IJAAR 1 (2013) 27-36

International Journal of Advance Agricultural Research
www.bluepenjournals.org/ijaar

# Experimental model to estimate draught force for mouldboard ploughs; incorporating effects of plough geometric parameters

**Mahfoud Amara*, Ilham Guedioura and Mohamed Amine Feddal**

Agricultural Engineering Department, Ecole Nationale Supérieured' Agronomie, Algeria.

Article History
Received 11 December, 2012
Received in revised form 28 March, 2013
Accepted 02 April, 2013

**Key words:**
**Energy,**
**Draught force,**
**Ploughing,**
**Geometrical characteristic,**
**Modelling.**

***Full Length Research Article***

**ABSTRACT**

**Several models have been proposed in literature to calculate agricultural tools draught force for ploughing. These models generally disregard the geometrical characteristic of active surfaces of working parts. For this reason, tests on channel of traction were carried out to check the validity of two models frequently used, namely those of Gorjachkin and Gee Clough. Results obtained show that for the same form and similar work conditions, the efforts were different from one model to another. Tests were also carried out on two active forms of surfaces. Draught force calculated using separately; one of these two models gave the same results for two different surfaces. Whereas, the values determined on channel were significantly different from one form to another. This paper proposes a more universal model that connects draught force with soil state and especially, geometrical characteristics of active surfaces. The model established by Amara in 2009; using the modelling method Buckingham-Vachy was checked and compared with Gorjachkin and Gee Clough models which account for two forms of active surfaces of ploughs made in Algeria by commercial companies [ENPMA (cultural form) and SACRA (cylindrical form)]. The calculated force using Amara's model was closer to the values recorded on channel when compared to those calculated with Gorjachkin and Gee Clough models.**



## INTRODUCTION

In the last few years, several models have been developed for the evaluation of draught force of which soil opposed their working parts. These models are of two types: The first with two dimensions relates to the tools. It is considered simple because it uses the blades and the ploughshares; the second type called three dimensions relates to the tools with complex active surfaces like those of ploughs. The interest of this paper will be focused on this second type.

The models usually used for the determination of draught force were chronologically proposed by Gorjachkin and Sohene (1960), Larson (1968) Binesse (1970), Gee Clough et al. (1978), Kuczewski (1978), Oskoui et al. (1982), Grisso and Desai (1983), Qiongand et al (1986). In a general way, these models introduced work depth, width and speed as well as physical and soil mechanics characteristics; like cohesion and density. However, the geometrical characteristics of active surfaces such as the working angles and dimensions were not taken into account.

Among the models quoted above, the model suggested by Gorjachkin introduced a coefficient ε, characterizing the shape of the plough used. Considering the complexity of shapes of the many existing ploughs, the determination of this coefficient (ε) is very difficult. Its values vary between 1500 and 2000 $N.s^2\ m^{-4}$. Ros (1993)

*Corresponding author. E-mail: mah_amara@yahooo.fr.

studied the angles and dimensions of active surfaces of plough and described working parts and their effects on the qualitative indices of work on the soil but did not calculate the effort. Nichols and Kummer (1932), Doner and Nichols, (1934), and GaoQiong et al. (1986), attempted to describe the active surfaces of plough and to classify forces produced during the execution of ploughing and to determine the relationship between these forces and the soils properties. In fact, many models predicting the efforts of ploughs were developed on the basis of dimensional analysis (Larson, 1968; Gee Clough, 1978).

In addition, the choice of a model to assess (with good precision) the force of draught is often difficult. Indeed, if we consider, for example, Gee Clough (1978) and Gorjachkin Sohene (1960) (1960) models, assuming the same form of active surface and under the same conditions of soil and employment, it will give different force values. In this case, which of them will thus be the most reliable model for a precise evaluation of consumption of energy? This study aimed to answer such a question by proposing an experimental model that calculates draught force (taking into account) the form of active surfaces of plough. The selected geometrical characteristics are shown in Figure 1:

The angle of penetration: $\alpha$

The angle of attack: $\gamma$

Angle of inclination of active surface: $\theta$

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 of active surfaces. In addition to these parameters, the speed (v) and the dry density of the soil (d) were taken into account considering their effects on the draught force.

