Research of machines for mulching near-trunk strips in perennial fruit plantations

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Abstract: The article presents the results of experimental studies to improve the productivity and quality of mulch substrate application in the stem bands of perennial orchards. The authors proposed a model of an effective means of mechanization and substantiated the optimal parameters of its operation when performing this operation. In the article the authors presented the results of experimental studies to determine: the productivity of feed and transverse conveyors, geometric parameters of the latter, the distance of laying mulch in the roll depending on the height of its placement above the soil surface and the speed of rotation of the drive drum component mechanisms. The authors proved that to prevent the undesirable excessive accumulation of substrate in the receiving hopper of the machine, the productivity of the feed conveyor should not exceed 5 m³/min. The article establishes that the required application rate is provided by the selection of the optimal operating speed of the unit and the productivity of the feed conveyor and can be 0.03-0.25 m³/m², and changing the same parameters allows depending on the needs to change the height of the roll within 0.05–0.15 m.

1. Introduction
The most common methods of soil retention in gardens are tillage between rows and black steam in the stem strips 1.0-1.6 m wide [1]. Application of the latter in the first 2 years after planting [2] is recommended to carry out mechanical tillage [3], and then use herbicides 2-3 times per season [4]. However, the use of herbicide vapor, along with the positive aspects, is characterized by a number of significant disadvantages: rapid loss of moisture in the dry season from an unprotected surface [5]; formation of a surface crust after rain [6], which prevents the enrichment of the soil with air [7]; the need for regular fertilization of plants with mineral fertilizers due to the lack of replenishment of nutrients due to the decomposition of plant residues [8], which occurs, for example, when using mechanical means of cultivation [9]; pollution of the environment with chemicals that [10], falling on the leaves of trees [11], can inhibit their development [12], and accumulate in the fruit, harm the health of consumers [13].
Today, an alternative way to maintain the soil in optimal condition in terms of plant physiology, reduce environmental pollution and improve fruit quality is to cover the interstitial strips with mulch substrate [14]. The material for this can be sawdust, shavings, flax trusts, chopped branches, grass, straw or a mixture thereof [15], used fungal substrate, litter for keeping animals [16]. Mulch reduces moisture evaporation [17], protects plant roots from freezing in winter, improves soil structure, enhances microbiological processes in it, reduces daily temperature fluctuations [18], inhibits weed germination and as a result improves the marketable quality of fruits [19], has a positive effect on their storage [20]. One of the reasons holding back the spread of this technology is the lack of special means of mechanization for its implementation [21].

The aim of research is to increase the productivity and quality of mulching substrate application in the stem strips of perennial orchards by developing an effective means of mechanization and substantiation of the optimal parameters of its work during this operation.

2. Materials and methods
Laboratory field experiments were carried out taking into account agrotechnical technological and technical and economic requirements [22], a priori information and conclusions made on the basis of engineering calculations [23]. Processing and analysis of the obtained data were performed using the methods of mathematical statistics [24]. The program of experimental researches provided definition: productivity of nutritious and cross conveyors [25], geometrical parameters of the last, distance of laying of mulch in a roll depending on height of its placement over a soil surface and speed of rotation of a drive drum [26], norms of mulch introduction at change of a mode of operation of the unit and its components [27].

To conduct research, a prototype machine was developed and manufactured, which is mounted on a spreader of solid organic fertilizers type RS-6M (figure 1). The machine (figure 1) consists of a receiving hopper 1, a belt cross conveyor 2, a hanging device 3, a torque transfer mechanism 4 and auxiliary equipment, and a spreader – a body 5, a longitudinal chain-bar (feed) conveyor with a drum of its displacement 6, a crushing and dosing mechanism 7 and the mechanism for actuating the working bodies 8.

The design of the hanging device allows to hang and dismantle the machines without special efforts that does the spreader more universal in use. During the operation of the unit, the mulch is fed by a feed conveyor through the crushing and dosing mechanism into hopper of machine. Then the crushed mass is moved by belt conveyor to the area of tree trunks where a roll of the required size is formed from it.

3. Results
The analysis of the obtained results shows that the productivity of the feed and cross conveyors can vary in the range from 1.2 to 9.0 m³/min and from 2.0 to 5.3 m³/min. Accordingly, when increasing the speed of rotation of the power take-off shaft of the tractor, as well as when moving the ratchet regulator to a higher mark (the first conveyor) and change the position of the dosing valve (second) (figure 2 and figure 3). Therefore, to prevent the undesirable excessive accumulation of substrate in the receiving hopper of the machine, the productivity of the feed conveyor should not exceed 5 m³/min, which is possible with the appropriate position of the ratchet mechanism.

The distance of laying mulch in the roll relative to the transverse conveyor (figure 4 and figure 5) can vary from 0.40 to 1.30 m depending on the height of the latter above the soil surface and the speed of rotation of the shaft of selection of power of a tractor. This dependence can be used to compensate for possible deviations of the trajectory of the unit relative to the centerline of a number of trees during the operation in order to ensure the required accuracy of laying the roll.
Figure 1. Schematic representation and model of the machine for making mulch substrate in the stem strips of perennial orchards.

