RESEARCH ON THE DRAFT FORCE ESTIMATION OF VARIABLE WIDTH PLOUGHS

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Ploughing is one of the most important germination bed preparation works. In order to achieve this, the ploughs that are used can be with fixed working width or with variable working width. The plough with variable working width can be used for special works, with required working depths and widths so that the quality of the works is appropriate. The working process of ploughs with variable working width depends on the physical characteristics of the plough as well as on the physical properties of the soil on which the ploughing is performed. The document presents the experimental research carried out in the purpose of mathematical modelling of the traction force depending on the parameters of the work process and soil conditions.

Keywords: variable width plough, soil conditions, tillage.

1. Introduction

Agricultural machinery is considered as one of the most important aspects for performing almost all agricultural operations, the agricultural productions being significantly improved since tractors have been used for obtaining them [1].

Crops growing is done usually on tilled soil, tillage being the most expensive operation in terms of energy consumption. For this reason, there are numerous attempts to maximize the efficiency of performing soil tillage works, having several options for deep soil tillage [2].

There are numerous research made in order to predict the draft force and slippage for tractors during various works, including ploughing, this aspect being extremely important both from the point of view of agricultural work quality and fuel consumption [3, 4, 5]. Their main purpose was to identify a way for optimal usage of tractor during work for maximum draft force versus minimum slippage and fuel consumption. However, most of the models have different particularities

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which makes them hard to be considered as universally valid in all instances. Also, there are constructive differences between tillage agricultural machinery which led to development of several models for draft force estimation of chisel ploughs, deep soil loosening machines, mouldboard ploughs, variable width mouldboard ploughs etc.

Ploughing is the oldest process for tillage to establish agricultural crops and is carried out with the help of ploughs. Along with the need to increase the working capacity, the width of the ploughs has increased a lot lately, by increasing the number of mouldboards. The operation of high-capacity plough was possible due to the increase in power and traction performance of tractors.

If in the past classic ploughs were towed, today attached or semi-attached plough are used. The number of mouldboards increased steadily. The current ploughs have 4 -5 mouldboards in the attached version, or even 8-12 or even 20 mouldboards for semi-attached or towed ploughs. The increase in the weight and size of the ploughs has led to an evolution of the fastening systems to the tractor. At first, the ploughs had a single point attachment, later they had a two-point attachment for hydraulically operated ploughs with distributor control.

To meet the agrotechnical requirements, ploughing must be carried out in accordance with the following conditions.

• To be executed in the optimal time interval, respecting the conditions of temperature, moisture, etc;
• The working depth should be adjusted according to the crops decided to be established, and the deviation should not be greater than 5% of the nominal value (+/- 1 cm for a ploughing depth of 20 cm);
• The furrows must have a constant width and to be completely overturned, ensuring the coverage of plant residues and their incorporation into the soil in a percentage higher than 95%;
• The previously administered organic fertilizers to be completely incorporated;
• The soil should be shredded over the entire working depth, more than 75% of the soil fractions should have an average size below 5 cm;
• The surface of the ploughed field to be uniform, with well-turned furrows, without ridges and ditches;
• There should be no mistakes and the ends of the plots should be closed with the last furrow turned inwards;
•The lands with a slope angle greater than 6% should be ploughed according to the contour line, with the overturning of the furrow towards the hill [6].

To know exactly the energy required to operate the ploughs and to be able to follow the influences of the various factors involved, it is necessary to know the causes that determine the resistance forces that appear during the ploughing work. The tensile strength of the ploughs is a sum of all the forces resulting from the interaction of the active and auxiliary bodies with the ground, in a horizontal direction.

It is dependent on many factors, and following studies, these factors can be grouped into three categories:

• Soil-dependent factors, namely: soil type; physical and mechanical properties of the soil (composition, texture, structure, etc.); soil condition (moisture, degree of compaction, degree of weeding, etc.); relief conditions; surface micro-relief;

• Constructive factors: the shape and type of active bodies; the quality of the surfaces of the active bodies (material, roughness, coefficient of friction, etc.); the technical condition of the active edges (degree of wear of the coulter edge); shape, type and technical condition of the auxiliary bodies; plough mass;

• Exploitation factors: furrow dimensions (depth, width); the number of mouldboards; working speed; manner of connecting to the tractor; the correctness of the adjustments that were made.

