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The quality and energy efficiency of rototiller operation

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Abstract: *The quality and energy efficiency of rototiller operation*. The work presents theoretical correlations that influence the quality of work and energy efficiency of rototillers. It also discusses the most recent research results on the impact of working components, that is, the blades – in particular, their shape and dimensions – on the quality of work and energy efficiency. Research was conducted under laboratory conditions – in a soil bin – and under natural conditions, during additional tillage of soil in the field. In order to achieve good quality of rototiller work, it is necessary to get familiar with many aspects of impact of the rototiller units on the soil. This is significant due to agrotechnical reasons, since substantial crumbling of the soil does not lead to increased yield – sometimes, the effect is opposite: excessive crumbling leads to yield reduction. Research conducted has indicated that the best soil structure is achieved by cutting pieces of length of 15 to 25 cm with a blade 55–75 mm wide. During rototiller operation, most energy is consumed by discharging of soil pieces (30.5–72.4%). The disks with blades should be reset by the angle of 12–14° in order to ensure even torque distribution; however, resetting by angle above 30° eliminates problems associated with soil sticking to components.

Key words: soil cultivation, cultivating machines, work quality, energy efficiency

INTRODUCTION

Cultivating machines have movable working parts, and due to enforced movement of these parts, their impact is several times more intensive in comparison with passive tools. Therefore, they should be used carefully, depending on the field conditions, as improper use may easily damage the fine soil structure, or the quality of treatment may be insufficient [Buliński et al. 2010, Zbytek and Talarczyk 2011].

Due to the wide scope of applications, substantial advantages resulting from shortening of the soil cultivation time, as well as the increasing demands faced by farms due to the free market economy conditions, the significance of these machines is increasing. Obtaining of good effects of their operation requires familiarity with many aspects of impact of these working units on the soil.

THE QUALITY OF WORK OF ROTOTILLERS IN THE LIGHT OF THEORY AND RESEARCH

In a rototiller, the working unit consists of disks with curved cutting blades, mounted in alternate directions. The main shaft, to which the working components are fixed, is set horizontally, perpendicular to the direction of movement of the machine, and during operation, it is responsible for both the rotating movement of the working components and for forward movement of the entire machine [Bernacki 1981, Gach et al. 1991] – Figure 1.

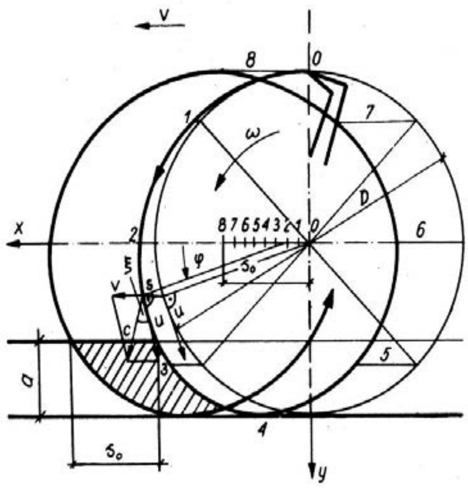

FIGURE 1. The rototiller blade trajectory while the drum rotates in the same direction: *D* – drum diameter, *ω* – angular velocity, *a* – working depth, *u* – peripheral speed, *v* – forward speed of the machine, *c* – resultant speed, *a* – working depth, s_o – piece length

The rototiller blade ends rotate with peripheral speed:

$$u = \frac{\pi D\, n}{60} \tag{1}$$

where:
u – peripheral speed [m·s^{-1}];
D – drum diameter with blades [m];
n – drum rotational speed [rpm].

Depending on the ratio of peripheral speed of rotational movement to forward movement speed, we receive the resulting trajectory of the working unit points in relation to the ground. This trajectory forms a curtate cycloid – the so-called trochoid. Two adjacent trajectories in the assumed depth zone determine the cross-section of the soil piece cut by a single blade along the drum perimeter. In practice, on the perimeter of the drum, several blades are mounted within the same plane, therefore, the piece length is defined by the following equation:

$$s_o = \frac{60\, v}{n\, z} = \frac{\pi D}{\frac{u}{v} z} = \frac{\pi D}{\lambda z} \tag{2}$$

where:
s_o – piece length [m];
v – forward movement of the working unit [m·s^{-1}];
z – the number of blades cutting soil pieces within a single plane;
λ – kinematic indicator,
and

$$\lambda = \frac{u}{v} \tag{3}$$

When examining equation (2), it can be noted that the length of the piece cut by the knife is directly proportional to forward movement of the machine and inversely proportional to peripheral speed. This is of key significance from the perspective of the quality of work of the rototiller, since the piece length determines the degree of soil grinding. The shorter the pieces, the greater the number of cuts, and thus the thinner layer of the soil being cut each time.

