

INVESTIGATING THE KINEMATICS OF THE COVERING UNIT IN A MACHINE DESIGNED FOR THE CONTINUOUS PLANTING OF FRUIT TREE SAPLINGS

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Abstract

This study presents a theoretical investigation of the kinematic behaviour of the covering unit in a machine designed for continuous planting of fruit tree saplings. In existing planting practices, soil preparation and sapling covering are performed as separate operations, with the covering process predominantly carried out manually, leading to increased labour intensity and operational costs. To improve efficiency, a continuous planting machine integrating furrow opening, sapling placement, soil covering, and compaction into a single technological process is considered. The research focuses on the kinematic analysis of the covering unit, which performs combined rotational motion about its axis and translational motion along with the machine. The motion of points on the working surface is described within a three-dimensional Cartesian coordinate system. Analytical expressions for velocity and acceleration are derived, enabling evaluation of the influence of key parameters such as operating speed, unit diameter, installation angle, and curvature radius on the soil covering process. The results demonstrate that the kinematic parameters of the covering unit significantly affect soil movement intensity and the quality of sapling covering. The obtained relationships provide a

theoretical basis for selecting rational design and operating parameters of continuous planting machines.

Keywords: Fruit tree saplings, planting machine, covering unit, kinematics, continuous planting, soil covering process, rotational and translational motion, agricultural machinery optimization

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Introduction

In modern horticulture, the establishment of orchards requires a series of sequential soil preparation operations prior to sapling planting. In Uzbekistan, this process typically includes ploughing to a depth of 30–35 cm, chiselling, and subsequent harrowing. After completing these operations, planting pits are prepared either manually or using specialized digging machines such as KYa-100, KNYu-100, and KRK-60, usually with dimensions of 60×60×60 cm [1]. However, the process of covering saplings with soil and compacting it around the root system is still predominantly performed manually. This leads to increased labour intensity, time consumption, and overall operational costs.

In response to these challenges, a continuous planting machine for fruit tree saplings has been developed at the Research Institute of Agricultural Mechanization. This machine integrates several technological operations into a single process, including furrow opening, sapling placement, soil covering, and compaction. Such integration significantly reduces manual labour and improves planting efficiency [2].

A critical component of this machine is the covering unit, which ensures proper soil distribution and compaction around the sapling roots. The effectiveness of this process largely depends on the kinematic characteristics of the covering mechanism. During operation, the covering unit performs a complex motion that combines rotational movement around its own axis and translational movement along with the machine.

The aim of this study is to investigate the kinematic behaviour of the covering unit during operation. In particular, the motion of points on the working surface of the unit is analysed within a three-dimensional Cartesian coordinate system (XYZ). Based on theoretical analysis, mathematical expressions describing the trajectory and motion parameters of the covering unit are derived [3].

The results of this research provide a theoretical foundation for optimizing the design and operational parameters of continuous sapping planting machines, thereby improving the quality of soil covering and reducing energy and labour requirements in orchard establishment.

$$x = V_i t + R \sin \varphi_i \cos \alpha \cos \omega t + R(1 - \cos \varphi_i) \sin \alpha; \quad (1)$$

$$y = R(1 - \cos \varphi_i) \sin \alpha - R \sin \varphi_i \sin \alpha \cos \omega t; \quad (2)$$

$$z = -R \sin \varphi_i \sin \omega t, \quad (3)$$

Here, V_i is the translational velocity of the covering unit together with the machine, m/s;

t – time, s;

φ_i – half of the central angle determining the spatial position of the considered point “i”;

ω – angular velocity of the covering unit during rotational motion, rad/s.

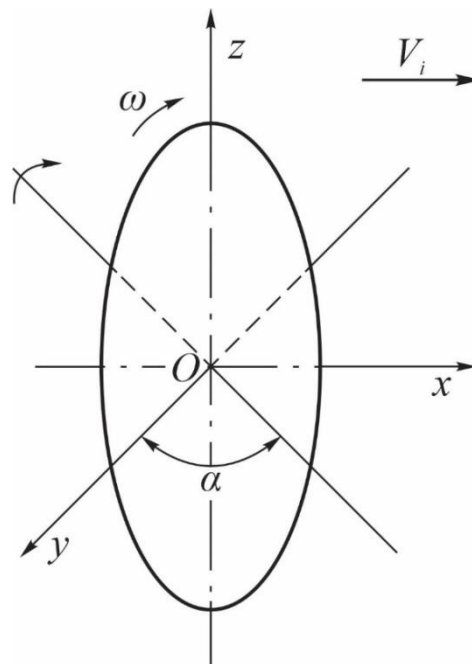


Figure 1. Schematic diagram for investigating the motion of the covering unit during operation.

