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Determining Parameters Affecting the Balance of Compost Fertilizer Mixing Machine

Amir Naghdi-Nasab¹, Gholamhosein Baraderan² , Ali Mostafavi³  

¹ Department of Biosystems Engineering, Faculty of Agriculture, Shahid Bahonar University of Kerman, Kerman, Iran.

² Department of Mechanical Engineering, Faculty of Engineering, Shahid Bahonar University of Kerman, Kerman, Iran.

³ Department of Chemistry, Faculty of Science, Shahid Bahonar University of Kerman, Kerman, Iran.

 Corresponding author amostafavi@uk.ac.ir

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ABSTRACT

Deviation from the traction path affects the operation of composting machines that work in an offset manner and reduces their performance. In this article, a compost mixing machine behind a tractor, which deviates from the movement path during operation, was investigated and evaluated. The equations governing the performance of the extraction machine and the effective parameters in the optimal performance of the device were determined and their effect on the deviation of the device was investigated. The results of this research show that by changing the parameters of the machine without increasing its weight in order to reduce the deviation from the movement path, it is possible to significantly increase the balance of the machine and work efficiency and reduce the deviation from the movement path. In this investigation, it was found that by changing several parameters such as the longitudinal and transverse distance of the composting machine, the friction coefficient, etc., the deviation angle of the machine decreases from 17 degrees to less than 4 degrees. Based on the theory presented in this article, the device was designed, built and used in Gulab Zahra Kerman Company, and its performance is satisfactory, and the practical review of each of the parameters presented in this article will be presented in other articles.

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INTRODUCTION

Compost fertilizer is produced in different ways in the world, the most widely used of which is the production of fertilizer from the waste of agricultural products, which is known as the windrow method (Oyetunji et al., 2022). In this method, the materials used in the production of fertilizer are prepared in long rows and are stirred by the device used for this purpose. These devices are usually divided into three categories: front-mounted devices, tractor-pulled devices, and self-propelled devices. In the front-mounted and self-propelled types, the power generation and the work-performers are a single unit, and the compost mass with different qualities is mixed. But in the second type that is being discussed, the mass stirring device is pulled by the tractor and stirs the mass using a rotor that gets its power from the tractor's PTO. Since these devices are placed on one side of the tractor, they are closed and work in an offset manner. Due to special working conditions and limitations, offset devices, if they are connected to the belt and there is no balancer on the opposite side of them, when the useful forces of the soil work in them, they usually create a circulation effect and tend to rotate and deviate from the traction path (Bochtis et al., 2014; Fagnoli & Lombardi, 2019; Murphy et al., 2010).

Therefore, according to the working conditions and the loads on them, measures should be taken to reduce the deviation from the movement path in these devices to the minimum possible. In general, a device that works at a constant speed in the soil is under the influence of three main forces, including the forces from the soil on the device, the force of gravity on the device, and the effective forces between the device and the driving device, which must be in balance so that the device does not deviate (Zhang et al., 2020).

Soil reaction forces are divided into useful and non-useful forces; Useful forces of the soil are forces that the device in contact with the soil must overcome by cutting, breaking and shifting, and non-useful forces of the soil are the forces that (including friction or rolling resistance) act on stabilizing plates or wheels. Under certain conditions and with a particular device, the driver has little control over the useful forces of the soil, but the designer and the driver have some control

over the non-useful forces of the soil. In the field of machines that work in the form of offset in agriculture, not much research has been done. The first complete analysis of force on offset discs is attributed to (Daniyan et al., 2017; Hermawan et al., 1996, 1997).

The mentioned research was carried out in the field and on one-knee discs and to determine the factors affecting the operation of this device in the state of deviation from the center of tension. In this article, a traction and offset composting machine, which has the technical form of deviation from the movement path during operation, has been investigated. In this device, weights are used to make it heavy so that it is in line with its pulling device in working mode. But the question that arises is to what extent heavy weights should be used to control side loads or whether other parameters are effective in this device that can be changed to reduce the weight of the device. Because as the weight of the device increases, the amount of tensile force increases and a stronger puller will be needed (Kroulik et al., 2015; Novák et al., 2014).

