# RESEARCHES REGARDING THE OPTIMIZATION OF THE ENERGETIC CONSUMPTION OF DIGGING SOIL MACHINE IN GREENHOUSES

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***Abstract:*** *The researches object in this paper consists in theoretical and experimental researches of the optimization possibility for the energetic consumption to preparing the germination bed in greenhouses with the digging soil machine.The technology for preparing the germination bed in greenhouses is an ensemble of activities, works and agricultural operations, economical and agro technical justified, ordered and carried in time, respecting the established condition and using a précised range of machines and agricultural equipments. In these works the overthrow, the raising, the shredding, the levelling, the compaction and the modelling of soil takes place. Most times to these works may be associated land cleaning from remaining plants of the previous farming, the organic and chemical fertilizer, thermal and chemical disinfestations, marking of the plantation station etc., which transforms the preparing of the germination bed into an important energy consumer. In most technologies for preparing the germination bed, is included also the digging soil work, by which the overthrow, the raising and the shredding is realized .The digging soil machines in greenhouses are build on several principles (with plane movement, by throwing furrow back parallel with the direction of advancing, with lateral soil digging towards right, with working organs having a rotation movement ), in all these cases the energy consumption being high. Based on the kinematics and dynamics research of these machines, a complex mathematical model of the energy consumption on digging soil in greenhouses is made, on which afterwards an optimization study is realized. Mainly, the mathematical model presented in this paper offers the possibility for theoretical research on energy consumption variation depending on the speed and depth work. Results that digging the same surface with increased working speed helps reducing the specific energy consumption, in particular due to influenza of step size screeds on this parameter. At the same time the energy consumption of digging soil work increases with increasing the work depth. The theoretical researches were completed with important experimental researches, effectuated with an agricultural aggregate composed of tractor U 445L and digging soil machine in greenhouses MSS 1,40 , both manufactured in Romania. For researches accuracy was necessary a soil monitoring, for humidity and resistance to penetration, by using a latest generation equipments. It was consisted an optimal soil humidity existence from a agricultural view but also the digging resistance. Also the hardened the soil is (higher soil penetration) the greater the energy consumption is on digging soil work. The energetic consumption on digging soil work was experimental determinate by measuring the combustible consumption (for working and free movement ), for different speed and depth works. The experimental energetic consumption values were compared with the theoretical obtained values, allowing a correct mathematical model to be realized. Based on this model, researches which can assure an optimal energy consumption for preparing the germination bed with digging soil machines in greenhouses can be done. The concrete results are presented in the paper.*

***Key words*:** *greenhouses, soil digging machine, energetic consumption, optimization.*

## INTRODUCTION

Soil digging machines used more frequently in greenhouses are those with organ works and plane movement. In figure 1 is presented the design of such a machine. The machine is composed from : crankshaft 1, crank 2, digs rod 3, lever 4, joint rod 5, fixed joint on the cars chassis 6 and the dig 7. The digging machine is having 4 or 6 symmetrical digs mounted on the crankshaft through rods and levers, which forms a quadrilateral mechanism (1-2-3-4) . [PASTOR,J. ],[ CAPROIU.ST,S.A.].

In the working process the dig is cutting soil under cutting force $\vec{F_t}$ (figure 2) action. The soil is opposing by friction force $\vec{F}_f$, equal, but opposed sense comparing with the cutting force. The friction force $\vec{F}_f$ is calculated with the relation :

$$\vec{F}_f = \mu \cdot \vec{R} \text{ [N]}, \quad (1)$$

where: $\mu$ is the friction coefficient between soil and dig; $\vec{R}$ - resisting soil force, which oppose throwing soil slice, in N. $\vec{R}$ can be represented by it's components $\vec{R}_x$ and $\vec{R}_y$ .