Speed of the rototiller blade tip (*c*) is the result of forward movement speed (*v*) and peripheral speed (*u*), and it has been determined on the basis of a parallelogram. The resulting c, identified with the speed of soil cutting by blade, is deviated from the tangent to the trajectory, and thus, from the peripheral speed, by angle, which defines the correlation:

$$\mathrm{tg}\,\xi = \frac{v\cos\varphi}{u - v\sin\varphi} = \frac{\cos\varphi}{\frac{u}{v} - \sin}\varphi \qquad (4)$$

where:
ξ – angle of a disk with blades [°];
$\varphi = \omega t$ – rotation angle during time (t) [rad].

The resulting speed is defined on the basis of the following formula:

$$c = v\frac{\frac{u}{v} - \sin\varphi}{\cos\xi} \qquad (5)$$

The above correlation indicates that the cutting speed changes as the drum with blades rotates. The angle of positioning of the blade should be set to make sure that even at the least favorable cutting angle, soil compaction by the rear part of the blade is avoided, as friction of the blade against the soil during compacting increases greatly power consumption by the rototiller drum [Kuczewski 1991]. Reduction of variability of loads due to changes in the cutting angle and speed during each drum rotation can be achieved thanks to appropriate spacing of blades along the drum; they are usually arranged helically [Bernacki 1981, Gach et al. 1991].

The subsequent blades working in the soil ensure a comb-like shape of the bottom of the soil layer – similar to that left by a disk harrow. The height of these „combs" depends on the kinematic parameters of work of the rototiller drum [Bernacki 1981, Gach et al. 1991, Kuczewski 1991].

A detailed analysis of rototiller operation has been conducted by Lejman and Szulczewski, who considered the issues of blade kinematics [2007a] and geometry [2007b]. Within the framework of achievement of the objective of the study, it was assumed that it would be necessary to combine the kinematic parameters, described in literature, which are a prerequisite for proper soil treatment [Lejman and Szulczewski 2007a]. During theoretical analysis, the following preliminary and simplifying assumptions were made:

- The rotor turns in a plane perpendicular to the field surface and parallel to the movement direction of the machine during rotation in the same direction;
- The working depth is within the range of from a_{min} to a_{max};
- In the depth range assumed, soil cutting may take place without changing the kinematic parameters;
- The comb-like shape of the bottom of the soil layer must be within the limits acceptable for a given crop;
- When cutting soil pieces, the working surface of the tool must exert continuous pressure on the soil.

As a result of the theoretical analysis conducted, the authors developed a correlation that linked the structural and working parameters of the machines, and they used a simulation program in DELPHI language. The existing correlations were applied in a computer simulation – its results, in form of a set of parameter values, served as a basis for visualization of correlation and animation of movement of the cutting component. On the basis of simulation calculations, the following correlations were found between the assumed (decisive) and calculated parameters:

- Decreasing of the number of blades, increasing of the maximum working depth and reduction of minimum depth result in increase of the kinematic coefficient value; at the same time, the gradients of this coefficient upon depth modification decrease as the number of blades increases;
- For analogical values of minimum and maximum depth, the kinematic coefficient value depends only on the number of cutting blades;
- The radius of the drum of an active cultivating machine increases along with the number of blades and maximum and minimum depth; at the same time, maximum depth exerts a much greater impact on this radius.

On the other hand, in the study [Lejman and Szulczewski 2009b], it was assumed that the analysis of geometry of the cutting module would be conducted on the basis of the following preliminary and simplifying assumptions:

- The blade angle and minimum clearance angle values are enforced by agrotechnical and structural requirements;
- During cutting, the value of the clearance angle must not be lower than the assumed limit value;
- The blade length must not exceed the limit value due to the prerequisite of distribution of soil pieces in the direction opposite to the machine movement;
- The cutting blade thickness is a negligible parameter.

Kinematic parameters of an active cultivating machine exert direct impact on geometry of its cutting module, as presented by Figure 2.

The authors, like previously, wrote a simulation program in DELPHI language, which made it possible to set the optimum geometric parameters, animation of the blade movement and graphic verification of the assumptions made.

