RESEARCH ON ROOT PRUNING METHODS APPLIED TO ORCHARD TREES
/
CERCETARI PRIVIND METODE DE TAIERE A RADACILOR POMILOR FRUCTIFERI

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ABSTRACT
Root pruning is a widely adopted practice in modern orchard management, with the primary goal of stimulating regeneration and optimizing annual fruit production. There are numerous researches on the architecture of the root system of trees, the volume and depth of root development, as well as the importance of cutting them in fruit growing. Also, the specialized literature presents different types of equipment intended for cutting roots, but there are few studies that address aspects related to the resistance forces encountered during this work. This paper presents research conducted using a specialized root-cutting implement equipped with a chisel-type blade. The study outlines the technical characteristics and performance indicators of the equipment, which was tested on various soil types to evaluate its working parameters. As a result of the experiments, the following were determined: the root cutting resistance at different working depths and across three soil categories - sandy, clayey, and loamy - as well as the corresponding working speeds required to maintain efficient operation under maximum tractor power conditions. Using the experimentally determined values, the variation diagrams of these indices were plotted, such as: the stress distribution diagram and the speed variation depending on the cutting resistance, the maximum total cutting resistances were identified, at the maximum depth of 50 cm, at the most unfavorable blade inclination angle of 45°. The maximum values determined for these were 768.5 daN for sandy soil, 1185.5 daN for clay soil and 1602.5 daN for loamy soil. These results highlight the influence of soil type and working parameters on the mechanical stresses of the blade during root pruning work in fruit plantations.

REZUMAT
Lucrarea de tăierea rădăcinilor pomilor este o lucrare des folosită în pomicultură, scopul acesteia fiind acela de a determina stimularea şi regenerarea plantației în vederea gestionării producției anuale de fructe. Exista numeroase cercetări privind arhitectura sistemului radicular al pomilor, volumul și adâncimea de dezvoltare a rădăcinilor, precum și importanța efectuării lucrării de tăiere a acestora în pomicultură. De asemenea, literatura de specialitate prezintă diferite tipuri de echipamente destinate tăierii rădăcinilor, însă sunt puține studii care abordează aspectele legate de forțele de rezistență întâmpinate în timpul acestei lucrări. Articolul prezintă cercetările efectuate cu un echipament de tăiat rădăcini prevăzut cu cuţit de tip daltă, pentru care sunt prezentate caracteristicile și indicii de performanță aferenţi, testat pe diferite categorii de sol, în vederea determinării indicilor de lucru ai acestuia. În urma realizării experimentărilor s-au determinat: rezistența de tăiere a rădăcinilor, la diferite adâncimi de lucru, pe diferite tipuri de sol (nisipos, argilos și argilos), precum și vitezele de lucru în funcție de rezistența totală la tăiere, pentru utilizarea puterii maxime a tractorului. Utilizând valorile determinate experimental s-au trasat diagramele de variație ale acestor indici, precum: diagrama de distribuție a tensiunilor şi variaţia vitezei în funcţie de rezistenţa la tăiere, s-au identificat rezistențele totale maxime de tăiere, la adâncimea maximă de 50 cm, la cel mai nefavorabil unghi de înclinare a cuțitului de 45°. Valorile maxime determinate pentru acestea au fost de 768,5 daN pentru sol nisipos, 1185,5 daN pentru sol argilos și 1602,5 daN pentru sol lutos. Aceste rezultate evidențiază influența tipului de sol și a parametrilor de lucru asupra solicitărilor mecanice ale cuțitului în timpul lucrărilor de tăiere a rădăcinilor în plantațiile pomicole.

INTRODUCTION
The process stimulating and regenerating a tree involves removing some of the tree's surface roots to encourage the growth of deeper, stronger roots. Pruning shallow roots reduces the tree's need for water and nutrients and encourages the growth of deeper roots. These deeper roots are better able to absorb water and nutrients, which helps the tree grow and produce more fruit.