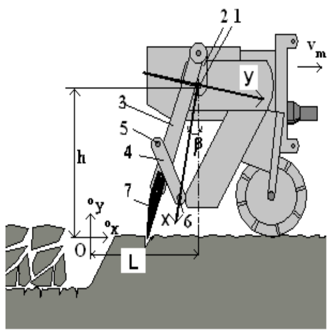

Figure 1. Design of digging soil machine with digs with plane m

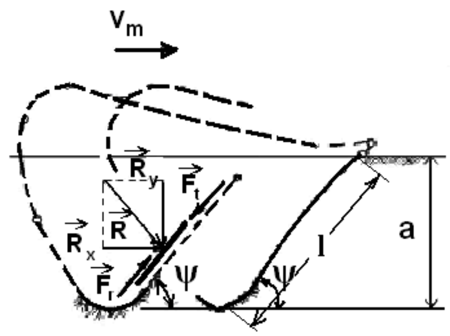

Figure 2. Forces operating on the dig

During the soil slice deployment it can be considerate:

$$R_y = m \cdot g \text{ [N]}, \quad (2)$$

where $m$ is the deployed soil mass, in kg.

The deployed soil mass can be calculated with relation:

$$m = b \cdot a \cdot s \cdot \rho \text{ [kg]}. \quad (3)$$

In relation (3) $b$ is the dig width, in m; $a$- working depth, in m; $s$- the machine step, in m; $\rho$ – the soil volumetric mass, in kg/m$^3$.

The step or the advance is the travelled space by a digging machine on a complete rotation of the crankshaft. It's calculated with relation:

$$s = v_m \cdot \frac{2\pi}{\varpi} \text{ [m]}, \quad (4)$$

where: $v_m$ is the machine work speed, in m/s; $\omega$- the crankshaft angular speed, in rad/s.

With the help of the relations (2), (3) and (4) it is obtained the relation for soil resistance $R$ :

$$R = \frac{R_y}{\cos\psi} = \frac{b \cdot a \cdot v_m \frac{2\pi}{\varpi} \rho \cdot g}{\cos\psi} \text{ [N]}, \quad (5)$$

where $\psi$ is the dig attack angle, which is variable and can be calculated (figure 2) with relation

$$\psi = 2\pi - \theta_2 - \alpha . \quad (6)$$

$R_x$ force is acting by pushing, is variable because $\theta_2$ angle is variable and time dependent and it can be calculated with relation:

$$R_x = R\sin\psi = \frac{b \cdot a \cdot v_m \frac{2\pi}{\varpi} \rho \cdot g}{\cos\psi} \cdot \sin\psi = \frac{2\pi}{\varpi} \cdot a \cdot b \cdot \rho \cdot g \cdot v_m \cdot tg\psi \text{ [N]}. \quad (7)$$

**MATERIAL AND METHODS**

The study general method used in this paper consists in mathematical modelling and experimental research of the energetic consumption of digging soil machine in greenhouses and results comparing to mathematical model improvement.[ KOOLEN,A.J.]

Total energy necessary to soil digging with this machine can be represented by relation:

$$E_t = E_{sap} + E_{pierd} \text{ [J]}, \quad (8)$$

where: $E_{săp}$ is the necessary energy for soil digging, in J; $E_{pierd}$ – the consumed energy by the digging soil machine mechanism losses, in J:

$$E_{sap} = L_{ms} = P_{ms} \cdot t_{ms} \text{ [J]}, \quad (9)$$

where: $L_{ms}$ is the consumed mechanical work in digging soil process, in J; $P_{ms}$ – the necessary power for soil machine training, in W; $t_{ms}$- the digging time, in s. In this way relation (2) becomes :

$$E_t = P_{ms} \cdot t_{ms} + E_{pierd} \text{ [J]}. \quad (10)$$

*The necessary power for the digging soil machines training* with plane movement, $P_{ms}$ is having the following components:

$$P_{ms} = P_d + P_t + P_a + P_i \text{ [W]}, \quad (11)$$

where: $P_d$ is the necessary power for the machine movement, in W; $P_t$ – the necessary power for soil cutting and displacement, in W; $P_a$ – the necessary power for displaced soil throwing, in W; $P_i$ – the used power for machine pushing, in W.

