Investigation of the interaction of the working bodies of the soil harvesting machine with the greenhouse soil when removing the sanitary layer

A O Vezirov*, P I Pavlov and A V Levchenko

Saratov State Vavilov Agrarian University, 1, Teatralnaya squ., Saratov, 410012, Russian Federation

* E-mail: vezirov2008@mail.ru

Abstract. Growing plants organically in greenhouse industry involves a lot of work with greenhouse soil. After a certain period of operation of the greenhouse soil, its complete or partial replacement is required. To mechanize this process, a newly designed soil harvesting machine with a moldboard working body has been developed. One of the main indicators characterizing the work of the soil harvesting machine is the power required to carry out the technological process of removing the soil layer from the greenhouse. The analysis of the interaction of working bodies with the soil layer is carried out. Theoretical studies have obtained analytical expressions to determine the power required for effective removal of greenhouse soil. Experimental studies have made it possible to confirm the reliability of the theoretical provisions and to establish the effect of the height of the greenhouse soil layer and the forward speed on the total thickness. Also, as a result of processing the experimental data, a regression equation and graphical dependence were obtained. The established equations and dependencies make it possible to determine the power required to drive the soil harvesting machine at various values of the height of the removed soil layer and the forward speed.

1. Introduction
The cultivation of vegetable products in greenhouses, which requires the use of specially prepared greenhouse soil, is widespread. This method of growing plants provides the population with vegetable products with improved marketability and taste [1]. In the Russian Federation, by 2021, it is planned to increase the production of greenhouse vegetables by 3.5 times and bring their consumption to 12 kg per person per year [2].

The technology of growing plants using greenhouse soil requires complete or periodic replacement of the top (sanitary) layer of greenhouse soil 18–20 cm thick with a new one every 1–3 years [3-4]. If this replacement is not done on time, then soil degradation and a decrease in yield may occur [5].

Currently, there are practically no special machines that facilitate the process of soil removal. For this operation, unsuitable technical means are used with the involvement of a large number of maintenance personnel, which leads to an increase in the cost of manufacturing the final product.

Development and justification of the parameters of the machine for the removal and loading of greenhouse soil allows mechanizing the process, increasing productivity and reducing the cost of finished products.
2. Materials and methods

Based on the analysis of production experience and research carried out, a machine for harvesting and loading soil in greenhouses has been developed [6]. The machine includes (Figure 1): a conveyor (1), a support frame (2), a bucket (6), a linkage mechanism (7) and a drive mechanism (4), rods (3). The bucket (6) is connected to the conveyor (1) by means of rods (3), and the linkage mechanism (7) and drive mechanism (4) are fixed on the upper wall bucket (5). This arrangement of the linkage and drive mechanisms allows reducing the size of the machine, making it more compact, which is necessary when working in greenhouses. The conveyor is located behind the bucket, with the lower part behind the edge of the bucket bottom, to ensure the capture of the greenhouse soil mass coming from the bucket.

When the loader moves after the tractor, the traction force is transferred to the components by the supporting frame. The bucket penetrates into the soil layer located on the surface of the greenhouse. The separated soil layer along the bottom of the bucket moves to the conveyor, which is rigidly connected to the bucket by means of rods. During movement, the conveyor rests on a supporting frame and is driven by a drive mechanism. The soil layer separated by the bucket falls on the conveyor and then moves to the vehicle. Since the lower part of the conveyor is located behind the trailing edge of the bucket, all soil separated by the bucket falls on the conveyor [7].

Due to this device, the machine effectively removes used soil in the limited space of greenhouses. In Figure 2, the arrows show the movement of the separated parts of the soil along the bucket and conveyor. Initially, the separation of the sanitary layer occurs with the front edge of the bucket bottom, and then the side edges act on the separated layer along the working width. Under the influence of cutting edges, there is a complete separation of the removed layer from the main body. After separation, parts of the greenhouse soil move along the inclined plane of the bucket bottom and along the curved surfaces of the side walls to the unloading conveyor.

