RESEARCH ON THE DEVELOPMENT OF A CALCULUS ALGORITHM TO ESTIMATE THE RESISTANT FORCE OF SELF-VIBRATING CULTIVATORS USED FOR SEEDBED PREPARATION

Neluș-Evelin GHEORGHIȚĂ[1], Sorin-Ștefan BIRIȘ[2], Valentin VLĂDUȚ[3], Nicoleta UNGUREANU[4], Edmond MAICAN[5], Mihai MATACHE[6]

The paper presents the results of some theoretical and experimental research on the dependence of the resistant force on functional parameters such as working speed and working depth. Because soil cultivation requires a large amount of energy, even a small economy that emerges as a result of this process could be quite valuable. Seedbed preparation under difficult working conditions, moisture and general porosity preservation, and a reduction in soil compression degree are all advantages of using vibro-combinators. Simulated tests on the vibrocultivator unit were carried out at University Politechnica of Bucharest and National Research - Development Institute For Machines And Installations Designed To Agriculture And Food Industry - INMA Bucharest. The experiment aimed to determine the qualitative working indices on three plots of agricultural soil. Three repetitions were performed for each determination, and the average values were calculated.

Keywords: tillage, autovibrations, draft force, resistant force

1. Introduction and review

Tillage separates the soil layer from its natural environment, altering its stability, aeration, and wetting conditions, and throwing biological activities into disarray [4]. Soil becomes an artificial body as a result of many works, with a different regime of infiltration and superficial leakage of rainfalls, with direct repercussions for the washing of superior horizons and erosion production, as well as significant potential for water loss through evaporation [4].

Agricultural studies have found that designing and developing an effective tillage system can help in achieving the desired soil behavior while using less draft

[1] Ph.D. Stud. eng., Dep. of Biotechnical Systems, Politehnica University of Bucharest, Romania, e-mail: evelin_gheorghita@yahoo.com
[2] Prof. Ph.D. eng., Dep. of Biotechnical Systems, Politehnica University of Bucharest, Romania
[3] S.R. I, Ph.D. eng., National Research - Development Institute For Machines And Installations Designed To Agriculture And Food Industry - INMA Romania
[4] Lect. Ph.D. eng., Dep. of Biotechnical Systems, Politehnica University of Bucharest, Romania
[5] Prof. Ph.D. eng., Dep. of Biotechnical Systems, Politehnica University of Bucharest, Romania
[6] S.R. I, Ph.D. eng., National Research - Development Institute For Machines And Installations Designed To Agriculture And Food Industry - INMA Romania

force and energy [9]. Another study discovered that a 2–5 cm thick pan forms in sandy soil after a few tillage machine passes [5].

As a result, the primary focus of research is on the use of low-draft implements that can help farmers save money by reducing soil compaction and preparing fields efficiently [12]. Both implement designers and farmers benefit greatly from accurate predictions of tillage implement forces [1]. It is a well-known fact that oscillation of tillage equipment can help reduce draft and drawbar power requirements, which can help solve this problem [11]. Several research have been published on the effect of oscillation angle, frequency, forward speed, and amplitude on cutting tool draft and power consumption, as well as optimum settings for effective operation [8].

Because tillage equipment requires a major percentage of the energy used to produce the crop, reducing the energy required to modify the physical qualities of the soil is an important factor [2]. Because of the high quantity of energy required for soil cultivation, even a tiny economy that develops as a result of this process may be of substantial value [6].

Combinators are agricultural machines featuring a variety of working bodies (arrows, claws, coulters, stars, and so on) that grind, loosen, and level the top layer of soil in a sequential manner. These equipments are used in soil tillage to prepare for sowing [10]. The benefits of using vibrocombinators include: seedbed preparation under tough working conditions, moisture and overall porosity preservation, and a reduction in soil compression degree [7].

Two of the most used spring tine options in field and laboratory tests were the Gamma tine, which is shaped to work the soil to a fine tilth without overturning the tilled layer, and respectively the Delta tine, which involves a minimal soil overturning, being useful in controlling weeds that have emerged after the primary tillage, or for incorporating crop residues into the tilled layer.

a) b)

Fig.1. Vibratory tines mounted on elastic supports [14]

a) Gamma type; b) Delta type

The working tools are active when the translational movement of the machine through the autovibrations generated by the discreetly variable resistance of the soil to the interaction with the working tools.

