U.P.B. Sci. Bull., Series D, Vol. 77, Iss. 1, 2015 ISSN 1454-2358

RESEARCHES IN THE FIELD OF THE ENERGETICS OF THE MISCANTHUS PLANTER. (1) – DETERMINATION OF THE TRACTION FORCE

Ion-Cristian POENARU[1], Petru CARDEI[2], Gheorghe VOICU[3], Gigel PARASCHIV[3], Mirela DINCA[4], Valentin VLADUT[2], Gabriel MATACHE[2]

The article presents original results obtained by the authors in the field of miscanthus planters energetics. An original mathematical model is presented for tensile strength of miscanthus rhizomes planters, obtained by an original theoretical-empirical method, based on the experimental data obtained using original conceptual experiments.

Key words: miscanthus, planter, coulter, traction force

1. Introduction

Estimation of tensile strength for agricultural machines is a very important issue, involved in the conception, design and optimal operation of agricultural aggregates. Although in this area there are many papers dedicated to these problems (eg [1], [2], [3]), many of them remain actual, especially when a new car, new working bodies or new combinations of working bodies appear. This is also the case of miscanthus planter. On the other hand, in the entire literature some aspects are still incompletely approached. New approaches as well as new solutions, demonstrating cohesion between mechanics of agricultural machines and classical mechanics are necessary and the formulations must be made in only common language.

Taking into account the above we have introduced different resistance coefficients deformation of soil for different working bodies because they work in depths sensibly different and in soils which are successively processed by working bodies of each section. Also, the shapes of organs differ sufficiently so that the coefficients that depend on their form be different sensitive as values.
Neither friction coefficients are not all the same because on the one hand, the work at different depths and on the other hand quality surfaces of working bodies which differ in shape and degree of processing.

[1] PhD. Student, Dep. of Biotechnical Systems, University POLITEHNICA of Bucharest, Romania
[2] Researcher, National Institute of Research-Development for Machines and Installations Designed to Agriculture and Food Industry - INMA Bucharest
[3] Prof., Dep. of Biotechnical Systems, University POLITEHNICA of Bucharest, Romania
[4] Lect., Dep. of Biotechnical Systems, University POLITEHNICA of Bucharest, Romania, e-mail: mirela_dilea@yahoo.com

The working process of the aggregate tractor - miscanthus rhizomes planter is complex, including about fifty important parameters, some of which (over thirty) are included in modeling the interaction between aggregate and soil, being listed in Table 1.

Table 1

List of parameters of the mathematical model

Parameter's name	Notation	SI unit
Tensile strength corresponding to the coulter, coverage disk, press wheel, wheel with wings in V and the friction of train movement (the framework with wheels of the planter)	R_b, R_d, R_t, R_v, R_f	N
Tensile strengths of miscanthus planter in the two versions of the operating working (coulter, coverage disks plus press wheel, in the former, and plus two wheels and wings in V, in the second version)	R_1, R_2	N
The coefficients of friction between the coulter, coverage disks, press wheel, wheels with wings in V or train movement, and soil	μ_b, μ_d, μ_t, μ_v, φ	-
Soil resistance coefficients to deformation for the coulter, coverage disks, press wheel, wheels with wings in V	k_b, k_d, k_t, k_v	N/m^2
Coefficients of resistance to deformation of soil that depend on the soil and the shape of the active surface of the working bodies: coulter, coulter, coverage disks, press wheel, wheels with wings in V	ε_b, ε_d, ε_t, ε_v	-
The areas projections of effective working surfaces of the working bodies of the miscanthus planter sections on normal plane to the direction of advancement of the aggregate	s_b,s_d,s_t,s_v	m^2
The weights distributed on the coulters, coverage disks, press wheels, wheels with wings in V and on the train movement	G_b, G_d, G_t, G_v, G_r	N
The working depth	a	m
The vector of the working depths experimentally conducted	$\{a_i\}_{i=1,...,75}$	m
The vector of the working speeds intensities experimentally conducted	$\{v_i\}_{i=1,...,75}$	m/s
The vector of the tensile strength forces recorded during the experiments	$\{F_{ti}\}_{i=1,...,75}$	N
The vector of fuel consumption recorded during the experiments	$\{C_i\}_{i=1,...,75}$	l/ha
The working speed	v	m/s
Soil density (the specific mass)	ρ	kg/m^3
The diameter of the coverage disks	D	m
The share of lag on the vertical between the working depth of the coulter and the coverage disks	h	m
The angle at the arc of center of the disk that works in the soil	φ_a	rad
The angle of inclination of the disk towards soil surface	β	rad
The global functional and on sections (groups of experiments with the same working configuration of the miscanthus planter	ψ, Φ	N
The quality parameter of interpolation	r	%