In this article, the parameters affecting the performance of such devices were investigated and the results are given. The remarkable thing about this device is that in addition to the theoretical examination of the parameters shown, considering that this device was not available in the country, a reverse engineering of the German model was done at the suggestion of the German consultant of Gulab Zahra Kerman Company. By receiving information such as its dimensions and useful parameters, the device was identified in the design software, the parameters affecting the operation of the device were made and its performance was checked. Fortunately, with the support of the mentioned company, the device was made at a price equal to 1/4 of the foreign model, and its performance was satisfied by the managers of that complex.

MATERIALS AND METHODS

Several commercial mixing machines were studied and analyzed to find the optimum characteristics for the proposed machine. As a result, a German compost mixing machine suggested by Golab Zahra company's German consultant (Figure 1) was selected and it was

simulated in Catia software. After the design, the balance equations governing the system were determined and the effect of these parameters on the amount of deviation of the device and the appropriate location of the concrete weights to

control the lateral loads and their effect on changing the deviation angle of the device were investigated using MATLAB software.

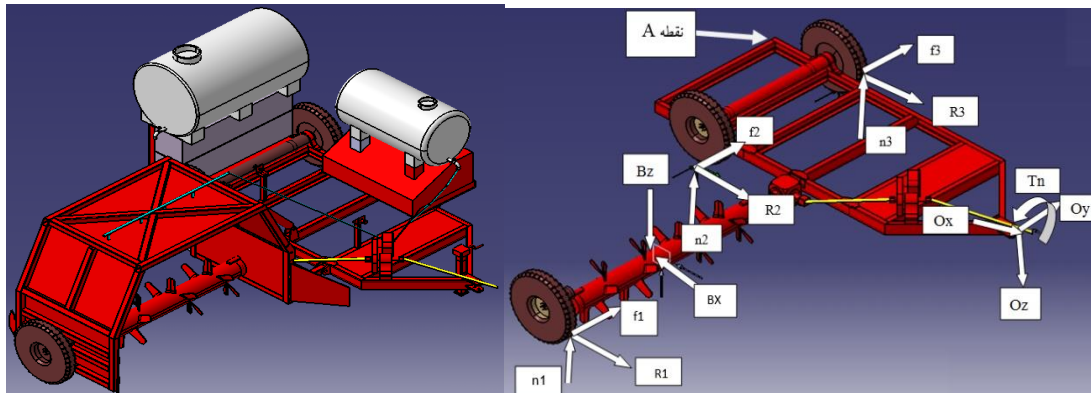


Figure 1. German stirring compost device (right side) and Iranian sample (left side)

Determining the forces and equations governing the system

In Figure 2, the point of effect of the forces applied to the device, including the forces applied to the wheels, the forces applied to the rotor and the force caused by the weight of the device,

which leads to imbalance and deviation from the working path, is shown. To calculate the amount of deviation of the machine from the main working path, first, having known parameters, unknown parameters were calculated and then the value of the angle of deviation was determined according to the loads applied to the machine.



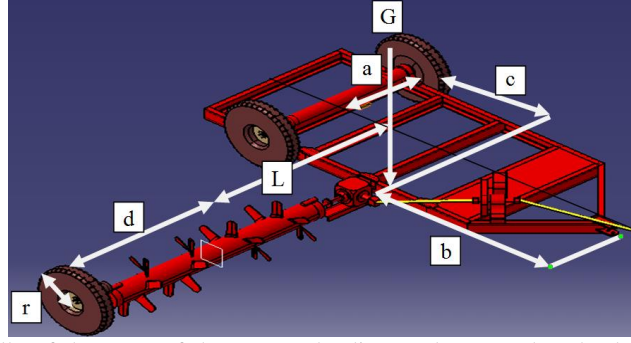
The force applied by the compost pile in z direction
 The rolling friction force in the x direction
 Surface reaction forces in Z direction

