Műszaki Tudományos Közlemények vol. 16. (2022) 47–51.
DOI: Hungarian: https://doi.org/10.33895/mtk-2022.16.09
English: https://doi.org/10.33894/mtk-2022.16.09

STUDY OF THE EFFECT OF SOIL VOLUMETRIC WEIGHT ON THE ENERGY REQUIREMENT FOR A SPADING MACHINE BY SIMULATION

Judit PÁSZTOR,[1] Ferenc TOLVALY-ROȘCA,[2] Zoltán FORGÓ[3]

[1] *Sapientia Hungarian University of Transylvania, Faculty of Technical and Human Sciences, Târgu Mureş, Department of Mechanical Engineering, Romania, pjudit@ms.sapientia.ro*

[2] *Sapientia Hungarian University of Transylvania, Faculty of Technical and Human Sciences, Târgu Mureş, Department of Mechanical Engineering, Romania, tferi@ms.sapientia.ro*

[3] *Sapientia Hungarian University of Transylvania, Faculty of Technical and Human Sciences, Târgu Mureş, Department of Mechanical Engineering, Romania, zforgo@ms.sapientia.ro*

Abstract

In this paper, we simulate the operation of a spading machine on three soil types; easy to work, medium to work and heavy, using a previously validated SimuLink model of an MSS-1.40M spading machine. We determine the forces during spading. We explore the physical and mechanical properties of the soil that play a role in the spading process. By simulation of the spading process with the MSS-1.40M spading machine, we determine the torque on the drive shaft and the required mechanical work on the three soil types.

Keywords*: spading machine, soil volumetric weight, simulation.*

1. Introduction

The physical and mechanical properties of the soil influence the energy consumption and the energy required by the tillage machine, at the same time the work of the tillage machine changes depending on the physical and mechanical properties of the tilled soil.

During tillage the soil is rotated, loosened, crushed, mixed, compacted and surface-formed. The tillage work can be classified into basic work and seedbed preparation.

Basic tillage work is a rotation operation, the deepest soil work. This process is most energy intensive.

The basic tillage work in greenhouses is carried out with the spading machine **[1]**, **[2]**. The spading machine mimics the work of the spade; turns, shreds, loosens and mixes the soil.

The spading machine is an active tillage machine. Its implements are spades, which, in addition to towing, are also driven by the tractor's PTO shaft. Because of this, it has a high specific energy requirement yet less traction requirement. The area performance of PTO-driven tillage machines is not advantageous, but they produce better results in fuel consumption and soil shredding **[3]**.

Determining the energy demand of soil tillage at the frontier of energy and agricultural sciences is always timely **[4]**, **[5]**.

Soil is a complex, open dynamic system that results from the interaction of soil-forming factors and tillage. The soil affects the machines, but the machines also affect the soil **[6]**. this paper we examine the energy required of spading on different soil types. The energy required for digging is determined by simulation for three soil types.

A simulation is a study in which the process is studied using a computer model. Scientific modelling is playing an increasingly important role in the study of the tillage process and in the scientific approach to the tillage process **[7]**.

2. Work and method

For our study we use a real spading machine model, the MSS-1,40M, and a previously validated SimuLink simulation **[8]**.

We explore the physical, mechanical properties of the soil that play a role in the spading process. Based on the literature [8], we determine their values for soils that are easy to cultivate, moderately cultivable and difficult to cultivate [8].

Following that, we simulate the spading process on the three soil types.

The values of the moments and the required mechanical work during the spading process on the studied soils are determined.

2.1. The MSS-1,40M spading machine model

The assembly model was built using Autodesk Inventor software based on the actual dimensions of the MSS-1.40M spading machine [8].

The simplified assembly model (Figure 1) shows the spades, the arms of the spades, the frame of the machine, the parts of the drive shaft, and the two sliders involved in adjusting the working depth.

The trajectory of the tip of the digging edge can be determined by motion simulation (Figure 2).

The trajectory provides an opportunity to illustrate the movement of the spade in the soil and to study the work of the spade.

The four stages of the spading work (Figure 2) [9]:

– the spade penetrates the soil and cuts the soil chip, A-B;
– the spade separates the soil chip from the soil, B-C;
– the spade raises the soil chip, C-D;
– the spade moves to a new position while the raised soil strikes the cover plate, D-A.

With the trajectory, the forces manifested on the spade can be identified (Figure 3) [8]:

– on part A-B, bit force: F_b;
– in section B-C shear force: F_s;
– on section C-D inertia force: F_i.