Pruning is usually done during the tree's dormant season, which is in the fall or spring, before active growth begins. It is important to do this carefully and avoid cutting too many roots to avoid damaging the tree's health too much (*Wade et al., 2020*).

The consequences of root cutting include root degradation, root structural depth, root location, root regeneration, drying of fine roots, formation of rounded roots, scorched roots, and root grafts *(Watson et al., 2014)*. The root system architecture and a possible root orientation can be adapted for mechanical reinforcement (*Beier et al., 2020*).

The sizes and shapes of root systems for different plant growth forms vary depending on above-ground plant size, climate, and soil texture. With the exception of trees, root systems tend to be shallower and wider in dry, warm climates, and deeper and narrower in cold, wet climates. Shrubs are more shallowly rooted in regions with summer rainfall compared to those with winter rainfall *(Schenk and Jackson, 2002)*.

A study on cherry trees aimed to examine the influence of root pruning on tree vigor, with the goal of managing the harvest through more compact canopies (*Perry, 2015*).

Tree roots play a crucial role in various aspects such as soil penetration, degradation, root architecture, root defects, available rooting space, regeneration, deep root structure, and root extension (*Watson et al., 2014*).

In other research, issues related to rooting depth, lateral root spread, and aboveground/belowground allometries of plants have been explored *(Schenk et al., 2002)*. Additionally, studies have examined the effects of root pruning on leaf nutrient content, photosynthesis, and tree growth in a poplar plantation. These studies aimed to investigate the impact of root pruning on tree growth and physiology by quantifying the extent of root pruning through allometric analysis, taking initial steps toward developing a practical tool for arborists to support root management and care decisions (*Da-wei Jing et al., 2018; Jing DW et al., 2017*).

To stimulate growth, some researchers performed root pruning twice a year, 60 cm away from the trunk and 30 cm deep, as follows: the first pruning was done on one side of the row before autumn leaf fall, and the second in spring during flowering (*Mitre et al., 2012*).

Various methods of classifying individual roots have been documented. Based on their distribution, roots are categorized as either vertical or horizontal, while in terms of length and thickness, they are classified as either skeletal or fibrous. Horizontal roots grow more or less parallel to the soil surface, typically at a depth of about 30 to 100 cm, whereas vertical roots extend downward into the soil. Skeletal roots are characterized by their considerable length and thickness - ranging from a few centimeters to several meters long - and can reach several centimeters in diameter. In the management of mature trees, it is critical to assess the diameter at breast height (DBH) prior to any root pruning activity. Current guidelines recommend avoiding the cutting of roots located within a radial distance of less than five times the DBH from the trunk. For example, in a tree with a DBH of 12 inches, root pruning should be limited to areas beyond a 60-inch radius from the trunk. Younger trees exhibit greater resilience and may tolerate root cuts at a closer distance - approximately three times the DBH. Nevertheless, in all cases, root pruning should be conducted as far from the trunk as practicable to minimize physiological stress. When performed with care, root pruning can be compatible with tree health; however, imprecise or overly aggressive interventions may compromise structural integrity, disrupt water and nutrient uptake, and ultimately result in tree decline or mortality. The severity of damage caused by root pruning increases significantly with proximity to the trunk. It is generally recommended not to remove more than 25% of a tree's root system, as exceeding this threshold may result in tree decline, structural failure, or mortality. A recovery period of at least two years should be allowed between successive root pruning interventions. Additionally, root pruning should be avoided during the spring period following bud break (*Cofie, 2001*). Roots are commonly classified based on diameter into six main categories: very fine (< 0.5 mm), fine (0.5–2 mm), small (2–5 mm), medium (5–10 mm), large (10–20 mm), and very large (> 20 mm) (*Gliński and Lipiec, 1990*).

