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INNOVATIONS FOR SHREDDING AND UTILIZING BRANCHES IN ORCHARDS

The article highlights the pressing issue of disposing of plant residues generated during the pruning of fruit trees in orchards. Pruning is an important agricultural operation that ensures crown formation, increased yield, tree rejuvenation, and removal of diseased, damaged, or dry branches. However, one of the most difficult and inefficient stages of this process remains the disposal of pruned wood. Traditional methods, which involve manual collection, loading, transportation, and burning of branches, are inefficient, labor-intensive, and have a negative impact on the environment. In addition, such methods are characterized by irrational use of resources and low transport load factors.

The article proposes an innovative technical solution–the use of a universal garden machine that allows for the comprehensive mechanization of the processes of collecting, shredding branches, and incorporating prunings into the soil between rows. The use of such equipment contributes to a significant reduction in manual labor costs, increased productivity of garden work, and environmentally safe disposal of residues. Shredded wood, incorporated into the soil to a depth of 7–12 cm, decomposes quickly, especially when combined with organic or mineral fertilizers. This not only enriches the soil with organic matter, but also improves its agrophysical, chemical, and biological properties.

The results of the study indicate the feasibility and effectiveness of implementing the proposed technology in horticulture. This approach is promising for both farms and large industrial enterprises specializing in fruit cultivation, and contributes to the development of sustainable agriculture.

Keywords: *branch disposal, garden machine, wood chipping, row spacing, agrotechnical efficiency, mechanization of horticulture, milling.*

Introduction. In modern agro-industrial production, issues of effective and environmentally safe management of organic waste are becoming increasingly relevant. One of the most common types of such waste in horticulture is wood pruning, which is generated during the regular shaping of fruit tree crowns. This agrotechnical measure is an integral part of tree care technology aimed at increasing yield, extending the productive life of plantings, and reducing the risk of disease spread.

Crown pruning is carried out taking into account the biological characteristics of trees, their age structure, type of fruiting, growth intensity, and agroclimatic conditions of the region. As a result of this operation, a significant amount of wood material–dry, old, or damaged branches – accumulates each year. Traditional methods of disposal, such as manual collection, transportation, and burning, require significant labor and material resources, are inefficient, and harm the environment by polluting the air with combustion products [1, 2].

In practice, the problem of mechanizing the process of collecting and disposing of cut branches in various types of orchards–from small farms to industrial ones–is particularly relevant. In most cases, farms use manual labor or outdated equipment that does not meet modern requirements for productivity, environmental friendliness, and economic feasibility. Due to limited load capacity and the difficulty of packing branches tightly into vehicles, the efficiency of logistics operations is significantly reduced. In addition, burning wood in landfills or directly in orchards is prohibited by environmental legislation in a number of countries, which further complicates the situation.

One promising solution is the use of a new generation of mobile garden machines that can not only shred wood but also simultaneously incorporate it into the soil as a source of organic matter. This approach solves several problems at once: it reduces waste, improves soil structure and biological activity, lowers fertilizer costs, and reduces environmental impact.

In this regard, special attention should be paid to the development and implementation of an innovative universal garden machine, the design of which allows for the comprehensive performance of all technological operations related to wood utilization– from collection to incorporation of shredded material into the upper biologically active soil layer. Such a machine must meet modern requirements for ergonomics, energy efficiency, adaptability to operating conditions, and environmental friendliness.

This article presents the concept and technical solution for a universal garden machine designed for the mechanized disposal of branches by shredding and incorporating them into the soil. It provides a description of the design, principle of operation, and kinematic diagram of the working parts drive, as well as the agrotechnical effect of using this technology in small and medium-sized farms.

Analysis of recent research and publications. The disposal of fruit tree prunings is a technological process that is traditionally performed manually or using primitive means of small-scale mechanization. In agricultural practice in Ukraine, particularly on farms with medium-sized orchards (up to 10–20 hectares), pruned branches are mostly disposed of by manually loading the wood onto trailers or transport sleds that move between rows. The branches are taken to the edge of the plot, where they are either burned or stored for further disposal.

