WORK PROCESS ANALYSIS OF THE MACHINES WITH WORKING PARTS ENTRAINED, IN SEEDBED PREPARATION WORKS
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ANALIZA PROCESULUI DE LUCRU AL MAŞINILOR CU ORGANE DE LUCRU ANTRENATE, LA LUCRĂRILE DE PREGĂTIRE A PATULUI GERMINATIV

Tolvaly-Roșca F., Pásztor J.[1],
Sapientia Hungarian University of Transylvania, Faculty of Technical and Human Sciences, Târgu Mureş / Romania;
Tel: 0040720399662; E-mail: pjudit@ms.sapientia.ro
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ABSTRACT

Ensuring phytotechnical conditions, as well soil preservation and protection are obtained by adjusting working parameters with appropriate fuel consumption. Efforts have been made to study the physical phenomena that occur during the work with active machinery, including the determination of cutting trajectories, shapes and dimensions of soil slices. A stated purpose of numerous studies is to track not only the economic aspects, but also the environmental aspects of burning fossil fuels. The paper proposes a CAD approach to study the geometrical dimensions that characterize the minimum tillage, their connections to the kinematic parameters, and highlights the connection between the specific cutting surface and the energy consumption.

REZUMAT

Asigurarea condițiilor fitotehnice, dar și conservarea și protecția solului sunt obținute cu ajustarea parametrilor lucrărilor,cu un consum corespunzător de combustibil. S-au făcut eforturi pentru a studia fenomenele fizice ce au loc la lucrările cu utilaje antrenate, incluzând și determinarea traiectoriilor de tăiere, a formelor și dimensiunilor așchiilor de sol. Un scop declarat a numeroaselor studii este urmărirea pe lângă aspectele economice și a aspectelor ecologice cauzate de arderea combustibililor fosili. Lucrarea propune o abordare CAD a studiului dimensiunilor geometrice ce caracterizează lucrările reduse, legătura acestora cu parametrii cinematici, și evidențiază legătura dintre suprafața specifică de tăiere și consumul energetic.

INTRODUCTION

Soil is the base of the agricultural system and influences the biosphere trough the cultivated plants. Worldwide, every year, degraded soil batches multiply. The degradation is related to physical, chemical, and biological changes of the processes that affect soil productivity at the base of erroneous human activities (*Marin et al, 2012*). We are witnessing three major challenges: sustainable cultivation, precision farming, including precision of soil processing and reduced climate damage. In soil works, emphasis is placed on preserving and protecting soil rather than implicit plant needs (*Birkás et al, 2017*). Therefore, the role of soil processing is also the protection of soil and the improvement of damaged soil.

The soil is subject to the following technological processes: turning, loosening, shredding, mixing, levelling, compaction. Soil technology has evolved considerably due to the diversification of soil-processing equipment and energy sources. In the conception of the development of sustainable agriculture, it is unanimously accepted that there is no valid universal soil working system. Soil conservation systems in different areas must have specific characteristics in relation to the ecological characteristics of the site and the technological characteristics of the cultivated plants, so that differentiation becomes mandatory (*Guş and Rusu, 2011*).

Minimum tillage works are done with rotating working parts and driven from the power take-off. Increased interest is raised for power harrow and rotary tiller, because they can process both the ploughed and unploughed land. Their work process is intensively studied and is characterized by qualitative work indices. The most important qualitative indices are: the soil breakage degree; soil volumetric mass; resistance to soil penetration; the average working depth of the soil works equipment; degree of soil loosening; level of soil leveling etc.