## MATERIALS AND METHODS

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 2, 3 and 4). These small-scale models were used to determine the draught force (Ft) on channel of traction (Figure 5). The use of the channel allowed the control of the work conditions and to analyse the effect of the geometrical characteristics of the active surface on the draught force Ft. The results obtained are used to build a mathematical model of the effort Ft taking into account the geometrical characteristics of the active surface. The established model was then checked and compared with Gorjachkin and Gee Clough models.

### Geometrical characterization of the two active surfaces

Our tests were related to two bodies of ploughs which are mostly used in Algerian farms (Figures 6 and 7). The geometrical main features of the two shapes of plough are shown in Table 1 and Figure 1.

### Effect of the geometrical parameters on draught force

The force analysis corresponding to the two shapes of plough used was carried out on a channel of traction (Figure 1) and ploughs models on three scales, reduced to 1/4, 1/3 and 1/2 (Figures 2, 3 and 4).

### Modelling of the draught force

The principal stages leading to the mathematical model are respectively:

1) Establishment of a general equation form according to the expression:

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

2) Definition and characterization of all the parameters of the equation. The various parameters of this equation are defined in Table 2.
3) Correlation between the dependant parameter (Ft) and the independent ones (E, d, v, $\alpha$, and $\theta$, k, $k_1$, $k_2$).

This analysis aimed, among others, to confirm the significant effect of these various parameters on the effort and to maintain them or not on the final equation.

Considering the angle of attack $\gamma$, this one being indirectly considered in the ratio k=a/b, (sin ($\gamma$) = b/length of the sharpened of the plough) it was not introduced on the model. The equation obtained by polynomial regression is as follow:

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

The analysis of this relationship enabled us to classify parameters according to their importance, regarding the force. We also noticed that the coefficient of the angle of inclination had the greatest absolute value (222,45) and this shows the importance of the effect of active surface

