GENERAL STRUCTURE OF TILLAGE DRAFT FORCE. CONSEQUENCES IN EXPERIMENTAL AND APPLICATIVE RESEARCHES

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STRUCTURA GENERALA A FORTEI DE TRACTIUNE. CONSECINTE IN CERCETARILE EXPERIMENTALE SI APLICATIVE

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ABSTRACT

The empirical and theoretical estimation of the draft force of agricultural machinery for soil tillage has been the target of scientific research for about one hundred years. The results obtained so far may seem contradictory or divergent. The article presents the results of some research on the usual calculation formulas of the draft force of agricultural machines for soil tillage. Although apparently these formulas are different, analyzing the structure of the formula, we find cohesion and coherence embodied in a simple generalization and easy to use both theoretically and experimentally. Moreover, the formulas are convertible between them, the two languages used for their definition (the mechanics of deformable solids and that of the phenomenological description), are only different forms of expression for the same phenomenon. Another problem that is addressed in the research whose results are presented in this article is that of highlighting the dependence of the draft force on the tool speed (in the field) of the soil tillage machine. Exposure is complemented by an algorithm that highlights the dependence of the draft force on the tillage tool speed. Also like a consequence of the draft tillage force structure, finally, a third problem addressed in these researches and whose results and perspectives are given in this paper is that of optimizing the working processes of agricultural machinery for soil tillage. The treatment of the problem starts from the hypothesis of the most general formula of the traction resistance force and proposes some ways to solve the optimal problem.

REZUMAT

Estimarea empirică și teoretică a forței de tracțiune a mașinilor agricole pentru prelucrarea solului a fost in atenția cercetării științifice timp de aproximativ o sută de ani. Rezultatele obținute până acum pot părea contradictorii sau divergente. Articolul prezintă rezultatele unor cercetări privind formulele obișnuite de calcul al forței de tracțiune a mașinilor agricole pentru prelucrarea solului. Deși aparent aceste formule sunt diferite, analizând structura formulei, găsim coeziune și coerență integrate într-o generalizare simplă și ușor de folosit, atât teoretic cât și experimental. Mai mult decât atât, formulele sunt convertibile între ele, cele două limbaje utilizate pentru definirea lor (mecanica solidelor deformabile și cea a descrierii fenomenologice) sunt doar forme diferite de exprimare pentru același fenomen. O altă problemă abordată în cadrul cercetării, ale cărei rezultate sunt prezentate în acest articol, este aceea a evidențierii dependenței forței de tracțiune de viteza in câmp a organului de lucru montat pe mașina de prelucrare a solului. Expunerea este completată de un algoritm care evidențiază dependența forței de tracțiune asupra vitezei instrumentului de prelucrare. De asemenea, ca o consecință a structurii forței de tracțiune, în final, a treia problemă abordată în aceste cercetări și a cărei rezultate și perspective sunt prezentate în lucrare este cea a optimizării proceselor de lucru ale mașinilor agricole pentru prelucrarea solului. Abordarea problemei pornește de la ipoteza celei mai generale formule a forței de rezistență la tracțiune și propune câteva modalități de rezolvare optimala a problemei.

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INTRODUCTION

The specialists considered that the working speed does not influence the draft force or its influence is insignificant compared to the static component of the same force. Among the formulas that take into account only the static component, one can notice the formulations based on soil mechanics (*McKyes, 1985),* developed especially for tools working in soil (agricultural machines or machines used in land or civil engineering or mining) at a low speed. The influence of the working speed is considered in many papers, *(Letosnev, 1959; ASAE, 2003; Toma et al., 1978; Sandru et al., 1983; Tecusan and Ionescu, 1982; Scripnic and Babiciu, 1979; Gill and Vanden, 1968).* In some of the last mentioned papers, the authors also consider reduced formulas, particular cases of general formulas that contain the working speed and which can be used also in the absence of terms that contain the speed of work.