This approach has a number of significant drawbacks: [3, 4].

1. High labor intensity. The entire process of collecting and loading prunings is mostly done manually, which requires significant human resources, especially in orchards with a large number of trees.
2. Low transportation efficiency. Due to the bulkiness and irregular shape of the branches, the fill factor of transport vehicles is extremely low, which leads to an increase in the number of trips and fuel consumption.
3. Dependence on weather conditions. In rainy or snowy weather, it is difficult to use self-unloading trailers, so farms are forced to resort to less efficient methods, such as using sleds, which further complicates mechanization and increases labor costs.
4. Violation of environmental standards. Burning wood residues in open areas not only harms the environment, but is also prohibited by law in most regions, as it is a source of CO_2, particulate matter, and other harmful emissions.
5. Loss of organic matter. Wood that could be used as a source of organic matter to improve soil fertility is lost as a result of burning or removal.
6. Lack of integrated solutions. Existing techniques for disposing of trimmings mostly perform only one function – shredding or transportation. Machines capable of performing several technological operations simultaneously in a single work cycle are rare.

Some types of garden shredders used today are capable of shredding wood, but do not ensure its further disposal or incorporation into the soil. Usually, after shredding, the chips remain on the surface between rows, where they can become a breeding ground for pests or pathogens in the absence of proper control.

Thus, an analysis of existing approaches to the disposal of cuttings indicates the absence of a comprehensive technical solution that would ensure: [8, 9].

- mechanized collection of branches from the soil surface;
- high-quality shredding of wood to the state of wood chips;
- incorporation of wood chips into the biologically active soil layer by milling;
- minimization of manual labor and fuel costs;
- increased agrotechnical effect from disposal.

The universal garden machine proposed in this article allows for the implementation of such an integrated approach to the utilization of prunings, which meets the modern requirements of sustainable agriculture.

The purpose of the study. The aim of the study is to develop a universal garden machine design that provides a comprehensive solution to the problem of disposing of branches obtained after pruning fruit trees. The technological process involves the mechanized collection of cuttings, their shredding, and the subsequent incorporation of shredded wood into the soil between rows of garden plantings.

To achieve this goal, the following main tasks were set:

1. Analyze existing methods of recycling pruned wood and identify their shortcomings;
2. Develop a design for a garden machine that meets environmental, energy efficiency, and versatility requirements;
3. Describe the operating principle of the proposed machine, highlighting its main functional components;
4. Create a kinematic diagram of the working parts drive;
5. Justify the agronomic feasibility of adding shredded wood to the soil as organic fertilizer;
6. Identify the operational advantages of the machine compared to traditional disposal methods.

The implementation of these tasks allows for the creation of an effective, economically viable, and environmentally safe technology for the disposal of organic residues in horticulture, tailored to the needs of small and medium-sized agricultural enterprises [7].

Results. A universal garden machine designed for mechanized collection, shredding, and incorporation of fruit tree prunings into the soil is a mounted unit that can be attached to a general-purpose tractor. The design allows for the simultaneous performance of three main operations: picking up branches from the surface between rows, shredding them, and milling the shredded material to a depth of up to 18 cm [6].

The main structural elements of the machine are:

- Frame – a rigid supporting structure on which all working parts and transmission mechanisms are mounted. It is made of profiled steel, which provides sufficient strength while maintaining the permissible weight of the unit.
- Hitch – triangular type, allows the machine to be aggregated with a tractor of traction class 1.4–2.0.
- Feed rollers – rotate by means of a chain drive, pick up cut wood from the soil surface and transport it to the shredding unit. Scraper pads are used to improve gripping.
- Shredder – a two-roller mechanism with knife elements located on counter-rotating shafts. It works by combing the wood and then fragmenting it.
- Cutter – an active organ that loosens the soil and simultaneously incorporates the shredded wood particles. Equipped with curved knives that promote better mixing of the mass with the soil.
- Relief copying system – support skis and wheels ensure a stable position of the machine relative to the soil and adjustment of the depth of wood incorporation.
- Guards – protect the operator and the environment from debris and soil ejection.