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[1] *Tolvaly-Roșca F., Ph.D. Eng.; Pásztor J., Ph.D. Eng.*

The soil breakage degree, after the work of rotary tiller and power harrow, is studied and compared by *Watcharachan et al.*, in 2017. The average values of the soil breakage degree by tilling and harrowing were 10.03 mm and 7.82 mm respectively. The soil breakage degree depends on humidity, so the authors propose the subsequent study of soils with different moisture contents (*Watcharachan et al, 2017*). The total porosity, the surface area and the size of the soil pores are related to the kinematic parameters of the tilling process. Using a cutter with a high kinematic index leads to a reduced mean porosity (*Destain et Houmy, 1990; Matin et al, 2014*). The geometry of tools and their peripheral speed influence the shredding phenomenon, the mixing of soil aggregates, which is reflected in the energy required for soil cultivation and soil levelling (*Kazuaki et al, 2013*).

The driven working partsare carrying out a complex soil processing, performing a vigorous processing of the soil. There is a grinding, loosening and deep mixing of the soil layers for the seedbed. Grinding occurs because of the shock received from the active partalong the minimum cohesion surfaces of the soil clods, thus protecting the natural soil structure (*Naghiu et al, 2004*). The energy input of soil processing is significant, approximately 20% of the total energy, and is characterized by energy indices as specific consumption, required power etc. (*Naghiu et al, 2004*). Specific consumption is influenced by kinematics and dynamics of working parts (*Vlad et al, 2013; Pasztor et al, 2015*). The power required for tilling the unit surface decreases as the tractor speeds up at a constant speed of the power take-off (*Kazuaki et al, 2013; Drunek, 2009; Brătucu et al, 2011*). In *Saimbhi et al (2004)* the minimum tillage study uses computer modelling methods of the working process.

This paper aims to implement a CAD modelling procedure of the active processes and a comparison of the obtained results with some theoretical calculations and experimental results. In the case of some concluding results, the developed method will be implemented to study several different types of soil works.

MATERIALS AND METHODS

The CAD modelling method proposed by the authors was implemented in a study of the working processes of the tilling blades disposed on a single rotor and the works of two working blades on a rotor of vertical axis rotary harrow. This modelling also allows comparison of different types of soil processing methodsbased on qualitative and energy indices. The CAD-specific processes were used by the authors firstly tosimulate the generation of mechanical gears by the chipping process, which allows besides studying kinematics, the possibility to determine values that characterize the soil breakage degree and a presumptive energy consumption of the studied machines.

In seedbed preparation with minimum tillage works, are important: the breakage degree of the worked soil, the energy consumption of the work, the specific soil cutting surface S_{sp}, the specific mechanical work L_s (both characterize soil breakage degree) and the energy consumption of the work (*Scripnic et al, 1982; Naghiu et al, 2004*). The two specific indicators are: the specific area of cutting relative to the worked soil volume unit and the specific mechanical work.

The specific cutting surface is the surface of the worked soil volume unit (*Scripnic et al, 1982*):

$$S_{sp} = \frac{S_t}{V} \tag{1}$$

The cutting surface is a geometric parameter of the soil slice dislodged by a tilling blade, approximated in (*Drunek, 2009*) with:

$$S_t = S_{ABCD} + S_{BCE} \approx lb + \frac{as_f}{2} \tag{2}$$

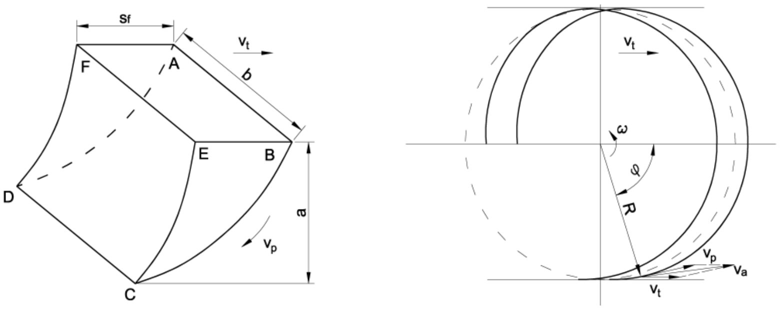

Fig. 1 – The dislodged soil slice dimensions and the contact angle between the blade and the soil