B_z
 (R_1, R_2, R_3)
 (N_1, N_2, N_3)

The force applied by the compost pile in the x direction
 torque of power axis
 Sliding friction force in the y direction

B_x
 T_n
 (F_1, F_2, F_3)

Figure 2. Compost mixer and the forces acting on it



The distance from the middle of the rotor of the device to the outlet of the drawbar	L	The distance between the wheel and the vertical axis of the p.t.o	a
wheel radius	r	Longitudinal distance between the rotor axis and the connection drawbar of the tractor	b
Effective center of mass of the device	G	The longitudinal distance of the axis of the rear wheels of the machine to the rotor	c
		The distance between the wheel and the center of the machine rotor	d

Figure 3. Distance between forces in equilibrium equations

Assuming that there is no torque at point O (where the device is connected to the tractor), we will have:

$$\sum Mo_x = 0 \Rightarrow -Tn \cos \theta - WY - N_1 a + N_2 a + N_3(L + d) - bzL + (F_1 + F_2 + F_3)(r + h) = 0 \quad (1)$$

$$\sum Mo_y = 0 \Rightarrow -Tn \sin \theta + WX - (N_2 + N_1)(b + c) - (R_1 + R_2 + R_3)(r + h) - B_x h + (B_z - N_3)b = 0 \quad (2)$$

$$\sum Mo_z = 0 \Rightarrow (F_1 + F_2)(b + c) + (R_1 - R_2) a - B_x L - R_3(d + L) + f_3 b = 0 \quad (3)$$

$$R_i = \mu_r N_i \begin{cases} R_1 = \mu_r N_1 \\ R_2 = \mu_r N_2 \\ R_3 = \mu_r N_3 \end{cases} \quad (4)$$

$$F_i = \begin{cases} \mu_s N_i \sin(K\theta) & \theta < \theta_0 \\ \mu_s N_i & \theta > \theta_0 \end{cases} \quad (5)$$

$$k = \frac{\pi}{\theta_0} \quad (6)$$

That:

μ_r : coefficient of rolling friction (0.01-0.18),

μ_s : coefficient of sliding friction (0.8-0.9),

θ : the total deviation angle of the device relative to the direction of movement of the device and

θ_0 is 20-25 degrees.

The speed of the tractor was 0.07 m/s and the output torque of the P.T.O axis of the Massey Ferguson tractor was determined according to the output power of the rear shaft 559.27 Nm. The cross-sectional area of the compost mass

according to its width and height is 22.3 m², the density of the compost mass is 1200 kg/m³, the cross-sectional area of the part of the rotor involved with the mass is 1.04 m², and the volumetric flow rate of the rotor mass according to the speed of the rotor and the surface of the mass is 0.24 m³/s was calculated.

The force acting on the rotor in the direction of movement and perpendicular to the direction of movement of the machine are B_x and B_z , which are caused by shear stress and the forces caused by the mass moved by the rotor. These forces

were calculated by determining the shear stress from the mass to the rotor, the mass flow rate and the collision speed of the mass with the rotor.

$$B_x = (-\tau b r) \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \sin \alpha d\alpha - (\rho Q) [R \alpha \cos \alpha] \quad (7)$$

$$= 12488/8 \text{ n}$$

$$B_z = (\tau b r) \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \cos \alpha d\alpha - (\rho Q) [R \alpha \sin \alpha] \quad (8)$$

$$= 33884/4 \text{ n}$$

To determine the center of mass, the compost mixer with all its physical characteristics was drawn in Catia software. The coordinates of the center of mass of the device were determined in a two-dimensional coordinate system, whose center is located at the end of the right side of the device (point O) according to Figure 2, at the position of 1.3 m from the x-axis and 1.38 m from the y-axis.

After determining the above parameters and using the system equations, the unknown parameters including the deviation angle of the device is 17.06 and the forces N_1 , N_2 and N_3 which were the reaction of the ground on the wheels were determined as 3936.9, 3936.9 and 18226 N respectively.