The working tool is excited in elastic regime for each position of the equipment movement so that the variable effect in relation to time generates a kinematic excitation of the following shape:

$$x = x_0 \cdot \sin \omega t \quad (1)$$

In Fig. 2 are presented various technical solutions of working bodies for vibrocultivator [14].

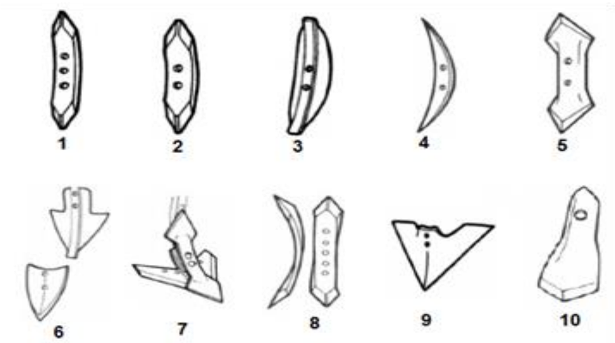


Fig. 2. Constructive types of working bodies for vibrocultivators [15]

Following the tools, there is a twin crosskill roller, which is aggressive on the remaining clods, and a levelling bar for the final levelling. The spring tines work in conjunction with the front and rear crosskill rollers, which minimize the clodding in the soil, leaving behind levelled soil ready for seeding [15].

2. Theoretical considerations

The draft force of the vibrocultivator presented in Figure 3, $R_{m,}$equal to the draft force of the tractor F_t is obtained from the equation of projections of forces on the direction of movement.

$$F_t = R_m = R_{rm} + R_{im} + R_{xn} + R_{xt} + R_{xs1} + R_{xs2} + R_{xk1} + R_{xk2} \quad (2)$$

Resistant force due to machine inertia is:

$$R_{im} = \frac{G_m}{g} \cdot \frac{dv}{dt} \quad (3)$$

If$v = ct \ \rightarrow \ R_{im} = 0$

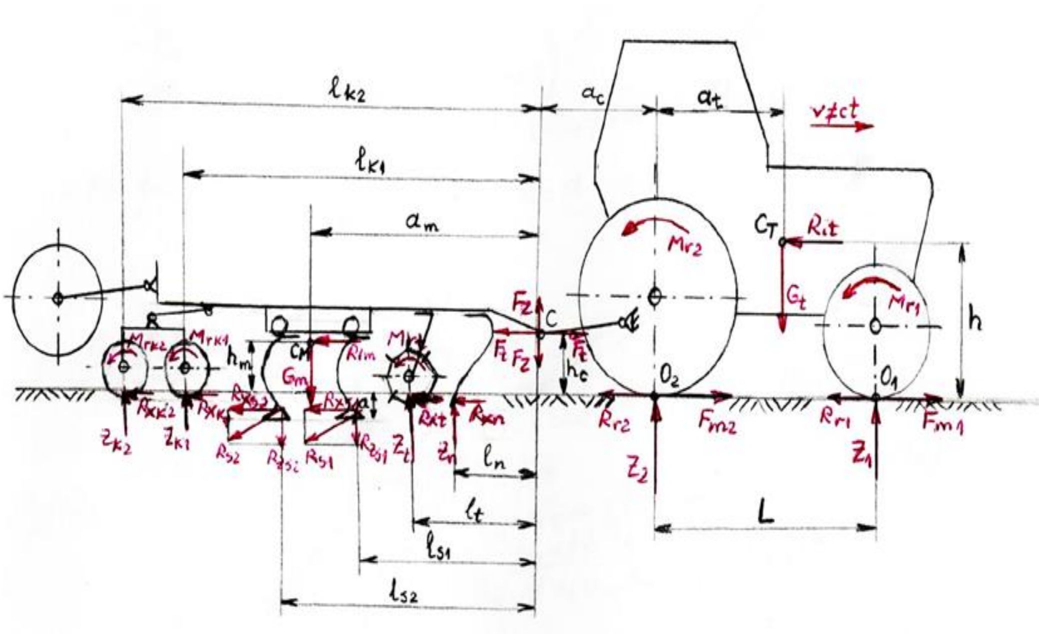
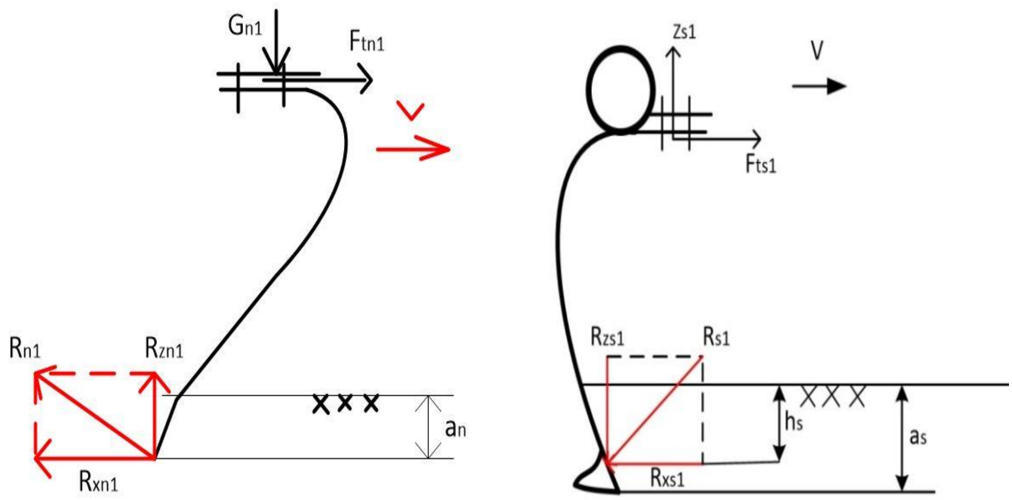