The length of the soil slice in tilling (Fig.1, left) can be calculated with *Naghiu et al (2004)*:

$$l = \varphi_0 r \tag{3}$$

The contact angle, the soil volume displaced by a blade, the feed on the blade and the kinematic index are (*Drunek, 2009*):

$$\varphi_0 = \arccos\frac{r-a}{r}, \qquad V_f = \frac{abs_f}{2}, \qquad s_f = \frac{2\pi r}{\lambda z_p}, \qquad \lambda = \frac{v_p}{v_t} \tag{4}$$

According to the relations in (4), the specific surface area of the tilling can be calculated with:

$$S_{spf} = \frac{2\left[\arccos\left(\frac{r-a}{r}\right)\right] rb + \frac{as_f}{2}}{abs_f}, \tag{5}$$

where S_t is the dislodged soil surface area in [m^2]; V is the dislodged soil volume in [m^3]; l is the length of the slice, in [m]; a is the working depth, in [m]; b is the thickness of the slice at the surface of the soil in [m]; s_f is the feed on the milling blade in [m]; φ_0 is the contact angle in [rad]; r the rotor radius in [m]; z_p is the number of milling cutters on the same side of the rotor; v_p is the peripheral speed of the rotor in [m/s], v_t the forward speed of the machine in, [m/s]; V_f is the soil volume dislodged by a blade at one revolution in [m^3].

The cutting surface and the soil slice volume dislodged by a vertical axis power harrow (Fig.1, right) are approximated with (*Naghiu et al, 2004*):

$$S_{gr} = \frac{2\pi R}{2\lambda}, \qquad V_{gr} = S_{gr}\frac{2\pi R}{2}a \tag{6}$$

According to the relations in (6) the specific surface for the vertical axis rotary harrow is:

$$S_{spgr} = \frac{\lambda}{\pi R}, \tag{7}$$

where S_{gr} is the feed rate on a blade, [m]; R is the radius of the harrow rotor, [m]; λ is the kinematic index of the grape; V_{gr} is the volume of soil displaced by a blade at a revolution, [m^3]; a is the working depth, [m] and S_{spgr} is the specific cutting surface area for the power harrow.

The S_{sp} specific cutting surface area on the volume unit determines the energy consumption of the work *(Scripnic et al, 1982; Naghiu et al, 2004)*.

Using the theoretical relations (1) - (7), calculations were made and corroborated by the experimental data acquisition (*Drunek, 2009*), where the fuel consumption was measured for the tilling work in greenhouse conditions, during operation and when idling. For various working conditions, from the difference between operating and idling consumption, the energy consumed for tilling was calculated. From the acquired data (*Drunek, 2009*) the specific area at the cutting surface was calculated (Table 1).

Table 1

Experimental fuel consumptions and calculated energy indices for rotary tiller

Working speed [m/s]	Working velocity [km/h]	Fuel consumption [cm^3] on 19.5 m^{2}and 0.2 m depth	Specific fuel consumption [kJ/m^3]	Specific cutting surface [m^2/m^3]
0.501	1.80	18.58	160.169	58.68204391
0.568	2.04	17.58	151.548	57.99893005
0.907	3.26	16.46	141.893	47.5170009

The results are presented in the graphs in Fig. 2, from where it can be concluded: specific consumption is inversely proportional to the linear displacement velocity, which is inversely proportional to the specific cutting surface.