On the basis of calculations, the following correlations between the assumed and simulated parameters were found:

- The static (structural) value of the cutting angle, which is contained between the blade plane and the tangent to the circle of movement of the blade, increases along with the increase of the minimum working depth and the number of blades, and it decreases along with increase of maximum depth; for analogical values of $a_{\min}$ and $a_{\max}$, the value of this angle depends only on the number of blades;

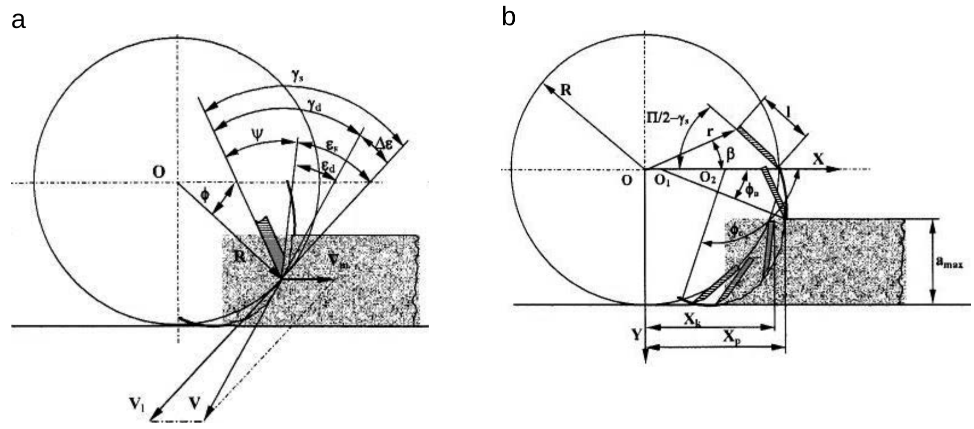

FIGURE 2. Cutting blade geometry: a – basic angles, b – blade length

- The maximum blade length increases along with the blade and clearance angles and the number of blades, as well as the maximum cutting depth; on the other hand, no visible impact of minimum depth on this length has been found;
- The dynamic cutting angle reaches its minimum value at the rotor rotation angle at the time of contact of the blade with the field surface; further increase in the rotation angle results in increase in the cutting angle value, and the increase gradient goes up as the kinematic coefficient goes down.

On the other hand, Celik et al. [2008] state that rototillers are characterized by uneven depth of operation, if they are improperly constructed and used. In such cases, soil mixing and crushing in the topsoil layer is not uniform, and substantial comb-like structures are formed. On the basis of geometric relationships between the structural and operating parameters of the rototiller, a model was developed in order to determine the height of “combs” found in the lower topsoil layer. The comb height was defined for various combinations of peripheral speed, machine forward speed, drum and blade radius and the number of blades within a single plane (Fig. 3).

It was found that the height of “combs” in the lower layer of topsoil resulting from operation of the rototiller increases along with increase in the forward movement speed and working depth, and it decreases along with increase in the blade peripheral speed, drum radius, the number of blades within one disk plane and the ratio of the blade peripheral speed to the machine forward speed. A significant linear relationship was found between the “comb” height and the forward movement speed, and an exponential relationship between the blade peripheral speed and the “comb” height. As the working depth increases,

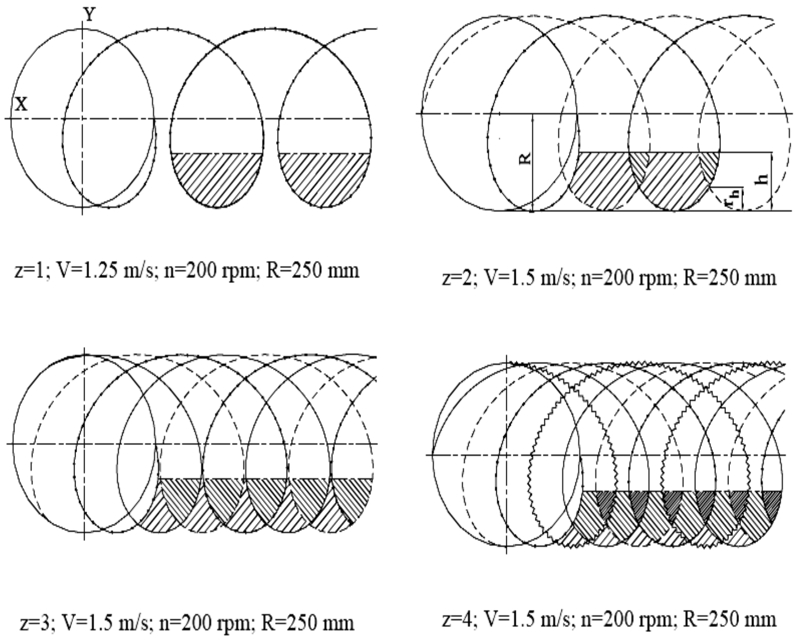

FIGURE 3. Trajectories made by rototiller blade ends for different values of: the number of blades (*z*) and the machine forward movement speed (*V*) and the constant number of rotations of the drum with blades (*n*), radius (*R*) and working depth (*h*), parameter (r_h) indicates the "comb" height

the comb height grows exponentially. Comb height also increases as the ratio of peripheral speed of blades to forward movement speed decreases. Combination of low forward movement speed, high rotational speed of the drum and a large number of blades on one side of the disk allows for soil cultivation without the comb-like shaped bottom.