RESULTS AND DISCUSSION

To determine the effective parameters on device deviation, the effect of each parameter on the device deviation was investigated using MATLAB software, and the parameters that had a negligible effect on the device performance were omitted.

The distance between the axis of the rotor and the connection point of the mixer composter to the tractor was considered to be 1.3 m and the interval between 0.5 and 3 m was tested to determine its effect on the deviation angle. As can be seen in diagram 1, if the distance between the rotor axis of the compost mixer and its connection to the tractor is increased from 1.3 to 3 m, the deviation angle of the device will decrease from $\theta = 17.06$ to $\theta = 5.7$ degrees. This reduction shows that by changing this distance, the value of the deviation angle can be significantly reduced, or with this change, the balance weights of the device can be reduced with the same deviation angle. This diagram also shows that if we reduce the distance between the rotor and the drawbar

connection, the deviation angle of the device increases greatly, so that if this distance is reduced by only half a meter, the deviation angle of the device doubles.

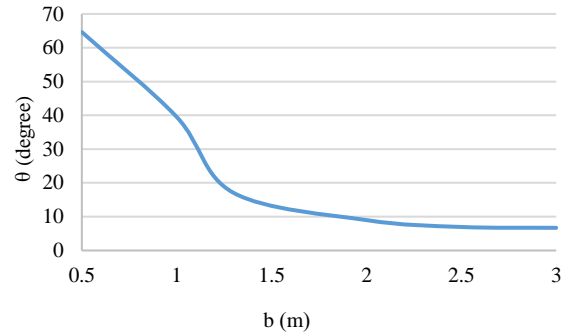


Diagram 1. The effect of the longitudinal distance between the rotor axis and the joint of the drawer on the value of the deviation angle

The transverse distance between the axis of the rotor and the drawbar connecting point of the tractor was considered to be 2.5 m. Diagram 2 shows that if this distance is reduced, the value of the deviation angle will decrease and if this distance is increased by half a meter, the value of the deviation angle will increase rapidly and almost double. Therefore, it is better to consider the length of compost mixer rotor as an essential factor in designs.

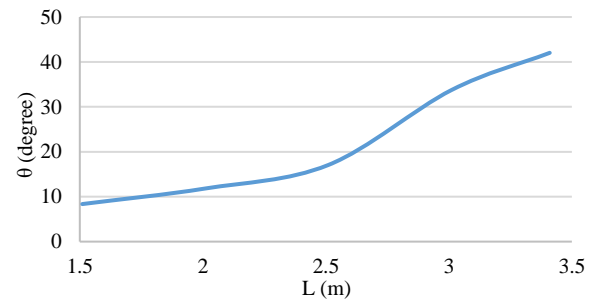


Diagram 2. The influence of the transverse distance between the rotor axis and the drawbar connection point of the tractor on the value of the deviation angle

Another effective parameter on the angle of deviation of the compost mixer is the height of the drawbar Connection point of the tractor relative to the ground level, which was half a meter. Diagram 3 shows that if the height of the drawbar decreases, the value of the angle of deviation decreases, and if this height increases, the value of the angle of deviation increases.

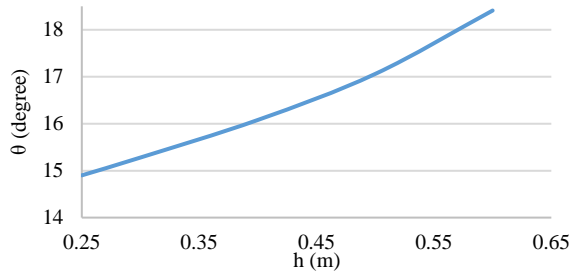


Diagram 3. The effect of the height of the drawbar Connection point of the tractor on the value of the angle of deviation

With the increase of these forces, the deviation angle decreases (diagram 4). But because this force is proportional to the force that is applied to the rotor in the direction of movement and that force is useless, therefore, increasing this force causes an increase in the opposite force and its effect is much less.