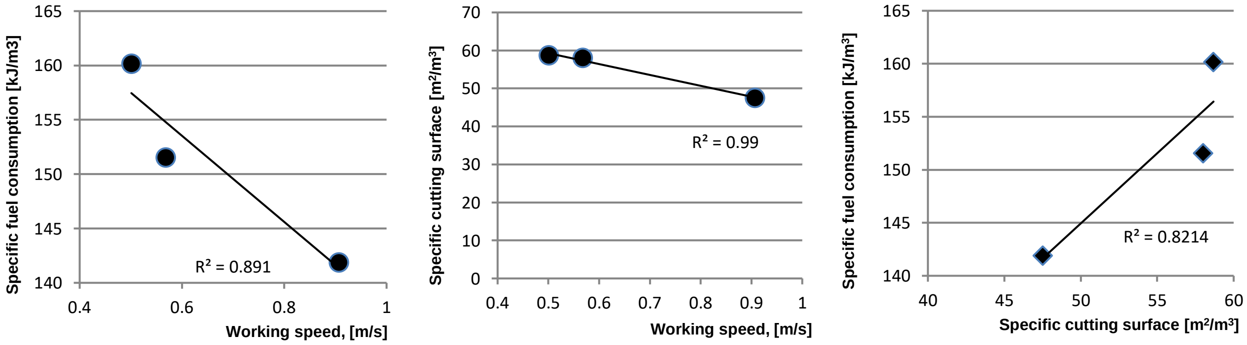

Fig. 2 – The correlation between the specific cutting surface and fuel consumption

The third graph demonstrates a direct proportionality relation between energy consumption and the specific cutting area (linear correlation coefficient $R^2 = 0.8214$).

Considering the correlation between the energy consumption and the specific cutting surface, as well as the obvious gross theoretical approximation errors, it was proposed to develop specific CAD methods to determine more accurately the specific surfaces in case of various kinematic parameters, but also to compare them for the rotary tiller and power harrow with vertical axis.

The evaluation of the geometry and the length of the processing trajectories, the specific surfaces of the soil slices or the displaced soil volume are indicators of energy consumption, efficiency of the processing method (*Scripnic et al, 1982, Naghiu et al, 2004*) and can be determined with varying precision. The dislocation of soil by driventools is a very complex physical phenomenon, which depends on the geometry of the blades, the trajectory of their movement and by many physical characteristics of the soil. Taking into account the physical characteristics, aggregation states, compaction level or humidity are mainly experimental tasks. A more accurate assessment of the cutting trajectories, the shapes and sizes of soil slices, the displaced soil volume, specific to the various machining methods, is possible by using computer-aided design (CAD). In this way it is also possible to accurately determine the motion trajectories, effective processing lengths due to multiple blade tools (2, 3, 6 ... etc.), which partially overlap during the movements.

Modelling the working parts and the soil as rigid bodies, the Solid Subtraction Method can be used to determine the displaced soil volume, obviously neglecting the real physical characteristics of the soil. With this method, considering a non-deformable and homogeneous soil, the geometry of the cutting chips can be determined. Although it has obvious shortcomings due to the complex physical phenomena that occur at real processing, it makes possible to compare different regimes within the same type of processing, or to compare the different type of soil works from the point of view of the processing time, or of the energy needs.

In a first step, a simplified 3D solid model (only the blades and rotors, without fasteners) of the rotary tiller, the power harrow and soil was created (Fig. 3a and Fig. 3b). The precision of geometry modelling is around ± 1 mm.