At the same time, soil cultivated in this manner is susceptible to erosion, and the plant growth conditions are not favorable [Lejman and Szulczewski 2007, Buliński et al. 2010].

Shekofteh et al. [2012] are of opinion that application of a rototiller as one of the most effective machines for horticulture and in orchards is reasonable and often met in practice. They also underline that overgrinding of the soil is associated with emergence of additional stresses in the soil, which is unfavorable in operation of these machines. In this research, the soil cutting process is modelled using the finite element method – FEM. Variability of operating parameters is taken into account – that is, forward movement speed of the machine, the speed of the drum with blades, as well as soil moisture content. When combining different operating parameters, we obtain a variable shape and dimensions of the soil pieces cut with blades, as well as the associated stress values (Fig. 4).

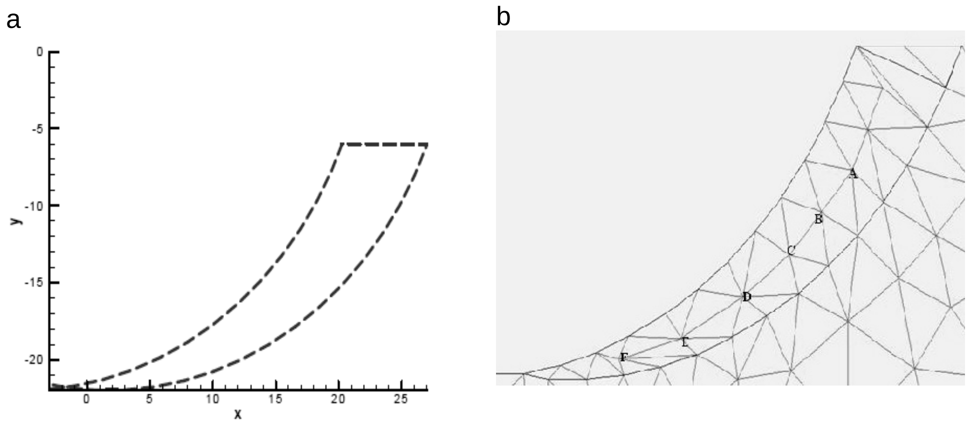

FIGURE 4. A soil piece cut by rototiller blades for forward movement speed of 2.23 km·h^{-1} and drum rotation speed of 183 rpm: a – piece shape, b – stress determination points

It was found that increasing of the movement speed reduces the stress, while increasing of rotational speed and soil moisture cotent led to increasing of the values of stress, observed in the soil.

Rotational speed of the rototiller rotor is within the range of 100–400 rpm, however, during operation, the most frequently used speeds are within the range of 200–300 rpm [Buliński et al. 2010]. Excessive peripheral speed is particularly unfavorable in rototillers, where a large number of the blades and low forward movement speed of the machine is accompanied by cutting of too small soil pieces (several millimeters in length), which often leads to damaging of the soil structure (excessive grinding, damaging of water-resistant units, deterioration of water and air conditions etc.).

Finely ground soil does not always bring a good yield. This depends mostly on the type of crops cultivated. In our country, active cultivation is applied mainly to cereals and vegetables. Therefore, with a certain degree of simplification, it can be assumed that during seed bed preparation, the best quality of treatment is achieved if in the topsoil layer, the number of clods of diameter not exceeding 25 mm does not exceed 20% at the soil density within 1–1.3 g·cm^{-3} and porosity ensures the air content in the soil at the level of 15–25% (with reference to soil volume) [Buliński 2000].

This has been confirmed by other research results, in which the authors have stated that the farmers' belief that finely ground soil and its smooth surface provide the best sowing conditions s not always confirmed by research [Buliński et al. 2010]. In many cases, plant emergence under such conditions is better in comparison with field surface with a substantial lump content; nevertheless, the yields are usually lower. Therefore, some authors [Anken and Hilfiker 1997] recommend that the surface of the soil prepared for sowing should contain 15–25 clods per square meter, of a slightly larger diameter, that is, from 30 to 40 mm. Leaving of soil lumps of small size on the surface of the field limits greatly the occurrence of unfavorable phenomena, associated with water and air erosion, and minimizes the threat of formation of crust on the soil after intensive rainfall.

