A Force Prediction Model for the Plough Introducing its Geometrical Characteristics and its Comparison with Gorjachkin and Gee Clough Models.

Amara Mahfoud, Feddal Mohamed Amine
Laboratoire de MachinismeAgricole
Génie Rural- ENSA

Abstract

To calculate the effort of the agricultural tools for the ploughing, several mathematical models are proposed. These models generally disregard geometrical characteristic of active surfaces of the working parts. For this reason, tests on channel of traction were carried out to check the validity of two models very frequently used, namely those of Gorjachkin and Gee Clough. The results showed that for the same form and in identical work conditions, the efforts were definitely different from a model to another.
Tests were also carried out on two active forms of surface. The effort calculated using separately one of the two models is the same one for two different surfaces. Whereas the values determined on channel, are completely different from a form to another. From where interest to propose a more universal model connecting the effort with the state of the soil and especially the geometrical characteristics of active surfaces.
The model establishes by the modelling method (Buckingham-Vachy) form:

$$Ft = \boldsymbol{\mu}.R.\, e^{-14.54} \cdot \left(\frac{v^2}{g \cdot b}\right)^{0.15} \cdot E^{4.13} \cdot \alpha^{5.94} \cdot \theta^{-16.01} \cdot k^{0.98} \cdot (k_1)^{12.98} \cdot (k_2)^{2.74} \cdot g \cdot d \cdot b^3$$

This model then was checked and compared with the models of Gorjachkin and Gee Clough on two forms of active surfaces of ploughs made in Algeria by companies ENPMA (farming form) and SACRA (cylindrical form). The efforts calculated using this model, are closer to the values measured on channel, than those calculated with Gorjachkin and Gee Clough models.

Key words: Energy, Effort, Speed, ploughing, geometrical characteristic, modelling, Width, depth

Résumé :

Pour calculer l'effort de résistance à la traction des outils aratoires pour la préparation du sol, plusieurs modèles mathématiques sont proposés. Ces modèles font généralement abstraction des caractéristiques géométriques des surfaces actives des pièces travaillantes.
Pour cette raison, des essais sur canal de traction ont été réalisés pour vérifier la validité de deux modèles très fréquemment utilisés, à savoir ceux de Gorjachkin et de Gee Clough. Les résultats ont montré que pour la même forme et dans des conditions de travail identiques, les efforts de résistance à la traction étaient nettement différents d'un modèle à un autre.
Des essais ont été également réalisés sur deux formes de surface actives. L'effort calculé à l'aide d'un des deux modèles et ce séparément est le même pour deux surfaces différentes. Alors que les valeurs déterminées sur canal, sont totalement différentes d'une forme à une autre. D'où l'intérêt de proposer un modèle plus universel mettant en relation l'effort avec l'état du sol et surtout les caractéristiques géométriques des surfaces actives.
Le modèle établit par la méthode de modélisation (Buckingham-Vachy) est de la forme :

$$Ft = \boldsymbol{\mu}.R.\, e^{-14.54} \cdot \left(\frac{v^2}{g \cdot b}\right)^{0.15} \cdot E^{4.13} \cdot \alpha^{5.94} \cdot \theta^{-16.01} \cdot k^{0.98} \cdot (k_1)^{12.98} \cdot (k_2)^{2.74} \cdot g \cdot d \cdot b^3$$

Ce modèle a été ensuite vérifié et comparé aux modèles de Gorjachkin et de Gee Clough sur deux formes de surfaces actives de corps de charrue à socs fabriqués en Algérie par les entreprises ENPMA (forme culturale) et SACRA (forme cylindrique).
Les efforts calculés à l'aide de ce modèle sont plus proches des valeurs mesurées sur canal, que celles calculées avec les modèles de Gorjachkin et de Gee Clough.

Mots clef: Energie, Effort, vitesse, labour, caractéristiques géométriques, modèle, largeur, profondeur.

1. Introduction

In the last few years several mathematical models were developed for the evaluation of the effort which the soil opposes to the working parts advance. These models are of two types, the first with two dimensions relates to the tools known as simple such as the blades and the ploughshares; the second type called to three dimensions, is relating to the tools on complex active surfaces like those of the bodies of ploughs. In what follows the interest will be related to this second type.