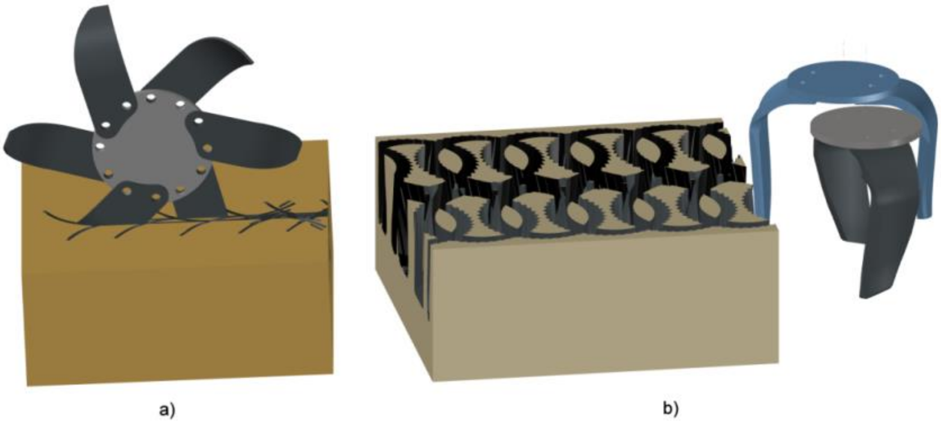

Fig. 3 – The simplified 3D models

a) rotary tiller; b) power harrow

The solid models were imported into AutoCAD, where an AutoLISP script performed the simulation of processing. The program, which uses the Solid Extraction method, consists in consecutive positioning of the tools relative to the soil, according to the relative movements and the parameters specified in the literature. The relative movement of the knives to the ground is constituted by a translational motion of the machine and the rotary motion of the blades. The relative motion is achieved by discrete rotational steps of the tool, with the angular value specified by the user: 0.7° ÷ 5°. Each rotation motion is followed by a linear displacement movement relative to the kinematics index λ. After performing an angular step and translation step, a CAD solid subtraction operation is performed to extract the tools from the soil, perform the new steps, followed by a new extraction, until the desired position (distance) is achieved. The result of modelling is the consecutive extraction of the blades from the soil model in discrete positions of the continuous motion. Depending on the discreet steps size, we will obtain a solid soil model with a readable residual volume inside the application, which decreased from the initial volume of the soil, gives us approximately the volume of soil displaced by the blades.

The continuous solid subtraction method was developed to generate complex gear surfaces and to visualize the teeth generation processes. Due to solid models, the method has a major inconvenience: decreasing the value of discreet steps, which means increasing the accuracy, the generation time exponentially increase. Increasing the value of the steps will result a more imprecise, step-like pattern, observable for example in case of 7° step generation. Due to this, it was necessary to use step parameter that gives result in a reasonable modelling time (up to 30 minutes), the accuracy remaining relatively high, and compensated by the fact that all modelling was done with the same 3° step generation angle, resulting a comparative error of the calculated volume.

The modelling carried out aimed to determine the displaced soil volumes for two types of processing within the kinematic indexes indicated in the literature. Due to the fact that the modelling method is independent of the time, it was sufficient to calculate the translational displacements required for each 1° rotations, corresponding to indices λ of 2 - 3,5 - 5 - 8 for tilling and 1,5 - 3 - 4,5 to 6 in the case of the power harrow with vertical axis (Table 2).

To determine the trajectories, an AutoLisp program was used, which generates a set of polylines according to the geometric and kinematic data entered, which are looped cycloids described by the extreme points of the edges over a length of 1m.

Fig.4 (top) shows the solid soil models, obtained for the specified kinematic parameters (top images for tiller and lower images for the harrow) and the trajectories of the external points of the blades edges for the same parameters.

To reduce the generating time, only 3 blades were used from tiller, and therefore the results were multiplied by 2. In trajectory generation process, 3 curves were generated, the other 3 blades performing the same trajectory at the same lengths, with offset of 60° (the results were also multiplied by 2). The larger diameter circle is the outer diameter of the blades, and the smaller one is the theoretical rolling circle of the looped cycloid.