Thus, the following forces will exert resistance to the separation of the soil layer (Figure 3): \( F_{\text{rep}x} \) is the friction force on the bucket surface, \( F_o \) is the force required to deform the soil on the bucket, \( F_{\text{con}} \) is the resistance force to the movement of the side walls of the dump, \( F_{\text{rep}d} \) is the friction force on the dump surface, \( F_s \) is the force required to deform the soil on the dump, \( F_p \) is the force of resistance to cutting the soil by the front edge of the bucket, \( N_o \) is the reaction of the dump surface, \( N_e \) is the reaction of the bucket surface.
Theoretically, the inertial force $F_i$ also acts on the particles, however, taking into account the movement of the machine, and the soil at the initial moment of time relative to the earth (along the OX axis) remains virtually motionless, the inertial force can be neglected. Then the dump overcomes resistance only from frictional forces and from soil deformation. The gravity force $F_g$ is added along the OY axis.

Let's compose the equations of forces along the axes OX and OY. The sum of the projections of forces on the OX axis is the following:

$$\Sigma F_x = -F_a - F_{ot} = -F_p - (F_n + F_{mpc})/\cos\beta - F_o - (F_{mpo} \cos\gamma)/\cos\beta$$  \hspace{1cm} (1)
\[ \Sigma F_y = - F_g - (F_u + F_{mpg})/\sin \beta - (F_{npu} \sin \gamma)/\sin \beta \] (2)

After substitution of the parameters included in the forces, we get:

\[ \Sigma F_x = F_x^* + F_{con} = \tau_p B \delta + \sigma_0 bh + (ma + m_g f_\sigma)/\cos \beta + \tau_o l s + (m_o g f_\sigma \cos \gamma)/\cos \beta \] (3)

where: \( \tau_p \) is the cutting stress of the soil; \( B \) is the width of the cutting edge; \( \delta \) is the thickness of the cutting edge; \( \sigma_0 \) is the fracture stress of the soil layer, \( b \) is the width of the soil layer, \( h \) is the height of the soil layer, \( m_e \) is the mass of the soil on the bucket, \( a \) is the acceleration, \( g \) is the acceleration of gravity, \( f_\sigma \) is the coefficient of friction of the soil on the surface of the bucket; \( \tau_o \) is the shear stress of soil parts on the dump, \( l \) is the length of the lateral projection of the dump, \( s \) is the height of the soil layer on the dump, \( m_o \) is the soil mass on the dump, \( f_\sigma \) is the coefficient of soil friction over the dump surface, \( \beta \) is the slope of the dump surface, \( \gamma \) is the average blade surface angle.

\[ \Sigma F_y = - mg - (ma + m_g f_\sigma)/\sin \beta - (m_o g f_\sigma \sin \gamma)/\sin \beta \] (4)

3. Results

The performed force analysis made it possible to establish analytical expressions for the power required to carry out the technological process of removing the soil layer from the greenhouse.

Power for moving the separated soil horizontally (along the OX axis) is the following:

\[ P_r = \Sigma F_x v \] (5)

\[ P_r = \{(\tau_p B \delta + \sigma_0 bh + (ma + m_g f_\sigma)/\cos \beta + \tau_o l s + (m_o g f_\sigma \cos \gamma)/\cos \beta)\} v \] (6)

Power for lifting the separated soil when the machine is working on the surface of the muck:

\[ P = \Sigma F_y v_y = (mg + (ma + m g f))/\sin \beta + (m g f sin \gamma)/\sin \beta)v \] (7)

Where \( v \) is the rate of vertical rise of the soil, \( v = v \sin \beta \)

\[ P = \Sigma F_y v_y = (mg + (ma + m_g f_\sigma)/\sin \beta + (m_o g f_\sigma \sin \gamma)/\sin \beta)v \sin \beta \] (8)

The total power to carry out the process of removing the soil layer from the greenhouses will be equal to the sum of the power to move the removed layer horizontally; capacity for lifting the separated soil along the surface of the muck to the unloading conveyor; power to drive the unloading conveyor and to move the machine itself during operation.