Climatic changes affect the agriculture in a way which require the adaption of farm management and machinery in order to mitigate the effect of prolonged draught periods followed by floods. For this reason, variable width ploughs could become a valuable tool to be used for different environments due to variable geometry which could be changed by the farmer in function of the environmental conditions.

Within this paper was proposed a mathematical model for the draft force necessary for drawing a variable width plough and the experiments made to validate the model were presented. The model took into consideration the soil characteristics as well as also the imposed working parameters: tillage depth, working width and drawing speed. The experiments were performed on stubble field, using a variable width plough with three mouldboards.

2. Material and method

To establish the draft force necessary for the execution of the ploughing work with the plough, the opposite resistance force of the plough must be determined. In general, the tensile strength depends on the physical-mechanical properties of the worked soil (composition, moisture, compactness, etc.), the dimensions of the cut furrow (depth and width), the working speed, the shape of the active surfaces, etc.

During ploughing work, there is always a force that does not depend on the working depth or the speed. It is the effect of the frictional forces that appear in the support points of the plough such as: the friction of the mould blades on the bottom of the furrow, the frictions in the wheel bushes, the friction and the rolling resistance of the wheels, etc. Each of these resistant forces, taken separately, is proportional to the weight of the plough returning to one support point or another. All the resistant forces indicated above can be assessed as proportional to the weight of the tractor-plough unit.

$$F_1 = \mu G \quad (1)$$

where: μ is a coefficient similar to the coefficient of friction;

G is the weight of the plough;

The value of the resistance force F_1 is not determined by the useful mechanical work performed, but represents a resistance force that always accompanies the operation of the plough.

Secondly, a resistance force F_2 appears due to the cutting and deformation of the furrow. This resistance force is considered independent of speed, but is proportional to the furrow section, with *a* and *b* being the dimensions of the section:

$$F_2 = kanb \quad (2)$$

where: k is a coefficient that characterizes the specific resistance to soil deformation;

a is the working depth;

b is the width of the mouldboard;

n represents the number of mouldboards.

In the third line, a resistance force F_3 occurs due to the acquiring of the kinetic energy of earth particles when they are moved laterally by the plough.

$$F_3 = n\varepsilon abv^2 \quad (3)$$

where: ε is a coefficient that depends on the shape of the active surface of the mouldboard and the properties of the soil [7];

a is the working depth;

b is the width of the mouldboard or furrow;

v is the working speed;

Thus, the formula for calculating the force required to draw the plough with one mouldboard, one of the most common models in the speciality literature is presented below:

$$F_t = F_1 + F_2 + F_3 = \mu G + kanb + \varepsilon anbv^2 \quad (4)$$

where: F_t is the draft force.

This is the relation of the expression of the tensile strength, widely used in the Eastern European speciality literature, [8, 9, 10, 11, 12], totally or partially. However, the values of the coefficient *k* that characterize the specific resistance to soil deformation are usually taken from tables of values that have been determined under specific conditions of particular soils located in different areas of the country, which generates model errors. To eliminate them, starting from the basic form (4), we propose the formula for calculating the draft force which introduces the dependence on the physical characteristics of the soil, mainly on its density and penetration resistance, on the characteristics of the working process (speed) and the constructive characteristics of the plough (mouldboards orientation angle):

$$F = fG + n\left[k_1 r + k_2 \rho_{sol} v^2\left(1 - cos(\gamma)\right)\right]ab + \varepsilon nabv^2 \tag{5}$$

where: *k1* and *k2* are model coefficients that will be determined from the experimental data by the least squares method. Through them, the coefficient that characterizes the specific resistance to soil deformation is expressed as a function of the resistance to soil penetration, soil density and mouldboard angle as following:

$$k = \left[k_1 r + k_2 \rho_{sol} v^2\left(1 - cos(\gamma)\right)\right] \tag{6}$$

where: r is the resistance to soil penetration;
ρ_{sol} is the density of the soil;
γ is the angle of the mouldboard in relation to the forward direction;

We denote the total working width by $B = nb$.