An interesting separation can be made between the views of two schools with profound contributions to the development of formulas for the estimation of the traction draft force of the soil tillage machines: the North American school (USA and Canada) and the Russian (Soviet) school, but whose results have been used successfully throughout the Eastern Europe. The results of the American school are represented in the works (*McKyes, 1985; Owen, 1989; Larson, 1964*; *Gill and Vanden, 1968*; *Ibarra, 2001*; *Fielke, 1994; Sharifat, 1999).* The results of the Russian school are represented by (*Letosnev, 1959; Krasnicenko, 1964; (Asmolovsky and Nosnikov, 2014)* and in Romania, by (*Toma et al., 1978; Sandru et al., 1983; Tecusan and Ionescu, 1982; Scripnic and Babiciu, 1979; Sandru et al., 1982).*

The proposed calculation formulas differ in form, as sense of terms and factors, in part. However, a simple analysis shows that all formulas converge and that terms are convertible from one formula to another. Moreover, there is a generalizing formula from which all other formulae are obtained, by customization.

The structure of the draft force formulas has profound implications in the experimental plan and in the theoretical and experimental plan of identifying possible optimal working regimes of agricultural machinery for soil tillage. The two issues are briefly discussed in this paper.

MATERIALS AND METHODS

The most general form of the draft force of tools for the soil tillage machinery is, according to (*ASAE, 2003)*:

$$F = A + B \cdot v + C \cdot v^2 \tag{1}$$

where the parameters in the formula are explained in Table 1.

Table 1

Parameters of the interaction process between soil and the soil tillage machinery: notations, significance and units of measurement

Notation	Name	Unit[2]
F	Draft force	N
A	The static coefficient of term of the draft force	N
B	The coefficient of the term that depends on the working speed of the draft force	Kg/s
C	The coefficient of the term that depends on the square of the working speed, of the draft force	Kg/m
F_i	Dimensionless factor describing the influence of soil texture: i = 1 fine, i = 2 average, and i = 3 coarse.	-
K	Parameter specific of the tillage machine	MPa
D	Parameter specific of the tillage machine	$\text{Kgm}^{-2}\text{s}^{-1}$
E	Parameter specific of the tillage machine	kg/m^3
v	Working speed	m/s
b	Working width	m
a	Working depth	m
k	Coefficient that characterizes specific soil deformation resistance	MPa
ε	Coefficient which depends on the shape of the active surface of the body and the soil properties[3]	kg/m^3
δ	Angle of friction between tillage tools and soil	rad
f	Coefficient analogous to friction coefficient	-
G	Plough weight	N

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[2] *For ease of computation and comparisons, as well as for the unification of language, we have transformed the measurement units of all authors into the international system (SI) of measurement units.*

[3] *The coefficient ε, according to (Letosnev, 1959), has the unit $\text{kgf}\cdot\text{s}^2/\text{m}^4$, which by simplification returns to the mass density unit.*

Notation	Name	Unit^2
g	Gravitational acceleration	m/s^2
ρ	Soil mass density	Kg/m^3
C_o	The apparent cohesion of the soil	MPa
C_a	Adhesion of the soil to the surface of the tool	MPa
μ	Angle of friction between soil and metal	rad
q	Overpressure acting vertically on the surface of the soil	MPa
N_ρ	Factor depends on soil friction resistance, tool geometry and soil properties.	-
N_c	Factor depends on soil friction resistance, tool geometry and soil properties.	-
N_{ca}	Factor depends on soil friction resistance, tool geometry and soil properties.	-
N_q	Factor depends on soil friction resistance, tool geometry and soil properties.	-
N_a	Factor depends on soil friction resistance, tool geometry and soil properties.	
ϕ	Angle of internal soil friction	rad
α	Horizontal blade angle (rake angle)	rad

The general formula (1) for the draft force is a theoretical mathematical model of this force. For the calculation of coefficients or model parameters experimental data can be used. This procedure customizes the formula for different types of tillage tools and environmental conditions (soil type, humidity, etc.).

Another category of mathematical models of the draft force is that of the statistical models, based on experimental data subjected to the regression analysis.

Finally, another category of mathematical models for traction resistance force is formed by the formulas obtained through dimensional analysis. Generating formulas through this method requires the use of experimental data, and consequently involves the customization of machine-based formulas and environmental conditions.

RESULTS

Particular structures, general formula

In formula (1), the parameters A, B, C can be explained by various expressions, obtaining particular forms commonly used in the literature and in the design and exploitation of machines for soil works.