Using equations (1)–(3), the absolute velocity and acceleration of the considered point on the working surface of the covering unit can be determined. Since the covering unit performs a combined motion consisting of translational motion together with the machine and rotational motion around its own axis, the absolute velocity of any point on its

working surface is expressed as the vector sum of these two motion components. Accordingly, the absolute acceleration is determined by differentiating the velocity components with respect to time.

This approach makes it possible to describe the trajectory of the working surface point, determine its instantaneous velocity and acceleration, and evaluate the influence of the main kinematic parameters on the soil-covering process. The obtained relationships serve as a theoretical basis for selecting rational values of the translational speed of the machine and the angular velocity of the covering unit.

Using equations (1)-(3), we determine the absolute velocity and acceleration of the point on the working surface of the tool:

$$V_a = \sqrt{\left(\frac{dx}{dt}\right)^2 + \left(\frac{dy}{dt}\right)^2 + \left(\frac{dz}{dt}\right)^2} \quad (4)$$

va

$$W_a = \sqrt{\left(\frac{d^2x}{dt^2}\right)^2 + \left(\frac{d^2y}{dt^2}\right)^2 + \left(\frac{d^2z}{dt^2}\right)^2}, \quad (5)$$

$$\text{bunda } \frac{dx}{dt} = V_i t - \omega R \sin \varphi_i \cos \alpha \sin \omega t; \quad (6)$$

$$\frac{dy}{dt} = \omega R \sin \varphi_i \sin \alpha \sin \omega t; \quad (7)$$

$$\frac{dz}{dt} = -\omega R \sin \varphi_i \cos \omega t; \quad (8)$$

$$\frac{d^2x}{dt^2} = -\omega^2 R \sin \varphi_i \cos \alpha \cos \omega t; \quad (9)$$

$$\frac{d^2y}{dt^2} = \omega^2 R \sin \varphi_i \sin \alpha \cos \omega t; \quad (10)$$

$$\frac{d^2z}{dt^2} = \omega^2 R \sin \varphi_i \sin \omega t. \quad (11)$$

Taking this into account, expressions (4) and (5) take the following form:

$$V_a = \sqrt{V_i^2 - 2V_i \omega R \sin \varphi_i \cos \alpha \sin \omega t + \omega^2 R^2 \sin^2 \varphi_i} \quad (12)$$

va

$$W_a = \omega^2 R \sin \varphi_i. \quad (13)$$

It is known from the literature [4]

$$\omega = \frac{2V_i \cos \alpha}{D} \quad (14)$$

Substituting this value of ω into equations (12) and (13), we obtain the following expressions:

$$V_a = 2V_i \sqrt{\frac{1}{4} - \frac{R}{D} \cos^2 \alpha \sin \varphi_i \left(\sin \frac{2V_i \cos \alpha}{D} t + \frac{R}{D} \sin \varphi_i \right)} \quad (15)$$

And

$$W_a = \frac{4V_i^2}{D^2} R \sin \varphi_i \cos \alpha \quad (16)$$

The analysis of these expressions shows that the degree of soil impact exerted by the covering unit, and consequently its performance indicators, depend on its operating speed, diameter, installation angle relative to the direction of motion, and the curvature radius of its working surface.

Conclusions

The theoretical analysis established that the covering unit performs a complex motion consisting of rotational motion about its own axis and translational motion together with the machine.

The derived expressions show that the absolute velocity and acceleration of points on the working surface of the covering unit depend on the machine operating speed, the diameter of the covering unit, its installation angle relative to the direction of motion, and the curvature radius of the working surface.

It was determined that these parameters directly influence the intensity of soil movement, the degree of soil impact on the sapling root zone, and the quality of covering during continuous planting.

Therefore, the obtained analytical relationships can be used as a theoretical basis for selecting rational design and operating parameters of the covering unit in machines intended for continuous planting of fruit tree saplings.

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