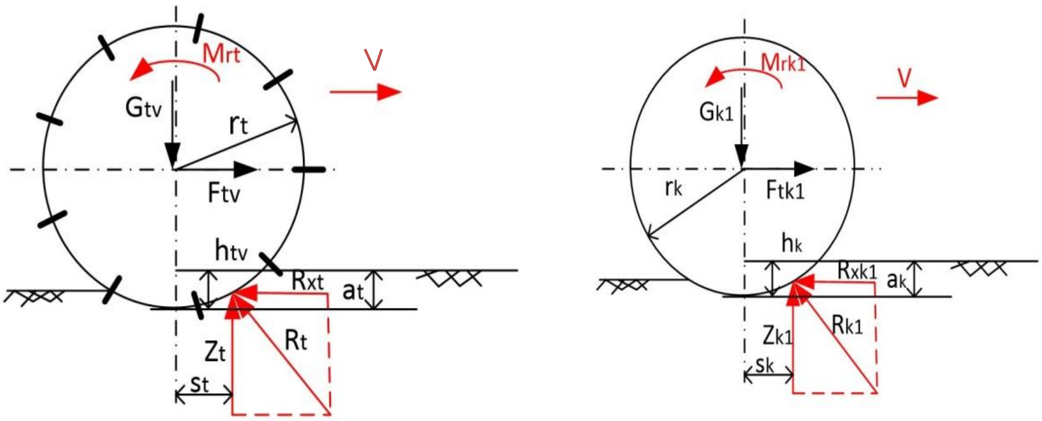
Fig. 3. Projections of forces on thedirection of movement of the vibrocultivator

Where: Mr1, Mr2- rolling resistant moments; Fm1, Fm2- tangential active forces;
Rr1, Rr2- forward resistant forces in translational motion.

From the forces projections of the cultivators parts presented in Figure 4, can be obtained many formulas for the resistant force of each tool.



a) b)



c) d)

Fig. 4. Forces projections on the cultivator parts
a-blade leveller; b-arrow-type active tool; c-roller; d-crosskill roller.