Most fine roots are concentrated within the surface layer of approximately 1 m^2 of medium-textured soil, with the majority of fine, non-woody roots located at a depth of about 15 cm. This distribution is largely influenced by genetic factors under favorable growth conditions in the topsoil (*Craul, 1993*).

Approximately 70% of roots are located within the humus layer of the soil profile (*Wasterlund, 1989*). Key morphological characteristics of individual roots include surface texture, color, and diameter (*Fitter et all, 1991*).

Several studies have sought to establish correlations between root parameters - such as number, diameter, and spatial orientation - and aboveground plant dimensions, including stem and crown diameter. Notably, highly significant positive correlations have been identified between stem diameter measured at 1.3 m above ground level and total root biomass (*Kuiper and Courts, 1992*).

Roots may be classified based on several criteria:

A - According to their growth orientation within the soil profile, roots are categorized as follows:

- horizontal roots - those that grow nearly parallel to the soil surface or form an angle between 60° and 90° with the vertical axis;
- oblique roots - those that form an angle between 30° and 60° with the vertical axis;
- vertical roots - those that grow at an angle of up to 30° relative to the vertical axis.

B - According to size, roots can be classified into the following categories:

- skeletal roots, these are roots longer than 30 cm and thicker than 3 mm, with diameters that can exceed 10–15 cm. The primary skeletal root is the taproot (or embryonic root);
- filling roots (also referred to as fibrous or transitional roots) - these roots occupy the spaces between skeletal roots and measure between 0.5 and 30 cm in length and 1–5 mm in diameter;
- absorptive roots characterized by their small size - 0.1 to 0.4 cm in length and 0.1 - 1 mm in thickness - these roots are typically white and have a short lifespan of 15 to 25 days. They are covered with numerous root hairs or, in certain species such as walnut, hazelnut, and currant, replaced by mycorrhizae, which fulfill the absorptive function (*Cichi, 2011*).

Two descriptive models are commonly used to characterize root system parameters: root density as a function of soil depth and root density as a function of horizontal distance from the plant (*Van Noordwijk et al., 1996*).

Modeling the mechanical reinforcement of soil by root networks is inherently complex and requires the application of advanced computational methods. One such method involves finite element analysis, which incorporates appropriate constitutive equations to simulate soil–root interactions. The finite element software PLAXIS - short for Plasticity Axisymmetric - is widely used for such analyses (*Brinkgreve and Vermeer, 1998*).

Trenches excavated closer to the trunk than the recommended tree protection zones did not compromise the stability of two commonly occurring tree species. Although *Tilia cordata* exhibited lower overall stability compared to *Acer platanoides*, neither species showed significant adverse effects even under the most severe trenching treatments (*Pallafray et al., 2024*).

Additionally, studies have quantified both the average and maximum vertical forces required to uproot stumps in a single piece. These investigations also considered the influence of soil type and uprooting techniques. It was hypothesized that increasing soil moisture content and employing preparatory treatments - such as the application of initial mechanical forces - would decrease the subsequent force needed for stump extraction (*Lindroos, et al., 2010*).

Various types of equipment for tree root cutting have been developed globally by renowned manufacturers. An Italian company has produced the *Root-cutting tool SHARK*, which features a lamellar blade with hydraulically adjustable working depth and operates without a pendulum mechanism. This equipment is designed to perform effectively in light soils free of stony inclusions (*AGROFER*). Additionally, a Dutch company has developed the *Root Pruner*, which incorporates a stability system based on a wheel train to enhance operational control (*BORECO*). However, neither manufacturer provides detailed information regarding the mechanical stresses acting on the cutting blades during operation, nor do they present comprehensive research on the equipment's performance across different soil types or under varying working conditions. This study presents the results of experimental research on the root pruning of fruit trees, carried out using a prototype device specifically designed for this purpose and tested under varying soil conditions.

MATERIALS AND METHODS

Based on the considerations outlined above, INMA Bucharest, developed an experimental root-cutting device for trees. This equipment was employed in the present study, and its main components are illustrated in Figure 1.