The training digging soil machine power with plane movement it’s calculated with relation :

$$P_{ms} = f \cdot G_{ms} \cdot v_m + \frac{\mu \cdot \rho \cdot g \cdot a^2 \cdot b \cdot v_m}{\sin\psi \cdot \cos\psi} \cdot z \cdot \frac{\omega \cdot t}{2\pi} + \frac{B \cdot a \cdot \rho \cdot v_m \cdot v_x^2}{2} + R \cdot \sin\psi \cdot v_m \text{ [W]}, \quad (12)$$

In this way the total energy relation (10) becomes:

$$E_t = \left( f \cdot G_{ms} \cdot v_m + \frac{\mu \cdot \rho \cdot g \cdot a^2 \cdot b \cdot v_m}{\sin\psi \cdot \cos\psi} \cdot z \cdot \frac{\omega \cdot t}{2\pi} + \frac{B \cdot a \cdot \rho \cdot v_m \cdot v_x^2}{2} + R \cdot \sin\psi \cdot v_m \right) t_{ms} + E_{pierd} \text{ [J]}. \quad (13)$$

The mathematic model of energy consumption on digging soil work with digging machine is build with formula:

$$E_{tms} = f \cdot G_{ms} \cdot v_m \cdot t_{ms} + \frac{\mu \cdot \rho \cdot g \cdot a^2 \cdot b}{0.45} \cdot z \cdot \frac{\varpi \cdot t_{ms}}{2\pi} \cdot v_m \cdot t_{ms} + \frac{B \cdot a \cdot \rho \cdot v_m \cdot (-4.37)^2}{2} \cdot t_{ms} +$$
$$+ 0.62 \cdot \frac{2\pi}{\varpi} \cdot a \cdot B \cdot \rho \cdot g \cdot v_m^2 \cdot t_{ms} + E_{pierd} [\mathrm{J}]. \quad (14)$$

By neglecting the lost energy in machines mechanism is obtained this relation:

$$E_{tms} = f \cdot G_{ms} \cdot v_{mms} \cdot t_{ms} + \frac{\mu \cdot \rho \cdot g \cdot a^2 \cdot b}{0.45} \cdot z \cdot \frac{\varpi \cdot t_{ms}}{2\pi} \cdot v_{mms} \cdot t_{ms} + \frac{B \cdot a \cdot \rho \cdot v_{mms} \cdot (-4.37)^2}{2} \cdot t_{ms} +$$
$$+ 0.62 \cdot \frac{2\pi}{\varpi} \cdot a \cdot B \cdot \rho \cdot g \cdot v_{mms}^2 t_{ms} [\mathrm{J}], \quad (15)$$

where: $f$ is rolling resistance; $G_{ms}$- digging soil machine weight, in N; $a$- working depth, in m; $b$ – the dig width, in m; $v_{mms}$- the digging soil machine speed, in m/s; $t_{ms}$ – the digging time, in s; $\omega$- the angular speed of the crankshaft, in rad/s; $z$ – the digs number; $\rho$ – the soil volumetric mass, in kg/m$^3$ .

For the working conditions, characterized by: f = 0,15; $G_{ms}$ = 6100 N; μ=0,36; b = 0,1m; ω=17 rad/s, ρ=1500 kg/m$^3$ , is obtained *the mathematical model*:

$$E_{tms}(a, v_{mms}, t_{ms}) = 915 \cdot v_{mms} \cdot t_{ms} + 1949045 \cdot a^2 \cdot v_{mms} \cdot t^2{}_{ms} + 2005175 \cdot a \cdot v_{mms} \cdot t_{ms} +$$
$$+ 480974 \cdot a \cdot v_{mms}^2 \cdot t_{ms} [\mathrm{J}], \quad (16)$$

The energy consumption mathematical model for digging soil wok in greenhouses in real working condition and concrete machine (16) offers the possibility for theoretical research of the energetic consumption variation depending on speed and depth work, cases that are presented in figure 3 and figure 4.