Table 2

The coefficients from the formula (1) of the draft force, for four particular reference cases, and generalization

Formula	A	B	C
Goreacikin*, (*Letosnev, 1959)*	$fG + kab$	0	εab
The USA Standard**, (*ASAE, 2003*)	$F_i Kab$	$F_i Dab$	$F_i Eab$
Reece (1965)***, (*McKyes, 1985)*	$(\rho g a N_\rho + C \cdot N_c + q \cdot N_q) \cdot a \cdot b$	0	0
Simplified formula****, (*Sandru et al., 1983*)	$K_b \cdot b$	0	0
(*Owen, 1989; Al-Neama and Hertzilius, 2017*)	$(\rho g a N_\rho + C_o N_c + C_a N_{ca} + q N_q) ab$	0	$\rho N_a ab$
Generalizations, (*Owen, 1989; Al-Neama and Hertzilius, 2017*)	$(\rho g a N_\rho + C_o N_c + C_a N_{ca} + q N_q) ab$	Dab	$\rho N_a ab$

[*] The coefficients *f* and *ε* are given, for example in (*Letosnev, 1959),* for different types of soil or general and the coefficient *k*, is tabled for different types of soils.

[**] The coefficients F_i, K, D, E are given in (*ASAE, 2003),* for every usual agricultural machine or equipment in American agriculture.

[***] The coefficients N_ρ, N_c, N_q ,and N_{ca} are given in formula (2).

[****] The coefficients K_b are tabulated, in the works where the formula is used, by categories of agricultural machines, (*Toma et al., 1978*), for example.

$$N_\rho = \frac{1}{2}(1+\sin\phi)\left(1+\frac{tg\phi}{tg\mu}\right), N_c = \left[\left(\frac{1+\sin\phi}{1-\sin\phi}\right)-1\right]ctg\phi, N_q = \frac{1+\sin\phi}{1-\sin\phi},$$
$$N_{ca} = \frac{1-ctg\alpha ctg(\beta+\phi)}{\cos(\alpha+\delta)+\sin(\alpha+\delta)ctg(\beta+\phi)} \tag{2}$$

By coefficients (2), which depend on soil characteristics (internal friction angle, angle of friction between soil and tool steel and soil density), traction force depends implicitly on the soil moisture, texture and physico-chemical properties of the soil. If the influence of humidity is partly known and quantifiable, the influences of soil texture and its physico-chemical composition are difficult to quantify.

It can also be observed that in the formulas in *(McKyes, 1985; Owen, 1989; Al-Neama and Hertzilius, 2017*), there is a term which depends on the square of the working depth, in the static term, which can often be neglected in relation to the other components of the same static term.

Variation of draft force with working speed of the soil tillage machine

Taking into consideration the general shape of the draft force (1) and the numerous theoretical, experimental or mixed studies dealing with the influence of the working speed on the draft force, this subchapter attempts to give some indications to those interested in a way to address this issue. First of all, it should be remembered that the working speed for some agricultural works is limited by the proper quality of the work: sowing, spraying, phytosanitary treatments, possibly soil tillage, etc. The most important result of this chapter is that it is possible to estimate the working speed that an agricultural aggregate needs to achieve in order for the load-dependent component of the draft force to be significant in relation to the component static.

To calculate the critical work speed at which the component that depends on the speed of the traction resistance equals the static component of the same force, the next second-degree equation must be solved:

$$Bv + Cv^2 = A \tag{3}$$

Taking into account that all the coefficients *A, B, C* are positive (see Table 1), it follows that if *C* is not null, the only acceptable root is the positive one:

$$v_{cr} = \frac{\sqrt{B^2 + 4AC} - B}{2C}, C > 0 \tag{4}$$

Solution (4) is valid for those forces of traction resistance that depend on the square of velocity. For the cases where the draft force depends only linearly on the working speed (concrete cases are given in the American standard (*ASAE, 2003*), i.e. *C* is null and *B* is non null, there is another critical speed given by the formula:

$$v_{cr} = \frac{A}{B}, C = 0, B > 0 \tag{5}$$

For draft force formulas that do not depend on the working speed or the dependence is insignificant, the critical speed value does not exist. The expressions of the critical working speed at which the dynamic component of the draft force become equal to the static component are calculated for the models considered in Table 2 and are written in Table 3.

