of soil separation:** a – average loam; b – clay

Changing the frequency n_p (5) in the accepted range has a less significant effect on the completeness of soil separation. Thus, the increase in the frequency from 7.5 s^{-1} to 10.5 s^{-1} at q_k = 230 kg·s^{-1} leads to an increase in the value of the coefficient from 0.80 to 0.83, and an increase in n from 9.0 s^{-1} to 10.5 s^{-1} gives a minimum increase in the value of the coefficient (0.82 to 0.83). Thus, the choice of oscillation frequency n in the range of 7.5-9.0 s^{-1} is the most acceptable, as further increase in frequency does not significantly increase the completeness of the separation, but leads to increased energy costs and reduced operational reliability of the machine.

Conclusions

1. The optimal speed of the machine for digging seedlings in the nursery grown on vegetative rootstocks is in the range of 0.5-1.0 m·s^{-1}. Further increase in the speed of movement led to a significant deterioration in the quality of soil separation, especially on clay, heavy soils. In addition, with increasing operating speed from 0.5 m·s^{-1} to 1.5 m·s^{-1}, increases the traction resistance of the working body from 12.3 kN to 16.8 kN.
2. Changing the frequency n_p in the accepted range has a less significant effect on the completeness of soil separation. Thus, the increase in the frequency from 7.5 s^{-1} to 10.5 s^{-1} at q_k = 230 kg·s^{-1} leads to an increase in the value of the coefficient from 0.80 to 0.83, and an increase in n from 9 s^{-1} to 10.5 s^{-1} gives a minimal increase in the value of the coefficient from 0.82 to 0.83. Thus, the choice of oscillation frequency n in the range of 7.0-9.0 s^{-1} is the most acceptable, because further increase in frequency does not significantly increase the completeness of the department, but leads to increased energy costs and reduced technological efficiency of the machine for digging seedlings on vegetative rootstocks.

Author contributions

Conceptualization, I.R.; methodology, L.T.; software, L.T.; validation, I.R. and L.T.; formal analysis, I.R. and L.T.; investigation, I.R., L.T. R.S., O.B. and O.N.; data curation, I.R. and L.T.; writing – original draft preparation, O.B.; writing – review and editing, L.T. and O.B.; visualization, O.N.; project administration, I.R.; funding acquisition, I.R., L.T. R.S., O.B. and O.N. All authors have read and agreed to the published version of the manuscript.

References

[1] Neilsen G., Hogue E., Neilsen D., etc. Use of organic applications to increase productivity of high density apple orchards. Acta Horticulturae, 2020, vol. 638. pp. 347-356, DOI: 10.17660/ActaHortic.2004.638.46.
[2] Schmidt J.H., Hallmann J.B. Bacterivorous nematodes correlate with soil fertility and improved crop production in an organic minimum tillage system. Sustainability, 2020, vol. 12, pp. 6730.

[3] Oljaca M., Raicevic D., Ercegovic D., etc. Special tillage machinery for soils with increased clayey type mechanical composition marsh soil case. Agriculture & Forestry, 2012, vol. 58(1), pp. 53-60.
[4] Rogovskii I.L., Titova L.L., Gumenyuk Yu.O., etc. Technological effectiveness of formation of planting furrow by working body of passive type of orchard planting machine. IOP Conference Series: Earth and Environmental Science, 2021, vol. 839, pp. 052055. DOI: 10.1088/ 1755-1315 /839/5/052055.
[5] Hammermeister A. Organic weed management in perennial fruits. Scientia Horticulturae, 2016, vol. 208, pp. 28-42.
[6] Islam F., Wang J., Farooq M., etc. Potential impact of the herbicide 2,4-dichlorophenoxyacetic acid on humanand ecosystems. Environment International, 2017, vol. 11, pp. 89-102.
[7] Walter M.S.J. Dimensional and geometrical tolerances in mechanical engineering – a historical review. Machine Design, 2019, vol. 11(3), pp. 67-74.
[8] Rogovskii I.L., Titova L.L., Voinash S.A., etc. Research of machines for mulching near-trunk strips in perennial fruit plantations. IOP Conference Series: Earth and Environmental Science, 2021, vol. 723, pp. 042041, DOI: 10.1088/1755-1315/723/4/042041.
[9] Jain A., Palekar U. Aggregate production planning for a continuous reconfigurable manufacturing process. Computers & Operations Research, 2005, vol. 32(5), pp. 1213-1236.
[10] Rogovskii I.L., Titova L.L., Voinash S.A., etc. Modeling the weight of criteria for determining the technical level of agricultural machines. IOP Conference Series: Earth and Environmental Science, 2021, vol. 677, pp. 022100, DOI: 10.1088/1755-1315/677/2/022100.
[11] Mashkov S., Ishkin P., Zhiltson S., etc. Methods of determining the need for agricultural machinery. IOP Conference Series: Earth and Environmental Science, 2019, vol. 403. pp. 012079.
[12] Mráz M., Urbanovičová O., Findura P., etc. Use of information systems to support decision making according to analysis machines. Agricultural Machinery, 2019, vol. 2, pp. 89-93.
[13] Nazarenko I., Mishchuk Y., Mishchuk D., etc. Determiantion of energy characteristics of material destruction in the crushing chamber of the vibration crusher. Eastern-European Journal of Enterprise Technologies, 2021, vol. 4(7(112), pp. 41-49. DOI: 10.15587/1729-4061.2021.239292.
[14] Zejun T., Tingwu L., Jun Z. The sealing process and crust formation at soil surface under the impacts of raindrops and polyacrylamide. Ecology and Evolution, 2020, vol. 6, pp. 456-462.
[15] Dubbini M., Pezzuolo A., De Giglio M., etc. Last generation instrument for agriculture multispectral data collection. CIGR Journal, 2017, vol. 19, pp. 158-163.
[16] Mashkov S., Ishkin P., Zhiltson S., etc. Methods of determining the need for agricultural machinery. IOP Conference Series: Earth and Environmental Science, 2019, vol. 403, pp. 012079.
[17] Timmermans S., Tavory I. Theory construction in qualitative research from grounded theory to abductive analysis. Sociological Theory, 2012, vol. 30(3), pp. 167-186.
[18] Brown R., Richards A. Engineering principles of agricultural machinery. ASABE, 2018, vol. 84(2), pp. 1120-1032.
[19] Bilous O.A., Hovorun T.P., Berladir K.V., etc. Mathematical modeling of the mechanical characteristic of the activated PTFE-matrix using the method of planning the experiment. Journal of Engineering Sciences, 2017, vol. 5(1), pp. 1-11.
[20] Gandhi G., Sharma G. The pallet conveyor system application in the industrial lines - a new design system with improvement of productivity. International Journal of Mechanical and Production Engineering Research and Development, 2019, vol. 9(3), pp. 257-266.
[21] Nagy P., Kincses I., Lang T., etc. Importance of orchard floor management in organic fruit growing (nutritional aspects). International Journal of Horticultural Science, 2010, vol. 16(3), pp. 61-67.