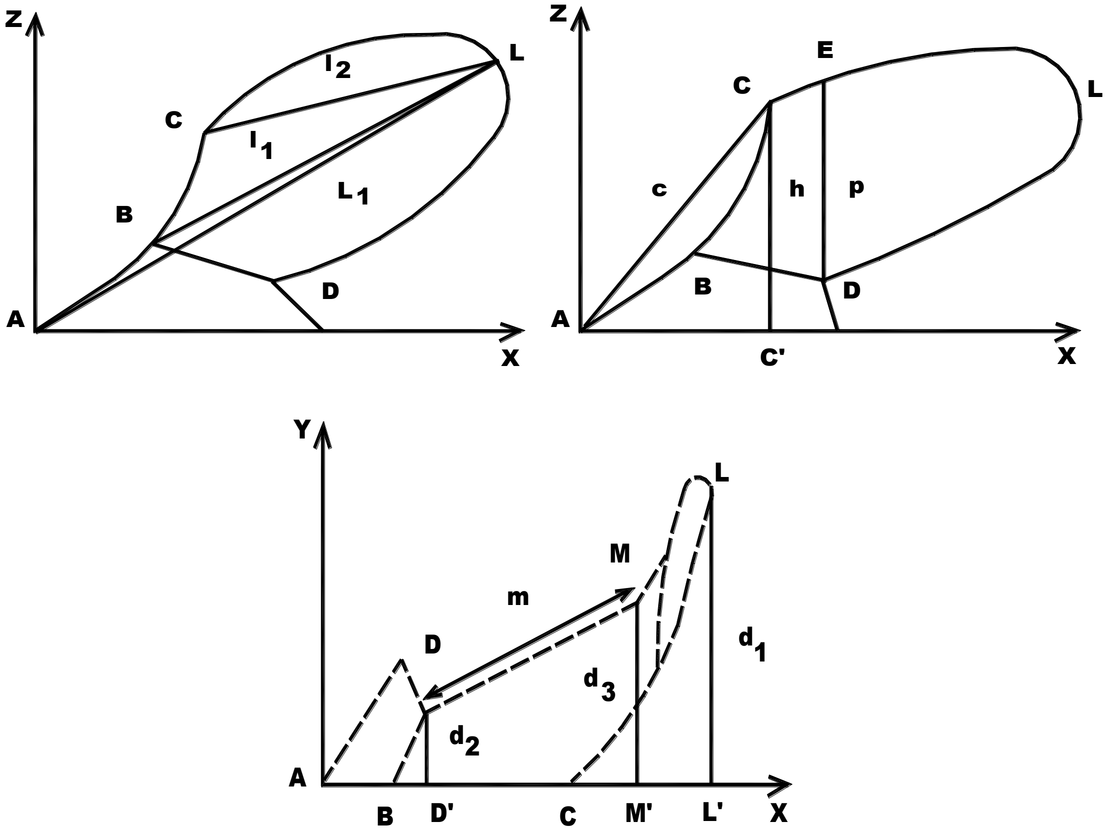


**Figure 1.** Dimensional specifications of plough used to determine $k_1$ and $k_2$.

**Table 1.** Initial constructive characteristics of used ploughs.

| Body of plough | ENPMA (cultural) | SACRA (cylindrical) |
|---|---|---|
| Height of the body h (mm) | 440 | 425 |
| Projected length l (mm) | 940 | 740 |
| Width b (mm) | 350 | 310 |
| Initial value of penetration angle α (°) | 29 | 17 |
| Initial value of attack angle γ (°) | 38 | 39 |
| Initial value of inclination angle θ (°) | 35 | 33 |

form on the force Ft.

4) Determination of the dimensional parameters (π-terms).

The definite dimensional parameters are:

$$\pi_1 = \frac{Ft}{d.g.b^3};\ \pi_2 = \frac{v^2}{gb};\ \pi_3 = k;\ \pi_4 = k_1;\ \pi_5 = k_2;\ \pi_6 = \alpha;\ \pi_7 = \theta$$

Taking into account the theorem of Buckingham-Vachy (Langhaar, 1954), the holding relationship will be:

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

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

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


**Figure 2.** Models reduced on scale 1/4.


**Figure 3.** Models reduced on scale 1/3.

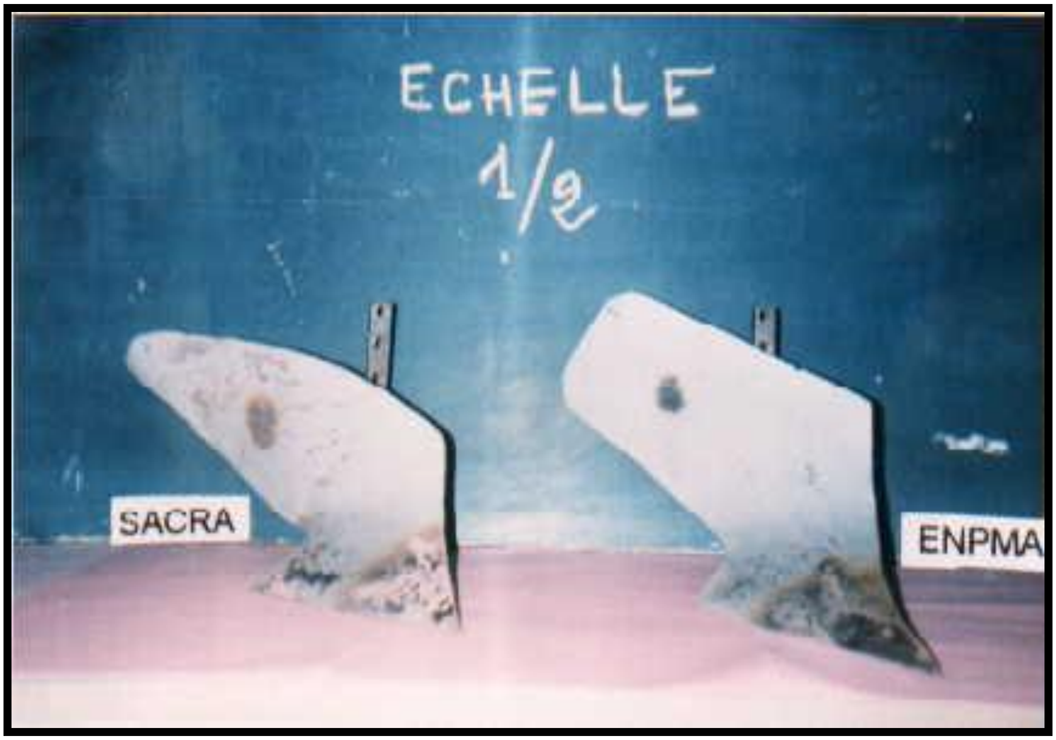


**Figure 4.** Models reduced on scale 1/2.

**Figure 5.** Small-scale ploughs models assembled on channel of traction.

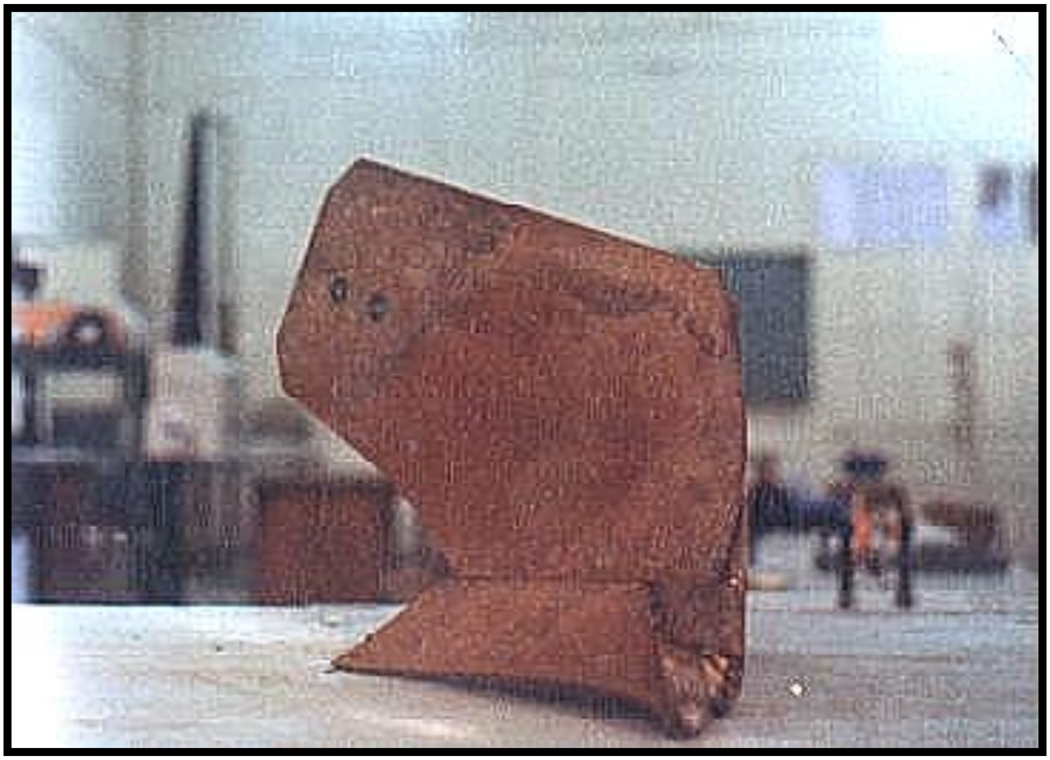

**Figure 6.** Form ENPMA (cultural form).

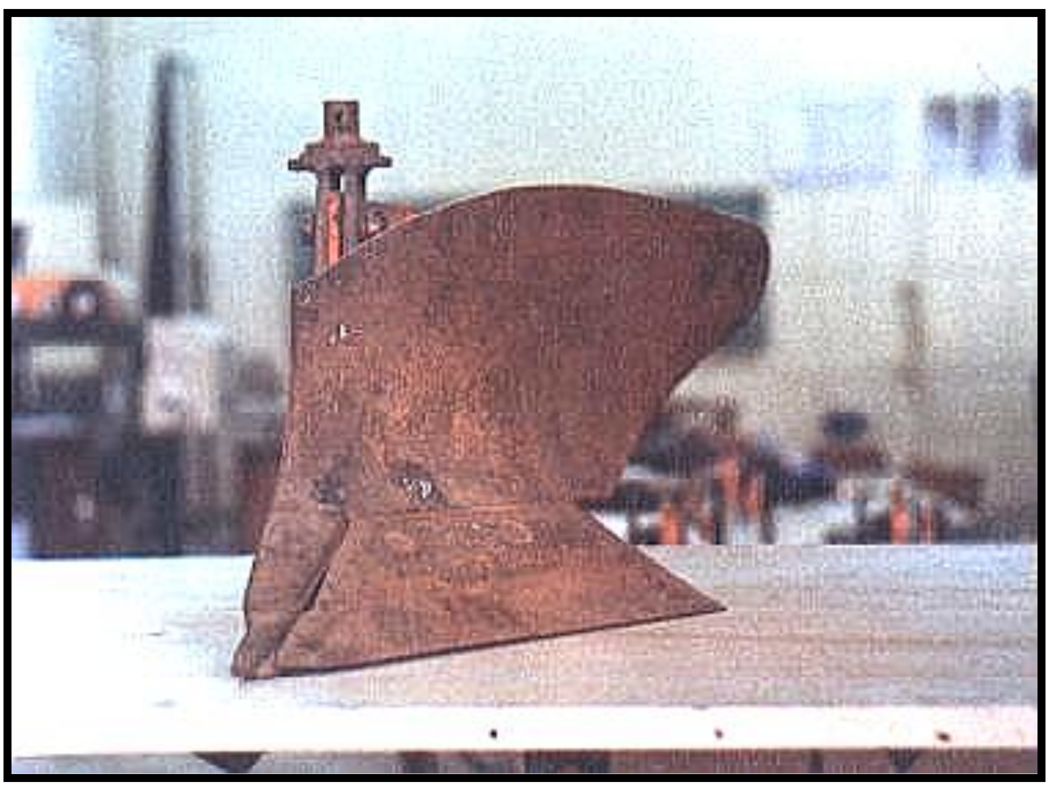

**Figure 7.** Form SACRA (cylindrical form).

**Table 2.** Definition and characterization of the parameters of equation.

| Parameter | Symbol | Unit | Dimension |
|---|---|---|---|
| **Dependent parameter** | | | |
| Force | Ft | daN | $[M.L.T^{-2}]$ |
| **Independent parameter** | | | |
| **Work condition** | | | |
| Speed | v | m/s | $[L.T^{-1}]$ |
| Built density of the soil | d | $g/cm^3$ | $[M.L^{-3}]$ |
| Scale | E | - | - |
| **Constructive angle** | | | |
| Angle of penetration | α | radians | - |
| Angle of attack | γ | radians | - |
| Angle of inclination | θ | radians | - |
| **Ratio length** | | | |
| 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 | $k_2$ | - | - |
| Acceleration gravity | (g) | $m/s^2$ | $[M.T^{-2}]$ |

The problem consisted of determining the values of the powers a, b, c, d, e, f and the constant (Cste). To solve it, the use of the logarithms properties is necessary. Tests on channel of traction were realized in this purpose which aimed to determine the parameters effect on the force. The final model which gives the effort Ft in relation to the geometrical characteristics of active surfaces is:

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