The experimental data obtained made it possible to establish the influence of the height of the soil layer and the forward speed on the total power on the implementation of the process of removing the
soil layer from greenhouses. Based on the obtained experimental data, a regression equation was constructed (9).

\[ P = 6443.37 - 479.61v - 84.651h + 17413.2v^2 + 162.321vh + 0.377h^2 \]  

(9)

Graphically, this equation is presented as a three-dimensional surface in Figure 4.

**Figure 4.** Influence of the layer height \( h \) (mm) and the speed of movement of the machine \( v \) (m/s) on the power spent on the movement of the machine.

The analysis of the obtained dependence of the influence of the investigated parameters shows that the power spent on the movement of the machine increases in the entire investigated range of the movement speed. The change in power occurs almost linearly, while the intensity increases with an increase in the height of the layer to be separated. With a height of the separated soil layer of 60 mm, an increase in the speed from 0.11 to 0.17 m/s leads to an increase in the power from 4043 W to 4794 W, i.e. by 18.6%.

At a layer height of 100 mm, an increase in the speed in the indicated range leads to an increase in the power from 3983 W to 4923 W, i.e. by 23.6%. A similar nature of the change is also observed for other values of the investigated parameters.

4. Conclusion

The developed design of a soil harvesting machine with a moldboard working body and an unloading conveyor corresponds to the conditions of use in greenhouses. Effective removal of the top “sanitary” layer is ensured. Theoretical and experimental studies have obtained dependencies for determining the drive power of the machine, depending on various parameters. The change in thickness with the layer height is not linear. With a low layer height, the thickness practically remains constant, with an increase in the soil layer height of more than 80 - 100 mm, it begins to increase intensively. The change in power from the forward speed is almost directly proportional, while the intensity increases with an increase in the height of the layer to be separated. This influence of the investigated parameters is due to the fact that with an increase in both the speed and the height of the layer, the moved mass increases, which increases the power required for movement. This character of change is shown by expressions 7, 8 and the regression equation 9. With an increase in the investigated parameters, the required drive power increases.
To further substantiate the parameters of the soil harvesting machine, it is required to investigate and determine the minimum value of energy intensity with optimal parameters.

References

[1] Autko A A et al. 2004 Influence of the type of substrate on the content of polysaccharides and phenolic compounds in tomatoes in protected ground Proceedings of the National Academy of Sciences of Belarus Agrarian series 3 62-4

[2] Soldatenko A V, et al. 2020 Greenhouse facilities - an overview of the current state of the Russian agro-industrial complex Vegetables of Russia (2) 3-11 https://doi.org/10.18619/2072-9146-2020-2-3-11

[3] RD-APK 1.10.09.01-14 2014 Guidelines for the technological design of greenhouses and greenhouse plants for growing vegetables and seedlings System of recommendation documents of the agro-industrial complex of the Ministry of Agriculture of the Russian Federation Moscow

[4] Hupenyu A M and Mnkeni P N S 2018 Optimizing the vermicomposting of organic wastes amended with inorganic materials for production of nutrient-rich organic fertilizers: a review. Environmental Science and Pollution Research 25(11) 10577-95

[5] Liang Y, Lin X and Yamada S 2013 Soil degradation and prevention in greenhouse production Springer Plus 2(2) 1-10

[6] Pavlov P I et al. 2017 Trailed machine for removing and loading soil in greenhouses Patent of the Russian Federation No. 2621041 Date of publication: 05/31/2017

[7] Pavlov P I et al. 2018 Mechanization of soil preparation for greenhouses International Journal of Mechanical Engineering and Technology 9 (3) 1023-30