The models usually used for the effort determination are chronologically consigned below:

GORJACHKIN and SOEHNE model(1960)

$$F_t = f.G + K.a.b + \varepsilon.a.b.v^2$$

Modèle LARSON and al (1968)

$$F_t = \gamma.b^3\left[0.42 + 1.53.tg\phi.\left\{0.23.\left(\frac{C}{\gamma.a}\right)^{1.50}\right\} + 0.42 + 1.53.tg\phi.\left\{0.035.\left(\frac{C}{\gamma.a}\right)^{1.37}\right\}.\frac{v^2}{g.b}\right]$$

BINESSE model (1970).

$$F_t = S.\left[\frac{C}{\cos\phi}.(0.85 + \sin\phi)\right]$$

GEE GLOUGH and al model (1972)

$$F_t = a.b.\left\{13.30.\gamma.a + 3.06.\gamma.\frac{v^2}{g}\right\}$$

KUCZEWSKI model (1978)

$$F_t = F_{XY} + F_{ZY} + F_{XZ}$$

OSKOUI and al (1982)

$$G = K_1.CI + K_2.\gamma.(1 - \cos\phi).\frac{v^2}{g}$$

GRISSO and al model(1983)

$$F_t = a.b.(\gamma.b.N_\gamma + c.N_C + A_d.N_a)$$

QIONG and al (1986)

$$Ft = \gamma.a.(b_1 + b_2.v^2)$$

The analysis of these models shows:

In a general way, these models introduce the work depth, its width and speed as well as physical and soil mechanics characteristics, like cohesion and the density.

However, the geometrical characteristics of active surfaces such as the working angles, dimensions characteristic of surfaces are not taken into account.

Among the models quoted above, themodel suggested by Gorjachkin introduces a coefficient ε, characterizing the shape of the plough used.

Considering the shape complexity of the many existing plough, the determination of this coefficient (ε) is very difficult. Its values lie between 1500 and 2000 N. s^2/m^4.

According to Ros V. (1993), if the angles and dimensions of active surfaces of the plough were studied, it is practically within the framework of the description of these working parts or in that their effects on the qualitative indices of work of the soil, but not to calculate the effort.

Work of Nichols and Kummer, 1932; Doner and Nichols, 1934; and those of GaoQiong and al., 1986, were carried out to describe the active surface of the plough and to classify the forces produced during the execution of the ploughing as well as the relation between these forces and the properties of the soil.We will also announce that several of these models predicting the effort for the plough like those of Larson et al., 1968 and of Gee Clough et al., 1972, were developed on the basis of dimensional analysis.

Lastly, the choice of one of these models for the evaluation with precision of the effort is often delicate. Indeed, if we consider for example the models of Gee Clough (1972) and Gorjachkin (1960), we will notice that for the same form of active surface and under same terms of soil and employment, the values obtained are very different. Which will be thus the most reliable model for a precise evaluation of consumption in energy?

To answer this need, the objective of this work is the proposal for a mathematical model of the effort withmore precision and taking account of the form of active surfaces of plough.
The selected geometrical characteristics for mathematical modelling are respectively:

The angle of penetration: α
The angle of attack: γ
Angle of inclination of active surface: θ
The k ratio = a/b
The k_1 ratio = L_1/h
The k_2 ratio = d_1/d_3

The k_1 and k_2 ratios were selected in order to differentiate the two studied forms active surfaces. In addition to these parameters, the speed (v) and the dry density of the soil (d) were taken into account considering their unquestionable effects on the effort.

2. MaterialsandMethod

After geometrical characterization of the two shapes of active surfaces studied (cylindrical and farming form), three small-scale models (scales 1/4,1/3 and 1/2) for each form were designed (figures 5,6 and 7).These small-scale models were used to determine the effort (Ft) on channel of traction (figure4).The use of the channel allowed the control of the work conditions and to correctly analyze the effect of the geometrical characteristics of active surfaces on effort (Ft).
The results obtained allowed the establishment of a mathematical model of the effort Ft taking account geometrical characteristics of the active surface.The established model then is checked and compared with Gorjachkin and Gee Clough models.

2.1. Geometrical characterization of two active surfaces

Our tests related to two bodies of plough (figures 1 and 2) most usually used on the Algerian farms.