Table 3

The critical speeds of the variants of the draft forces given in Table 2

Formula	v_{cr}
Goriacikin*, (*Letosnev, 1959)*	$\sqrt{\frac{k}{\varepsilon} + \frac{fG}{ab} \cdot \frac{1}{\varepsilon}}$
USA Standard**, (*ASAE, 2003)*	$\sqrt{\frac{K}{E} + \frac{D^2}{4E}} - \frac{D}{2E}, if\ E \neq 0\ and\ \frac{K}{D}\ if\ E = 0\ and\ D \neq 0$
(*Owen, 1989; Al-Neama and Hertzilius, 2017*)	$v_{cr} = \sqrt{ag\frac{N_\rho}{N_a} + \frac{C_o}{\rho} \cdot \frac{N_c}{N_a} + \frac{C_a}{\rho} \cdot \frac{N_{ca}}{N_a} + \frac{q}{\rho} \cdot \frac{N_q}{N_a}}, N_a \neq 0$
Generalization (*Owen, 1989; Al-Neama and Hertzilius, 2017)*	$v_{cr} = \sqrt{ag\frac{N_\rho}{N_a} + \frac{C_o}{\rho} \cdot \frac{N_c}{N_a} + \frac{C_a}{\rho} \cdot \frac{N_{ca}}{N_a} + \frac{q}{\rho} \cdot \frac{N_q}{N_a} + \frac{D^2}{4\rho^2 N_a^2}} - \frac{D}{2\rho N_a}, N_a \neq 0$

For the draft force formula given in (*Letosnev, 1959*), according to the data in this paper, the minimum critical speed is 2.13 m/s, or 7.7 km/h (for light or very light soils). For the machines included in the American Standard (*ASAE, 2003*), the critical speed varies between 11.07 and 20.53 km/h or between 3.07 and 5.7 m/s.

It is noted that in general the critical speed calculation formulas, starting from which the component that depends on the working speed, of the draft force exceeds the static one, are of the same nature as the formula of the movement speed of some types of waves in the soil. According to data from (*Obrzud and Truty, 2012; Kezdi, 1974; Prat et al., 1995*), the speeds of the elastic waves in the ground start at 15 km/h, reaching values above 1500 km/h. This specification is made because there is the possibility of breaking or pre-breaking compacted areas using mechanical waves produced by special plows. By producing suitable mechanical waves (whose velocity, wavelength and frequency depend on the humidity and soil structure), some resonances became possible to appear that produce remarkable cracks in the soil before the tillage tool, which would reduce the effort of cutting and of friction.

In the Table 4 critical speeds are calculated, according to the American standard (*ASAE, 2003*) and the formulas from Table 3.

Table 4

Critical speed for the American standard, (*ASAE, 2003*) machinery

Implement	***K***	***D***	***E***	***critical speed, m/s***
MAJOR TILLAGE TOOLS Subsoiler/Manure Injector narrow point	22600	0	2332.8	3.11
30 cm winged point	29400	0	3110.4	3.07
Moldboard Plow	65200	0	6609.6	3.14
Chisel Plow 5 cm straight point	9100	1944	0	4.68
7.5 cm shovel/35 cm sweep	10700	2268	0	4.72
10 cm twisted shovel	12300	2628	0	4.68
Sweep Plow primary tillage	39000	6840	0	5.70
secondary tillage	27300	4788	0	5.70
Disk Harrow, Tandem primary tillage	30900	5760	0	5.36
secondary tillage	21600	4032	0	5.36
Disk Harrow, Offset primary tillage	36400	6768	0	5.37
secondary tillage	25400	4752	0	5.34
Disk Gang, Single primary tillage	12400	2304	0	5.38
secondary tillage	8600	1620	0	5.31
Coulters smooth or ripple	5500	972	0	5.65
bubble or flute	6600	1188	0	5.55
Field Cultivator primary tillage	4600	1008	0	4.56
secondary tillage	3200	684	0	4.68
Row Crop Cultivator S-tine	14000	2520	0	5.55
C-shank	26000	4680	0	5.55
No-till	43500	7848	0	5.54
Rod Weeder	21000	3852	0	5.45
Disk-Bedder	18500	3420	0	5.41

The effects of the structure of the draft force on the optimal problem of the working process of the machines for the soil tillage

The optimization of the working processes of the agricultural machinery for the soil tillage has two main types of objective functions: the functions related to the economic performances (energy consumption, the working capacity) and the functions related to the quality of the soil tillage performed. Less commonly used objective functions, are related to the wear of tillage tools or to the quantity of pollutant emissions in the environment (although these are implicitly considered by the reduction of energy consumption, the separate considerations being directed to the use of green from renewable sources). The objective functions that reflect the quality of the tillage done are difficult to consider as they require a very high number of experiences and, on this way, depend by many specified factors. However, the beginnings of broader approaches, have already emerged, (*Al-Suhaibani and Ghaly, 2010; Deshpande and Shriwal, 2017*). As a result, taking into account the subject of this paper, the first category of objective functions is only referred to.