According to Olsen and Borresen [1997], field cultivation using active machines with horizontal axis of rotation does not always bring the best agrotechnical results, as the soil, along the entire depth of the blade access range, has a similar structure. According to Ptaszyński [2001], this has some negative effects – as a result, both on the surface and in the sowing zone, there is a mixture of fine and coarse, humid and dry particles, which results in insufficient water content in the soil layer adjacent to seeds.

In the study of Vorob'ev and Marcenko [1990], it was found that for soil moisture content of 24 to 30%, the best structure is achieved by cutting pieces of length of 150 to 250 mm at the blade width of 55–75 mm.

Energy efficiency of rototiller operation

Power requirements of a rototiller can be calculated on the basis of specific work, that is, the amount of work calculated per soil volume unit [Bernacki 1981, Gach et al. 1990].

$$A = \frac{2\pi M}{s_0 abz} \tag{6}$$

where:
A – rototiller specific work [kJ·m^{-3}];
M – working drum torque moment [kN·m];
s_0 – soil piece length per blade [m];
a – machine working length [m];
b – machine working width [m];
z – number of blades [pc].

Specific work can be treated as the total of the static and dynamic part:

$$A = A_s + A_d \tag{7}$$

Static work does not depend on the piece length, or on the ratio of peripheral speed to forward movement speed, but on the type of soil, identified on the basis of the appropriate coefficient:

$$A_s = C_0 k_0 \tag{8}$$

where:
A_s – static work [kJ·m^{-3}];
C_0 – coefficient characterizing the rotating tool;
k_0 – coefficient characterizing the soil type [kN·m^{-2}].

Coefficient C_0, depends on the type of the working unit, and for rototillers, it is assumed to be within the range of 2.5 to 3.5. Coefficient k_0 depends on the soil type, for average soils it is assumed to be k_0 – 40, and for compact soils – 50 kN·m^{-2}.

Dynamic work is associated with charging the crushed and swept soil with energy, and it can be calculated depending on peripheral speed of the rototiller rotor or the machine movement speed:

$$A_d = \alpha_u u^2 = \alpha_v v^2 \tag{9}$$

where:
A_d – dynamic work [kJ·m^{-3}];
α_u, α_v – coefficients.

For the purpose of practical calculations, the first part of this expression is applied, since coefficient α_u is rather stable and it can be assumed at the level of 3–5 kNs·m^{-4}.

On the other hand, coefficient α_v depends strongly on the rototiller movement speed and it can be calculated on the basis of the following equation:

$$\alpha_v = \alpha_u \left(\frac{u}{v}\right)^2 \tag{10}$$

where:
u – peripheral speed [m·s^{-1}];
v – forward movement speed [m·s^{-1}].

Knowing the specific work, it is possible to calculate requirement for power:

$$N_c = \frac{Aabv}{\eta_c \eta_z} \tag{11}$$

where:
N_c – the necessary engine power [kW];
η_c – power transmission efficiency coefficient, taking into account transmission gear losses (the assumed value of η_c = 0.9);
η_z – engine power reserve coefficient assumed within the limits of η_c = 0.7–0.8.

Taking advantage of the above relationships, it is possible to use a graphic method to design the transmission gear in the rototiller in order to obtain the planned soil piece length in cooperation with a tractor that has a small number of gear ratios [Bernacki 1981, Gach et al. 1991] and this has been proven in practice in the study of Gach et al. [1989]. It is also possible to define the possibilities of cooperation of a given tractor with a given rototiller.

The calculations of specific work and power needed for operation of a rototiller, presented above, represents a simplified approach that generates approximate results.

As a result of the research conducted, it was shown that coefficient α_u changes along with the diameter of the rototiller working drum [Kuczewski 1982, Gach et al. 1991].

Moreover, at a constant peripheral speed of the blades, specific work does not change. However, in field research, variability of specific work was confirmed also at the constant peripheral speed of the blades [Kuczewski 1982], which was proven by studies conducted at the Agriculture and Forestry Mechanization Institute of Warsaw University of Life Sciences. The rototiller working width was 2.75 m, while the drum diameter with blades was 0.47 m. The rototiller cooperated with a tractor of power of 110 kW, it was driven by the tractor P.T.O. at rotational speed of 1,000 rpm, and three different rotor rotational speeds were applied: 209, 279, 364 rpm. The study was conducted in a field directly after harvesting of barley.

On the basis of results of the measurements made [Majewski et al. 1982], Kuczewski conducted a multi-parameter regression analysis to come up with the following equation:

$$A = A_{s0} + 64.3a + (7.01 - 22.0a - 2.41v)u^2 \tag{12}$$

where:
a – working depth [m];
v – machine (unit) speed [m·s^{-1}];
u – peripheral speed of the rotor blades [m·s^{-1}].