2. Theoretical elements

The calculation formulae for the soil resistance to deformation in the working process of certain agricultural aggregates contain geometrical characteristics of working bodies (working width and depth), physical characteristics of the planter (mass, weight), and physical characteristics of the soil in contact with the working bodies and other parts of the machine (specific resistance to deformation of soil, coefficient of friction, coefficients that depend on the shape of the active surface of the working bodies and soil properties). One of the most important treaties in the field of agricultural machines, [1] shows that the parameters of the calculation formulae from the last category mentioned above must be determined experimentally. According to [1], "the attempts to determine the three coefficients from several dynamometers of the coulter on the same soil but at different speeds and depths of working, using the method of the least squares have proved to be quite complicated and without practical application". Then, [1] proposes for the simplification, determination through separate experiments of some coefficients, such as the coefficient of friction by dynamometers of the coulter in a initially open furrow.

We have taken into account these remarks from the literature and the main goals regarding the use of such formulae in optimizing the working process energetics of an agricultural aggregates and we have developed a strategy of experimentation which includes many working processes that are not natural in the sense that in practice, the machine will never work in some of the experimental configurations.

2.1. The theoretical processing fundamentals of the experimental data

In order to determine traction force for each component of the miscanthus planter's working sections, two ways of solving can be approached. The first is typical for researchers from fields studying links between parameters without physical units or having well-defined physical units and deduce relationships between them as simple as possible without asking the calculated coefficients to have a well defined physical interpretation (unit of measure and significance within an existing theory).

The second way of solving starts from the theoretical foundations accepted in literature and, using experimental data, values of the coefficient in relations that define the the dependencies between various parameters in a mathematical model are identified.

The coefficients thus determined have exact the physical dimensions and must fit in an acceptable physical interval. In this article is described the approach result of the second way of solving.

In order to define the formulae or the relations used to determine the coefficients, one starts from the relationships of Goreacikin, [1], which are discussed separately.

2.2 The mathematical model of the tensile strength corresponding the sections components of the miscanthus rhizomes planter

The formulae proposed in this paragraph are only hypotheses, but based on a long experience in the field of agricultural machines for soil.

For coulter, the following formula for calculating the tensile strength is proposed:

$$R_b = \mu_b G_b + k_b s_b(a) + \varepsilon_b \rho s_b(a) v^2 \quad (1)$$

For the tensile strength of the coverage disks, one can work with the formula:

$$R_d = \mu_d G_d + k_d s_d(a) + \varepsilon_d \rho s_d(a) v^2 \quad (2)$$

For the press wheel, the following hypothesis can be adopted:

$$R_t = \mu_t G_t + k_t s_t(a) + \varepsilon_t \rho s_t(a) v^2 \quad (3)$$

Generally, for the press wheel only the first term is considered.