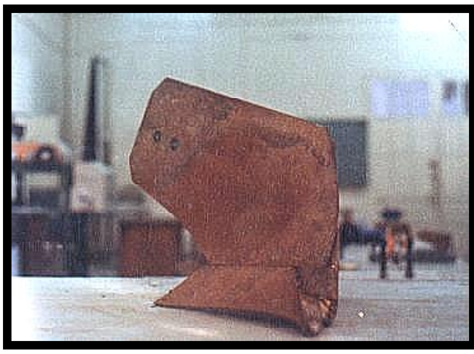
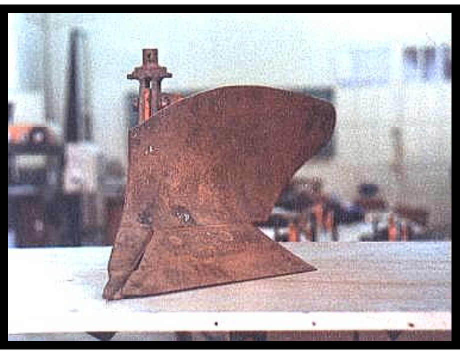

figure1:Form ENPMA (farming form) ***figure.2:Form SACRA (cylindrical form)***

The geometrical main features of the two shapes of plough are consigned in table 1:

Table 1: Constructive characteristics of used ploughs.

Body of plough	ENPMA (farming)	SACRA (cylindrical)
Height of the body h (mm)	440	425
Projected length l (mm)	940	740
Width b (mm)	350	310
Angle of penetrationα (°)	29	17
Angle of attack γ (°)	38	39
Angle of inclination θ (°)	35	33

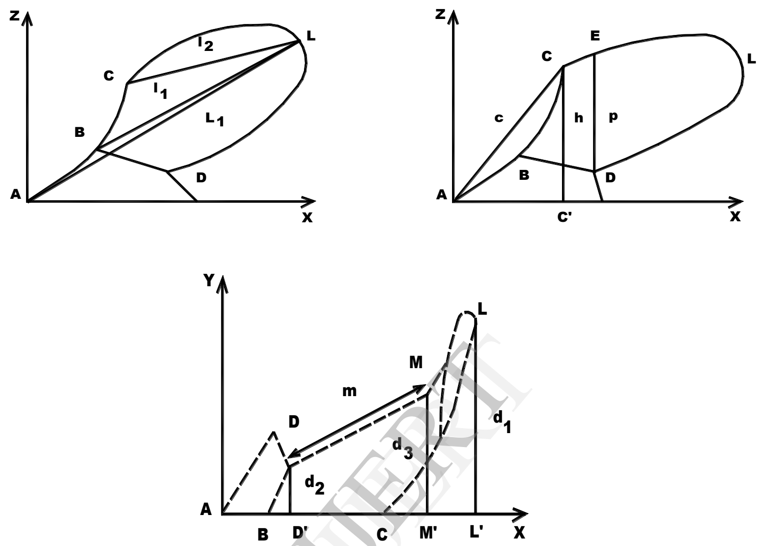

***figure*3: Dimensional specifications of a plough used to determinek_1 and k_2**

2.2. Effort analysis required by these two forms

The effort analysis was carried out on a channel of traction (figure: 3) with ploughs models on three scales reduced to 1/4, 1/3 and 1/2 (figures 5,6et7).

figure 4: Small-scale Ploughs models assembled on channel of traction

figure 5: Models reduced on scale 1/4

figure6: Models reduced on scale 1/3

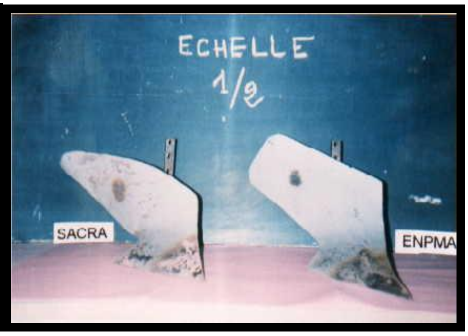

figure7: Models reduced on scale 1/2

2.3. Modelling of the effort

The principal stages of the establishment of the mathematical model are respectively:

- Establishment of the general equation: the required general equation is form:

$$Ft = f(E, d, v, \alpha, \theta, k, k_1, k_2, g)$$

- Definition and characterization of all the parameters of the equation: The various parameters of this equation are defined on table 2 following:

Table 2: Definition and characterization of the parameters of equation

symbolsunitsdimensions

<u>- DependantParameter</u>:

Effort.................... ……………………………….............FtdaN [M.L.T^{-2}]

<u>- Independent Parameters:</u>

- Works conditions

Speed ………. ....v m/s [L.T^{-1}]