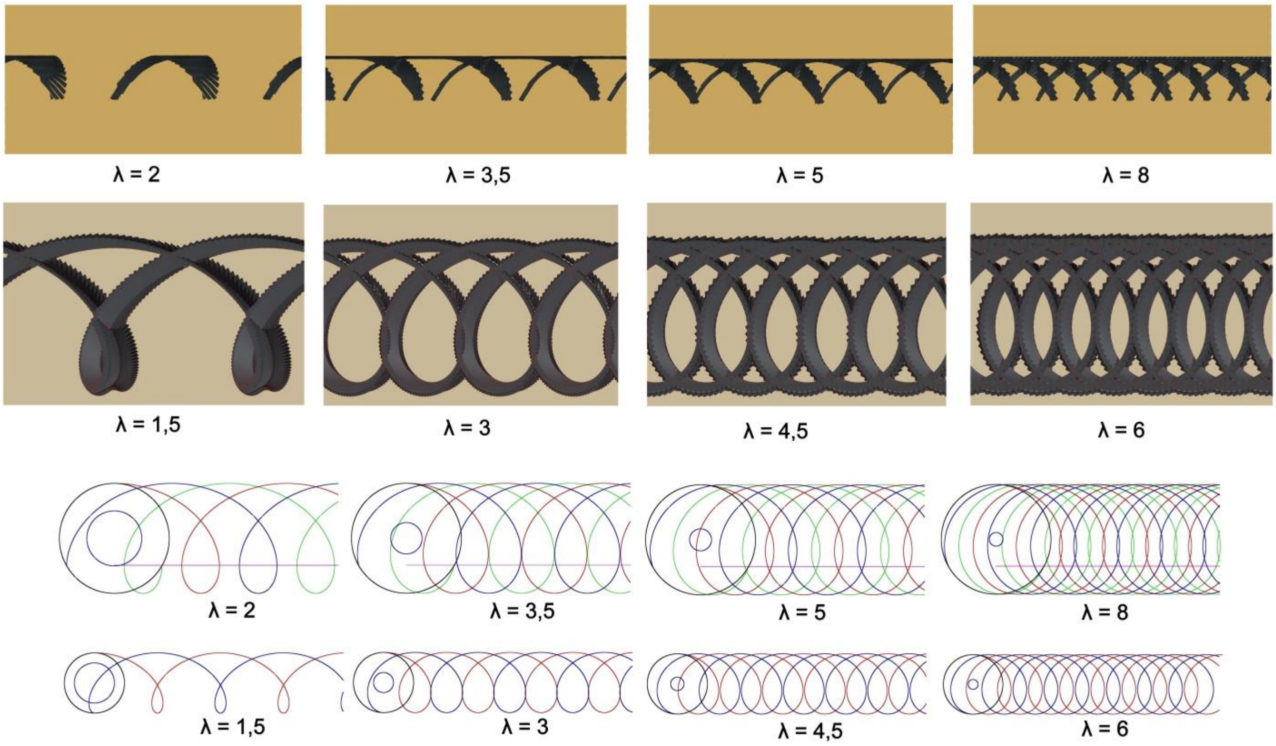

Fig. 4 – The solid models of the processed soil and the tools trajectories for different kinematic indexes

It can be noticed that with the increase of the kinematic index, the processing trajectories partially penetrates the cuts of the previous blades practically not doing a complete mechanical work on the tool's entire trajectory (the blade penetrates the fragmented soil). In order to determine the effective cutting lengths, the trajectories must be shortened until the previous trajectories are met. The cutting depth limits also the area where mechanical work is done to dislodge soil (the horizontal lines from Fig. 4 and Fig.5b); therefore work trajectories are located below the horizontal line.

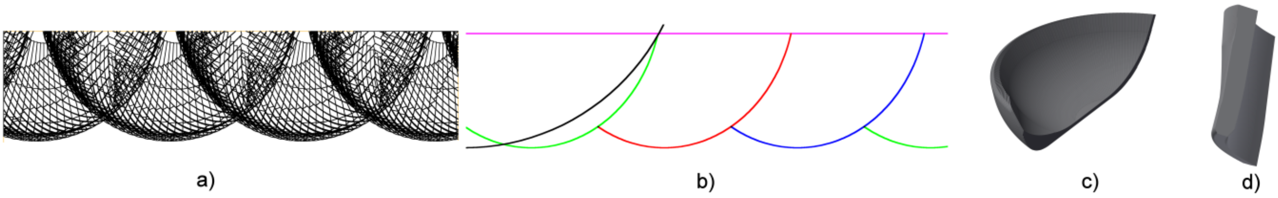

Fig. 5 – Tilling cutting trajectories and the soil chips for rotary tiller and power harrow

After all cuts made, the actual trajectories are revealed and the length parameter is obtained with a simple AutoCAD length query command, summing the partial lengths of the remaining trajectories.