Principle of operation (Fig. 2). As the unit moves between the rows of the tractor, the feed rollers pick up the branch cuttings (12) from the surface and transport them to the shredder (4). The shredder breaks the wood into pieces measuring 3–8 cm. The shredded material is ejected onto the soil surface through a deflector plate (7). The cutter (5), located at the rear of the machine, loosens the soil and simultaneously mixes it with the shredded wood to a depth of 7–18 cm, creating a uniform application of organic matter. The entire machine is kept in a stable position by support elements (skis and wheels), which allow it to copy the micro-relief of the row spacing.

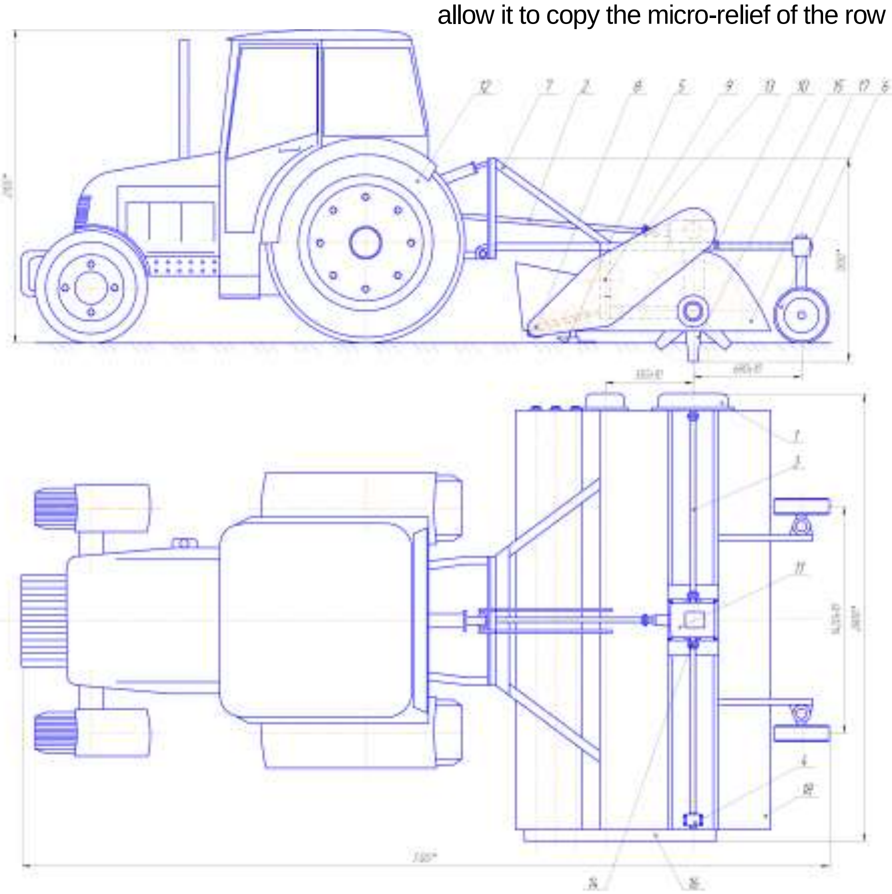

Fig. 1. Project machine: 1 – Side gearbox; 2 – Cardan shaft; 3 – Cross shaft; 4 – Bearing assembly; 5 – Ski; 6 – Support wheel; 7 – Mounting device; 8 – Feed rollers; 9 – Shredder; 10 – Frame; 11 – Bevel gearbox; 12 – Tractor; 13 – Safety clutch; 14 – Connecting clutch; 15 – Cutter; 16 – Protective shield; 17 – Side shield; 18 – Deflector shield.