The values of R defined as a proportionality factor are R=1,931 for the cylindrical form and 1,976 for the cultural form; for the small-scale model with scale 1/2.

The values of μ (coefficient of correction) are respectively: μ=1000 for the form SACRA (cylindrical form plough) and μ=10 for form ENPMA (cultural form plough). The two values of μ show that the form of the active surface has an important effect on the force. The units of the various parameters of this model are, Force: Ft (daN), Speed: v (m/s), Angles: α and θ (radians), Bulk density: d ($kg/m^3$), Gravity acceleration: g ($m/s^2$), Width of work: b (m) and Characteristics of the form: k, $k_1$ and $k_2$ (without unit).

## Application of the proposed model

The application of this relation (assuming field conditions), gives the following results:

### *Real conditions of work*

1. Speed of ploughing: v = 1.5 m/s (5.4 km/h)
2. Density of soil: d = 1.29 $g/cm^3$ (1290 $kg/m^3$), this last transformation are necessary for the application of Gorjachkin and Gee Clough models.
3. Width of ploughing: b = 0.31 form SACRA form and b=0.35 form ENPMA form
4. Depth of ploughing: a = 0.25 m
5. 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 ploughs active 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 $k_2$ = 1.46

**Table 3.** Force values (Ft) calculated using the model proposed by Amara (2009).

| 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 |

**Table 4.** Force (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.** Force (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 |

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

Introducing these inputs in the suggested relation (Amara, 2009) gives the following results in Table 3.