In order to determine the specific surface of the chip, it has been seen that the shape of the chips is relatively simple in the case of the power harrow (a part of the continuous chip in Fig. 5d) and has an extremely complex geometry in case of the tilling procedure (fig.5c). The width of the chip for the harrow can be appreciated almost constant and equal with the working depth. Whilst in case of the tilling, the dimensions of the chips change depending on the angle of rotation of the blades and the kinematic index. The width of the chip can be only approximated as an average of the dimensions determined from the solid model Fig. 5c. For the modelled blade, this average width is approximately 125 mm.

RESULTS

The data determined with the 3D model for the tilling having: r = 245.5 mm, z_p = 3, z = 6, distance between the flanges 185 mm, working depth a = 120 mm; and for the harrow having: R = 121 mm, distance between the rotors 200 mm, working depth a = 120 mm, are shown in Table 2.

Table2

Data obtained from solid modelling

No.	v_p [m/s]	v_t [m/s]	λ [-]	V_{1m} [mm³/m]	L_{1m} [mm/m]	V_{tot} [m³/m²]	L_{tot} [m/m²]
Rotary tiller							
1	2	1	2	3779424	2668	0.0204	14.0161
2	3	0.86	3.5	5650128	5287.12	0.0305	19.1640
3	3.5	0.7	5	7931756	7628.936	0.0428	25.7280
4	5	0.625	8	10530236	13796.74	0.0569	38.6128
Power harrow							
1	3.5	2.333	1.5	11320260	3187.9	0.0566013	15.9395
2	3.5	1.167	3	15931242	5933.97	0.0796562	29.66985
3	3.5	0.778	4.5	20787480	8775.68	0.1039374	43.8784
4	3.5	0.583	6	24621256	11230.15	0.1231063	56.15075

Where: V_{1m} is the total volume of soil dislodged by working parts, per unit of length travelled; L_{1m} is the total cutting length of working parts, per unit of length travelled; V_{tot} is the total volume of soil dislodged by the working parts, per unit area in; L_{tot} is the total cutting length, per unit area.

The data calculated based on relations (1)-(7) and read from the 3D modelling are presented in Table 3.

Table3

Data calculated from theoretical approximation and obtained from 3D models

λ[-]	S_{sp}3D model [m²/m³]	S_{sp} calculated [m²/m³]	V_{asch}3D model [m³]	V_{asch}calculated [m³]
Rotary tiller				
2	85.8458	24.4683757	0.000486	0.001927
3.5	78.5133	36.8196576	0.000415	0.001101
5	75.0849	49.1709394	0.000408	0.000771
8	84.8798	73.873503	0.000338	0.000482
Power harrow				
1.5	33.79321676	3.94799179	0.002867	0.011548
3	44.69685414	7.89598358	0.002018	0.005774
4.5	50.65941615	11.8439754	0.001755	0.003849
6	54.73392584	15.7919672	0.001559	0.002887

Where: S_{sp} and V_{asch} are the specific surface and volume of a piece of soil cut by a blade calculated or determined from CAD models in [m²/m³].

The graphs in Fig. 6 show the comparison between the theoretically approximated results and those determined using the proposed new method.