After the regression analysis for all available results, the determined value of the constant static specific work coefficient for a rotor with four blades (that is, two blades in the same plane) was A_{s0} = 126.12 kJ·m^{-3}, and for a rotor with six blades (three blades in the same plane), it was A_{s0} = 238.14 kJ·m^{-3}.

The regression equation obtained is adequate to the operating conditions specified; however, it can be used for comparative analyses, in particular, to determine the power requirement for rototillers of varying structural and operating parameters.

Zareiforoush et al. [2010] used the method described above to examine the rototiller power requirement. The subject of the study was the rototiller manufactured by Mitsubishi – model VST SHAKTI 130D. The operating width of this rototiller was 0.70 m and it was adapted to the installed engine power. The default diameters of shafts with blades ranged from 0.30 to 0.50 m. Research showed that diameter of 0.50 m turned out to be more adequate for field cultivation. The maximum working depth of the rototiller was 0.15 m in first gear. Research indicated that unit energy input could be reduced by increasing the machine forward speed.

Libin et al. [2010] developed a power requirement model for a typical rototiller with L-shaped blades. Moreover, the work presents a multi-variant analysis of probability of the rototiller working parameters, such as: the machine forward movement speed, rotational speed of the drum with blades and the soil working effect. These parameters can be optimized using MATLAB software. The authors developed an algorithm to optimize these work parameters of the rototiller with regard to power requirement. Moreover, the impact of mechanical soil cultivation on its physical characteristics and crop productivity was also presented. The authors also mentioned the fact of use of such rototillers at tea plantations in south-eastern China. The optimization model discussed allows for reduction of maximum power necessary to cultivate soil using the rototiller examined to 0.185 kW. Moreover, the optimum rotational speed of working blades is 400 rpm, while the optimum machine driving speed is 0.9 m·s^{-1}.

On the other hand, the study by Martin et al. [2015] was dedicated to the characteristics of torque and power requirement in strip tilling, using three different structures of the rototiller working blades. The authors also mention that analysis of treatments associated with strip tilling in developing countries is associated mainly with the structure of conventional rototillers, designated for full opening of the soil at a certain depth. The objective of the study was to optimize the geometry of the rototiller working blade and its operating parameters. Three different geometry designs were used: conventional, narrower by one half than the conventional one, and a straight blade.

Research was conducted at four rotational speeds of the working drum: 125, 250, 375 and 500 rpm. The authors examined the impact of these parameters on the torque, power and energy requirement. A single working drum had the working width of 0.05 m and operated at the working depth of 0.05 m. The experimental drum with blades was tested in a soil bin, filled with loamy sand. In order to conduct observations of the cultivation process at varying rotational speeds of the drum, a video recorder was used to make quick photos. For all three blade structures, the average power requirement increased visibly as the rotational speed of the drum exceeded 375 rpm.

The straight blade required the smallest torque and 20–25% less power in comparison with the conventional blade and the blade of reduced width, while the average power requirement and optimum energy consumption was achieved at the drum rotational speed ranging between 375–500 rpm. The study led to conclusion that the straight blade structure turned out to be optimum for all parameters of effective work of the rototiller in the case of strip tilling.

Similar research was conducted by Asl and Singh [2009], using three blade types: C, L and RC (Fig. 5).

a b

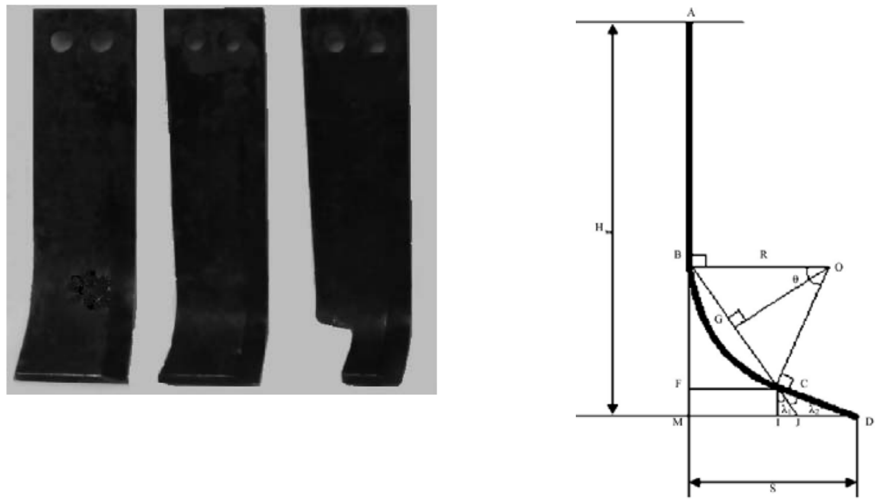

FIGURE 5. The examined rototiller blades: a – type C, type L, type RC (from the left), b – characteristic blade dimensions

The objective of the study was an attempt to reduce the power requirement during soil cultivation thanks to optimization of parameters that influence the working blade resistance. For this purpose, a mathematical model of power requirement was developed for the rototiller drum with blades, and an equation for power in relation to the unit of volume of soil cultivated, as well as the cutting angle, and computer programs were developed to solve these equations.