The following formulas were used to calculate the acting forces [8], [10]:

$$F_b = 2k_1 A_1 [\sin \beta/2 + \mu \cos \beta/2] + 2\mu k_2 A_2 \text{ [N]}, \quad (1)$$

$$F_s = s\, l\, \tau = s\, l\, (c + \sigma \tan \varphi) \text{ [N]}, \quad (2)$$

$$F_i = V \rho a_s \text{ [N]}, \quad (3),$$

where:

A_1 is the active surface of the spade edges [m²];
A_2 is the surface of one of the sides of the spade, in contact with the soil [m²];
β is the lip angle of the spade [°];
μ is the friction between the soil and the spade;
φ is the internal friction angle of the soil [°];
k_1, k_2 are the specific resistance to soil deformation [N/m²];
c is the cohesion of soil [N/m²];
σ is the surface pressure [N/m²];
τ shear tension [N/m²];
s is the spading step [m];
l is the working length of the spading edge [m];
V is the volume of the lifted soil chip [m³];
ρ is the soil volumetric weight [kg/m³];
a_s is the displaced soil acceleration [m/s²].

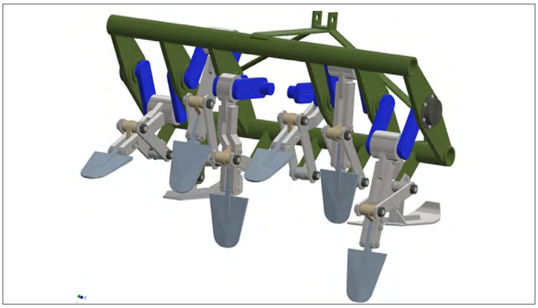

Figure 1. *MSS-1,40M spading machine assembly model.*

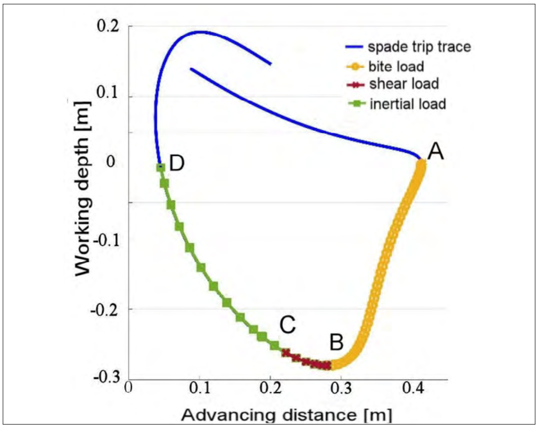

Figure 2. *The trajectory of the apex of a spade edge.*

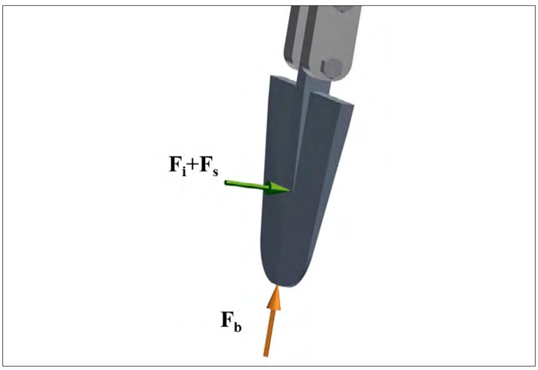

Figure 3. *The forces on the spade.*

2.2. Physical and mechanical soil characteristics influencing spading

The physical and mechanical characteristics of the soil, which play a role in the spading process, can be identified from equations (1÷3):

$$F_b = f(\mu, \phi, k_1(\varphi), k_2(\varphi)) \quad (4)$$

$$F_s = f(\phi, c, \sigma, \tau), \quad (5)$$

$$F_i = f(\rho). \quad (6)$$

The dynamics of spading are affected by:

- μ the coefficient of friction between soil and steel;
- ϕ the internal friction angle of the soil;
- k_1, k_2 the specific resistance to soil deformation;
- c the cohesion;
- σ the surface pressure;
- τ the shear strength;
- ρ the soil volumetric weight.

The physical and mechanical characteristics of the soil depends on the type of soil. The soil types we examined:

– easy to work, sandy loam;
– medium machinable, loam;
– clay loam, that is more difficult to machine.

The values of the physical and mechanical characteristics used in the literature to characterize soil types can be found in **Table 1.** **[11]**.

Note: The easy-to-use, measurable soil characteristic is ρ, the soil volumetric weight. The soil volumetric weight is the mass of soil in its natural structural state per unit volume. Unit: kg/dm³, kg/m³, t/m³. We accept this as the main feature.