The objective functions aimed at economic performance (reducing consumption, increasing productivity, decreasing specific consumption, etc.) are based almost invariably on the draft force and continuing with the power consumed, the energy consumed on the surface unit worked, etc. Some of the more complex models also consider the traction tool skating function. This article does not take into account skating, because it does not have as a specific objective the optimization of agricultural aggregates for soil tillage.

The draft force (1), which is a continuous and differentiable function in report to the working speed (second degree function of the working speed), has positive coefficients *A*, *B* and *C*. This can be seen in Table 2. It can be seen that the coefficients N_p, N_c, N_{ca}, N_q, are positive from their definition formulas given in (*McKyes, 1985*). For the coefficient N_a, there is no information from (*Owen, 1989; Al-Neama and Hertzilius, 2017)*, but there is no physical reason to consider it negative. As a result of these considerations, it seems that the traction resistance force has a minimum point relative to the working speed, but the value of this speed that minimizes the draft force, is negative. This result has no physical meaning for the modeled work process, so that in the usual working range, the draft force is rising monotonously. Likewise, it turns out that the power required to overcome traction resistance has optimal positive speeds.

One possibility to obtain an optimal (potential[4]) point of the soil tillage process is to consider the objective function called the *traction resistance force specific to the unit of productivity*[5], defined as the ratio between two process parameters:

$$H(v) = \frac{F(v)}{bv} = \frac{A + Bv + Cv^2}{bv} \tag{6}$$

The *H* function, defined by (6), has a positive minimum of coordinates:

$$v_{\min} = \sqrt{\frac{A}{C}}, H_{\min} = \frac{2\sqrt{AC} + B}{b} \tag{7}$$

Obviously, the optimal point with coordinates (6) and (7) exists only for machines for which the draft force depends on the square of working speed, that is $C \neq 0$. The expressions of the resistance to traction and productivity given in (8) are obtained:

$$F_{opt} = F(v_{\min}) = B\sqrt{\frac{A}{C}} + 2A, W_{opt} = b \cdot v_{\min} = b\sqrt{\frac{A}{C}} \tag{8}$$

According to the data from (*ASAE, 2003*) only three pieces of equipment in the US standard list show optimal points of type (7) - (8). The values of the coordinates of these points and the performance of the equipment for these optimal working regimes are given in Table 5. We underline once again that, according to (*ASAE, 2003*), the coordinates of the critical speed of the optimal point, do not depend on the ground, the width and the working depth or the number of working parts.

Table 5

Coordinates of optimal points and aggregate performance in this case, calculated after (*ASAE, 2003*)

Implement	Optimal speed m/s	Draft force per productivity unit N/m^2	Pt. prod, ha/h	Optimal draft, kN
MAJOR TILLAGE TOOLS Subsoiler/Manure Injector narrow point	3.11	13.45	1.68	94.92
30 cm winged point	3.07	132.82	1.66	123.48
Moldboard Plow	3.14	57.66	1.70	273.84

Note 1: The critical speed (4) is equal to the optimal speed (7), if B = 0 (cases C = 0 or A = 0 being uninteresting). Like the critical point (4) - (5), the optimal point given by (8) must be validated experimentally. Experiences are not simple and should start from near the theoretically predicted speed, whether critical or optimal.

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[4] The optimal point is obtained theoretically and, for the time being, it is not validated experimentally.

[5] Only effective productivity is considered, so no account is taken of the returns at the ends of the plot and no technological breaks.

Note 2: The general problem of optimization of the draft force consider, not only in the working speed of agricultural aggregates for soil tillage, but also in terms of the geometric parameters of the tools, geometric parameters (rake angle, friction angle between the metal surface of the tools and soil) and parameters describing the soil's internal properties (cohesion, adhesion and the internal friction angle of the cohesive or non-cohesive soil, eventually in relation with humidity).

Obviously, at the higher level of optimization of the entire working process, the parameters of the traction means, especially skating, adherence, etc., will be taken into account.

Note 3: The formulas of the draft force written in Table 2 are not fully equivalent, even though, mathematically, the transformations of one of the formulas into another are relatively simple. This is mainly due to the limits of the validity of formulas. The limits of validity refer especially to the working depth. For example, the k-values of the Goriacikin model are tabulated in (*Letosnev, 1959*) only for depths of up to 15-20 cm.