To determine the values of the constant coefficients *f, k1, k2* and ε by linear regression, the functional $T(f,k_1,k_2,\varepsilon,G,\rho_{sol},a_i,B_i,v_i,r_i, \gamma_i)$ was formed as a sum of the squares of the differences between the values obtained by applying equation (6) and the real values measured in experiments $a_i,b_i,v_i, r_i, \gamma_i$. *G* is also constant and represents the weight of the tractor-plough aggregate unit used for experiments.

$$T = \sum(F - F_i)^2 = \sum\left(fG + \left(k_1 r_i + k_2 \rho_{sol} v_i{}^2\left(1 - cos(\gamma_i)\right)\right)a_i B_i + \varepsilon a_i B_i v_i{}^2 - F_i\right)^2 = min \tag{7}$$

To determine the coefficients *f, k1, k2* and ε, by mathematical regression, the condition was imposed for *T*, expressed by equation (7), to be minimal.

The minimum of function *T* in relation to *f, k1, k2* and ε is obtained by cancelling the partial derivatives of *T* in relation to the same coefficients, meaning $\frac{\partial T}{\partial f} = 0, \frac{\partial T}{\partial k_1} = 0$, $\frac{\partial T}{\partial k_2} = 0$ and $\frac{\partial T}{\partial \varepsilon} = 0$.

The partial derivatives of *T* function were determined according to each of them and the unique determined system was created, of 4 equations with 4 unknowns (relation 8).

$$\begin{cases} \frac{\partial T}{\partial f} = 2\sum\left(fG + \left(k_1 r_i + k_2 \rho_{sol} v_i^2 (1 - cos(\gamma_i))\right) a_i B_i + \varepsilon a_i B_i v_i^2 - F_i\right) G = 0 \\ \frac{\partial T}{\partial k_1} = 2\sum\left(fG + \left(k_1 r_i + k_2 \rho_{sol} v_i^2 (1 - cos(\gamma_i))\right) a_i B_i + \varepsilon a_i B_i v_i^2 - F_i\right) r_i a_i B_i = 0 \\ \frac{\partial T}{\partial k_2} = 2\sum\left(fG + \left(k_1 r_i + k_2 \rho_{sol} v_i^2 (1 - cos(\gamma_i))\right) a_i B_i + \varepsilon a_i B_i v_i^2 - F_i\right) \rho_{sol} v_i^2 a_i B_i (1 - cos(\gamma_i)) = 0 \\ \frac{\partial T}{\partial \varepsilon} = 2\sum\left(fG + \left(k_1 r_i + k_2 \rho_{sol} v_i^2 (1 - cos(\gamma_i))\right) a_i B_i + \varepsilon a_i B_i v_i^2 - F_i\right) a_i B_i v_i^2 = 0 \end{cases} \quad (8)$$

This system of equation can be solved numerically. At first, the constants were eliminated, and the following equivalent matrix expression was obtained:

$$ZY = X \quad (9)$$

where:

$$Z = \begin{pmatrix} \sum G^2 & \sum G a_i B_i r_i & \sum G \rho_{sol} a_i B_i v_i^2 (1 - cos(\gamma_i)) & \sum G a_i B_i v_i^2 \\ \sum G a_i B_i r_i & \sum (a_i B_i r_i)^2 & \sum \rho_{sol} r_i (a_i B_i v_i)^2 (1 - cos(\gamma_i)) & \sum r_i (a_i B_i v_i)^2 \\ \sum G \rho_{sol} a_i B_i v_i^2 (1 - cos(\gamma_i)) & \sum \rho_{sol} r_i (a_i B_i v_i)^2 (1 - cos(\gamma_i)) & \sum \rho_{sol} a_i B_i v_i^2 (1 - cos(\gamma_i)) & \sum \rho_{sol} (a_i B_i)^2 (v_i)^4 (1 - cos(\gamma_i)) \\ \sum G a_i B_i v_i^2 & \sum r_i (a_i B_i v_i)^2 & \sum \rho_{sol} (a_i B_i)^2 (v_i)^4 (1 - cos(\gamma_i)) & \sum (a_i B_i)^2 (v_i)^4 \end{pmatrix}$$

$$X = \begin{pmatrix} \sum G F_i \\ \sum F_i a_i B_i r_i \\ \sum F_i \rho_{sol} a_i B_i v_i^2 (1 - cos(\gamma_i)) \\ \sum F_i a_i B_i v_i^2 \end{pmatrix} \text{ and } Y = \begin{pmatrix} f \\ k_1 \\ k_2 \\ \varepsilon \end{pmatrix} \quad (10)$$