The other two can appear only if the wheel is blocked, stops rotating or suffers slippage. However, for symmetry, although k_t=0 ε_t=0, in the formal calculation we keep them for symmetry and when, in certain field conditions, it is necessary to reintroduce the non-zero values for them. A similar case is used for the tensile strength of the wheel with wings in V:

$$R_v = \mu_v G_v + k_v s_v(a) + \varepsilon_v \rho s_v(a) v^2 \quad (4)$$

For the tensile strength corresponding of the train movement, which has the role to limit working depth, we use a simple hypothesis

$$R_f(\varphi) = \varphi G_r \quad (5)$$

For the areas projections of effective working surfaces of the working bodies on a normal plane to the direction of advancement of the aggregate the following formula has been established:

$$s_b(a) = b_b a \quad (6)$$

for the coulter, and:

$$s_d(a) = \frac{D^2}{4}\left(\varphi_a(a-h) - \sin\varphi_a(a-h)\right) \quad (7)$$

for the coverage disks, where:

$$\varphi_a(a) = 2\arccos\left(1 - \frac{2a}{D\cos(\beta)}\right) \tag{8}$$

where β is the disk inclination angle towards the direction of advance, which is set in this case to the value of 10^o. Regarding the terms coefficients that depend on working speed, we preferred to introduce them through the product between a nondimensional coefficient and soil density, as suggested in [1], and confirmed in [9].

For the working surfaces areas corresponding to the wheels, the calculation process is more complex and is based on equalizing wheel pressure on the soil to the strength at static penetration. For this reason, in the formulae (16) and (17) the resistances of the wheels depend not only on the working speed but also on the working depth.

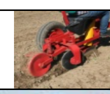
3. Material and method

3.1. The base material

In order to determine the desired characteristics five types of experiments were conducted for the miscanthus rhizomes planter MPM-4 (on four rows), equipped as described in Table 2. A total of 75 experiments under different conditions were performed.

Table 2

Categories of equipment used in experiments performed in INMA polygon

Experiment index	Number of active sections	The structure of the external sections	The structure of the central sections	Images
1 - 27	2	Coulter + coverage disks + press wheel	-	
28 - 48	4	Coulter + coverage disks + press wheels	Coulter + wheel with wings in V	
49 - 60	4	Coulter	Coulter	
61 - 68	2	Coulter + wheel with wings in V	-	
69 - 75	2	Coulter + coverage disks	-	

Miscanthus rhizomes planter is designed to work with a number of four sections, each equipped with two variants: coulter - coverage disk - press wheel, respectively coulter - wheel with wings in V. As it can be seen from Table 1, the planter configurations in the conducted experiments are not specific to the normal working in operation. The set of carried out experiments is designed in order to determine the influence of each of the sections working components on the tensile strength of the entire machine in operation.

In each of the experiments the working depth, the working speed, the tensile force required of involving the miscanthus rhizomes planter and fuel consumption in fixed configuration were measured (Table 2). It was kept under constant control sliding, and, for some types of experiments, the quality of work in terms of the geometry soil area was determined.

The experimental data vector is:

$$\{a_i, v_i, F_{ti}, C_i\}_{i=1,...,75} \tag{9}$$

where the depths and the tensile force are average values on a lot of recordings made within each experiment, and the working speed and the consumption are the overall sizes measured separately for each experiment.

3.2. The method of data processing

The parameters to be determined using experimental data are: μ_b, μ_d, μ_t, μ_v, k_b, k_d, k_t, k_v, ε_b, ε_d, ε_t, ε_v, φ. For determining the 13 parameters of the mathematical model of the proposed traction force one minimizes a functional which depends on these parameters and the experimental data (least squares method), [10], [11]:

$$\Psi(\mu_b, \mu_d, \mu_t, \mu_v, k_b, k_d, k_t, k_v, \varepsilon_b, \varepsilon_d, \varepsilon_t, \varepsilon_v, \varphi) = \sum_{i=1}^{N}\left(\Phi\left(\mu_b, \mu_d, \mu_t, \mu_v, k_b, k_d, k_t, k_v, \varepsilon_b, \varepsilon_d, \varepsilon_t, \varepsilon_v, \varphi, a_i, v_i, i\right) - F_{ti}\right)^2 \tag{10}$$

where :

$$\Phi = \begin{cases} 2\left(R_b + R_d + R_t\right) + R_f, \, if \ i = 1,...,27 \\ 2\left(R_b + R_d + R_t\right) + 2\left(R_b + R_d + R_v\right) + R_f, \, if \ i = 28,...,48 \\ 4R_b + R_f, \, if \ i = 49,...,60 \\ 2\left(R_b + R_v\right) + R_f, \, if \ i = 61...68 \\ 2\left(R_b + R_d\right) + R_f, \, if \ i = 69...75 \end{cases} \tag{11}$$

each function having specified arguments in formulae (1) - (5) and (10).