Figure 2. Change of productivity of the cross conveyor of the tractor depending on position of a dosing gate and speed of rotation of a shaft of selection of power of a tractor: curves 1, 2, 3 – positions of change of position of a gate.
Figure 3. Change of productivity of the feeding conveyor of the basic tractor depending on position of the ratchet mechanism and speed of rotation of a shaft of selection of power of a tractor: curves 3, 5, 7, 9, 11 – position of an eccentric of the ratchet mechanism.

Figure 4. Changing the distance of laying the roll relative to the transverse conveyor depending on the height of its placement above the soil surface and the speed of rotation of the shaft of the power take-off of the tractor: curves 30, 40, 50 cm – the height of the conveyor.
Figure 5. Change of width of a roll of a substrate depending on speed of rotation of a shaft of selection of power of a tractor and height of placement of the cross conveyor over a soil surface: curves 30, 40, 50 cm – change of height of placement of the conveyor above the soil surface.

The width of the roller also depends on the change in the speed of the tractor power take-off shaft, and hence on the speed of the cross conveyor belt. The latter can vary in the range from 0.8 to 2.5 m when changing the speed of the shaft of selection of power of a tractor from 250 to 500 min\(^{-1}\) (figure 5). The width of the roll increases with decreasing height of the conveyor above the ground and increasing the speed of the shaft of the tractor power take-off. Taking into account the current agronomic requirements (the width of the roll should not exceed 1.5 m), the recommended speed of the conveyor belt should be 2.0-3.0 m/s. This corresponds to the speed of rotation of the shaft of selection of power of a tractor with a frequency of 250-375 min\(^{-1}\).

The required rate of application of the substrate is provided by the selection of the optimal operating speed of the unit and the productivity of the feed conveyor and can be 0.03-0.25 m\(^3\)/m\(^2\), and changing the same parameters allows depending on the needs to change the height of the roll within 0.05-0.15 m.

4. Discussion
Production tests were carried out in the garden plantations of the National University of Life and Environmental Sciences of Ukraine with a row spacing of 5.0 m on an area of 0.5 ha. As a substrate used three different physical properties of the substance: fresh sawdust with moisture and bulk density of 30% and 250 kg/m\(^3\), respectively [28]; compacted sawdust with the corresponding indicators of 48% and 470 kg/m\(^3\); used mushroom substrate (65% and 590 kg/m\(^3\), respectively [29]).

The unit operated in two modes with substrate application rates of 0.05 and 0.10 m\(^3\)/m\(^2\). They were provided with the speed of the unit, respectively 1.2 and 0.5 m/s and the productivity of the feed conveyor of the base machine is about 2.5 m\(^3\)/min [30]. The latter was achieved by installing a ratchet regulator of the specified conveyor in the area of the fifth mark. According to the tests, the deviation of the actual application rate from the set did not exceed 12%, the average width and height of the cover roll were 1.30 and 0.048 m, respectively, in the first and 1.10 and 0.095 m in the second mode. The machine worked stably with all the mentioned types of substrates. There was no damage to the trees.
Productivity of the machines for an hour of the basic time made about 2.0, variable – 0.5 hectares. The coefficient of reliability of the technological process was 0.99, and the use of variable time – 0.40. Operational and technological indicators were determined based on the operating conditions of the machine in the garden with a row spacing of 5.0 m, operating speed of 4.2 km/h at a substrate application rate of 160 m$^3$/ha. Substrate losses in any mode of operation of the unit did not exceed 0.5%. Studies have shown that compliance with certain operating ranges and the optimal mode of the working bodies of the machine and the unit as a whole ensures the implementation of the technological operation in accordance with current agricultural requirements with high quality indicators. Thus, the deviation of the actual rates of application of the substrate, as well as the width and height of the cover roll from the specified does not exceed 12, 10 and 15%, respectively.

5. Conclusion
The capacity of the feed and cross conveyors can vary from 1.2 to 9.0 and from 2.0 to 5.3 m$^3$/min. To prevent unwanted excessive accumulation of substrate in the receiving hopper of the machine, the capacity of the feed conveyor should not exceed 5 m$^3$/min.

The distance of laying mulch in the roll relative to the transverse conveyor varies from 0.40 to 1.30 m depending on the height of the latter above the soil surface and the speed of rotation of the shaft of selection of power of a tractor. The dependence is recommended to be used to compensate for possible deviations of the trajectory of the unit relative to the centerline of a number of trees during the operation in order to ensure the required accuracy of laying the roll.

The productivity of the machine was 2.0 per hour of main time, variable time –0.5 ha. The coefficient of reliability of the technological process is 0.99, and the use of variable time –0.40. Substrate losses in any mode of operation of the machine did not exceed 0.5%.

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