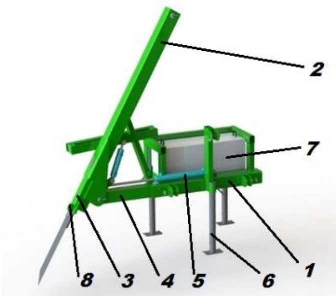

Fig. 1 - Schematic diagram of the experimental equipment for tree root cutting.

1. framework; 2. blade holder arm; 3. sliding pipe; 4. traverse; 5. hydraulic system;
6. foot support; 7. ballast block; 8. cutting force monitoring system.

During operation, the equipment should be positioned so that the cutting blade is aligned at the predetermined distance from the tree row, taking into account the age and size of the trees. The blade, actuated by a hydraulic system, is inserted into the soil to the specified depth, following the cutting protocol established by the operator. Once positioned, the tractor, coupled to the implement, is started, and the root-cutting operation is carried out.

Main technical characteristics:

- maximum working depth, 500 mm;
- maximum horizontal telescopic extension of the blade, 500 mm;
- adjustable blade inclination (working angle), 45°…70°;
- total equipment weight (including ballast), approximately 600 kg.

The equipment and measuring devices used for the experimental procedures consisted of the following components: a force transducer, a micro PLC 13, a force amplifier, and an operator terminal. An agricultural tractor with a rated power of 100 HP was employed as the energy source for operating the root-cutting implement.

Determination of root cutting resistance

The root-cutting operation, illustrated in Fig. 2, involves a sequence of mechanical actions performed by the cutting blade:

- Vertical soil penetration: the blade is inserted vertically into the soil to a predetermined depth, initiating the cutting process
- Horizontal soil displacement: As the blade moves forward, it deforms and displaces the surrounding soil laterally. The volume of displaced soil is defined by the difference between the physical volume of the blade and the volume of the deformed soil.
- Root severance: As the blade progresses, it encounters and severs tree roots located within its path.

This process is influenced by several factors, including soil type, moisture content, and root density. A clear understanding of these interactions is essential for optimizing the design and operation of root-cutting equipment.

The total resistance to root cutting R_t is calculated using relation (1):

$$\boldsymbol{R_t = R_c + R_d + R_f + R_{rc}} \text{ [daN]} \tag{1}$$

in which:

R_c - resistance to soil cutting, [daN];

R_d - resistance to soil deformation, [daN];

R_f - frictional resistance between the coulter and the soil, [daN];

R_{rc} - resistance to root cutting, [daN];

To further explain the components of relation (1), the following expressions (2), (3), (4) and (5) were used, adapted from *Scripnic and Babiciu*, (1979):

$$R_c = k_c \cdot l_c = k_c \cdot \frac{d_c}{\sin\beta} \tag{2}$$

$$R_d = k_d \cdot l_d \cdot l_c = k_0 \cdot \frac{t_c}{2} \cdot \frac{t_c}{\sin\alpha} \cdot \frac{d_c}{\sin\beta} \tag{3}$$

$$R_f = \mu_f \cdot G_c \tag{4}$$

$$R_{rc} = k_{rc} \cdot S_r \tag{5}$$

where:

k_c - specific resistance to soil cutting, [daN/cm];

k_d - specific resistance to soil deformation, [daN/cm^2];

k_0 - volume coefficient of deformation, [daN/cm^3];

d_c - working depth of the cutting blade, [cm];

l_c - contact length of the blade with the soil, [cm];

t_c - thickness of the cutting blade, [cm];

l_d - contact width of the blade with the soil in the cutting area, [cm];

α - sharpening angle of the cutting blade, [degrees];

β - penetration angle of the blade into the soil, [degrees];

μ_f - coefficient of friction between the blade and the soil;

G_c - portion of the equipment weight acting on the blade, [daN];

k_{rc} – specific resistance to root cutting, [daN/cm²];

S_r - total cross-sectional area of roots cut simultaneously, [cm²] (*Scripnic and Babiciu, 1979*).