For a levelling blade (Fig. 4a), the resistant force can be calculated with the following equation:

$$R_{xn1} = k_1 \cdot a_n \cdot b_n + \varepsilon_1 \cdot a_n \cdot b_n \cdot v^2 \quad (4)$$

For the whole leveler equipment, the resistant force is:

$$R_{xn} = n_1 \cdot R_{xn1} \quad (5)$$

For the arrow-type vibratory working tool (Fig. 4b), the resistant force is:

$$R_{xs1} = k_2 \cdot a_s \cdot b_s + \varepsilon_2 \cdot a_s \cdot b_s \cdot v^2 \quad (6)$$

$$F_{ts1} = R_{xs1}; \qquad R_{xs} = n_s \cdot R_{xs1};$$

The draft force applied to the roller (Fig. 4c) and crosskill roller (Fig. 4d):

$$F_{tv} = R_{xt} = f_{tv} \cdot z_t = f_{tv} \cdot G_{tv} \quad (7)$$

$$F_{tk1} = R_{xk1} = f_k \cdot z_{k1} = f_{k1} \cdot G_{k1} \quad (8)$$

where: $k_1 k_2$–specific resistance to tillage [N/m^2]; a_s, a_n–working depth [m]; b_s, b_n–working width [m]; $\varepsilon_1 \varepsilon_2$-coefficient that depends on the shape of the surfaces of the working tools [non-dimensional]; v–working speed [m/s]; R_{xn1}, R_{xs1}–resistant force of one working tool [N]; F_{ts1}, F_{tk1} - draft force for one working tool; n_s- number of working tools; R_{xs}- total resistant force [N].

3. Materials and methods

Simulated experiments of the vibrocultivator unit were performed both at University Politehnica of Bucharest and National Research - Development Institute For Machines And Installations Designed To Agriculture And Food Industry – INMA Bucharest. The objective of the experiment was to establish the qualitative working indices.

The experimental model of SANDOKAN 2 vibrocombinator is designed to carry out the operations of preparing the seedbed, loosening the soil, leveling the ground, at depths of maximum 12 cm for cereal crops, technical plants and vegetables. It is equipped with active vibrating tools of Gamma, Delta 1 or Delta 2 type, mounted on 4 modules with a width of 1.75 m. The experimental model used for the tests consists of two folding sections with a width of 3.5 m, equipped with leveling blades, roller blades, crosskill rollers and active tool modules.

Fig. 5. Sandokan vibrocultivator in transport position

The tractor used for the tests was a John Deer JD8530, for each determination, three repetitions being performed, and then the average values were calculated. The experiments were performed on three parcels (P1, P2, P3), geographically positioned according to Figure 6.

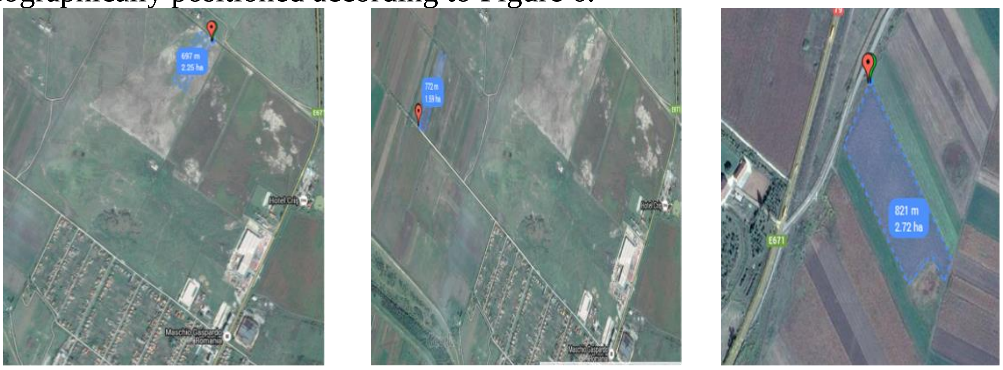


Fig. 6. Parcels of soil where the experiments were performed

The field test conditions are presented in Table 1.

Table 1

Field test conditions

Nr.crt	Characteristics	Results		
		P1	P2	P3
1	Type of soil	vertisol	vertisol	vertisol
2	Previous work	plowing performed at a depth of 25-30 cm followed by disking	autumn plowing performed at a depth of 25 - 30 cm	scarification
3	Previous culture	Corn	Corn	Corn
4	State of soil	Flat and smooth	Flat and smooth	Flat and smooth
5	Slope of field	0.8°	1.7°	2°
6	Mass of vegetable waste	110-120 g/m^2	180-190 g/m^2	370-380 g/m^2

Software Mathcad was used for the estimated calculation of the value of the total resistance force required to operate the equipment. Correlation of the resistant forces with the traction force of the tractor so that the skating of the driving wheels does not exceed 20%.