Density of the soil……..d g/cm^3 [M.L^{-3}]

Scale...E - -

- Constructive Angles:

Angle of penetration..…… αradians -

Angle of attack ....……….........γradians -

Angle of inclination ....θradians -

- Ratio lengths:

Depth/width of work ....k - -

Maximum length of the plough/maximum height..…….k_1 - -

Back width plough/width at the point of

maximum curve of the plough.……................................ k_2 - -

Aacceleration due to gravity..gm/s^2[M.T^{-2}]

- **Correlation between the dependant parameter (Ft) and those analyzes independent (v, d, E, α, and θ, K, k1, k2)**

The interest of this analysis is to confirm the significant effect of these various parameters on the effort and to maintain them or not on the final equation.

As regards the angle of attack γ, this one being indirectly considered in the ratio k = a/b, (sin (γ) = b/length of the sharpened of the plough) it will not be introduced on the model.The equation obtained by polynomial regression is the following one:

$$\mathbf{Ft = - 39{,}71 + 54{,}86\, E + 32{,}83\, d + 13{,}36\, v + 84{,}33\, \alpha - 222{,}45\, \theta + 30{,}75\, k + 21{,}84\, k_1 + 13{,}95\, k_2}$$

The analysis of this relation makes it possible to classify in the order of the effect importance of each parameter studied on the effort.We will notice that the coefficient of the angle of inclination had the greatest absolute value (222,45), this shows the importance of the effect of active surface form on the effort Ft.

- **Determination of the adimensional parameters (π- terms).**

The definite adimensional parameters are respectively:

$$\pi_1 = \frac{Ft}{d.g.b^3};\quad \pi_2 = \frac{v^2}{gb};\quad \pi_3 = k;\quad \pi_4 = k_1,\quad \pi_5 = k_2$$

$$\pi_6 = \alpha;\quad \pi_7 = \theta$$

Taking account the theorem of Buckingham-Vachy. (inLanghaar H.L. 1954), the final relation will be form:

$$\frac{Ft}{d\ .g.b^3} = f\left(\frac{v^2}{gb}, k, k_1, k_2, \alpha, \theta\right)$$

And according to Kuszewski, (1982) this equation will be written in the form of a product of powers:

$$\frac{Ft}{d\ .g.b^3} = \left(\frac{v^2}{gb}\right)^a . (k)^b . (k_1)^c . (k_2)^d . (\alpha)^e . (\theta)^i . e^{Cste}$$

The problem thus amounts determining the values of the powers a, b, c, d, e, f and the constantCste, for that the use of the logarithms properties, is necessary. For that tests on channel of traction were realized in order to determine the effect of the various parameters on the effort.The final model giving the effort Ft in relation to the geometrical characteristics of active surfaces is:

$$\boldsymbol{Ft} = \mu.\boldsymbol{R}.\, e^{-14.54} \cdot \left(\frac{v^2}{g \cdot b}\right)^{0.15} \cdot E^{4.13} \cdot \alpha^{5.94} \cdot \theta^{-16.01} \cdot k^{0.98} \cdot (k_1)^{12.98} \cdot (k_2)^{2.74} \cdot g \cdot d \cdot b^3$$

The values of R (proportionality factor) are respectively R = 1,931 for the cylindrical form and 1,976 for the farming form for the small-scale model with scale 1/2.
The values of μ (coefficient of correction) are respectively of:

μ = 1000 for the form SACRA (cylindrical form plough)

μ = 10 for form ENPMA (farming form plough)

The two values allotted to μshow that the form of active surface has an important effect on the effort.

The units of the various parameters of this model are:

Effort: Ft (daN)
Speed: v (m/s)
Angles:αandθ(radians)
Apparent density: d (kg/m^3)
Terrestrial acceleration: g (m/s^2)
Width of work: b (m)
Characteristics of form: k, k_1 and k_2(without unit)

2.4. Application of the model

The application of this relation for real conditions of work quoted below would give the following results:

Real conditions of work

- Speed of ploughing : v =1,5 m/s(5,4 km/h)
- Density of soil: d =1.29 g/cm3 (1290 kg/m^3), this last transformation are necessary for the application of the models of Gorjatchkin and Gee Clough.
- Width of ploughing : b =0,31 mfor SACRA form and b =0.35 mfor ENPMA form
- Depth of ploughing: a =0.25 meters
- Report/ratio k = a/b: k = 0,806 for the form SACRA form, and k = 0.714 for ENPMA form