Substituting (2), (3), (4), (5) into (1), the relation (6) results:

$$R_t = k_c \cdot \frac{d_c}{\sin\beta} + k_0 \cdot \frac{t_c}{2} \cdot \frac{t_c}{\sin\alpha} \cdot \frac{d_c}{\sin\beta} + \mu_f \cdot G_c + k_{rc} \cdot S_r,\ daN \quad (6)$$

The resistances acting on the blade during operation are schematically illustrated in Fig. 2.

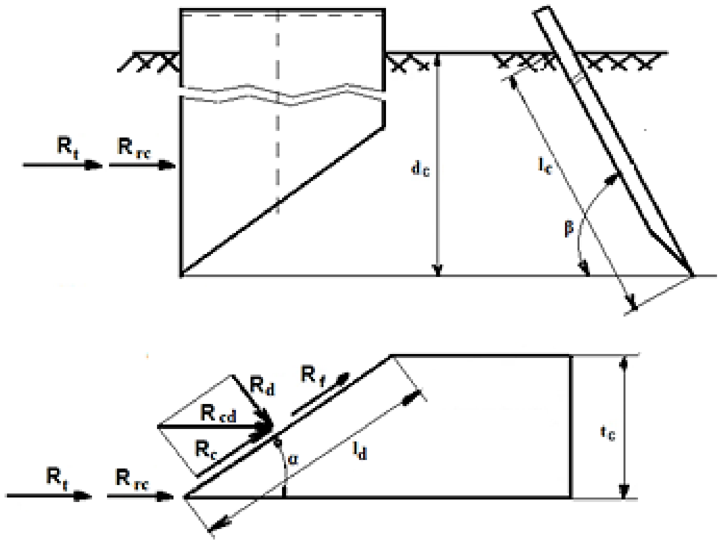

Fig. 2 - Schematic representation of the resistances acting on the cutting blade during operation

In the design of technical equipment for tree root pruning, two primary factors must be considered. First, the resistance encountered by the main cutting component, as defined in Equation (1), plays a critical role in determining the mechanical requirements of the system. Second, the type, condition, and characteristics of the soil, along with the tree species, must be taken into account, as these are governed by specific physical and chemical properties that influence root structure and resistance.

The working speed of the equipment, under specific operating conditions, is limited by factors such as the power of the tractor within the aggregate, the total resistance to root cutting, and the penetration angle of the blade into the soil. The relationship governing this limitation is expressed by Equation (7):

$$v = \frac{P}{R_t} \quad (7)$$

Where:

v - working speed of the equipment, [m/s];

P - available working power, [W];

R_t - total resistance to root cutting, [daN], (*Kepner et al., 1987*)

According to the fundamental principles of agricultural mechanics (*Kepner et al., 1987*), the working speed of an implement is directly proportional to the power developed and inversely proportional to the resistance exerted by the soil and biological material - in this case, tree roots.

RESULTS

The total resistance to cutting tree roots is influenced by several key factors, including:

- the type and condition of the soil;
- the distribution and development of roots within the soil profile;
- the working depth of the cutting blade and the penetration angle into the soil.

To evaluate the energy efficiency of the tractor-equipment aggregate during the root-pruning operation, it is necessary to calculate the total resistance encountered by the cutting mechanism. This resistance is determined using Equation (6).

The parameters and coefficients used in the calculation are as follows: k_c = 5…10 daN/cm; k_0 = 1…2.5 daN/cm^3; d_c = 50 cm; t_c = 1.5 cm;α = 15°; β = 45…70°; μ_f = 0.4…0.6 soil/metal (*Scripnic and Babiciu, 1979*); G_c = 100 daN, measured by weighing; R_{rc} = 60...75 daN, resistance to cutting an apple tree root with S_r = 1cm^2, the average value adopted in calculations was 67.5 daN.