Fig. 7. Experimental model of vibrocultivator Sandokan 2

The experimental model presented was tested in dynamic mode with loads in the form of the real spectrum of stress in transport, in the state mounted on a test stand according to Figure 7. The structure of the vibrocombinator was excited by means of a 100 kN hydraulic cylinder, moving and positioned under the front of the equipment. The reference signal was synthesized based on the signals recorded in the transport just above the support point of the cylinder piston.

At the in field trials temperature was 20.5 ^{o}C, atmospheric moisture of 45%, atmospheric pressure of 752 mm col Hg and wind speed of 0.2-0.4 m/s. In laboratory tests, the temperature was 23 ^{o}C, atmospheric moisture was 35%, and the atmospheric pressure was 752 mm col Hg.

4. Results and discussions

Experimental data, both for the values of input and output parameters considered and analyzed in this paper are presented in Tables 2, 3 and 4. Data obtained from the experiments were used to graphically plot the dependence of the resisting force on functional parameters.

Table 2

Qualitative and energetic indices determined for the Delta 1 active working tool

Nr.crt.	Average working depth, a_s [cm]	Average working speed [m/s]	Average draft force in field [kN]	Theoretical draft force [kN]
1	4.6	3.3	63.64	60.33
2	5.98	2.63	64.24	65.17
3	6	4.19	54.27	75.91
4	7.8	3.38	59.04	81.4

Table 3

Qualitative and energetic indices determined for the Delta 2 active working tool

Nr.crt.	Workind depth, a_s [cm]	Working speed [m/s]	Draft force in field [kN]	Theoretical draft force [kN]
1	7.75	3.8	61.63	73.27
2	8.25	3.91	61.56	76.91
3	8.55	3.69	62.32	76.54
4	8.63	2.47	74.92	67.92
5	8.8	3.38	62.73	75.16
6	9.2	3.33	64.75	76.71
7	11.5	2.66	82.95	81.7

Table 4

Qualitative and energetic indices determined for the Gamma active working tool

Nr.crt.	Workind depth, a_s [cm]	Working speed [m/s]	Draft force in field [kN]	Theoretical draft force [kN]
1	10.8	2.65	62.4	51.41
2	10.85	2.44	57.4	50.72

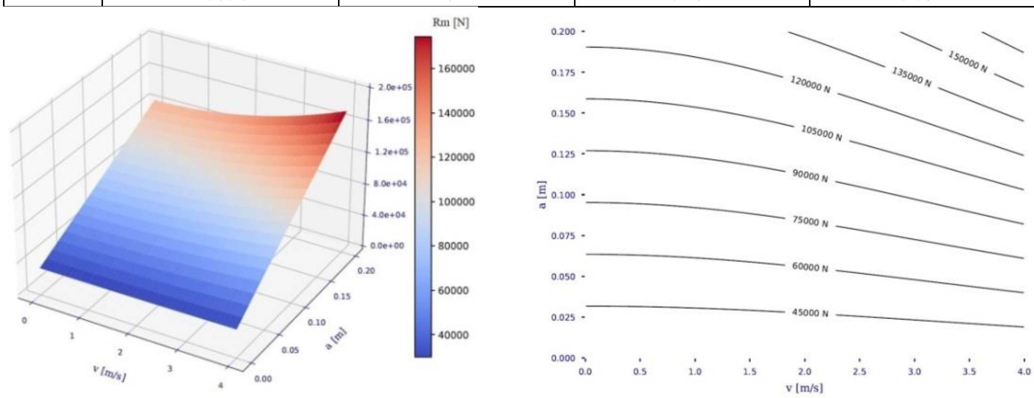


Fig. 8. Dependence of the resistant force on functional parameters for Delta 1 tool