Design advantages:

• Comprehensiveness: all operations—collection, shredding, incorporation—are performed in a single pass.

• Minimization of organic matter loss: wood chips are not removed but immediately become part of the agrotechnical cycle.

• Reduced labor costs: the tractor operator performs the entire cycle, eliminating manual labor.

• Improved soil structure: organic residues increase humus content and improve air and water permeability.

• Environmental friendliness: burning is eliminated, which reduces CO_2 emissions.

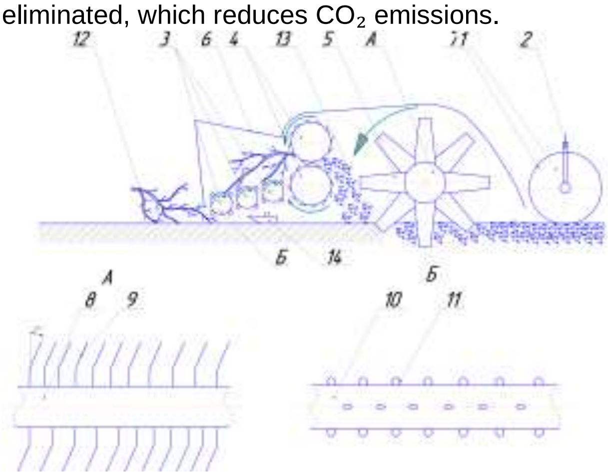

Fig. 2. Structure and operation of the design machine: 1 – Support wheel; 2 – Soil cultivation depth adjustment screw; 3 – Feed rollers; 4 – Crushing device; 5 – Cutter; 6 – Receiving plate; 7 – Deflector plate; 8 – Cutter shaft; 9 – Knife; 10 – Feed roller shaft; 11 – Scraper; 12 – Wood chips; 13 – Crushed chips; 14 – Soil relief copier.

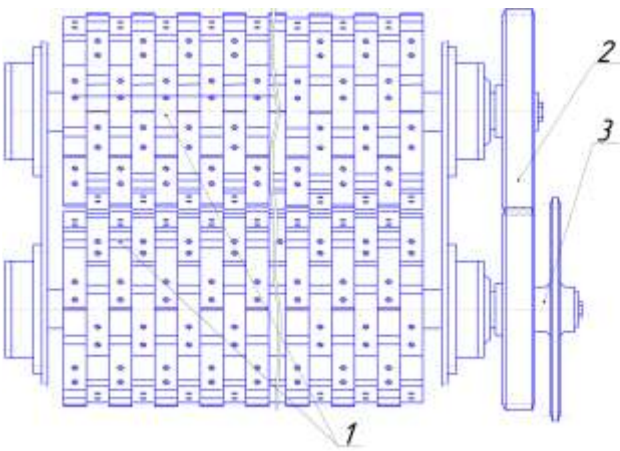

Fig. 3. Grinding device: 1 – Grinding shafts; 2 – Gear transmission; 3 – Shaft drive sprocket.

Kinematic diagram of the working parts drive. The kinematic diagram of the machine (see Fig. 4) is designed to ensure efficient and reliable torque transmission from the tractor's power take-off shaft (PTO) to the main functional units – feed rollers, shredder, and cutter. A combination of cardan, gear, and chain drives is used to achieve the required transmission ratio and stable operation of each unit.

