Article

Substantiation and Analysis of Vertical Shaft Rotary Tillers for Pre-Sowing Soil Preparation

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Abstract: The improvement of pre-sowing soil preparation technologies remains one of the important directions in agricultural engineering. In recent years, special attention has been paid to vertical shaft rotary tillers due to their ability to simultaneously perform soil loosening, crushing, leveling, and compaction operations. However, existing rotary tillers are characterized by high energy consumption, excessive metal intensity, and insufficient adaptability to local soil and climatic conditions. This study presents an analytical review of existing vertical axis rotary tillers developed in Germany, Turkey, China, Russia, and other countries, as well as patent solutions related to the optimization of rotary working bodies. The technological and constructive parameters of rotary tillers, including rotor rotational speed, blade geometry, and working depth, were comparatively analyzed. The influence of blade installation angle and kinematic parameters on soil crushing quality and energy consumption was evaluated. The analysis showed that most existing machines process the entire field width, which increases fuel consumption and may negatively affect soil structure and moisture conservation. Based on the conducted analysis, the necessity of developing a resource-saving vertical shaft rotary tiller capable of localized soil treatment in the seed placement zone was substantiated. The obtained results can be used for the development of energy-efficient combined tillage and sowing machines adapted to local agricultural conditions [1].

Keyword: vertical shaft rotary tiller, soil preparation, rotary blade, kinematic parameters, energy consumption, seedbed preparation, localized tillage, agricultural machinery.

Quoting: Shohjahon Kimsanov, Xudayarov Berdirasul, Avazov Ikrom. Agroengineering Solutions. **2026**, 3, 15, 2
https://doi.org/10.35938/AY-2026-3-00002

Received: 06.05.2026
Corrected: 02.06.2026
Accepted: 04.07.2026
Published: 08.07.2026

Introduction

Modern agricultural production requires the development of resource-saving tillage technologies capable of reducing energy consumption while improving soil quality before sowing. In cotton-growing regions, special attention is given to the preparation of a fine and uniform seedbed because the quality of soil preparation directly affects seed germination, moisture conservation, and crop productivity [2].

Conventional tillage technologies generally involve several sequential operations including plowing, harrowing, leveling, and cultivation, which lead to increased fuel consumption, soil compaction, and operational costs.

In this regard, vertical shaft rotary tillers have attracted considerable scientific interest due to their ability to combine several technological operations in a single pass. These machines can effectively loosen the soil, crush clods, level the surface, and prepare favorable conditions for seed placement.

Researchers and manufacturers from Germany, Turkey, China, Russia, India, and other countries have proposed various designs and technological solutions for improving rotary tillage systems [3].

Figure 1. Existing vertical shaft rotary tillers used for pre-sowing soil preparation

Figure 1 illustrates several existing vertical shaft rotary tillers widely used for pre-sowing soil preparation. These machines provide effective soil crushing and leveling; however, most of them require high-power tractors and considerable energy consumption. In addition, full-width tillage may negatively affect soil moisture conservation and increase operational costs.

The Zirkon 12 rotary tiller developed by LEMKEN (Figure 1a) is characterized by high soil fragmentation quality and stable operation at working depths up to 18 cm. However, the rigid monolithic structure of the rotor sections increases the probability of damage when interacting with hard obstacles and stones [4].

The Warrior 3000 rotary harrow produced by Agrolead (Figure 1b) uses vertically rotating blades driven through a gear transmission mechanism. The machine provides effective clod crushing and soil leveling, although its operation requires high-power tractors and considerable energy consumption [5].

The Chinese 1BQ-3 rotary tiller (Figure 1c) demonstrates satisfactory soil penetration and crushing performance. Nevertheless, the construction includes additional transmission mechanisms and possesses relatively high metal intensity, which increases operational complexity [6].

The PN07 vertical tillage machine developed in Russia (Figure 1d) combines deep soil treatment with leveling and compaction operations. The presence of heavy rollers improves moisture conservation; however, the large structural mass of the machine increases fuel consumption and requires powerful tractors.

The KE 02 Rotamix system manufactured by Amazone (Figure 1e) integrates soil preparation and sowing-related operations within a single technological process. Despite its high operational efficiency, the machine is characterized by significant structural complexity and high energy demand [7].

The performed analysis indicates that existing vertical shaft rotary tillers provide effective soil preparation quality; however, most constructions are characterized by excessive energy consumption, large structural mass, and insufficient adaptability to local soil and climatic conditions.