No different data were found in the literature for the value of surface pressure σ for soil types.

Table 1. *Values of soil characteristics used in the simulation*

Soil type	μ	φ [°]	k_1 [N/m²]	k_2 [N/m²]	c [N/m²]	σ [N/m²]	ρ [kg/m³]
Sandy loam	0,54	29	$11{,}14\cdot10^5$	23943,31	800	20000	1300
Loam	0,61	32	$10{,}96\cdot10^5$	24362,71	1000	20000	1500
Clay loam	0,64	38	$10{,}57\cdot10^5$	25353,17	1500	20000	1600

2.3. Simulation of the required mechanical work for spading

The required mechanical work for spading was determined using the Simulink simulation. A Matlab ® Simscape ™ model of a spade is shown in **Figure 4.** **[8]**.

The simulation was performed for the following parameters:

v_m = 0,35m/s advancing speed;
ω = 17,7 rpm drive shaft spindle speed;
s = 0,124 m spading step;
a = 0,3 m maximum working depth, using soil characteristics corresponding to the three soil types (**Table 1**).

The spading torque requirements for the three soil types were determined. The torque evolution is shown in **Figure 5**.

The spading of loamy clay, the difficult to work soil, has a higher torque requirement.

The simulation was used to determine the values of the mechanical work to be spaded on the six spades during one revolution of the drive shaft. The data are shown in **Table 2.**

The data in the table are shown in **Figure 6.**

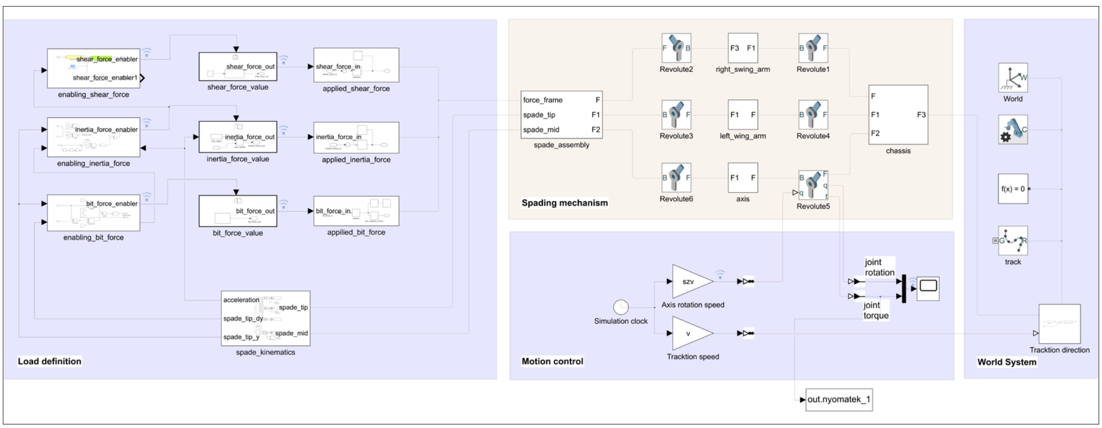

Figure 4. *A Matlab ® Simscape ™ model of a spade.*

The required mechanical work varies during the spading of different soil types (Figure 6). The spading of loamy clay soils is more energy intensive.

The correlation coefficient value $R^2 = 0.9833$ in the graph shows a very strong correlation between the soil volumetric weight and the energy requirement for spading.

The equation of the regression line shown in Figure 6 makes possible to determine the energy requirement for spading with the MSS-1.40M as a function of soil volumetric weight:

$$L = 0{,}12\ \rho - 8{,}92\ \ [\text{J/rev}]. \qquad (7)$$

3. Conclusions

The built model describes a working trajectory identical with the others found in the literature, so it can be considered suitable for numerical studies.

The required spading energy, determined using our previous SimuLink model, can be used in the development of cultivation technology and the further calculations of technological cost.

We would also like to apply the presented method to a physical and mechanical soil characteristic that can be determined in the open field. Thus, the energy requirement for the cultivability of a given soil could be estimated on the basis of open field soil characteristic measurements.