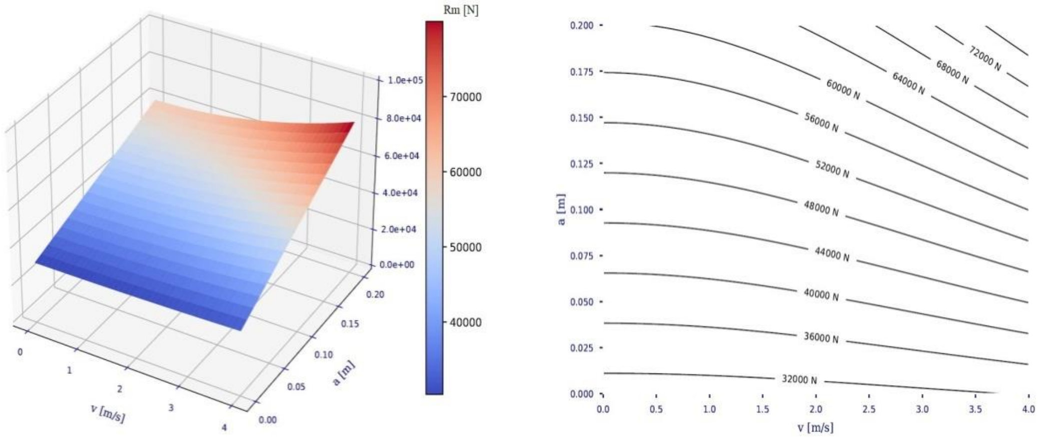


Fig. 9. Dependence of the resistant force on functional parameters for Delta 2 tool

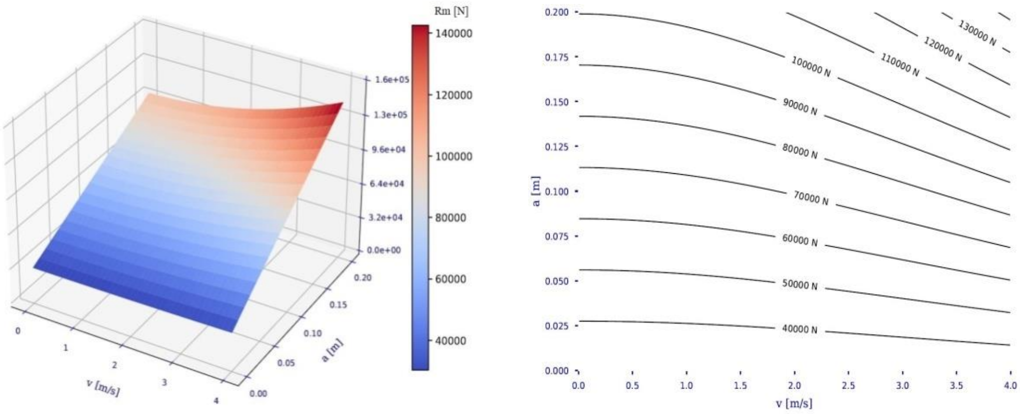


Fig. 10. Dependence of the resistant force on functional parameters for Gamma tool

In Tables 2, 3 and 4, for all three active tools, it can be noticed that the difference between the theoretical draft force and the actual draft force in field it is not higher than 13 kN. From the analysis of the values obtained, it was observed that is a good corellation between data resulted from calculus and those from field experiments.

From the analysis of Figure 8whichshow the dependence of the resistant force on functional parameters, it can be observed that the working depth has the highest influence on the studied process. Below the depth of 0.10 m, at a maximum speed of 4 m/s, the resistant force registers values of about 75 kN, which can be considered small enough not to have a significant impact on the optimal operation of the equipment.

In Figure 9, the resistant force reaches maximum values of 72 kN, which is the lowest value of all three. As a comparison with the first, at a working depth of

0.1 m and a speed of 4 m/s, the resistant force has a value of only about 50 kN. By analysing Figure 10, it can be seen that the values are in the same range.

Skidding of the drive wheelsfalls within the range of 6.3-9.7 % which is less than the maximum allowable value of 20 %.

5. Conclusions

Because the tillage equipment consumes a significant portion of the energy utilized to grow the crop, lowering the energy required to change the physical properties of the soil is essential.