The determination of the vector Y formed by the unknown coefficients *(f, k1, k2, ε)*, was done by the numerical solving, through mathematical regression of the equation (8), obtained from the matrix equation (10) by the inverse matrix method, using the data strings obtained from experiments:

$$Y = Z^{-1} X \quad (11)$$

In order to numerically solve the matrix equation (8), experiments were performed on the field for the direct measurement of the working parameters a_i,b_i,v_i, r_i, γ_i. as well as F_i.

For the experimental tests, the field was delimited by milestones, by obtaining 50 meters long experimental plots. A space of 10 m was left between the soles along the working length to allow the tractor-plough unit to reach the required working regime before entering the actual testing plot.

For the planning of the experiments, it was used the factorial experiment method [13]. An experiment is factorial complete if each level of one factor is combined with each level of the other factors in the experiment, meaning that experimental samples are given by any possible combination of factor levels. Taking into account the fact that there were a number of 3 factors combined (adjusted working depth, adjusted working width and adjusted working speed), which each take 3 distinct values (minimum, average, maximum) and a number of 1 repetition of the experiment (due to the fact that the test will take place over 50 m, there is a sufficient number of samples to obtain an average value as accurate as possible) for each possible combination of them, there is a need for 27 samples to describe the process of performing the ploughing work using a plough with variable working width.

The following conditions were imposed for the tests:

- working depth: 3 values were considered for the working depth, 10, 20 and 30 cm; the chosen working depths correspond to the minimum, maximum and average values set for the plough chosen for conducting the experiments.

- speed: the tests were performed at three speeds, determined according to the actual operating conditions and the characteristics of the tractor gearbox at a rated engine speed of 2200 rpm (gear I - 0.9 m / s, gear II - 1.5 m / s and gear III - 1.9 m / s), representing the usual speeds used in ploughing practice;

- working width: 3 adjustments of the working width were considered, respectively 80, 100 and 120 cm; The chosen working widths correspond to the minimum, maximum and average values set for the plough chosen for the experiments.

For experimental determination of draft force through measurements of the acting forces in the coupling elements between the plough and the tractor, it was used a measuring apparatus composed by a frame mounted between the 3-points linkage mechanism and the variable width plough.

The measuring apparatus is a rigid construction, from which are linked three strain gauge rings with a measuring range between 0.5-15 kN, and which are connecting the plough to the 3-point linkage mechanism.

The mean draft force is calculated by algebraic sum of the forces measured by the three strain gauge rings, which is later divided by the total number of recorded samples.

For data acquisition was used a QuantumX 1615 amplifier system, with 16 strain gage input channels, connect with a laptop which had installed CatMAN conditioning and data acquisition software.

Fig. 1. Apparatus for draft force measurement mounted between the plough and the tractor

3. Results

The experimental research was performed on the experimental field inside INMA Bucharest-Băneasa in order to characterize the behaviour of the ploughing unit according to the adjustable parameters of the work process (working width, working depth, speed).

The plough unit consisted of an 80 hp New Holland wheeled agricultural tractor and a variable plough with a variable working width with three mouldboards.

For the analysis from a dynamic and energetic point of view, the experimental research aimed at determining the forces acting on the agricultural unit during loading, both on the tractor and the plough, respectively, the dynamic and operating parameters (mean working speed, mean draft force, mean working depth, mean working width).

Figure 2 shows an example of graph of the actual traction measured as a function of time.