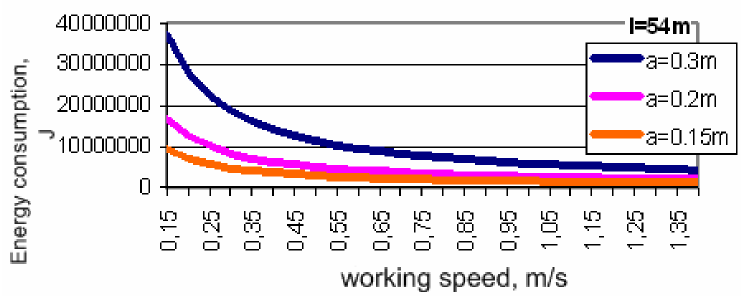


Figure3. Total energy consumption variation on digging machine, depending on working speed

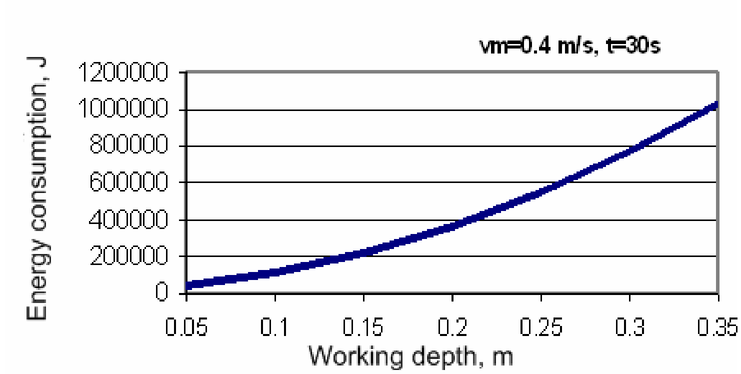


Figure 4. Total energy consumption variation on digging machine, depending on working depth

From the graphic presented in figure 3 is found that digging the same surface with increased working speeds contributes to the total energy consumption reduction of processing.

This is explained by the fact that at reduced speeds the digs act more often, the digs advance being small , fact that can be observed in figure 5.

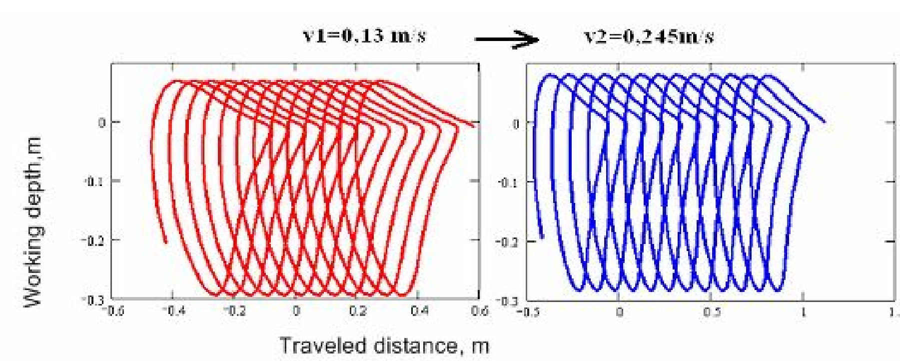


Figure 5. Digging soil machine advance variation with working soil speed

Small advances leads to increased frictions between soil and working organs. On the other hand, an advance that is to big leads to a low degree of crushing of the worked soil, this requiring additional crushing, which means another energy consumption.[ FECHETE,L.S.A.], [ PASTOR,J. BRATUCU.GH., JAKAB,S.]

The digs advance is calculated with formula (4), $s = v_m \cdot \frac{2\pi}{\varpi}$ [m]. Considering that $s \leq s_{\max}$ , and $s_{max} \approx$ 0,2m, the maximum speed that justifies the use of digging soil machines is determined with the formula:

$$v_{m\max} \leq \frac{s_{\max} \cdot \omega}{2\pi} \text{ [m/s].} \quad (17)$$

From relation (17) results that the digging soil machine maximum working speed is situated around 0,5 m/s, which is confirmed in specialized literature as well. [BRATUCU.GH], [ MITROI, A.],[ NAGHIU, A.]. The experimental research was realized on a agricultural aggregate formed by tractor U 445L and the digging soil machine MSS 1,40 used in greenhouses. The soil from the greenhouses in which the experimental researches where made, was verified under the humidity aspect (the portable humidymeter Kapacitiv KKT type PT 1 was used) and the penetration resistance (the static penetrometer Dickey-John was used), the obtained results showing that it is an optimal solution for carrying out germinal bed preparing works (the relative humidity varied between 4,45…6,66% depending on precursory crop, and the penetration resistance varied between 500…1500 kPa, depending on the investigated depth)