The index i changes the expression in functional Φ after the experiment index, which means changing the experimental conditions, more precise of the miscanthus rhizomes planter configuration.

The functional (10) is not continuous, this changing the expression to completion of each group of experiments with the change of equipment planter configuration. For this reason and for the fact that the functional has many arguments, the existence and uniqueness of the extremum point is difficult to prove. The deep theoretical study of this function remains an open question, with fundamental implications but whose outcome may not be very useful in solving our problem. In addition, if one would demonstrate the uniqueness even of a minimum point for the functional (10), it is likely that among the 13 coordinates are some whose values are physically unacceptable. In this situation, at least for the first approximation, a solution that in generally, in the scientific literature would go in the category of weak solutions is chosen. The meaning of this statement is that the functional (10) is minimized on a physically acceptable field of parameters, 13-dimensional domain, for which is accepted solutions located on the boundary of this area, thus solutions that are not local extreme. The priority is for us to get a physically meaningful solution. The measure of the "closeness" of the solution thus obtained from experimental data is determined following a common formula in such problems (F_t with bar above is the average value of the traction force):

$$r = \frac{\sqrt{\sum_{i=1}^{N} \left(\Phi\left(\mu_b, \mu_d, \mu_t, \mu_v, k_b, k_d, k_t, k_v, \varepsilon_b, \varepsilon_d, \varepsilon_t, \varepsilon_v, \varphi, a_i, v_i, i\right) - F_{ti}\right)^2}}{N\overline{F_t}} \cdot 100 \qquad (12)$$

In order to minimize the functional (10) an algorithm that forms the basis of the method used in Mathcad, [5] was used. For additional details see [6], [7], [8]. The solution is chosen as to comply with the restrictions and decrease as much as possible the interpolation parameter r from (12). The restrictions we have imposed on the end of a rather long string of tests are:

$$\begin{aligned} &0.2 \le \mu_b \le 0.85, 0.1 \le \mu_d, 0.2 \le \mu_t, 0.25 \le \mu_v, k_b \ge 20000, k_d \ge 5000, \\ &k_t \ge 0.0, k_v \ge 10000, \varepsilon_b \ge 1.2, \varepsilon_d \ge 1.7, \varepsilon_t \ge 0.0, \varepsilon_v \ge 1.7, \varphi \ge 0.3 \end{aligned} \qquad (13)$$

Using the starting point of coordinates:

$$\begin{aligned} &\mu_b = 0.35, \mu_d = 0.05, \mu_t = 0.35, \mu_v = 0.35, k_b = 50000, k_d = 5000, \\ &k_t = 0.0,\ k_v = 15000, \varepsilon_b = 2.0, \varepsilon_d = 1.0, \varepsilon_t = 0.0, \varepsilon_v = 1.0, \varphi = 0.3 \end{aligned} \qquad (14)$$

the used software gives the solution:

$$\begin{aligned} &\mu_b = 0.85, \mu_d = 0.1, \mu_t = 0.2, \mu_v = 0.25, k_b = 20000, k_d = 5000, \\ &k_t = 0.0,\ k_v = 10000, \varepsilon_b = 1.2, \varepsilon_d = 1.7, \varepsilon_t = 0.0, \varepsilon_v = 1.7, \varphi = 0.347 \end{aligned} \qquad (15)$$

For this solution of the problem a value of interpolation quality measure, r= 1.983% was obtained. The way the interpolated points enroll in the "cloud" of data points can be seen in Fig. 1.