Techniques for identifying the dependence of the draft force on the working speed

In order to estimate the coefficients of the function given in the formula (1) for the draft force, based on experimental data, a relatively simple calculation method is proposed in this chapter.

Suppose we have the experimental data (F_i, v_i), $i=1...n_v$, that forms a coordinate string, the first being the draft force measured, and the second corresponding working speed. The hypothesis that helps to solve the problem is that the draft force is of the form (1). Therefore, it is assumed that, with some approximation, the next relations are valid:

$$F_i = A + B\cdot v_i + C\cdot {v_i}^2,\ i=1,...,n_v \tag{9}$$

The three constants can be directly determined by the least squares method. In this paper another method will be given, based on the form (9) of the function sought.

The next matrix is constructed by definition of the elements:

$$\Delta F_{i,j} = F_i - F_j,\ i,j=1,...,n_v, v_i > v_j \tag{10}$$

Assuming that the draft force of the experimental data behaviour with satisfactory approximation, according to formula (9), result the relations:

$$\Delta F_{i,j} = F_i - F_j = B(v_i - v_j) + C(v_i^2 - v_j^2),\ i,j=1,...,n_v, v_i > v_j \tag{11}$$

The matrix with the elements is built:

$$\Delta R_{i,j} = \frac{\Delta F_{i,j}}{v_i - v_j} = B + C(v_i + v_j),\ i,j=1,...,n_v, v_i > v_j \tag{12}$$

Whether matrix:

$$Sv_{i,j} = v_i + v_j,\ i,j=1,...,n_v, \tag{13}$$

From relations (12) and (13), the next relationship is obtained:

$$R_{i,j} = B + C\cdot Sv_{i,j},\ i,j=1,...,n_v, \tag{14}$$

In order to conform to the usual computational algorithms in experimental data processing programs, the *R* and *Sv* matrices are transformed into vectors by line readings, with the exception of null elements. Then, obviously using the relations (14) for the resulting vector pair, the coefficient *B* is determined as the draft force value for the zero-working speed ("intercept" in the usual software language), and *C* is the slope of the right line ("slope", in the languages common software). The coefficient *A* is found by differences or by averaging differences between experimental data:

$$A = \frac{\sum_{i=1}^{n_v} F_i - B\cdot v_i - C\cdot {v_i}^2}{n_v} \tag{15}$$

CONCLUSIONS

Although, apparently, the calculation of the draft forces is made in many variants, following the study, there is a form that integrates all these variants. Two visible centres in which mathematical models of draft force have been developed are the North American (US and Canada), respectively the East European, with the centre in the Soviet Union (USSR). Both proposals are found in the generalized form of the American Standard.

The dependence of the draft force on the square of the working speed is found in most of the literature. In the formulas where the working speed does not appear, it is often neglected. The negligence of the traction resistance-dependent component is due to its low value compared to the static component value (under normal operating conditions, i.e. low operating speeds compared to critical speeds). This situation is found both experimentally and theoretically, from the proposed formulas.

American specialist literature prefer the introduction of the static component of draft force as the sum of terms imposed by soil properties (density, cohesion, adhesion, internal friction, vertical loading, so, in the terms of soil mechanics, convertible into the terms of the mechanics of continuous media) and the impact characteristics between the ground and the tool (friction between tool steel and ground, rake angle, general geometry of the tool). Eastern European literature uses global, phenomenological coefficients, directly defined, on concrete or general soils (*k*, *f*). As for the dynamic term (depending on the working speed), the situation, although seemingly the same as for the static term, is basically absolutely convergent, the soil density being one of the most important parameters that give the coefficient of the dynamic component. Although in Soviet literature the main coefficient giving the term dynamics is introduced as having its own meaning, the authors then show that its main component is, also, the soil density. In what concerns the first-degree coefficients in the working speed, there is very few information. In any case, the American standard gives a number of agricultural machines to which the coefficient of the first-degree term in the travel speed is nonzero.

The general structure of the draft force, (1) together with the detailed formulas, especially for the static component (Table 1), allow the binding of the draft force, and the mechanical characteristics of the soil (given in terms of the classical mechanics of the continuous media), of the soil-tool interaction data, width, work depth and working speed. In addition, knowing the humidity dependence on soil mechanical parameters and tool-to-soil interaction parameters, the soil moisture parameter can become an argument of the draft force function. This specification of factors that influence the strength of traction resistance also leads to the idea of multi-parametric optimization of the work process.