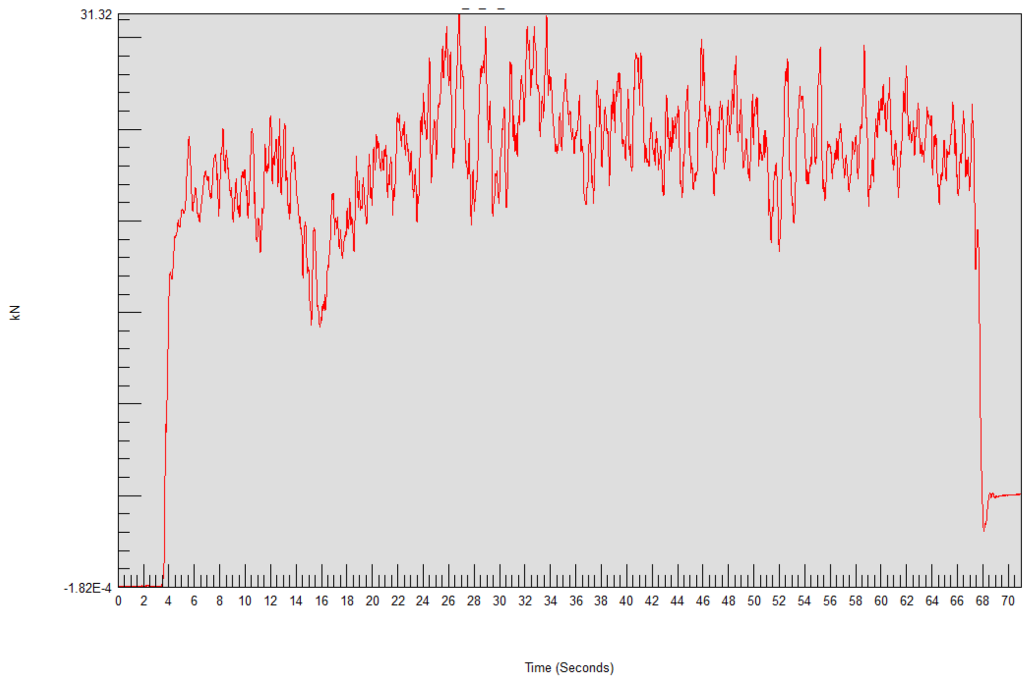

Fig. 2. Draft force evolution

Table 1 shows the values of the independent and dependent variables used in the mathematical regression operation on equation (8) performed using a calculation program in Mathcad. The values presented are the average values obtained during the experiments, all calculations being related to the average value.

The weight of the plough tractor unit *G* was constant, 49830 N, corresponding to a plough mass of 600 kg. The soil density ρ_{sol} was considered constant, 1500 kg / m^3.

Table 1

The values of the independent *a, B, γ,v* and dependent *F* variables

Test no.	Working width B_i [m]	Working depth a_i [m]	Mould blades angle γ[^{0}]	Speed v_i [m/s]	Medium penetration resistance r_i [Pa]	Average draft force F_i [N]
1	0.80	0.10	36.65	0.938889	728416.7	17150
2	0.83	0.12	36.65	1.569444	728416.7	17560
3	0.83	0.13	36.65	1.886111	728416.7	17590
4	0.83	0.20	36.65	0.908333	1155458	20960
5	0.83	0.22	36.65	1.347222	1155458	21170
6	0.83	0.23	36.65	1.816667	1155458	22100
7	0.82	0.30	36.65	0.886111	1571889	23530
8	0.83	0.33	36.65	1.25	1571889	23850
9	0.83	0.32	36.65	1.469444	1571889	24130
10	1.01	0.10	38.89	0.891667	728416.7	18240
11	1.04	0.12	38.89	1.472222	728416.7	19150
12	1.03	0.13	38.89	1.861111	728416.7	19970
13	1.04	0.20	38.89	0.877778	1155458	21760
14	1.04	0.21	38.89	1.294444	1155458	22060
15	1.04	0.23	38.89	1.733333	1155458	22950
16	1.04	0.30	38.89	0.805556	1571889	23560
17	1.04	0.31	38.89	1.188889	1571889	24320
18	1.04	0.32	38.89	1.597222	1571889	24480
19	1.20	0.10	41.13	0.869444	728416.7	20980
20	1.23	0.12	41.13	1.447222	728416.7	21160
21	1.23	0.11	41.13	1.741667	728416.7	21440
22	1.23	0.20	41.13	0.875	1155458	24280
23	1.23	0.21	41.13	1.269444	1155458	24320
24	1.22	0.20	41.13	1.694444	1155458	24720
25	1.23	0.30	41.13	0.797222	1571889	26240
26	1.23	0.31	41.13	1.138889	1571889	26840
27	1.23	0.30	41.13	1.744444	1571889	28130