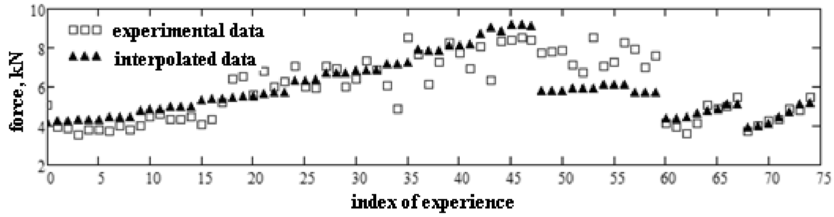


Fig. 1. The comparative distribution of the experimental and interpolated data, for the 75 experiments

This solution has been obtained after about 30 attempts the accuracy refusing to fall below 1.9% for other choices. Obviously, based on the test and there being no proof for the uniqueness of the solution (which probably does not exist in general), this solution can be improved.

3. Results

Using the solution (15), one can now write approximations for each of the corresponding tensile strengths of components working sections of miscanthus rhizomes planter, (1) – (5). We can write now these tensile strengths as a function of working depth and working speed only, parameters determined in (15) being considered constants of soil or soil-machine interaction (working body).

Consequently, we can write:

$$R_b(a,v) = R_b(\mu_b, k_b, \varepsilon_b, a, v),\ R_d(a,v) = R_d(\mu_d, k_d, \varepsilon_d, a, v),$$
$$R_t(a,v) = R_t(\mu_t, k_t, \varepsilon_t, v),\ R_v(a,v) = R_v(\mu_v, k_v, \varepsilon_v, v),\ R_f = \varphi G_r \quad (16)$$

Then, the expressions of the two classic versions of operation of miscanthus rhizomes planter in operation have the following expressions for the traction force:

$$R_1(a,v) = 4(R_b(a,v) + R_d(a,v) + R_t(a,v)), R_2(a,v) = 4(R_b(a,v) + R_v(a,v)) \quad (17)$$

In order to give a more complete picture of the behavior of these functions, some graphs are useful. Separate contribution of each of the compulsory and possible components of a miscanthus rhizomes planter section varies with the speed (in the range of experimental speeds), as shown in Fig. 2.

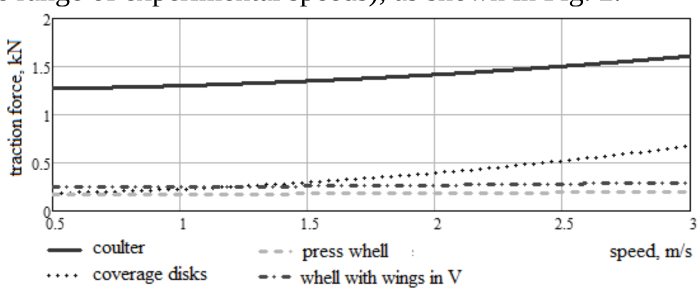


Fig. 2. The tensile strength variation of each components of miscanthus rhizomes planter section, for working depth of 12 cm (at the coulter)

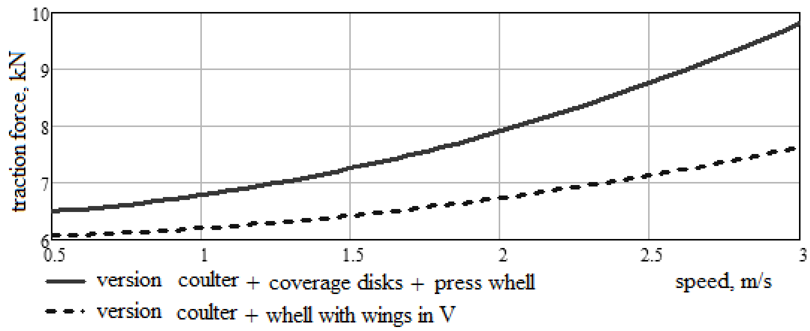


Fig. 3 The working speed variation of the two versions of operation of miscanthus rhizomes planter with four sections

Fig. 3 shows the comparative variation of the two versions of miscanthus rhizomes planter operation (coulter + coverage disks + press wheel and coulter + wheel with wings in V), with the working speed of the aggregate.

A graphical representation of the tensile strength variation as a function of two variables (working depth and working speed) is given as a surface in three-dimensional space in Fig. 4. The two approximately parallel surfaces correspond to the two working versions of miscanthus rhizomes planter: the version in which the working sections are equipped with press wheels and the version in which the working sections are equipped with wheels with wings in V.