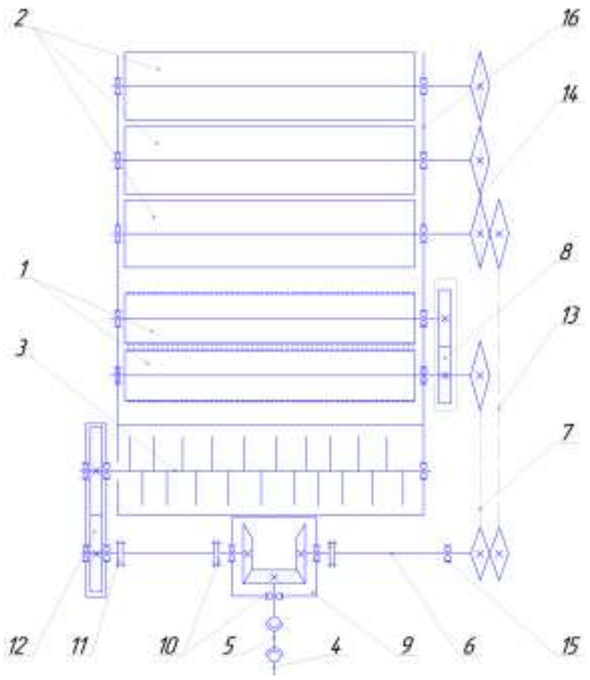

Fig. 4. Kinematic diagram of the machine's working parts drive: 1 – Roller shredder; 2 – Feed rollers; 3 – Cutter; 4 – Tractor power take-off shaft; 5 – Cardan shaft; 6 – Shredder and feed roller drive shaft; 7 – Chain drive of the crusher; 8 – Cylindrical gear drive; 9 – Bevel gearbox; 10 – Safety clutch; 11 – Connecting clutch; 12 – Side gearbox; 13 – Chain drive of feed rollers; 14 – Chain drive of rollers; 15 – Bearing assembly; 16 – Housing.

The main elements of the kinematic diagram (according to Figure 4):

1. Tractor power take-off shaft – the initial source of mechanical energy. The PTS speed is transmitted to the cardan shaft (4).
2. Cardan shaft – transmits torque to the machine drive shaft (5).
3. Bevel gearbox – changes the direction of rotation from vertical to horizontal and partially reduces the speed (9).
4. Safety clutch – protects components from overload, activates when the permissible torque is exceeded (10).
5. Connecting clutch – allows easy disconnection of the machine and tractor during maintenance (11).
6. Side gearbox – further reduces the rotation speed for driving the feed rollers (12).

7. Chain drive of the feed rollers – transmits rotation from the gearbox to the feed rollers (13).

8. Chain drive – synchronizes the rotation of both feed shafts, ensuring uniform material feed (14).

9. Shredder and feed roller shaft – transmits torque to both functional parts (1 and 2, respectively).

10. Cylindrical gear transmission – reduces the speed and increases the torque on the shredder (8).

11. Cutter – driven by a separate shaft via a chain transmission, which takes torque from the same drive as the shredder (3).

How it works. The tractor's power take-off shaft (~540 rpm) transmits power via a cardan shaft to a system of gearboxes, where the following occurs:

- The drive is split into two streams: one for the feed rollers and shredder, and the other for the cutter;

- Reduction of the rotation speed to values optimal for each working unit:

- Feed rollers – 60–80 rpm;
- Shredder – 300–500 rpm;
- Cutter – 200–350 rpm.

This design allows the machine to operate efficiently under real field load conditions without overloading individual components, while strictly adhering to the sequence of the technological process.

The design provides easy access to all components for scheduled maintenance. A safety clutch and a connecting clutch allow the drive to be safely stopped in the event of an emergency load or jamming of one of the working parts.

Technological parameters and operating modes of the designed garden machine.

To ensure high productivity and quality of garden plant processing, the designed machine has optimal technological parameters that take into account the characteristics of plant residues, the physical and mechanical properties of the soil, as well as operating conditions in different climatic zones.

Main technological parameters: [5].

• Working width: 1.5–2.0 m (depending on the machine modification and the width of the rows in the garden).

• Depth of incorporation of shredded material: 7–18 cm, adjustable with support wheels and an adjustment screw.