Using a calculation program in Mathcad, from the matrix equation (10) and the experimental data from table 1 the coefficients (f, k_1, k_2, ε),, were determined, resulting in the mathematical model 11 of the analytical function (5).

$$Fc = 0.386\, G + \left[0.012r + 49.261\rho_{sol}v^2\left(1 - cos(\gamma)\right)\right]aB - 15180aBv^2 \quad (12)$$

where Fc represents the calculated draft force.

Fig. 3 shows the distribution of the draft force on the three components (due to the cutting and deformation of the furrow, the speed dependence, respectively the component due to the movement in the furrow – (without load).

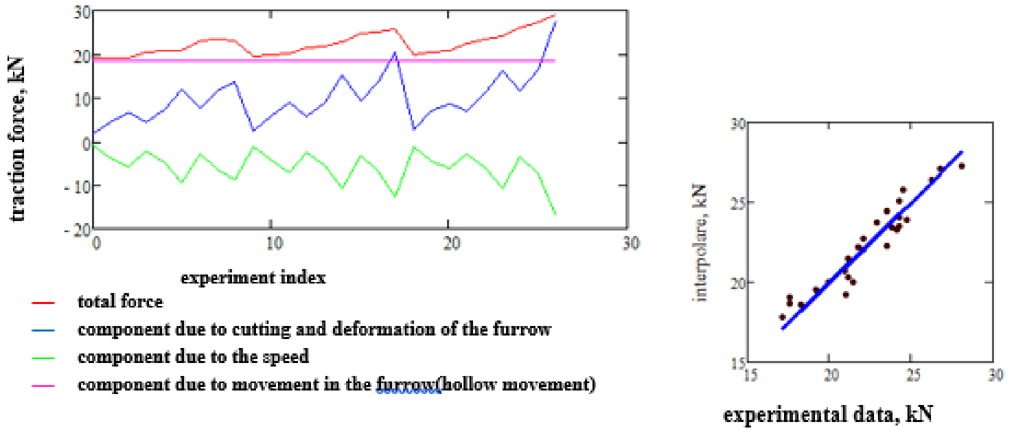

Fig. 3 . Goriachkin-type interpolation force distribution, by experiments and components (left) and the point cloud of experimental and interpolated force coordinates as well as the regression line (right, regression coefficient 0.954)

Next, an analysis was made regarding the degree of accuracy of the relation (10) for estimating the draft force, compared to the real data of the average draft force obtained in experiments.

Table 2 shows the values of the average draft force measured during the experiments and the values of the average draft force calculated using relation 12, calculating the estimation error.

Table 2

Comparative values measured force-calculated force

Test no.	Average draft force measured F_i [N]	Average draft force calculated Fc_i [N]	Error [%]
1	17150	19016.174	10.881
2	17560	19091.518	8.722
3	17590	19086.8	8.509
4	20960	20624.084	1.603
5	21170	20747.548	1.996
6	22100	20694.705	6.359
7	23530	22992.56	2.284
8	23850	23395.204	1.907

Test no.	Average draft force measured F_i [N]	Average draft force calculated Fc_i [N]	Error [%]
9	24130	23150.546	4.059
10	18240	19341.61	6.04
11	19150	19782.65	3.304
12	19970	20093.525	0.619
13	21760	21490.891	1.237
14	22060	21886.705	0.786
15	22950	22601.673	1.518
16	23560	24624.644	4.519
17	24320	25127.52	3.32
18	24480	25794.003	5.368
19	20980	19693.997	6.13
20	21160	20607.495	2.611
21	21440	20805.169	2.961
22	24280	22414.526	7.683
23	24320	23285.657	4.253
24	24720	23947.719	3.124
25	26240	26199.616	0.154
26	26840	27232.707	1.463
27	28130	28910.754	2.776

The maximum error determined between the experimental data and the calculated data was 10.881%, being recorded for the minimum working parameters (width, depth, and minimum working speed) corresponding to experiment 1. It is observed that as these parameters reach the average values, respectively maximum working, the error decreases resulting in a good accuracy of the proposed model. The calculated correlation coefficient was 0.938, demonstrating a very strong correlation between the series of data obtained experimentally and those calculated by the proposed relation.