Another result that contains interesting information can be simply observed using the graphical representation of Fig. 5. Plotting the component of the global tensile strength which depends on the working speed and the global static component, one can observe that the first can equal the second only at higher speeds than those achieved in the normal operation of the miscanthus rhizomes planter.

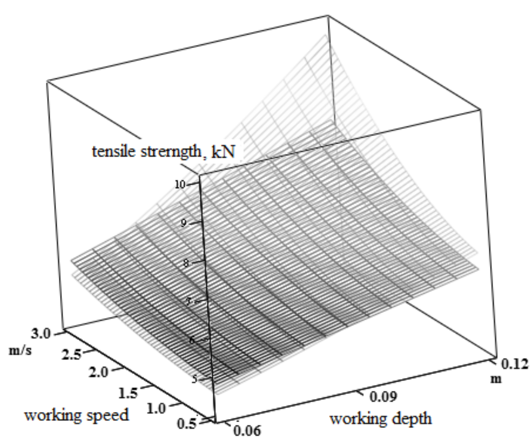


Fig. 4 Graphical representation of miscanthus rhizomes planter's tensile strength, in the two working versions, depending on the working speed and depth

The aggregate with miscanthus rhizomes planter in the variant of section composed of coulter + coverage disks + press wheel has the critical point in which the component of tensile strength dependent on the speed equals the static one at about 4.1 m/s (14.76 km/h), and in the version of section composed of coulter + wheel with wings in V, at a speed value about 5.9 m/s (21.24 km/h). Maximum speed during the experiments was about 2.728 m/s (9.821 km/h). One can notice that the critical speeds are not very different from the experimental working regime. Considering that the total traction force is not very high, and the 80 CP tractor that worked has a much higher traction availability, can be achieved and even exceeded these limits in operation. After reaching these working speed values, the working regime would enter into the critical area, because of domination of forces dependent on the working speed. Vibrations that produce oscillations of the work quality or discomfort in tractor may occur. But these phenomena remain to be investigated in further studies.

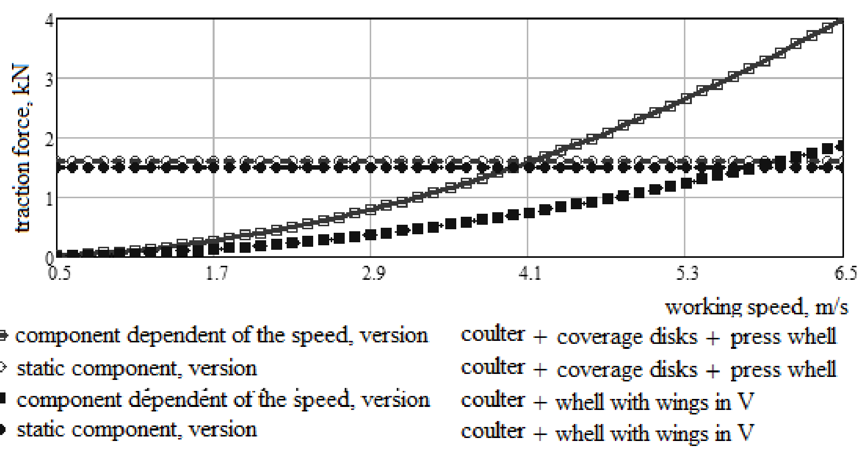


Fig. 5 Variation of the global tensile strength component of miscanthus rhizomes planter with the speed, compared with the static component

4. Conclusions

The research described in this paper has several original components. The results show only the most complicated mathematical model, but behind it stay tests with successively simplified models that have marked the stages of development and qualitative and quantitative leaps.

The first original aspect is addressing the problem of the tensile strength of a machine which does not have a single working body but several working bodies who work the soil one after the other.

Regarding the repetead processing of the same soil, the introduction of deformation resistance coefficients (static or dynamic) for each type of working body is also original, knowing that the soil shows different characteristics at different depths. It should also be noted that each working body acts is a soil already processed.