On the basis of results obtained from computer programs, geometric dimensions of the blades were selected, ensuring the optimum area of the blade and the cutting angle per unit of volume of soil cultivated. The results obtained from the model were verified on the basis of experimental research, conducted in a soil bin. Differences between calculated and experimental values were within the range from –6 to +3.1%, and thus they were small. Thanks to this, the model can be used to optimize the machine working parameters, where the criterion is minimization of requirement for power of the machine during tilling. It was also found that RC blades are characterized by lower values of specific work and the tilled soil volume is greater, as well as the blade efficiency, in comparison with other blade types.

Experimental research was conducted using all three blade types, diversifying their number, forward movement speed and the drum rotational speed. Specific work was characterized by relationship in form of an exponential function in relation to the soil piece length and a linear function with regard to speed for all blades tested. The highest score was obtained by RC blade.

When determining the value of energy consumption by the working unit of an active cultivating machine, it is necessary to keep in mind variability of the parameters that shape the operating conditions of the machine. Kuczewski [1991] showed that determination of energy consumption by the rototiller blade is based on the assumption that soil is cut only by the blade tip, while the rear part of the blade never touches the ground. In reality, this is true only at a certain ratio of the drum rotational speed to the unit forward speed and the blade length. If this ratio is different, the rear part of the knife exerts impact on the soil, compacting it, which is associated with substantial energy consumption.

The blade shape influences not only the work results, but also requirement for power. On the basis of research conducted by Gupta and Visvanathan [1993] using a rototiller with L-shaped blades in saturated loamy-sandy soil of moisture of 72.4%, cutting of soil pieces requires only 0.34–0.59% of the power. Most power was required for discharging of soil pieces – 30.5–72.4%. The rest was required by overcoming soil friction against steel – 0.62–0.99% and idle running – 23.1––64.6%. These results confirm the analysis performed by Shibusawa [1993].

Considering the operation of the rotational tool, four types of work were distinguished depending on the ratio of working depth to blade size and drum rotation direction to movement direction. As a result of the analysis conducted, it was stated that the largest share of power was required for re-processing (transferring through the rotor) of already tilled soil, which had not been discharged upon cutting of the soil piece and remained within the blade working zone.

Characteristics of energy efficiency of the rototiller are also influenced by the moment of hitting the tilled soil layer in relation to other blades. Operation of the rototiller blade is cyclical – there is the soil piece cutting and discharging phase, and then – idle running until the cycle start. Movement of blades fixed to adjacent disks along the perimeter by angle of 15 to 30° reduces fluctuations in torque requirement.

This assumption was verified for the soil of moisture of 29.2% and compactness of 1.17 MPa, at the working depth of 0.15 m [Vorob'ev and Marcenko 1989]. A significant impact of angular shifting of the blade on the degree of grinding of the soil and power requirement of the machine was found. It should be noted, however, that there is no such thing as a universal setting of the blades for any working conditions. Due to the torque, the angular shift should be as little as possible, not exceeding 12–14°, in order to ensure effective soil grinding. However, when cultivating a field of moisture of 28%, soil sticks to the drum and it is recommended that the angular shift is increased above 30°. Upon cultivation after pre-winter ploughing, the angular shift of the blade operation is of no significance. This is probably due to the fact that the soil that has been loosened is much easier to grind. This is confirmed by the fact that the soil was crushed almost two times less efficiently only behind the wheels of the tractor. Moreover, the high level of grinding results in fast drying of the soil, which is not recommended, particularly for seed bed preparation.