4. Conclusions

The results of experimental research are largely confirmed by theoretical research conducted by simulation using mathematical models. The differences are determined by randomly present factors (soil condition caused by areas with different moisture, the presence of plant debris on the ground and in the soil, etc.) or by some particularities regarding the plough settings, the technical condition of the working tools, etc.

The working width was 0.8, 1 and 1.2 m for the working depth of 0.1, 0.2 and 0.3 m respectively. The recorded working speeds were in the range 0.9 - 1.86 m / s.

It is observed that for the mathematical model represented by the relation (12), the influence of the force due to the movement in the furrow (without load) is constant, the variations of the total traction force being mainly caused by the force component due to cutting and deformation of the furrow. This component was dependent both on the soil characteristics (density and resistance to penetration) and on the regulated characteristics of the work process: speed, depth and working width. An increase of this component is observed with the increase of the adjusted parameters, a special value having the working width B.

R E F E R E N C E S

[1] *Kareem, I.K., Sven, P.*, Effect of ploughing depth, tractor forward speed, and plough types on the fuel consumption and tractor performance, Polytechnic Journal, vol. 9 (1), pp. 43-49, ISSN: 2313-5727, (2019).

[2] *Lukáš, R., Adam, P., František, B.*, The influence of using the traction booster of the semi-mounted plough on the performance parameters of the ploughing set, ACTA UNIVERSITATIS AGRICULTURAE ET SILVICULTURAE MENDELIANAE BRUNENSIS, vol. 66, no. 2, pp.381-388, (2018).

[3] *Antonio, L.T.M., Carlos, R.T.*, Draft prediction models for soil engaging tines in two soils of Rio Grande do sul, Brazil, Eng. Agric.Jaboticabal, vol. 33, no.1, pp. 167-175, (2013).

[4] *Schreiber, M., Kutzbach, H.D.*, Influence of soil and tire parameters on traction, RESEARCH IN AGRICULTURAL ENGINEERING, vol. 54, (2), pp. 43–49, (2008).

[5] *Algirdas, J., Gediminas, P., Antanas, J.*, Mathematical description of tractor slippage with variable tire inflation pressure, ENGINEERING FOR RURAL DEVELOPMENT, DOI: 10.22616/ERDev2018.17.N530, (2018).

[6] *Tudor, A., Glodeanu, M.*, Exploitation of agricultural machines, Sitech Publishing House, Craiova, (2009).

[7] *Cardei, P., Matache, M., Nutescu, C.*, Optimum working conditions for variable widthploughs, https://www.researchgate.net/publication/318983573, (2017)

[8] *Goryachkin, V.P.*, In: Luchinskii ND, editor. Collected works, vol. II, 2nd edition, pp. 62-63, Jerusalem: Israel program for scientific translations, (1972).

[9] *Letosnev, M.N.*, Agricultural Machinery. Theory, calculation, design, testing, State Agro-Forestry Publishing House, Bucharest, (1959).

[10] *Scripnic, V., Babiciu, P.*, Agricultural machines, Ceres Publishing House, Bucharest, (1979).

[11] *Şandru, A., Badescu, M., Sandru, L.*, Reducing energy consumption through the rational use of agricultural aggregates, Scrisul Romanesc Publishing House, Craiova, (1982).

[12] *Tecusan, N., Ionescu, E.*, Tractors and cars, Bucharest Didactic and Pedagogical Publishing House, (1982).

[13] *Montgomery, D.*, Design and analysis of experiments Eighth Edition, John Wiley & Sons, Inc., ISBN 978-1-118-14692-7, (2013).