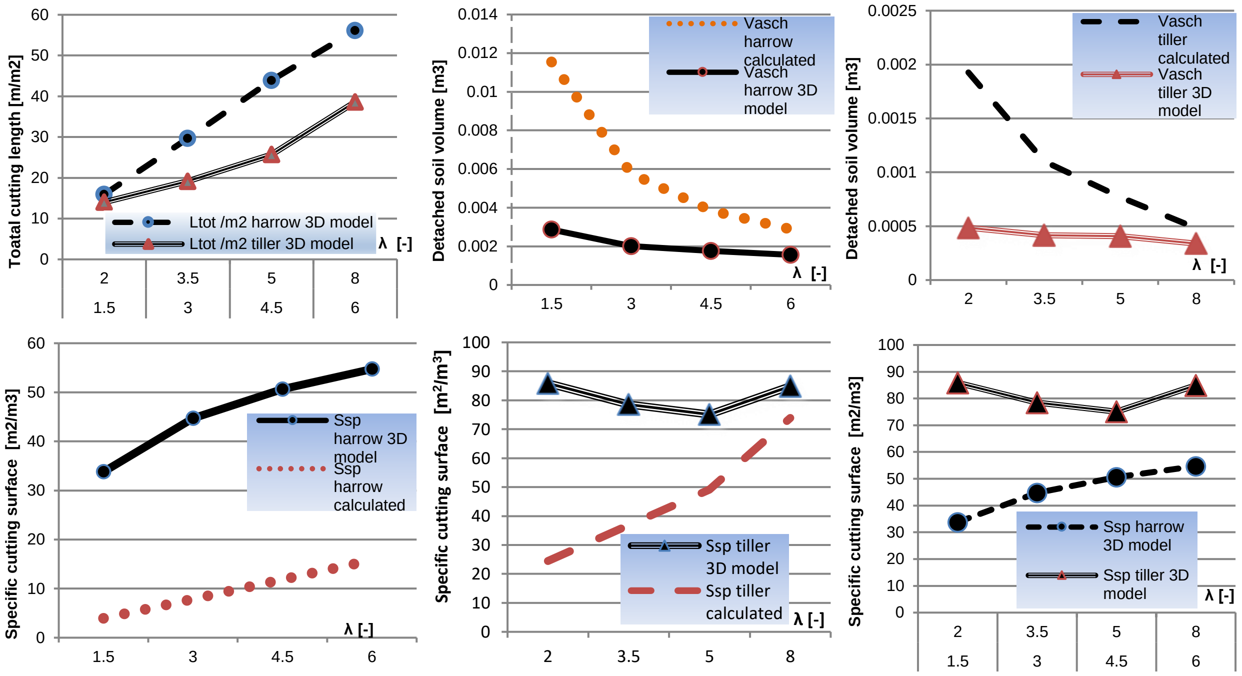

Fig. 6 – Comparison graphs of calculated and 3D measured data

CONCLUSIONS

Given that for the presented modelling the same physical characteristics of the soil were assumed, the comparison of results obtained for different kinematic parameters and different types of works is possible to be accepted.

- In both agricultural machines the increase of the kinematic index, implicitly the decrease of the advance speed, leads to the increase of the specific cutting surface;
- The differences between the calculated and the theoretically determined values are explained by the fact that the mathematical models applied to the theoretical calculations only grossly approximate the geometry of the soil chip. Determinations from 3D models leads to more accurate values;
- The specific cutting area of tiller is greater than in case of power harrow with vertical axis, which explains the higher energy consumption of the tilling works;
- The specific soil cutting lengths of the rotary harrow are longer, the power harrow fragments the soil more heavily than the rotary tiller;
- At low kinematic indices, the tiller has longer cutting lengths, so the tiller cuts the soil at higher kinematic indices more intensively than the power harrow;
- The physical qualities of the soil resulting from the minimum tillage are well-specified in the literature, the possibility of their corroboration with a minimum fuel consumption would mean, besides the obvious economic aspects also an ecological approach to the problem of the reduced works;
- A correct choice of qualitative indices and kinematic parameters of the agricultural tractor-agricultural machinery systems with driven working parts should be made, according to agro-technical requirements and given working conditions, but following also a minimum fuel consumption;
- The variation of the specific cutting surface of the tilling works presents a minimum point (approximately at λ = 5, from the literature recommended λ = 2 ÷ 8.33), which is not revealed by the theoretical approximations, point that should be verified in a future experimental research, since that can result in a lower fuel consumption;
- The developed methods allow a more precise determination of the specific cutting surfaces for various soil works and an assessment of energy consumption according to kinematic parameters and the possibility of comparing the fuel consumptions in case of different types of works.

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