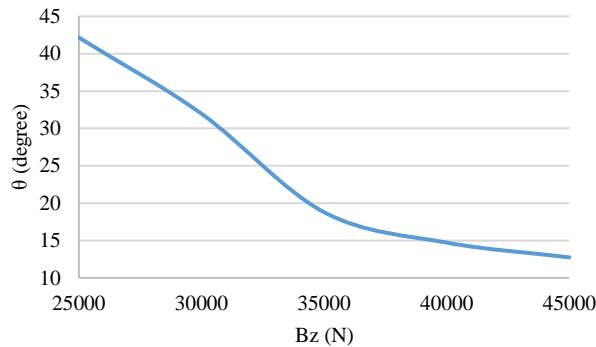


Diagram 4. The influence of the force on the rotor in the direction perpendicular to the movement on the value of the deviation angle

In diagram 5, it can be seen that with the increase of these forces, the value of the deviation angle increases and the effect of these forces on the value of the deviation angle is much greater than the forces perpendicular to the rotor.

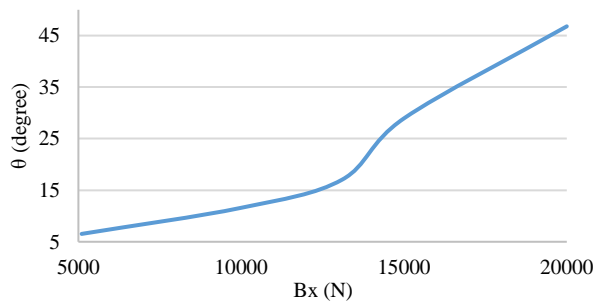


Diagram 5. The influence of the forces acting on the rotor in the direction of movement on the value of the deviation angle

Considering that the coefficient of rolling friction is different for different soils and conditions and it is between 0.01-0.03 in rolled soils and 0.16-0.18 for stubble lands, so the deviation is in the range of 0.01 to 18.00 0 was checked. Diagram 6 shows the effect of the bottom surface of the compost mass on the deviation of the device. According to this diagram, if the mass is disturbed on a smooth surface, the angle of deviation will decrease, and if the ground is not suitable, the angle of deviation will increase rapidly.

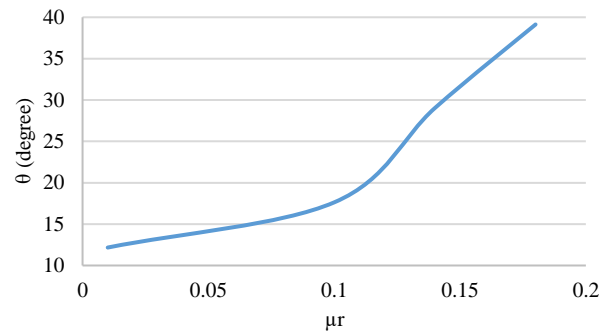


Diagram 6. The influence of the rolling friction coefficient of the surface under the compost on the value of the angle of deviation

The coefficient of sliding friction for different soils and conditions is between 0.8-0.9. Examining the amount of deviation in this range showed that with the reduction of the sliding friction coefficient of the surface under the compost pile, the value of the angle of deviation increases rapidly. Diagram 7 shows the effect of the sliding friction coefficient of the surface under the compost mass on the deviation of the device.

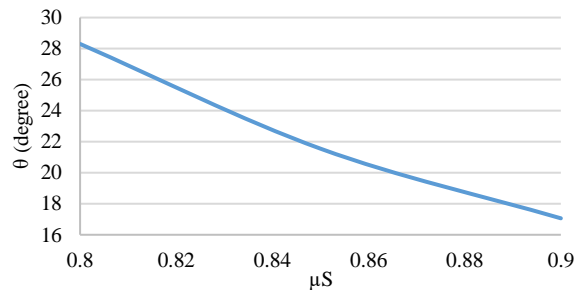


Diagram 7. The effect of the coefficient of sliding friction of the surface under the compost on the value of the angle of deviation

In diagram 8, the value of the angle of deviation according to the loads on the compost mixer machine is given. In this diagram, at a weight of 4000 kg, the deviation angle is equal to 17.06 degrees. With the increase in the weight of the composting machine, the angle of deviation decreases and with the decrease of its weight, the angle of deviation increases.