The measurement of the energetic consumption was made by measuring the consumed fuel on the aggregate movement without digging and while digging. A type EDM 1404 device was used, mounted in the tractor engine alimentation installation circuit, which indicates directly the horary fuel consumption and the specific fuel consumption, reported on the worked area. Theoretical energetic consumption and real energetic consumption (determined by experimental research) were measured finally in J, so comparisons could be made between the results of the mathematical model and those obtained trough experimental researches.

In experimental researches the following measurements were done: the effective working times were clocked; were measured the consumed fuel quantity of the agricultural aggregate along 15m and work width of 1,40m (21m$^2$).

The measurement of the fuel consumption was repeated 5 time for each speed gear. The leer movement of the agricultural aggregate was measured once for each speed gear. The results of the measurement were written in the measurement script presented in table 1.

*Table 1.*

Results of the experimental research for fuel consumption on soil digging with MSS- 1,40

| Working speed, m/s | Working time, s | Calculate working speed , m/s | Total fuel consumption, cm$^3$ / 21 m$^2$ | Leer movement fuel consumption, cm$^3$/21 m$^2$ | Fuel consumption for soil digging, cm$^3$/21 m$^2$ | Fuel consumption for soil digging, J/ 21 m$^2$ |
|---|---|---|---|---|---|---|
| | | $x_i$ | | | $y_i$ | |
| $V_1$ | 73 | 0.205479 | 95.4 | 27.7 | 67.7 | 2276074 |
| | 73 | 0.205479 | 95.2 | 27.7 | 67.5 | 2269350 |
| | 72 | 0.208333 | 94.2 | 27.7 | 66.5 | 2235730 |
| | 73 | 0.205479 | 95.6 | 27.7 | 67.9 | 2282798 |
| | 74 | 0.202703 | 96.4 | 27.7 | 68.7 | 2309694 |
| media | 73 | 0.205495 | 95.36 | 27.7 | 67.66 | 2274729 |
| $V_2$ | 42 | 0.357143 | 66 | 27.3 | 38.7 | 1301094 |
| | 43 | 0.348837 | 66.4 | 27.3 | 39.1 | 1314542 |
| | 43 | 0.348837 | 66.2 | 27.3 | 38.9 | 1307818 |
| | 44 | 0.340909 | 67.2 | 27.3 | 39.9 | 1341438 |
| | 42 | 0.357143 | 66.4 | 27.3 | 39.1 | 1314542 |
| media | 42.8 | 0.350574 | 66.44 | 27.3 | 39.14 | 1315887 |
| $V_3$ | 27 | 0.555556 | 54.5 | 26.8 | 27.7 | 931274 |
| | 30 | 0.5 | 56 | 26.8 | 29.2 | 981704 |
| | 30 | 0.5 | 56.2 | 26.8 | 29.4 | 988428 |
| | 29 | 0.517241 | 55.4 | 26.8 | 28.6 | 961532 |
| | 30 | 0.5 | 56.1 | 26.8 | 29.3 | 985066 |
| media | 29.2 | 0.514559 | 55.64 | 26.8 | 28.84 | 969600.8 |

## RESULTS AND DISCUSSIONS

From the graphic presented in figure 6 is noted the fuel consumption reduction trend by increasing the working speed on the digging soil work, fact observed also in the theoretical research (mathematical model).