The cutting resistance of the root R_{rc} was determined experimentally using a custom-designed cutting device equipped with a force transducer. This device was developed by the authors and manufactured within the institution where the research was conducted. By substituting both the known values and those determined experimentally into equations (2) through (5), the resulting resistances acting on the cutting blade were calculated for different soil types. These results, presented in Table 1, correspond to a maximum cutting depth of 50 cm and a blade inclination angle of 45°.

Table 1

Resistances on the root cutting blade, d_c = 50 cm, S_r = 1cm^2, β = 45°

Soil type	R_c [daN]	R_d [daN]	R_f [daN]	R_{rc} [daN]
Sandy soil k_c = 5 daN/cm; k_0 = 1 daN/cm^3; μ_f = 0.4	354	307	40	67.5
Loamy soil k_c = 7.5 daN/cm; k_0 = 1.25 daN/cm^3; μ_f = 0.5	530	538	50	67.5
Clay soil k_c = 10 daN/cm; k_0 = 2.5 daN/cm^3; μ_f = 0.6	707	768	60	67.5

Since the experimental equipment for cutting tree roots allows for the adjustment of both cutting depth and blade penetration angle, and is designed to operate across various soil types with differing characteristics, it is equipped with a monitoring system that records real-time values of total cutting forces. This feature enables the selection of optimal working parameters while ensuring that the resistance does not exceed the mechanical strength limit of the blade.

The diagram presented in Figure 3 illustrates the variation in total root cutting resistance as a function of cutting depth for three different soil types. This graphical representation supports the selection of an appropriate tractor for the implement, ensuring that the machine provides sufficient traction force to achieve the required working depth.

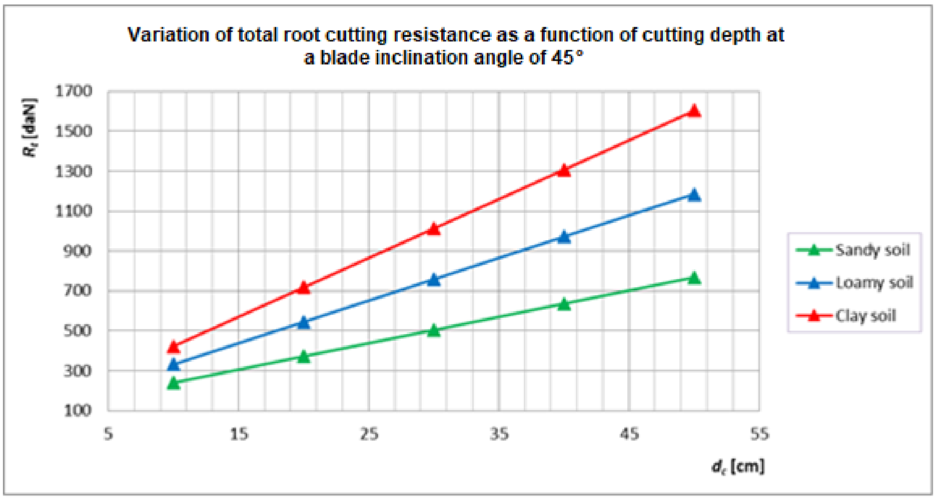

Fig. 3 - Variation of total root cutting resistance as a function of the working depth

Figure 4 illustrates the variation of total root cutting resistance as a function of the inclination angle of the cutting blade during operation, for the three soil types evaluated. The values obtained from this analysis can be used to adjust the cutting process according to the age and structural characteristics of the trees, ensuring that the operation aligns with the parameters defined by the established root pruning technology.