Scientific investigations conducted by T. Raparelli, A. Ivanov, G. Pepe, Chandrashekar, Jayant Singh, P. Balsari, A. Biglia, L. Comba, E. I. Amirkhanov, and other researchers mainly focused on the optimization of rotor rotational speed, blade trajectories, and soil interaction mechanisms.Their studies demonstrated that the efficiency of rotary tillers strongly depends on the relationship between tractor forward speed and rotor rotational velocity [9].

At the same time, several patent solutions proposed the installation of rotary blades at inclined angles relative to rotor radius in order to reduce soil reaction forces and improve cutting efficiency.

2 Materials and Methods

The study was based on analytical and comparative investigations of existing vertical shaft rotary tillers, scientific publications, and patent materials related to pre-sowing soil preparation technologies.

Technical characteristics of rotary tillers manufactured in Germany, Turkey, China, Russia, and other countries were comparatively analyzed.

The following parameters were considered during the analysis:

1-rotor rotational speed;

2-working depth;

3-rotor diameter; Qi Xiao, Changqi Lv, and Ziqiang Zhang. To reduce energy consumption, 4-

blade geometry;

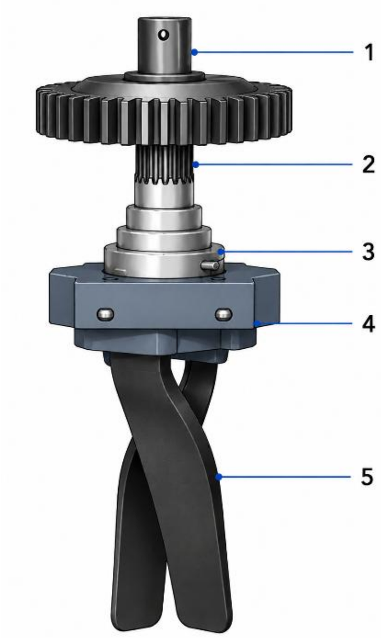
6-blade installation angle;

7-transmission system structure;

8-soil fragmentation quality;

10-energy consumption indicators.

Particular attention was paid to the interaction between rotary blades and soil, including blade trajectories, overlap characteristics, and the influence of kinematic parameters on soil crushing quality.



1 – Transmission gear wheel; 2 – gear shaft; 3 – fastening pin; 4 – cutting head assembly; 5 – rotary tiller blades.

Figure 2. Structural scheme of the Warrior 3000 vertical rotary harrow

Figure 2 shows the structural configuration of the Warrior 3000 rotary harrow. Power is transmitted from the tractor PTO through a gear transmission system to vertically rotating blades. The construction ensures effective soil fragmentation; however, the complex transmission mechanism increases structural mass and energy consumption.

Theoretical analysis of blade motion was carried out considering the relationship between tractor forward velocity and rotor angular velocity.

The kinematic coefficient λ was used as one of the main indicators characterizing rotor operation conditions.

The influence of blade installation angle α on soil cutting and compaction processes was also analyzed based on existing experimental and patent investigations.

Results and Discussion

The performed analysis demonstrated that existing vertical shaft rotary tillers possess high technological capabilities for pre-sowing soil preparation. However, most existing constructions are characterized by high metal intensity, excessive fuel consumption, and the necessity of using high-power tractors.

Scientific investigations showed that the interaction between rotary blades and soil strongly depends on the geometry of the working body and the arrangement of blade supports. Traditional rotary tillers usually position blade supports perpendicular to the rotor radius, which increases soil compression and resistance forces during operation.

Patent investigations demonstrated that optimization of blade support geometry significantly improves the operational efficiency of rotary tillers.

3 Results & Discussion

According to the results of the static structural analysis performed in the ANSYS environment, when only external loading was applied to the robot frame, the maximum total deformation was primarily concentrated in the central lower section of the frame. Minimal deformation was observed in the support regions and rigidly fixed structural components.