From the data presented in this paper it can be observed the dependence of the resistant force on functional parameters. The working depth affects the resistant force the most, more than the working speed. The values collected were analyzed, and it was discovered that there is a high correlation between the data produced via calculus and those gained from field investigations. The amount of skidding resulted on the drive wheels was between 6.3 and 9.7 %, which is less than the maximum permissible value of 20 %.

R E F E R E N C E S

[1] *A. AboAl-Kheer, M.G. Kharmanda, A. El Hami, A.M. Mouazen*, Estimating the variability of tillage forces on a chisel plough shank by modeling the variability of tillage system parameters, Computers and Electronics in Agriculture, Volume 78, Issue 1, Pages 61-70, 2011

[2] *Şt. Căproiu et al***.** Agricultural machinery for soil tillage, seeding and crop maintenance. Didactic and Pedagogic Publishing House, Bucharest, 1982

[3] *D.I. Vlăduț, S-Șt. Biriș, V. Vlăduț, D. Cujbescu, N. Ungureanu, I. Găgeanu*, Experimental researches on the working process of a seedbed preparation equipment for heavy soils. INMATEH - Agricultural Engineering, Volume 55, Pages 27-34, 2018

[4] *D.I. Vlăduţ, L. David, E. Marin, S.Şt.Biriş, I. Voiculescu, E. Maican, V. Vlăduţ, N. Ungureanu, L. Vlăduţoiu, L. Fechete, Şt. Croitoru, S.Boruz, I. Voicea, M. Matache, S.T. Bungescu.* Research on the development of a conservative technology, using optimized active bodies for soil tillage. Scientific Symposium with International Participation „Sustainable Development in Agriculture and Horticulture", 3rd Edition, 12-13.11.2015, Craiova. Annals of the University of Craiova – Agriculture, Montanology, Cadastre Series. Vol. XLV/2, pp. 247-252, 2015

[5] *Hammond C., Reid J.T., Seigler W.E.*, Seedbed preparation behind row subsoilers. Trans ASAE 24:897–901, 1981

[6] *M.I. Ghereș, M. Ghereș*, Research on determination of interaction tools-soil, ProEnviroment, vol.6, pp. 262-270, 2013

[7] *N. Boja, F. Boja, D. Vidrean, A. Teusdea, S.T. Bungescu, S.A. Borz,* Soil compression degree by using the vibro-combinator, INMATEH- Agricultural Engineering, Vol. 55, pp.77-85, 2018

[8] *Shahgoli G, Fielke J, Saunders C, Desbiolles J*, Simulation of the dynamic behaviour of a tractor-oscillating subsoiler system. BiosystEng 106:147–155, 2010

[9] *Shahgoli G, Fielke J, Desbiolles J, Saunders C*, Optimising oscillation frequency in oscillatory tillage. SoilTillage Res, 106:202–210, 2010

[10] *S.Șt. Biriș, V. Vlăduț, E. Marin, N. Ungureanu, S.T. Bungescu, A. Atanasov*, Conservative tillage technologies - state of the art, 4th International Conference on Thermal Equipment, Renewable Energy and Rural Development (TE-RE-RD), pp. 181-186, ISSN 2359-7941, 4-6.06.2015
[11] *P. Cardei, V. Muraru, N. Constantin, C. Muraru, T. Cilan, C.D. Hodre, M.G. Matache,* Mathematical modelling and comparative simulation of the vibrations of vibro cultivators and agricultural cultivators, INMATEH Agricultural Engineering, 2015
[12] *Prem M, Swarnkar R, Kantilal VDK, Jeetsinh PSK, Chitharbhai KB*, Combined tillage tools—a review. CurrAgric Res J4:179–185, 2016
[13] CIGR Handbook of Agricultural Engineering, *Plant Production Engineering*. Volume III. American Society of Agricultural Engineers, 1999
[14] ***, *S-tine harrows – Seedbeds Preparation in just one Pass*. Kverneland Prospect, 2018
[15] ***, *Cultivators – Thinking ahead*. VOGEL & NOOT Prospect, 2020
[16] ***, *Tillage& Cultivation – Seed Bed Cultivators*. Maschio Gaspardo Prospect, 2020