## ANALYSES AND DISCUSSION

In order to check the reliability of the established model, a comparative analysis with the Gorjachkin and Gee Clough models was carried out. For this purpose, the parameters used by these models were defined. The developed draught force expressions are:

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

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

The tests were carried on the same type of altered soil (light soil texture); the value of K was the same. It was 3500 daN/m$^2$ was the higher limit for the light soils and the lower limit for the soils known as average. These values was then applied to the Gorjachkin models. The values chosen for the coefficients of form (ε) was 200 daN.s$^2$ /m$^4$ for the cylindrical form and 150 daN.s$^2$ /m $^4$ for the cultural form. The choice of this parameter is often very difficult, because there are numerous active forms surfaces which must be accounted for. The force values obtained with these models for the same conditions of speed and soil are listed in Tables 4 and 5. The application of these two models for the force determination confirmed our results. In particular, the ENPMA farming form requires more energy for the ploughing realization. This result highlights the importance of the geometrical characteristics of the active plough surface introduced in our experimental model.

Figure 8 represents the speed dependence of the ploughing force, particularly when speed magnitude is higher than 0.45 (m.s$^{-1}$). It also shows a close agreement between the three considered models in case of cultural shape. The discrepancies between the forces that were observed in case of a cylindrical shape suggest an over estimation of Gorjachkin and Gee Clough models considering real ploughing conditions.

The simplification of the Gorjachkin model in the form Ft=k.a.b, without taking into account, the speed and form of active surfaces, gave the same value of Ft.

Furthermore, the analyses of the experimental model clearly showed the effect of the geometrical characteristics of active surface on the draught force. The angle of curve θ and the geometric coefficient $k_1$ are the main characteristics involved in the draught force calculation. When θ increases the effort decreases. On