Table 2. *Required mechanical work of spades*

Soil type	ρ (kg/m³)	Required mechanical work (J/rev)
Sandy loam	1300	147.7895
Loam	1500	168.1577
Clay loam	1600	184.6458

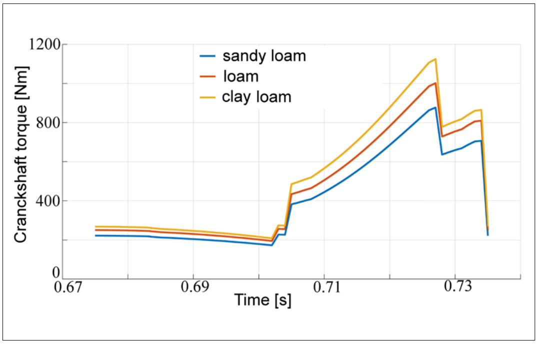

Figure 5. *The torque requirement of a spade during one revolution of the drive shaft.*

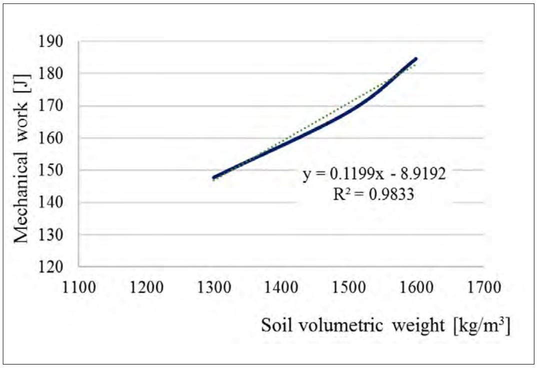

Figure 6. *The relationship between the required mechanical work of spading and the soil volumetric weight.*

References

[1] Giordano D. M., Facchinetti D., Pessina D.: *Te Spading Machine as an Alternative to the Plough for the Primary Tillage.* Journal of Agricultural Engineering, 46/1. (2015) 36–40. doi.org/10.4081/jae.2015.445.

[2] Cardei P., Nuţescu C., Matache M., Cristea O.: *Optimum Working Conditions for Variable Width Ploughs.* INMATEH Agricultural Engineering, 65/3. (2021)248–254. https://inmateh.eu/volumes/volume-65--no-3--2021/article/optimum-working-conditions-for-variable-width-ploughs.

[3] Pezzi F.: *Traditional and New Deep Soil Tillage Techniques in Italy.* American Society of Agricultural and Biological Engineers, 48/1. (2005) 13–17. https://doi.org/10.13031/2013.17935.

[4] Abbaspour-Gilandeh M., Shahgoli G., Abbaspour-Gilandeh Y., Herrera-Miranda M., Hernández-Hernández J., Herrera-Miranda I.: *Measuring and Comparing Forces Acting on Moldboard Plow and Para-Plow with Wing to Replace Moldboard Plow with Para-Plow for Tillage and Modeling It Using Adaptive Neuro-Fuzzy Interface System (ANFIS).* Agriculture, 10/12. (2020) 633. https://doi.org/10.3390/agriculture10120633.

[5] Dogra R. Dogra B., Gupta P. K., Sharma B. D., Kumar A.: *Effect of Spade Angle and Spading Frequency of Spading Machine on Specific Soil Resistance and Pulverization.* Agricultural Engineering International: CIGR Journal, 19/1, (2017) 65–73.

[6] Kokieva E. G., Voinash S. A., Sokolova V. A., Gorbachev V. A,; Fedyaev A. A.: *The Study of Soil Mechanics and Intensification of Agriculture.* IOP Conference Series: Earth and Environmental Science, 548/6. (2020) 1–6. https://doi.org/10.1088/1755-1315/548/6/062036.

[7] Saimbhi V., Wadhwa D., Grewal P.: *Development of a Rotary Tiller Blade Using Three-dimensional Computer Graphics*. Biosystems Engineering, 89/1. (2004) 47–58. https://doi.org/10.1016/j.biosystemseng.2004.05.011.

[8] Forgó Z., Tolvaly-Roșca F., Pásztor J., Kovari A.: *Energy Consumption Evaluation of Active Tillage Machines Using Dynamic Modelling*. MDPI Applied Sciences, 11/14. 6240. (2021). https://doi.org/10.3390/app11146240.

[9] Brătucu Gh., Pásztor J., Căpățână I.: *Comparative Researches Regarding the Quality and Efficiency of Germinating Bed Preparing in Greenhouses Through Hoeing and Cutting*. INMATEH - Agricultural Engineering, 31/2. (2010) 63–72.

[10] Máté M.: *Műszaki mechanika – kinematika*, EME Kiadó, Kolozsvár, 2010. 155–163.

[11] Sitkei G.: *Soil Mechanics Problems of Agricultural Machines*. Franklin Book Programs, New York, USA, 1976. 22–62.