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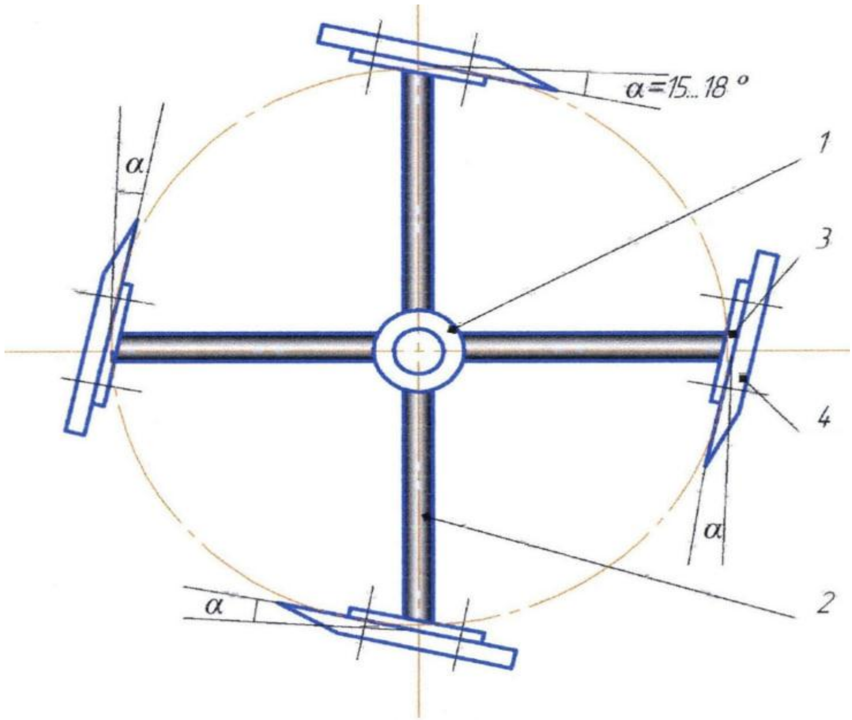

Figure. 3. Vertical shaft rotary tiller with inclined blade supports

Figure 3 illustrates the inclined blade support configuration proposed for reducing soil reaction forces. Inclining the blade support by α = 15–18° along the rotor rotation direction improves soil cutting conditions and decreases energy consumption during tillage operations.

Research results indicate that inclining blade supports by α = 15–18° along the rotor rotation direction improves soil cutting conditions and reduces energy consumption.

In this case, the blade enters the soil progressively, which decreases resistance forces and improves soil fragmentation quality. The analysis indicates that the installation angle of the blade support plays an important role in optimizing the interaction between the rotary blade and the soil layer during tillage operations [8].

Another promising direction in the improvement of vertical rotary tillers is the development of movable and self-adjusting working bodies capable of adapting to varying soil conditions during operation.

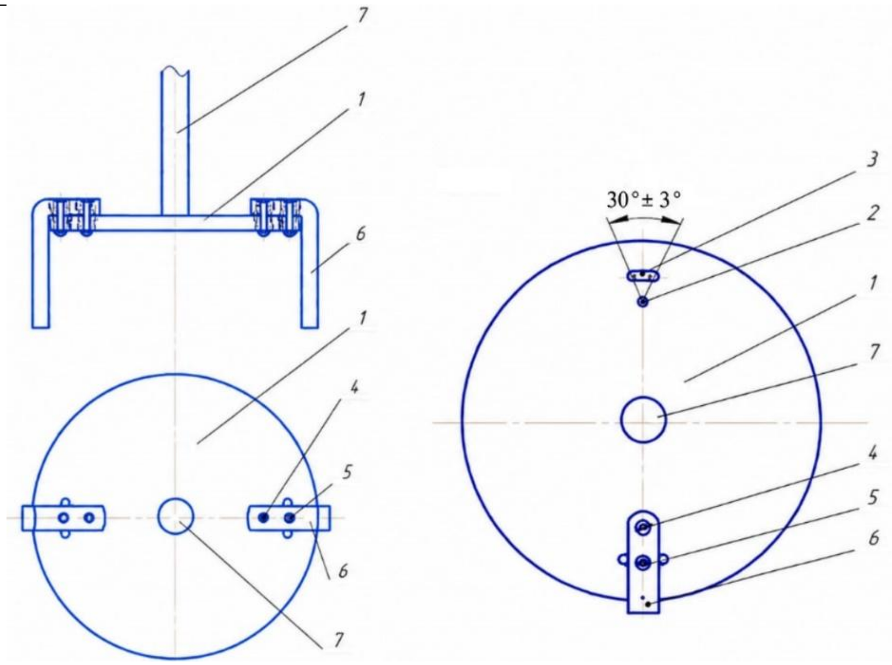

Figure. 9. Self-adjusting working body of the vertical rotary tiller

Figure 4 presents a self-adjusting working body designed for a vertical shaft rotary tiller. The main feature of this construction is the ability of the blade support to change its position dynamically under soil resistance forces.