• Maximum diameter of branches for shredding: up to 50 mm.

• Productivity: 0.3–0.5 ha/hour, depending on the speed of movement and the density of plantings.

• Working speed: 3–5 km/h.

• Shredder rotation speed: 300–900 rpm.

• Cutter rotation speed: 200–350 rpm.

The productivity of the rollers is determined by the formula [5]:

$$q = 47{,}1 \cdot [(D + 2 \cdot \delta)^2 - d^2] \cdot S \cdot K \cdot n \cdot \gamma \cdot C, \quad (1)$$

where *D* – is the diameter of the roller winding, *D* = 0,320м.;

d – roller shaft diameter, *d* = 0.05 m;

δ - radial clearance between the outer edge of the winding and the inner surface of the casing δ = 0,004 m;

S – winding pitch, *S* = 0,20 m;

K – filling coefficient, *K* = 1,0;

n – rotation frequency, *n* = 620 min^{-1} = 10,4 s^{-1};

C – coefficient that takes into account the decrease in the roller's throughput capacity from the angle of inclination to the horizon, at β = 0, *C* = 1;

γ - bulk density of the cargo, γ = 0,74 t/m^3.

We substitute the values into the formula and perform the calculation.

$$q = 47{,}1 \cdot [(0{,}32 + 2 \cdot 0{,}004)^2 - 0{,}05^2] \cdot 0{,}2 \cdot 1 \cdot 10{,}4 \cdot 0{,}74 \cdot 1 = 6{,}87$$ t/h,

We determine the required power for the drive using the formula [5]:

$$N = \frac{q}{367 \cdot 10^3 \cdot \eta} \cdot (L_2 \cdot \omega + H) \cdot К_1, \quad (2)$$

where η =0,96 – drive efficiency coefficient;

L_2 = horizontal projection of the load movement path, L_2 = 1,2m;

H = 0 – height of load lifting;

ω - coefficient of resistance to material displacement, ω = 4;

$К_1$ = 1,2 – coefficient that takes into account friction losses in bearings.

We substitute the values into the formula and perform the calculation.

$$N = \frac{6{,}87}{367 \cdot 10^3 \cdot 0{,}96} \cdot (1{,}2 \cdot 4 + 0) \cdot 1{,}2 = 1{,}2$$ kW,

We determine the circular speed using the formula:

$$\vartheta = \frac{\pi d n}{60}, \quad (3)$$

where *d*=0,32 m – winding diameter;

n=620 min^{-1} – rotation frequency.

We substitute the values into the formula and perform the calculation:

$$\vartheta = \frac{3.14 \cdot 0{,}32 \cdot 620}{60} = 10{,}3$$ m/s,

We determine the torque on the shaft using the formula[18]:

$$T = \frac{P}{\omega} = \frac{30P}{\pi \cdot n}, \quad (4)$$

We substitute the values into the formula:

$$T = \frac{30 \cdot 1{,}2 \cdot 10^3}{3.14 \cdot 620} = 18{,}5 \cdot 10^3 \text{ N mm},$$

Features of operating modes:

1. Chip collection mode: The feed rollers lift branches from the ground and direct them to the shredder area. Tubular shafts with scrapers ensure uniform and uninterrupted material feed.

2. Shredding mode: The shredder, equipped with two shafts with knives, works in the opposite direction, ensuring high-quality and uniform shredding of wood into fractions up to 3–5 cm in size.

3. Material incorporation mode: The shredded chips, falling onto the soil surface, are immediately incorporated by the cutter, which simultaneously improves the soil structure, increases its aeration, and creates conditions for accelerated decomposition of organic residues.

Adjusting the speed and working depth allows the machine to be adapted to different soil types and plant conditions. For example, in denser soils, it is recommended to reduce the working depth and speed to ensure high-quality incorporation of the shredded material.

Experimental research and evaluation of the efficiency of the designed garden machine.