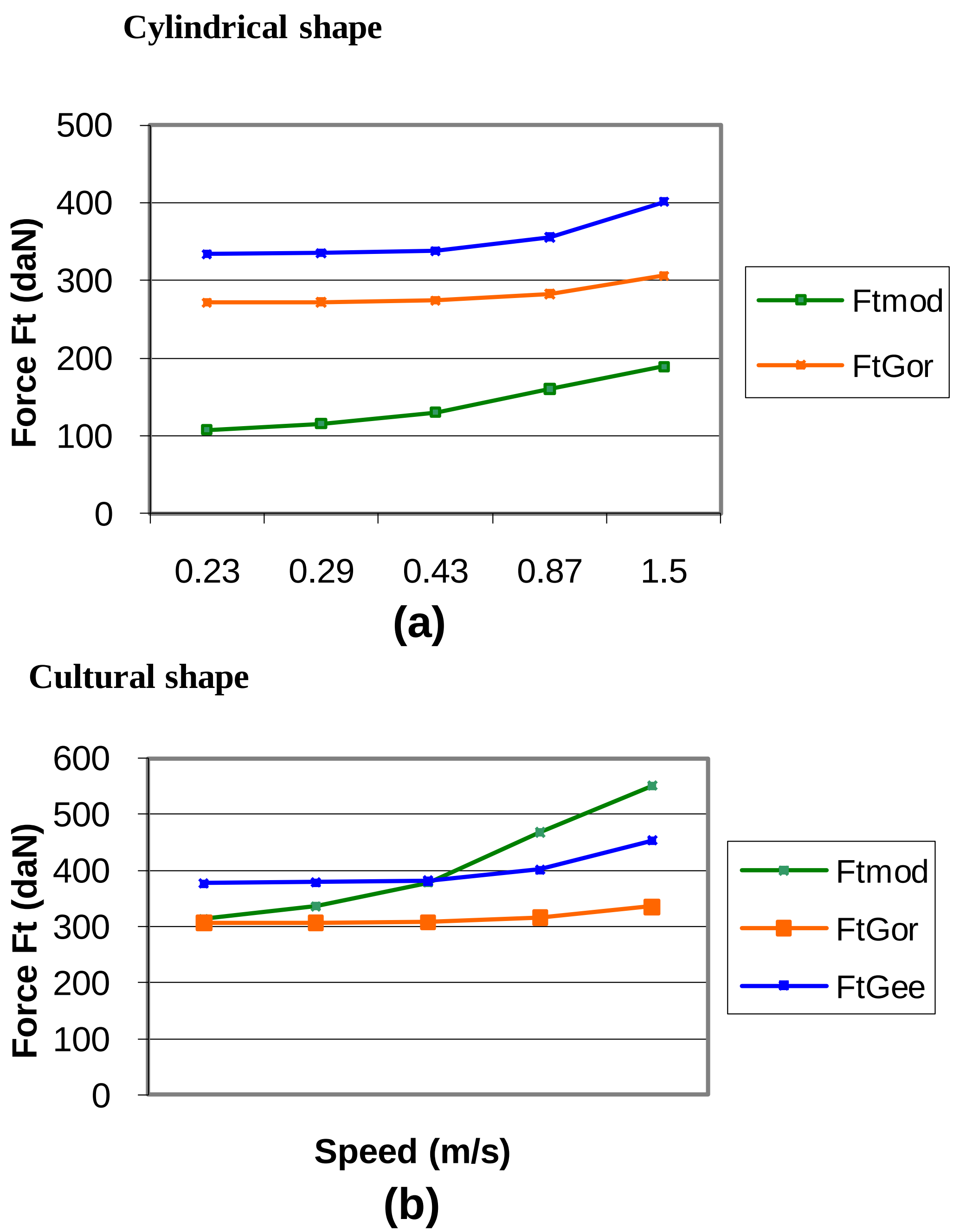


**Figure 8.** Benchmarking effort Ft according to the forward speed for each model and for each shape (form) a) cylindrical and b) cultural.

the other hand, when $k_1$ increased, the effort increased. The model suggested, can be use for draught force evaluation of any form of active surfaces of plough. The Gorjachkin and Gee Clough models are usable only for precise forms. For cylindrical forms, we used Gee Clough model and for the cultural forms the Gorjachkin model was be used.

## Conclusion

According to our results, two cases were considered for the use of the developed model: Firstly, if this model is used by agronomists for ploughing draught force evaluation, some parameters of the relationship are constant (constructive parameters) such as, the angles, the parameter k (depth/width), the parameters $k_1$ and $k_2$. It will be interesting to focus on the speed of work, soil density to cope with the best work conditions and reduce the energy requirement during the ploughing operation. Secondly, when this model is applied to designed agricultural tools, a particular attention may be allowed to the constructive parameters related to work and technical agro requirements conditions of ploughing. This will allow a more adapted designed plough to experimental conditions.

**REFERENCES**

Amara M. (2009). Contribution à la modélisation interface outils aratoires – sol. Optimisation de la forme et de l'effort de résistance à la traction des corps de charrues à socs et des outils à dents. Thèse d'état, Edition EDILIVRE APARIS Collection Universitaire. 75008 Paris - 2009.

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

Doner R. D. & Nichols M. L. (1934). The dynamic properties of soil dynamics on plow mouldboard surfaces related to scouring. J. ASAE 15(1):9-13.

GaoQiong, Pitt R. E. & Ruina A. (1986). A model to predict soil forces on the plough mouldboard. J. Agric. Eng. Res. 35:141-155.

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

Gorjachkin V. P. & Sohene (1960). Collected works in three volumes. Ed. N. D. Luchinskii. Translated 1972. Jerusalem, Israel: Ketter Press.

Grisso & Desai C. S. (1983). A soil model based on limit equilibrium analyses. Trans. ASAE 26(4):991-995.

Kuczewski J. (1978). Eléments Théoriques des Machines Agricoles. Edition Varsovie Pologne.

Langhaar H. L. (1954). Dimensional analysis and theory of models, Ed. New York .John Wiley and Sons, Inc.

Larson L. W. (1968). Predicting draft forces using mouldboard plows in agricultural soils. Trans. ASAE 11:665-668.

Nichols M. L. & Kummer T. H. (1932). The dynamic properties of soil: A method of analysis of plow moldboard design based upon dynamic properties of soil. Agric. Eng. 13(11):279-285.

Oskoui K. E., Rackham D. H. & Witney B. D. (1982). The determination of plough draught. Part II. The measurement and prediction of plough draught for two mouldboard shape in three soil series. J. Terrramechanics 19:153-164.

Ros V., Smith R. J., Marley S. J. & Erbach D. C. (1993). Analysis of a tillage tool geometry. ASAE Paper nr93, St.Joseph, Mich., USA.