Geometrical characteristics of the two ploughsactive surfaces

Dimensions

k_1 ratio = L_1/h = 1,714 for SACRA form and k_1 = 2,136 for ENPMA form

k_2 ratio = d_1 / d_3 = 1,290 for SACRA form and k_2 = 1,464 for ENPMA form

Angles:

SACRA Form

α = 17 degrees = 0,297 rad

θ = 33 degrees = 0,576 rad

ENPMA form

α = 29 degrees = 0,506 rad

θ = 35 degrees = 0,611 rad

Using these values in relation suggested, for a real plough size, we will have:

Table 3: Effort Ft calculated using the model suggested

Speed (m/s)	0,23	0,29	0,43	0,87	1,5
Ft (SACRA form) (daN)	104,50	112,03	126,08	155,76	183,42
Ft (ENPMA form) (daN)	304,38	326,30	367,23	453,69	534,23

3. Comparison between the model established and those of Gorjachkin and Gee Clough.

In order to check the reliability of the established model, a comparative analysis with the Gorjachkin and Gee Clough models frequently used was carried out. For that certain parameters used in these the last two models are defined. The relations of the effort of these two researchers are respectively:

$$F_t = f.G + K.a.b + \varepsilon.a.b.v^2$$

$$F_t = a.b.\left\{13.30.\gamma.a + 3.06.\gamma.\frac{v^2}{g}\right\}$$

The tests being realized on the same type of altered soil (light soil textures), the value of K is the same one. It is of 3500 daN/m2, this value is the higher limit for the light soils and the lower limit for the soils known as average.These values will be applied to the Gorjachkin models. The values chosen, for the coefficients of formεare respectively 200 daN.s^2 /m^4 for the cylindrical form and 150 daN.s^2 /m^4 for the farming form.The choice of this parameter is often very delicate to determine, the number of active forms surfaces being very important. The effort values obtained with these models, for the same conditions of speed and soil are:

Table 4: Effort Ft calculated using Gorjachkin model

Speed (m/s)	0,23	0,29	0,43	0,87	1,50
Ft (SACRAform)(daN)	272,07	272,55	274,11	282,98	306,12
Ft (ENPMAform) (daN)	306,94	307,35	308,67	316,18	335,78

Table 5: Effort Ft calculated using Gee Clough model

Speed (m/s)	0,23	0,29	0,43	0,87	1,50
Ft (SACRA form)(daN)	334,03	334,99	338,07	355,57	401,25
Ft (ENPMA form)(daN)	377,13	378,21	381,69	401,45	453,02

The application of these two models for the effort determination, confirms the results of our work, namely that the ENPMA farming form is more demanding in energy for the ploughing realization.That thus highlights the importance of the geometrical characteristics of the active plough surface introduced in the established model. These results are illustrated on the following graphs (Fig.8, a and b).
The simplification of the Gorjachkin model, in the form Ft = k.a.b, without taking account the speed and form of active surfaces, will give the same value for Ft some is the form of active plough surfaces.