Compared with rigidly fixed working bodies, the proposed mechanism allows the blade to adapt to changing soil conditions during operation. Such self-adjustment reduces excessive resistance forces and minimizes shock loading when the blade encounters hard soil particles or obstacles.

Another important advantage of this design is the improvement of energy efficiency due to the reduction of unnecessary soil compression. The self-adjusting mechanism also decreases the probability of blade damage and increases the service life of the working bodies.

The analysis shows that movable blade support systems can significantly improve the operational performance of vertical rotary tillers under variable field conditions [9].

Further improvement of vertical shaft rotary tillers is associated with the application of elastic support mechanisms capable of reducing dynamic loading during tillage operations.

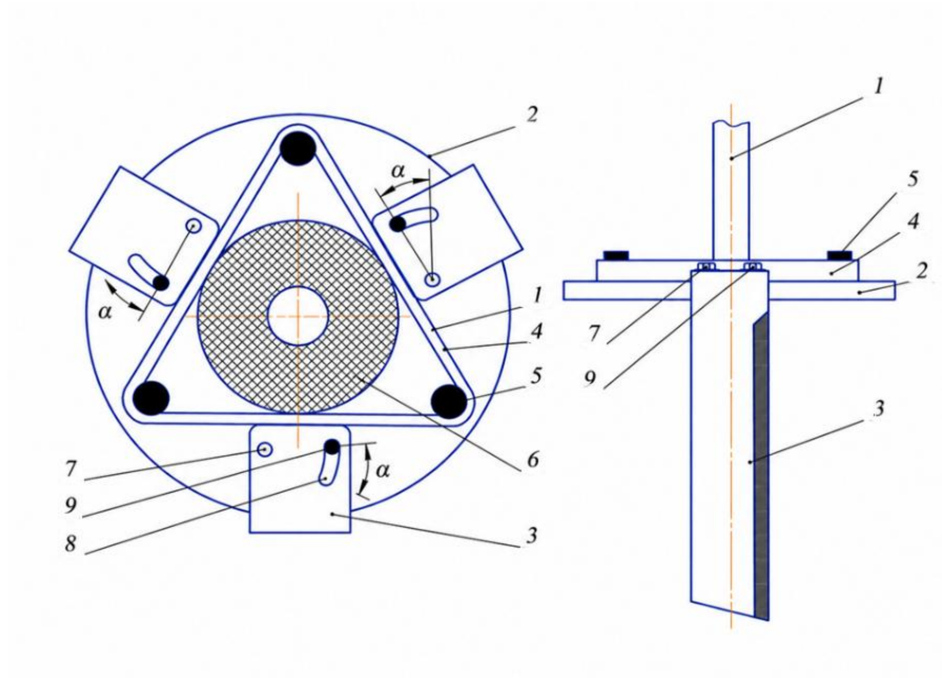

Fig.15. Vertical shaft rotary tiller with elastic blade support mechanism

Figure 5 demonstrates a vertical shaft rotary tiller equipped with an elastic blade support mechanism. In this construction, elastic elements and cylindrical joints allow the working body to oscillate and partially rotate under soil resistance forces.

The elastic support mechanism reduces dynamic loading during soil interaction and improves the adaptability of the rotary tiller to uneven field surfaces. When the blade encounters obstacles, the support mechanism absorbs part of the impact energy, thereby decreasing the risk of structural failure.

Furthermore, the ability of the blade support to rotate within a limited angular range improves the cutting process and reduces traction resistance. This contributes to lower energy consumption and more stable operation of the machine [10].

The performed analysis indicates that the application of elastic and movable support mechanisms is one of the promising directions for improving the efficiency and reliability of vertical shaft rotary tillers.

Conclusions

The conducted analysis demonstrated that modern vertical shaft rotary tillers possess high potential for pre-sowing soil preparation and can effectively perform soil loosening, crushing, leveling, and compaction operations in a single pass.

However, most existing machines are characterized by high energy consumption, excessive structural mass, and the necessity of using high-power tractors. In addition, full-width tillage negatively affects soil structure and moisture conservation.

The performed patent analysis showed that inclined blade supports, self-adjusting working bodies, and elastic support mechanisms significantly improve the interaction between rotary blades and soil. Such конструктив solutions reduce soil resistance forces, improve soil fragmentation quality, and decrease energy consumption.

Therefore, further development of energy-efficient vertical shaft rotary tillers adapted to local soil conditions remains an important scientific and practical direction in agricultural engineering.

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