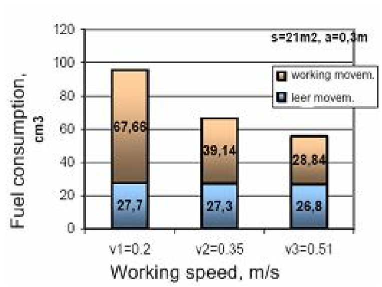


Figure 6. Average values measured in the experimental research with digging soil machine MSS 1,40

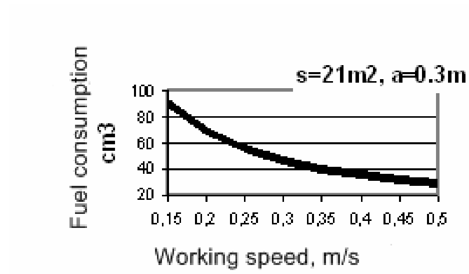


Figure 7. The variation of the fuel consumption in light of the working speed by soil digging with MSS 1,40

The measured values presents high homogeneity, small variability and representative media. The point distribution obtained after representation the measured results is showing fuel consumption dependence in light of working speed of hyperbolical type, as is presented in figure 7.

In figure 8 is presented the calculated and measured energetic consumption of the soil digging work on a 21m$^2$ area and working depth of 0,3 m, in previous specified concrete working condition. The fuel stored energy is calculated with relation:

$$Q = Cc \cdot \rho \cdot H \quad [J], \qquad (18)$$

where: *Cc* is the measured fuel consumption, in cm$^3$; $\rho$- fuel density, in kg/m$^3$; *H*- fuel caloric power, in J/kg, which are having the values: ρ=820…845kg/m$^3$ at 15°C, H=41…42,267 MJ/kg at ρ=820…845kg/m$^3$

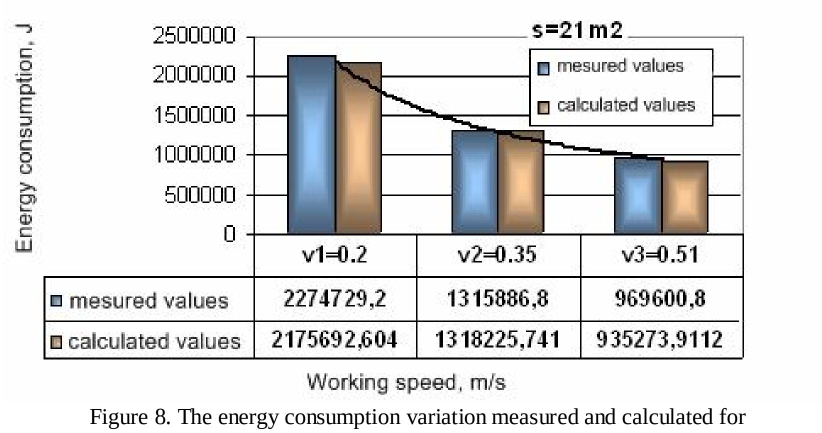


Figure 8. The energy consumption variation measured and calculated for soil digging in greenhouses

Din graficul prezentat reiese că valorile consumurilor energetice măsurate şi pe de altă parte calculate cu relațiile (27) şi (28) pentru cele trei viteze de lucru la săparea solului în sere sunt apropiate

**CONCLUSIONS**

- Using the digging soil machine for germination bed preparation in greenhouses is necessary and useful because it cuts slices of soil, turns him up side down and also mince, similarly to manual soil digging with spade. The working depth can reach to 30 cm, optimum value for assuring the best agro-technical conditions for plants.
- Because the soil digging work in greenhouses is a large energy consumer is necessary its optimization, activity which implies important theoretical and experimental researches, which can finally leads to selecting the corresponding agricultural aggregate and the optimal working regime for a greenhouse with known dimensions.
- By mathematical modelling of the energetic consumption in the work process of the soil digging machine in greenhouses it can be highlight different factors influences over this, specially the speed movement and working depth. From this paper results that by increasing the work depth the specific energy consumption is increasing, while by increasing the movement speed of the agricultural aggregate the energy consumption decreases.
- The experimental researches were made with an agricultural aggregate composed from the tractor U 445 L and the soil digging machine in greenhouses MSS 1,40. The fuel consumption on the digging soil work was measured with a high performance device type EDM 1404, placed on the tractor engine alimentation system.
- The program of the experimental research imposed the soil humidity and penetration resistance measurement on the working dept, also leer and working movements of the agricultural aggregate with different speeds.
- The experimental researches confirmed the theoretical mathematical model validity, fact that permits using it to energy consumption optimization on the soil digging work in greenhouses.

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