As far as the optimization of the traction force is concerned, it has very little chance to have optimal points within the range of variables of the function. Minimum or maximum points for draft force are only found on the border of the variance range of the function variables. The static term generally has no extremum points within the usual multidimensional range, except for one more complicated model than that given in Table 1, the case of the cohesive soil with the rough surface, isolated case, for which an experimental confirmation is difficult. Under these conditions, the optimization of the working process is sought by trying to use other functions involved in the modeling process or by minimizing some combinations of draft force and other functions describing the working process of the soil tillage machines (e.g. productivity). By any theoretical way optimal points that define an optimal working regime would be obtained, these results should be validated experimentally. Until a satisfactory experimental validation, theoretical outcomes remain within the hypothesis.

An alternative solution is the optimization in relation to parameters of the quality of the work, but this variant is very expensive (it requires a large amount of experimental research), the results having a low generality. Another more complex variant may consider the skidding of the traction means, and compaction of the soil, but this is also very demanding in terms of experimental costs, whether for validation only.

Attempts to obtain better performance formulas for traction resistance force using theoretical-empirical methods based on experimental data have the chance to make estimates slightly more accurate than the analytical formulas in Table 2. However, these attempts to introduce such formulas (theoretically empirical: of the polynomial form, in the form of products of factors at different powers), are affected by the following disadvantages:

- they have a profoundly particular character: they are only correct for the soils and the climate in which the experiences whose results have been used, have been conducted. For any other estimate in another geographic area, experiences must be resumed. Experiences should cover the full season as fully as possible, the state of the land being different in different seasons (soil moisture, vegetal remains, crop roots, etc.).
- the physical explanation of the coefficients introduced in the formulas (measurement units and their actual measurement) is deficient, especially in the polytropic functions, where even coefficients with unacceptable dimension, resulting from calculation, can occur.

As a first consequence, it is recommended to use the combinations of dimensional correct parameters in the theoretical - empirical analysis. A second consequence is the continuation of the use of the analytical formulas in various variants, even though some corrections should be made, but they can be easily applied to the coefficients that physically represent the currently used parameters of the soil: cohesion, adhesion, angle of internal friction, soil-steel friction angle, humidity, density etc.

A set of problems are left for study and clarification: the comparative study of the performances of the various formulas for calculating the tensile strength for a particular machine or category of machines, the optimal framework for the characteristics of the whole aggregate for the soil works, the estimation of the conditions in which the American standard can be applied in Europe and many more.

In conclusion, once again it is underlined that the theoretical formulas for estimating the draft force of the soil tillage machinery are consistent and convergent. Their architecture represents a natural development integrated into the physics of the deformable solid. The representative differences are given by the typical ways of describing used by the contemporary physics: the phenomenological approach (*https://en.wikipedia.org/wiki/Phenomenological_model*) (predominantly in early Russian school, subsequently used also in American school) and the theoretical approach (starting from principles and theoretical models of higher rank, preponderant in early American school). The two models converge to the same overall final shape that has been shown. The differences between them are minor and are based on the local and random structure of the soil and climate. In fact, viewed from the perspective of these categories of models, the formula in the American standard is a phenomenological description, just like the classical formula of the Russian school. However, by identifying it is concluded that the phenomenological coefficients can be expressed in terms of the mechanics of soil, regarded as a deformable solid (continuous media). Thus, it is possible to pass from the choice of coefficients in formulas by soil types (light, medium, heavy, etc.), in phenomenological terms, to the characterization of these coefficients by precise soil characteristics (also used in the field of civil constructions, etc.): cohesion, adhesion, angle of internal friction. Formulas thus get a form closer to a theoretical model. In addition to the last parameters of soil moisture and its composition, they allow the introduction of these characteristics into the calculation of estimation and search for optimal working regimes.

As far as possible, it is recommended that all users use all of the traction force computation formulas, even if the data for some of them is computed by conversion, using for example conversion relationships. Particular attention will be paid to the suitability of soil characteristics within experimentally admitted limits. Full equivalence through the control and validation of draft force calculation formulas remains a basic objective for the broader work to follow. In these papers, any corrections or adjustments should be studied to harmonize the results of the formulas in Table 2 for each major category of agricultural machinery for soil tillage.

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