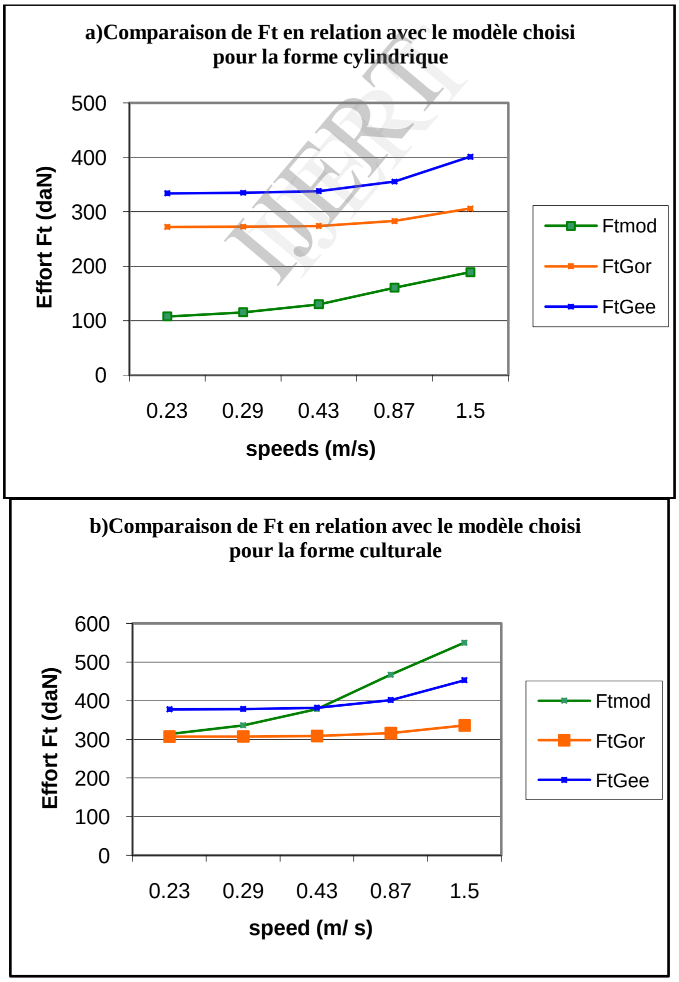

figure8 : Analyse comparative des efforts Ft en fonction de la vitesse d'avancement pour chaque modèle et pour chaque forme a) cylindrique et b) culturale

Analyses and discussion

Analyses of the established model watch clearly the effect of the geometrical characteristics of active surface on the effort.The angle of curveθand the characteristick_1 are the geometrical characteristics most influential on the effort. When θincreases the effort decreases on the other hand whenk_1 increases the effort increases.
The model suggested can be used for the evaluation of the effort of tensile strength for any form of active surfaces of plough. The Gorjachkin and Gee Clough models are usable only for precise forms. For cylindrical forms we use Gee Clough model and for the farming forms the Gorjachkin model will be used.

Conclusion
Two cases are to be considered for the use this model:

If this model is used by an agronomist, for the evaluation the required effort for the realization the ploughing, some of the parameters of the relation are constant (constructive parameters) such as the angles, the parameter k (depth/width), the parameters k_1 and k_2.It will thus be interested in the choice the speed of work, the soil density in order to correctly choose the best work conditions to reduce the energy needs at the time of the ploughings realization.

So on the other side, when this relation is used by an originator of agricultural tools, he will be interested more particularly in the constructive parameters by holding account obviously work conditions and technical agro requirements of the ploughings. That will allow the design plough adapted to preset conditions.

Bibliography

Binesse M., 1970 : Cisaillement et résistance spécifique du sol lors du labour classique. Etudes du CNEEMA, n°341-342 – France.

Doner, R.D. and Nichols, M.L , 1934 : The Dynamic Properties of Soil V. Dynamics of Soil on Plow Mouldboard Surfaces Related to Scouring. Journal of ASAE, Vol 15, n°1: 9-13

GaoQiong; Pitt, R.E.; Ruina, A. , 1986 : A Model to Predict Soil Forces on the Plough Mouldboard. Journal of Agricultural Engineering Research 35, p.141-155.

Gee Clough, D.G. et al., 1978: The empirical prediction of tractor implement field performance. J. Terramechanics, 15 (2) : 81-94

Gorjatchkin, V.P. et Sohene 1960 : Collected Works in Three Volumes. Ed. N. D. Luchinskii. Translated 1972. Jerusalem, Israel: Ketter Press.

Grisso et al., 1983 : A soil model based on limit equilibrumanalisio. Transaction of ASAE, vol. 26 n° 4 , p. 991-995

Kuczewski J. , 1978 : Eléments Théoriques des Machines Agricoles . Edition VarsoviePologne.

Langhaar H. L. , 1954: Dimensional Analysis and Theory of Models, Ed. New York . John Wiley and Sons, Inc.

Larson, L. W. et al. ,1968 : Predicting draft forces using mouldboardplows in agricultural soils. Transaction of ASAE, 11: 665-668.

Nichols, M.L. and Kummer, T. H. , 1932 : The Dynamic Properties of Soil IV. A Method of Analysis of PlowMoldboard Design Based Upon Dynamic Properties of Soil. Agricultural Engineering 13(11)279-285.

Oskoui K.E. et al, 1982 : The Determination of Plough Draught. Part II. The Measurement and Prediction of Plough Draught for Two Mouldboard Shape in Three Soil Series. Journal of Terrramechanics, 19, p. 153-164.

Ros V. et al., 1993 : Analysis of a Tillage Tool Geometry. ASAE Paper nr93, St.Joseph, Mich., USA. 1995