Although very original experiments were made in this area, as shown even in [1], however, the developed empirical strategy (which does not contain the experiments any normal working equipment of the machine) is original, allowing at least an approximate calculation of the tensile strength of each component of the miscanthus rhizomes planter's sections.

The method itself of deduction of tensile strengths functional shapes on each working body is original as scope and wide range of the approached aspects. The core of calculation using the method of least squares was approached in [1]. We worked, however, by minimizing the numerical calculation that makes the operator an artist who combines the mathematical calculation with the engineering experience, engineering itself being beyond calculation, pure art and intuition. The exposed working method is applicable in the field of all agricultural machines, but also outside of this area.

Functional forms derived with the proposed method starting from the experimental results, show that Goreacikin's classical formulae are viable, describe sufficiently well the role of various phenomena in establishing the intensity of tensile strength. The working speed dependencies are reduced, as it can be seen in Fig. 2 and 3, but still they exist. These influences would become more pronounced when the working speeds exceed appreciably the approached experimental interval, most times entering in the range of intangible speeds for agricultural machines, at least currently.

Also as a general conclusion, it should be specified that because that our results are based on experiments made on a single soil type and with a approximately constant humidity on horizons, the character of our results is a particular one. These results can be theoretically extended using new hypotheses, the experiments on other soil types and a wider range of humidities remaining however decisive.

The obtained results, with their particular character, can be applied as they are, in at least two directions. The first one is the estimated calculation of strength for the supporting structure of miscanthus rhizomes planter, that is application in designing. The second direction of application is the optimization of working processes of miscanthus rhizomes planter, meaning looking for optimal working regimes, issue that we will deal further in another paper.

Using the tensile strength formulae set out above, miscanthus rhizomes planter's users (eg. in a mechanization technology of the miscanthus crop), can calculate the traction capacity needed and then the necessary fuel even if they have no data about the soil on whicht hey work.

One can measure also the penetration resistance and then all the resistances can be taken proportional to the ratio of the average values of the vertical static penetration resistance to the working depths interval.

Acknowledgement

The work has been funded by the Sectoral Operational Programme Human Resources Development 2007-2013 of the Romanian Ministry of Labour, Family and Social Protection through the Financial Agreement POSDRU/107/1.5/S/76903.

R E F E R E N C E S

[1] *M. N. Letosnev*, Agricultural Machines, Ministry of Agriculture and Forests, State Agro-Silvica Publishing House, Bucharest, 1959, (in Romanian).
[2] *A. Şandru, S. Popescu, I. Cristea, V. Neculăiasa,* Exploatation of agricultural equipment, Didactic and Pedagogic Publishing House, Bucharest, 1983, (in Romanian).
[3] *N. Tecuşan, E. Ionescu*, Tractors and Automobiles, Didactic and Pedagogic Publishing House, Bucharest, 1982, (in Romanian).
[4] *V. Gioncu, M. Ivan,* Theory of critical and postcritical behaviour of elastic structures, Academy Publishing House, Bucharest, 1984, (in Romanian).
[5] Mathcad Professional User's Guide, 2001.
[6] *E. Polak*, Optimization-Algorithms and Consistent Approximations, New York, Springer Verlag, 1997.
[7] *W. Winston*, Operations Research: Applications and Algorithms, Wadsworth, Belmont, 1994.
[8] *P. Gill P., W. Murray, Wright M.*, Practical Optimization, San Diego, Academic Press, 1981.
[9] *P. Cardei, G. Kostandinov*, Soil farm machinery operating mode: from the optimization to the basis (2), INMATEH, vol. 37, No. 2/2012.
[10] *I. Gh. Sabac, P. Cocarlan, O. Stanasila, A. Topala*, Special mathematics, Didactic and Pedagogic Publishing House, Bucharest, 1983, (in Romanian).
[11] *C. Iacob, D. Homentcovschi, N. Marcov, A. Nicolau*, Classical and modern mathematics, Tehnical Publishing House, Bucharest, 1983, (in Romanian).