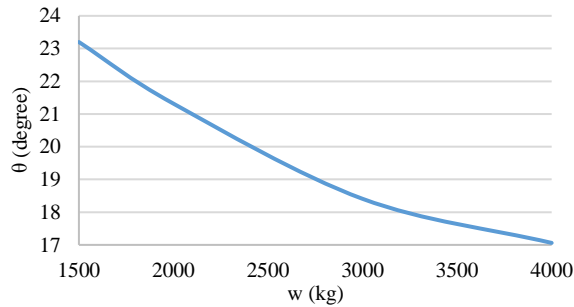


Diagram 8. The influence of the location of center of mass

And at the end, optimization of the best location of the center of mass of the device was done using MATLAB software (Figure 4). It was found that if the center of mass of the device is located at a distance of 2.6 m from the P.T.O axis on the x-axis and on the tension line on the y-axis, the device has the least amount of deviation. If a device with less weight is designed, the location of the center of mass in these coordinates will be the best place.

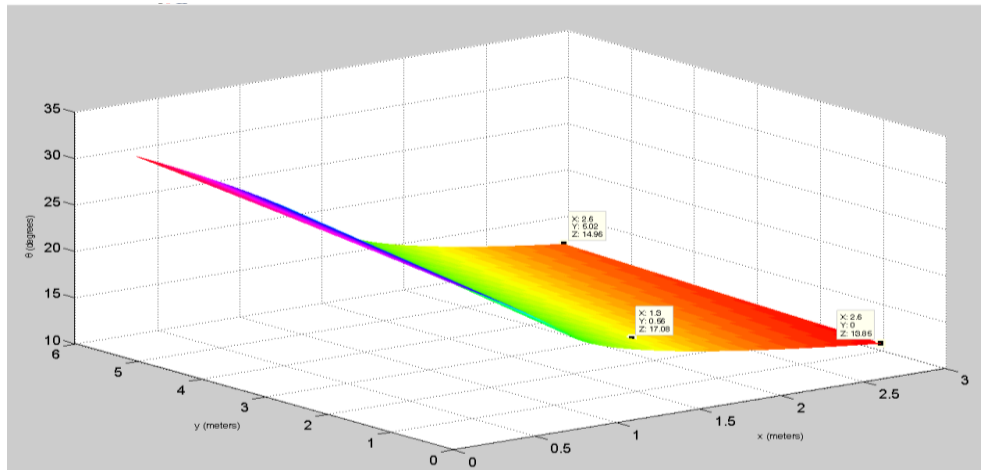


Figure 4. Optimizing the location of the center of mass of the composting machine

CONCLUSION

Excessive deviation of the compost mixer machine brings disadvantages such as creating a large tensile force, the possibility of breaking the power transmission shaft, tire wear, incomplete mixing of the pile, pulling the tractor steering wheel to one side, driver fatigue, etc. An increase in the weight of the stirred compost leads to a decrease in its deviation from the movement path. But by changing the parameters affecting the deviation of the device, it is possible to reduce the angle of deviation without increasing the weight of the device. The results of the investigations showed that with the increase of the transverse distance between the rotor and the drawbar connection point of the tractor, the deviation

angle decreases drastically. The use of rotors with a shorter length reduces the deviation angle of the device and by reducing the height of the connection point of the tractor to the lowest point considered, the deviation angle of the device can be reduced. Also, reducing the forces acting on the device in the direction of movement and increasing the forces acting perpendicular to the direction of movement will reduce the deviation angle and the effects of these two forces are interdependent. But since the reduction of force in the direction of movement has a much greater effect on the deviation angle, it is better to consider the reduction of force in this direction. The surface on which the stirring compost machine works has a great influence on the amount of deviation angle, so it is better that the

surface on which the machine works is smooth and beaten. The results of the tests showed that if the center of mass of compost is placed at the end of the right side of the machine, the deviation angle is reduced.

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