An important aspect of use of active machines is their high energy consumption. Power requirement to drive these machines amounts approximately to 10–12 $kW \cdot m^{-1}$ of the working width. Many practical observations of the authors and the studies published indicate that power requirement by an active cultivating machine during work depends greatly upon the shape and geometric dimensions of the working components, as well as the working depth and ratio of the rotor rotational speed to the speed of movement of the working unit [Makarov 2004]. The number of factors that exert impact on the size of energy requirement of the active cultivating machine is surely much greater. Among those, which are equally important, we can list the soil condition (compactness, moisture, type) at the time of cultivation, the type and drive of the drum with blades, the number and condition of blades on the disk, the type of blades used and their structural parameters, distances between disks, to which the blades are fixed, the direction of rotation in relation to the direction of movement of the machine and the drum diameter. Laboratory tests conducted by Suslov and Maksimov [1998] using drums with a varying number (1–2–4) of blades, working the soil at a rotational speed of 336 rpm and moving at the speed of 1.5 m·s^{-1}, showed that the greatest impact on power requirement was the initial level of loosening of the soil, the blade shape and structural parameters, physical characteristic of the soil and the drum rotational speed. The mutual proportions between individual factors are also significant. The research conducted [Kosutić et al. 1997] in order to find the best combination of working parameters (working speed, peripheral speed of the tines and working depth in relation to weighted average diameter of the clods, energy efficiency and requirement) showed that among eighteen combinations selected on the basis of statistical analysis, there were no significant differences between six of them. Due to efficiency and minimizing of energy consumption, the best was the combination of working speed of 4.87 km·h^{-1}, peripheral speed of the tines of 5.91 m·s^{-1} and working depth of 0.12 m. With such settings of the working parameters, the specific energy requirement amounted to 140.5 kJ·m^{-3} or 168.6 MJ·ha^{-1} at the efficiency of 1.31 ha·h^{-1}. The next favorable combination allowed for reduction of energy use by 23.9%, while energy efficiency of the machine was higher by 47.0%. This means that the issue of energy efficiency of working units used for soil cultivation should be approached taking into account many aspects, since even small changes in the values of individual parameters may result in substantial changes in the final effect, expressed as the quality and efficiency of work or the energy load value.

According to Ptaszyński [2005], the lowest power requirement has been determined to apply to a drum with angular blades. The power requirement of the rotor during work in soil of medium elasticity, when mixing grown post-harvest clover, at the working depth of about 0.10 m, speed of 4.7 km·h^{-1} and the drum rotational speed of 230 rpm, amounted to 14 kW·m^{-1}. Under the same conditions, the power requirement for a drum with paddle blades amounted to 17 kW·m^{-1}, for a drum with tines 25 × 25 mm – 20 kW·m^{-1}. When cooperating with cultivator U 424, the require for energy amounted to 9.5, 10 and 12 kW·m^{-1}, respectively. Effectiveness of work of machines with a drum working unit amounted to 0.4–0.55 ha·h^{-1}·m^{-1}.

Due to the substantial energy consumption and their mode of work, active cultivating machines are not recommended for light soils, where passive tools are sufficient. Due to intensive grinding, mixing of the soil and levelling off the field surface, active machines are often used together with seeders. In heavy, dry or excessively wet soils, these can be insufficient, as many unbroken clods may be left in the topsoil, hindering the operation of drill openers.

SUMMARY

A rototiller, due to the wide scope of applications and substantial benefits of shortening of the soil working time, is becoming a significant cultivating machine. Achievement of good effects of work of rototillers requires knowledge of many aspects associated with impact of working units on the soil.

Some authors conduct analyses while retaining the „comb" height range assumed; others aim at minimizing the comb effect, which results in a more levelled bottom of the topsoil layer; at the same time, it leads to overgrinding of the soil. As a result, the soil is susceptible to erosion and the plant growth conditions are not beneficial. The high degree of grinding of the soil leads to better plant emergence, which, nevertheless, does not result in better yields – sometimes it is even the opposite: the yield decreases. Research results quoted in this study indicate that the best soil structure is achieved by cutting soil pieces of the length of 15–25 cm with a blade, which is 55–75 mm wide.

These machines are recommended for heavy soils only. Due to intensive work of the blades, they grind the soil more than passive tools, making it more susceptible to drying. During operation of the rototiller, most energy is consumed by discharging the soil pieces (30.5–72.4%). The disks with blades should be reset by the angle of 12–14° for even torque distribution; on the other hand, resetting by an angle above 30° eliminates the problems associated with soil sticking to the blades.

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Streszczenie: *Jakość i energetyka pracy glebogryzarek.* W pracy dokonano przeglądu literatury w aspekcie zależności teoretycznych mających wpływ na jakość pracy i energochłonność glebogryzarek. Przedstawiono również wyniki najnowszych badań elementów roboczych, a więc noży, a w szczególności ich kształtu i wymiarów na jakość pracy i nakłady energetyczne. Badania te prowadzono w warunkach laboratoryjnych – w kanale glebowym, jak również w naturalnych – podczas doprawiania gleby w polu.

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