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Investigation results of kinematic and dynamic indicators of tiller with vertical rotation axis in orchards soil cultivation

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ABSTRACT

The results of experimental-theoretical investigations on the tillers with vertical rotation axis in soil cultivation and weed eradication in orchards are introduced in the article.

Upon the developed theory of rotary tiller kinematics and dynamics calculation the following points have been set up:

– In kinematics – functional dependence of the tiller work of technological and regime parameters enabling a high technological quality of soil weed mass cultivation;

– In dynamics – mathematical model of energy evaluation function of soil-weed mass cultivation technological process depending on constructive-regime parameters of the tiller with vertical rotation axis, providing the minimum amount of torque against the resistance towards soil cutting.

The reliability of the developed calculation theory has been verified through the results of conducted experiments, the difference hasn't exceeded 5%, which is explained by the inhomogeneity of the treated medium and changeability of the straightness of the garden rows.

Introduction

The main prerequisite of the further enhancement of economic efficiency of horticulture is the development and implementation of intensive cultivation technologies, especially the components of soil cultivation and elimination of weedy vegetation of the near-trunk and inter-trunk patches with the simultaneous cutting of irrigation furrow at a distance of 1,3–1,5 m from the tree trunks. The high-quality and timely implementation of these measures ensures yield increase up to 30% [1,2].

The soil cultivation and weeding of near-trunk patches with the contemporary technical means in a number of horticultural zones is carried out at a low agro-technical level, the flaws left after the application of technical means are refined manually.

For the cultivation of inter-trunk and near-trunk patches rotary tillers with horizontal and vertical rotation axis are currently used. However due to constructive-technological drawbacks these machines don't have wide industrial application. The tiller signaling mechanism of shoop, providing a transverse movement, cutoff of the tree trunk has delicate and sensitive structure and therefore, when encountering rigid weed or branch, it drives the hydraulic system, takes the tiller along the axis of a row of trees processing the near-trunk zones with defects.

Besides, in case of a very rigid link of the hydro mechanical system drive the damage to the tree bark is inevitable, which is an unacceptable violation in agro-technical conditions.

The above mentioned shortcomings are more vividly expressed in the soil conditions of the Armenian horticulture where stones and heavy sandy and sandy-clay soil types are available. This accounts for the fact that in conditions of Armenian orchards the machines for the cultivation of near-trunk and inter-trunk zones of the soil aren't applied widely yet. As a result of the problem study, we have developed a rotary tiller with the vertical axis of rotation: its main design property is that the tiller is coaxial from outside with a gap of 5 cm, a freely rotated rim with an elastic trunk-protective shell is set up. When working the tiller with its trunk-protective rim rolls around the trunk and from the 5 cm protective zone carries out a near-trunk flawless processing in the near-trunk strip and then an inter-trunk processing of the soil with weeding.

The device and the operation of the developed tilling machine is introduced in the works [3–5].

In order to determine the optimal geometric-kinematic

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parameters theoretical and a number of experimental studies have been introduced [4]. The machine is simple in design and easy to operate: it implements the inter- and near-trunk soil cultivation flawlessly and absolutely excludes the use of manual labor. Rolling along the perimeter of the trunk the tiller rim with an elastic shell doesn't damage the delicate tree bark.

Providing the orchards soil cultivation in consistent with agricultural requirements, the machine must be also energy-efficient. To establish the energy indicators of the machine, the dynamic studies of the tiller have been carried out. As a result the optimal parameters of the machine have been determined at which the minimal traction resistance of the aggregate is derived.

Objectives and methods

The employees of the scientific center of NAUA simultaneously and independently cooperated with the scientific centers engaged in the development of the machine for the inter-trunk soil cultivation in the fruit orchards. However, considering the considerable labor intensity of the manual processing of the hard-to-process soils strips left after the machine passage with the mechanical wire (probe) of input and output of the cutter from a number of tree rows the scientific workers of the agrarian university have developed a garden tilling machine for the near- and inter-trunk tree processing, the principle of the tilling machine operation for which is the following. Certificate of authorship has been received for this machine [6].

The working part of the developed machine-tiller consists of two cutters with the soil cultivating weeding universal knives, one of which is moveable and cultivates near- and inter-trunk zones of the whole row, it is coaxially installed in a driven, rubberized, trunk-protected rim with a gap of 5 cm. When the machine approaches the trunk, the protective rim rolls around the trunk and the cutter processes a circular near-trunk strip with the protective zone of 5 cm.