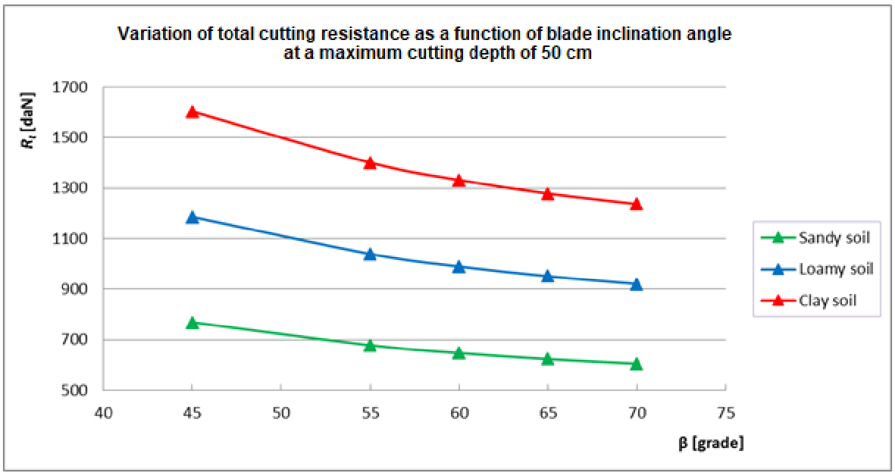

Fig. 4 - Variation of total cutting resistance as a function of blade inclination angle

The variation of working speed as a function of root cutting resistance, at different blade inclination angles, is presented in Figure 5.

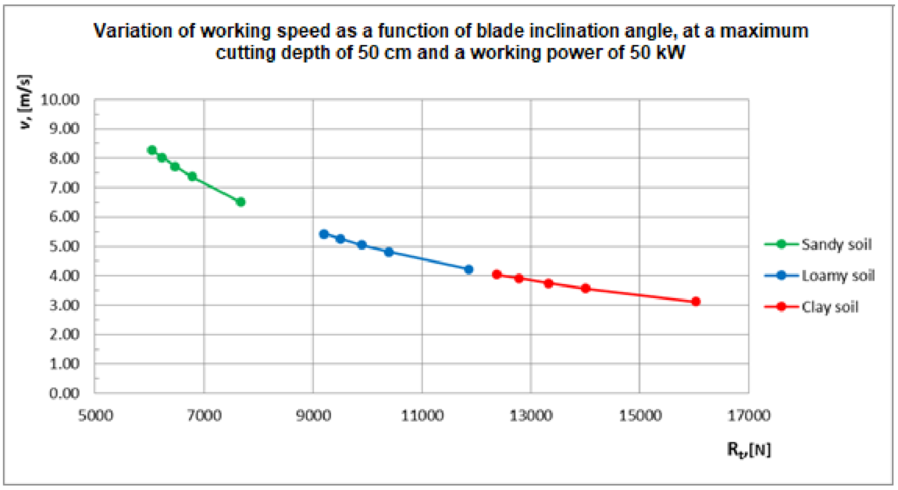

Fig. 5 - Variation of working speed as a function of total resistance to root cutting

This diagram provides practical guidance for operators who, based on the available tractor power and the resistance values presented in Figures 3 and 4, can determine the optimal working speeds for root cutting operations.

CONCLUSIONS

Root pruning is a valuable technique in pomology, aimed at improving tree health and enhancing annual fruit production.

The performance indicators of the experimental equipment were evaluated. The total resistance to root cutting varied with working depths from 10 to 50 cm, with values ranging as follows: 235…768 daN for sandy soil; 310…1185.5 daN for loamy soil; 405…1602.5 daN for clayey soil. The maximum achievable working speed, at a blade inclination angle of 50° and tractor power of 50 kW, ranged between: 6.5…8.5 m/s for sandy soil; 3…4 m/s for loamy soil; 4…5.5 m/s for clayey soil.

Equipping the device with a cutting resistance monitoring system allows for real-time adjustment of working parameters, ensuring the operation remains within mechanical safety limits. The findings of this study are significant both for the design of efficient root pruning equipment for fruit trees and for advancing research toward the development of intelligent, adaptive pruning technologies.

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