To confirm the effectiveness of the proposed universal garden machine, a series of field tests were conducted in different types of gardens and soils. The purpose of the research was to evaluate productivity, grinding quality, the degree of incorporation of the ground material, and the impact on soil structure.

The tests were conducted on three garden plots with different types of fruit trees (apple, cherry, pear) and typical soils (sandy loam, loam, black soil). The area of the experimental plots ranged from 0.5 to 1 hectare.

Research methods

• Measuring productivity: calculating the area treated per unit of time.

• Determining the quality of shredding: analyzing the size of the shredded fractions using sieve analysis.

• Measuring the depth of incorporation: using a special probe.

• Assessment of impact on soil: laboratory studies of aeration, moisture content, and structure before and after cultivation.

• Assessment of overall orchard condition: observation of tree growth and development in subsequent seasons.

Research results.

1. Productivity: The average productivity of the machine was 0.42 ha/hour, which corresponds to the design calculations and exceeds the productivity of traditional manual technologies for recycling cuttings by 3–4 times.

2. Shredding quality: The vast majority of shredded particles were 3–5 cm in size, which is optimal for rapid decomposition and soil fertilization.

3. Working depth: It was possible to precisely adjust the depth from 7 to 18 cm, which allows for the most effective incorporation of organic material into the biologically active soil layer.

4. Impact on the soil: Laboratory studies showed improved aeration, increased organic matter content, and increased microbial activity in the layer where the compost was applied.

5. Condition of the orchard: In the season following treatment, there was an improvement in the overall condition of the trees and an increase in their resistance to disease and drought.

The results of the studies confirmed the feasibility of introducing the project machine into horticultural practice, especially in small and medium-sized farms. The versatility of the machine, its high productivity, and the simultaneous performance of several operations (collection, grinding, incorporation) significantly reduce labor costs and improve the ecological condition of orchard plots.

Economic efficiency of introducing a project garden machine and recommendations for its operation.

The introduction of a universal garden machine for shredding and recycling pruning waste has significant economic advantages over traditional methods.

• Reduced labor costs. Mechanization of the process significantly reduces the need for manual loading and unloading, allowing for a 40-50% reduction in personnel.

• Increased productivity. Mechanized technology for processing clippings increases the area that can be processed by two to three times, reducing the time spent on garden maintenance.

• Resource savings. No need to use fuel for additional transport to remove prunings and reduced costs for their disposal (incineration, composting).

• Improved soil fertility. The addition of shredded material increases the organic matter in the soil, which has a positive effect on crop yields and long-term productivity.

According to preliminary estimates, for a garden area of up to 5 hectares, the investment in the project machine will pay for itself in 2-3 seasons due to reduced labor costs and improved soil condition.

Recommendations for use:

• It is recommended to use the machine during the period of active garden maintenance –

after pruning trees, when the largest amount of waste is generated.

• The depth of incorporation of the shredded material should correspond to the type of soil and the biological characteristics of the plantings (7–18 cm).

• Regular maintenance of working parts (shredder blades, cutters, rollers) ensures high quality of work and durability of the machine.

• To avoid overload and damage, strictly follow the manufacturer's recommendations regarding the maximum size of cuttings.

The impact of shredding and incorporating branches on the ecological condition of orchards

An innovative approach to shredding and incorporating prunings into the soil has a significant positive impact on the ecological condition of orchards:

• Reduced air pollution. Eliminates traditional branch burning, which is a source of smoke and harmful emissions that negatively affect the environment and human health.

• Preservation of organic matter in the soil. Shredded wood acts as a natural organic fertilizer that maintains the balance of nutrients and soil structure.

• Improvement of soil water retention capacity. Organic residues introduced into the soil increase its ability to retain moisture, which is especially important in drought conditions.

• Stimulation of soil microflora activity. The introduction of shredded wood residues creates favorable conditions for the development of beneficial microorganisms that promote faster decomposition of organic matter.

Technical characteristics of the universal garden machine design

Parameter	Value
Working width, m	1,2
Depth of incorporation of shredded material, cm	7 – 18
Productivity, ha/h	0,5 – 1,0
Tractor power consumption, kW	30 – 50
Machine weight, kg	450

Improving soil quality by adding organic residues improves growing conditions not only for fruit trees but also for other useful plant species, which has a positive effect on the overall ecological balance of the orchard.

Description of design improvements

• Double feed rollers: Increase the efficiency of branch collection and the stability of material feed to the shredder.

• Adjustable skids: Ensure accurate copying of the ground relief, allowing you to maintain a stable working depth.

• Protective shields: Improve work safety, reduce the ejection of small particles and dust.

• Adjustable support wheels: Allow you to precisely adjust the milling depth for different soil types.

Conclusions. The article discusses an innovative approach to shredding and recycling fruit tree branches using a universal mounted garden machine that combines the collection and shredding of tree cuttings with the simultaneous incorporation of the shredded mass into the soil between rows of garden plantings.

The developed machine design is characterized by high functionality and productivity due to the use of a two-roller shredder, adjustable feed rollers, and a cutter, which allows for the effective processing of prunings directly on site, while simultaneously improving soil quality.

The kinematic diagram of the working parts drive ensures reliable and economical operation of the machine by transferring power from the tractor's PTO through a system of gearboxes, chain drives, and couplings.

The innovative method of incorporating shredded material into the soil accelerates its decomposition, increases soil aeration, and improves soil structure and nutrient availability. This reduces the need for chemical fertilizers and promotes environmentally friendly horticulture.

The proposed machine is an optimal solution for small and medium-sized orchards, as it mechanizes the process of branch disposal and increases labor efficiency.

Further research should focus on optimizing the design to accommodate different types of fruit and berry crops, developing automated control systems, and improving energy efficiency.

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ІННОВАЦІЇ ДО ПОДРІБНЕННЯ ТА УТИЛІЗАЦІЇ ГІЛОК ПЛОДОВОГО САДУ

У статті висвітлено актуальну проблему утилізації рослинних залишків, що утворюються в процесі обрізання плодових дерев у садових насадженнях. Обрізка є важливою агротехнічною операцією, яка забезпечує формування крони, підвищення врожайності, омолодження дерев і видалення хворих, пошкоджених або сухих гілок. Проте одним із найбільш складних і малоефективних етапів цього процесу залишається утилізація обрізаної деревини. Традиційні методи, які передбачають ручне збирання, навантаження, транспортування та спалювання гілок, мають низьку ефективність, значну трудомісткість і негативний вплив на довкілля. Крім того, такі способи характеризуються нераціональним використанням ресурсів і низьким коефіцієнтом завантаження транспорту.

У статті запропоновано інноваційне технічне рішення – використання універсальної садової машини, яка дозволяє комплексно механізувати процеси збирання, подрібнення гілок і заробки щепи в ґрунт міжрядь. Застосування такого обладнання сприяє значному скороченню витрат ручної праці, підвищенню продуктивності садових робіт і екологічно безпечній утилізації залишків. Подрібнена деревина, внесена в ґрунт на глибину 7–12 см, швидко розкладається, особливо за умови поєднання з органічними або мінеральними добривами. Це не лише забезпечує збагачення ґрунту органічною речовиною, але й покращує його агрофізичні, хімічні та біологічні властивості.

Результати дослідження свідчать про доцільність і ефективність впровадження запропонованої технології в садівництві. Такий підхід є перспективним як для фермерських господарств, так і для великих промислових підприємств, що спеціалізуються на вирощуванні плодових культур, і сприяє розвитку сталого сільського господарства.

Ключові слова: *утилізація гілок, садова машина, подрібнення деревини, міжряддя, агротехнічна ефективність, механізація садівництва, фрезерування*.

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