Practically, with a pair of fixed cutters, the machine completely cultivates the near-trunk-inter-trunk zone, eliminating the need of manual labor.

Results and analyses

Optimization of the technological-energetic parameters of the developed garden machine has been conducted by the results of the computing theory and a series of special experiments.

Technological processes performed by the cutters with horizontal and vertical axis of rotation are outwardly similar, however as kinematic-dynamic mechanical systems, they are completely different.

The optimization theory of the new tilling machine parameters has been worked out in consistent with the specified technological-agro-technological requirements of the horticulture technique.

Through the developed calculated theory the kinematic and dynamic contents of the technological processes of soil cultivation and elimination of weedy vegetation at the near- and inter-trunk zones of the orchards carried out through the tiller with vertical axis have been identified.

The functional dependence of the core technological parameter-splinter thickness (δ), upon the controlled factor established by kinematic analyses of the operation looks like:

$$\delta = \frac{2\pi r}{\lambda Z}\cos\left(arc\tan\frac{1+\lambda\cos\omega t}{\lambda\sin\omega t}\right), \quad (1)$$

where r – is the tiller's radius, $\lambda = \frac{\omega r}{V_M}$ – is the tiller's kinematic parameter, Z – is the number of the tiller blades, ω – is the angular velocity of the tiller, $2\pi r/\lambda Z = S$ – is the discharge value.

This equation enables to comprehensively evaluate the technological quality of the soil cultivation with minimal energy consumption by the change of operation regime and geometrical parameters of the tiller within optimal ranges/thresholds: $\lambda = 10-12;\ z = 5-6;\ r = 20-35\ cm$, depending on the number of tillers 2–3. Depending on the soil properties and conditions and weed vegetation of the orchards, the discharge value should be selected within 2,5–3,0 cm, the rotation number of the tiller is 100–120 r/min.

From the technological perspective it is particularly very important to optimize the universal tilling blades performing two technological activities: cutting and loosening of the splinter with the vertical cutting element and cropping of the weeds with the horizontally installed lance shaped part. In both cases the cutting of the soil and weeds should be carried out with the slip at optimum values of installation angles.

The problem of the soil-weed mass cutting with the minimal energy consumption was solved by us in Refs. [5,7,8], where for practical application the cutting of the agricultural materials with blade is recommended to implement upon the slanting-oblique, sliding principle: at the transformed installation angle $\alpha_{tsf} = 20-22°$; slip coefficient $\varepsilon = 8.0-10.0$, providing the overlapping of the cut surface and trajectory of the main areas of the given strained-deformed situation. If these terms are fulfilled the cutting is converted into a forced development of the crack without any additional efforts which enables the abrupt decrease of the cutting resistance. When cutting the soil splinters the vertical (cutting) blade works along the entire processing depth (a). For such position of knife the calculation of the solution angle γ_n is determined by the following relationship [4]:

$$\frac{\lambda-\sin\omega t}{\cos\omega t} = \tan(\gamma_n+\beta), \quad (2)$$

where β – angle, upon the value of the tiller rotation depending on the angle [4].

By the equation analysis (2), for $\lambda = 10$, the average value $\beta_a = 50°$, the threshold of the angle change is derived $\gamma_n = 32-40°$, by which sufficient quality of soil splinters cutting and loosening is provided [4].

The angle of the second/weeding/knife is calculated through the well-known expression

$$\gamma_{opt} = \frac{90-\varphi_{max}}{2}.$$

To assess the indicator of the energy of the tillers the total torque/moment of inertia/of the tiller M_t, consisting of the knife resistance spent on the cutting and deformation of the splinter P_1, and on cropping of weed vegetation P_2 [2–4] is applied.

Following Goryachkin's doctrine on the determination of the soil cultivation resistance and taking into account our experiments according to which when the tiller is working with vertical axis, there is no constituent resistance of soil splinter rejection, we have derived the equation of knife resistance consisting of cutting force P_c and friction P_f :

$$\frac{M_t}{r\cos\left(arc\tan\frac{\cos\omega t}{\lambda-\sin\omega t}\right)} = P_c + P_f, \quad (3)$$

where upon the denominator of equation (3) the change of the radius value r of the action of tangential force is considered.

As a result of summarization, the external force factors affecting the tiller resistance value are derived [3,4]: