Experiment of rolling friction characteristic of organic fertilizer particle based on high-speed photography

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Abstract:
The physical properties of organic fertilizer particle, including the dimension feature, density, Poisson's rate, shear modulus, coefficient of restitution, coefficient of static fraction, and coefficient of rolling fraction are vital to the design of the drum and the simulation of its working process. There have been many relative studies on them, but no mature theory and accurate method to measure the coefficient of rolling friction has been developed. Only one method based on the principle of conservation of energy gave some enlightenment on the way to achieve it.
The experimental materials included several selected organic fertilizer particle, an angle adjustable frame of rail, and two rails which were made of steel, and organic fertilizer particle respectively.
The frame rate used in the experiment was 1000 fps. According to the results of the experiment, the coefficient of rolling friction of different moisture content organic fertilizer particle against steel, and organic fertilizer particle are known as $y = 0.0004x^2 - 0.0014x + 0.0246 \quad R^2 = 0.9998$, $y = 0.0004x^2 - 0.001x + 0.1521$ $R^2 = 0.9983$ respectively. The data measured can be used for design drum and simulation analysis.

Key words: organic fertilizer particle, experiments, friction, high-speed photography.

Introduction

Fertilizer addition is an important method of crop yield enhancement and has an irreplaceable role in agricultural production. However, the excessive use of chemical fertilizer inhibit further increases in agricultural production and increase production costs. At the same time, this situation also leads to a series of environmental problems, such as low fertilizer utilization rate, decline in soil productivity, and destruction of the soil micro-ecological environment[1,2] .
Organic fertilizers particle are biodegradable and environmentally friendly ,which makes better nutrient sources. The amount of nitrogen (N) and organic matter (OM) in organic fertilizers particle may directly affect the physical and chemical properties of soil and play a positive role in crop development[3] .
The application of organic fertilizer as particles is an effective means to solve problems such as soil compaction and fertility decline, and is being promoted and used in various regions[4,5,6]. At present, the main production process for organic fertilizer particles is granulation drying, but there is a lack of basic material characteristic parameters for organic fertilizer particles [7,8,9]. As a result, the physical characteristics of organic fertilizer particles used in the design of the drying device for organic fertilizer particles will directly affect their stress and movement status in the rotary drum, and thus affect the design parameters of the organic fertilizer particle drying equipment. These characteristics include: bulk density, particle density, water content, friction coefficient, elastic coefficient of restitution, etc. Several scholars have conducted numerous studies on the basic physical parameters of particulate materials, but a large number of scholars have used discrete element models to simulate and calibrate particulate materials. It was established a regression model through simulation testing and calibrated the parameters of an organic fertilizer discrete element model in combination with optimization based on physical testing[10]. It was carried out calibration of simulated physical parameters of clay loam based on accumulation test[11]. It was carried out a calibration of Physical Characteristic Parameters of Granular Fungal Fertilizer Based on Discrete Element Method[12]. In this study, a strategy is presented to identify and select a set of DEM input parameters of granular fertilizers using the central composite design (CCD) to establish the nonlinear relationship between the dynamic macroscopic granular fertilizer properties and the DEM parameters[13]. It was using the EDEM test, the parameters that had a significant impact on the compound fertilizer' resting angle were determined by the fertilizer – fertilizer collision recovery coefficient, fertilizer–fertilizer rolling friction coefficient, and fertilizersteel static friction coefficient14. In summary, researchers often use discrete element simulation analysis methods to calculate the rolling friction coefficient of granular materials. However, when using DEM for simulation experiments, the rolling friction coefficient, shear coefficient, and other parameters are used as input parameters for

simulation calculations. Therefore, it is necessary to find an experimental method to calculate the basic physical parameters of particles. This study measured the rolling friction coefficient of organic fertilizer particles through a series of experiments, providing basic support for guiding the design of organic fertilizer drying equipment.

Materials and methods

Test materials

The organic fertilizer particles are obtained by mixing biogas residue, cow manure, and human acid in a certain proportion through fermentation, deodorization, and granulation. The organic fertilizer products produced by the company are rich in nutrients such as organic matter, nitrogen, phosphorus, and potassium. Organic matter can improve soil physical, chemical, and biological characteristics, ripen the soil, and enhance soil fertility. Fig. 1 shows the physical image of organic fertilizer particles, which are made by a flat mold granulation mechanism and have a cylindrical shape. The particles can be directly sprayed by a fertilizer spreader, making it convenient to apply and stable in fertilizer efficiency.

Due to the fact that organic fertilizer particles are granulated through a flat mold granulator, the theoretical shape of the particles should be approximately cylindrical. The average length of the selected machine fertilizer particles is 9.00mm, and the average diameter is 5.87mm. When the moisture content is 23.79%, the stacking density of the organic particle is 0.70 g/cm³；Particle density is 1.14 g/cm³

Test principle

The appearance of organic fertilizer particles is standard cylindrical, and high-speed camera technology is introduced to measure the rolling friction coefficient between organic fertilizer particles and steel plates, as well as between organic fertilizer particles and organic fertilizer particles. Calculate the rolling friction coefficient based on the law of energy conservation by capturing the motion of particles on an inclined plate[15,16] .

As shown in the Fig. 2 , the particles roll from the top of the inclined plane to the bottom of the inclined plane, and are recorded using a high-speed camera a_1、 a_2、b_1、b_2 Four positions. Among them, a_1 and a_2 The distance between is L_1, b_1 and b_2 distance is L_2. Assuming that the speed of the process does not change for a shorter distance of L_1 and L_2. The instantaneous speeds of midpoints a and b can be calculated as va and vb based on the changes in the number of frames of the high-speed camera。 The rolling friction coefficient can be calculated from point a to point b according to the law of conservation of energy μ。

$$\frac{1}{2}mv_b^2 - \frac{1}{2}mv_a^2 = mgH_1 - \mu mg \sin\alpha L_3 \quad (1)$$

In the formula:

m - weight of organic fertilizer particles, kg;

v_a - instantaneous velocity of particles at point a, m/s;

v_b - instantaneous velocity of particles at point b, m/s;

H_1- Particle falling height, m;

L_3- Displacement of particles from a to b on an inclined plane, m

α— The inclination angle of the inclined plane,°;

μ— The friction coefficient between particles and the inclined plane

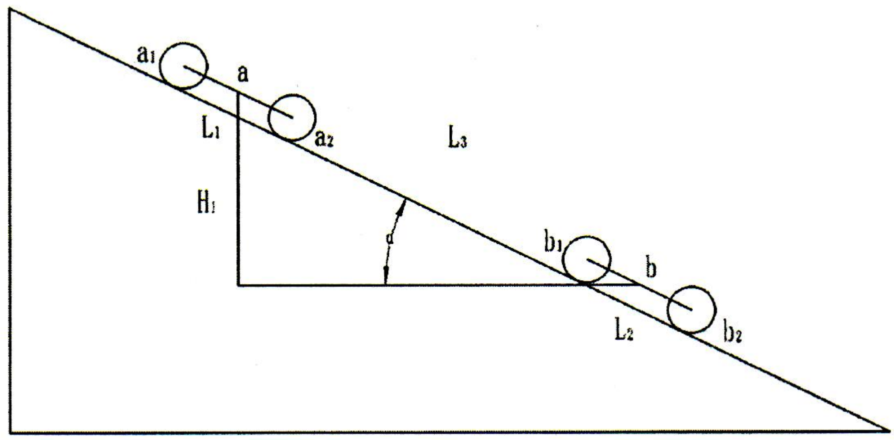
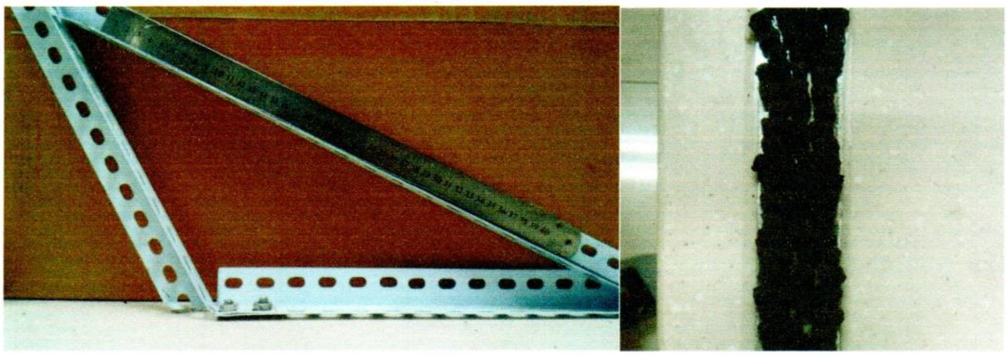


Figure 2 Test measurement system

Test measurement system

To apply this method to measure the rolling friction coefficient of organic fertilizer particles, a test bench needs to be built. The test bench is composed of three painted angle steels, which are connected together by bolts to form a stable triangular support, shown in Fig. 3a.. The angle between the inclined plane of the bracket and the horizontal plane is fixed at 30°, and it is directly placed horizontally on the test bench to maintain the stability of the entire test bench in all directions. Install a steel ruler with a graduation value of 1mm on the vertical plane of the inclined bracket to record particle displacement. Prepare two guide rails with a length of 500mm and a width of 30mm, made of Q235A material. One of the guide rails is coated with organic fertilizer particles shown in Fig 3b, to simulate the rolling friction coefficient between organic fertilizer particles. When pasting organic fertilizer particles, try to ensure the smoothness of the entire surface as much as possible; Another guide rail and the removal of rust on its surface is to maintain a smooth surface as the contact surface for measuring the friction coefficient between organic fertilizer particles and steel plates.



(a)Test Bench ***(b) Organic particle fertilizer particle gauide rail***

(c)High speed camera system
Figure 3 Rolling Friction Coefficient Test Device

The experiment introduced high-speed camera technology, with the main experimental equipment being the Phantomv9.1 high-speed camera and Nikon camera lenses, the High speed camera system shown in Fig 3c. The image processing program is PCC software, and a shooting frame rate of 1000 frames/s was selected in the experiment, which is 768mm × 768mm image acquisition area, 997 μ The exposure duration of s. The motion process video of organic fertilizer particles captured by a high-speed camera is displayed in real-time on a computer screen through a data cable. The Phantom software controls the number of frames played in the main system window video to process the collected video images. Select organic fertilizer particles that have not been dried and dry for different times to obtain the required organic fertilizer moisture content of 1%, 4%, 8.5%, and 17.4%, respectively. Conduct experiments on four organic fertilizer particles with moisture gradients.

Test methods

1) Fix the test bench and corresponding material guide rails, stick a steel ruler on the vertical surface of the inclined guide rails, and turn on the polishing equipment;
2) Open the driver program of the high-speed camera system, observe the image position displayed in the control software, adjust the position of the high-speed camera so that the guide rails are in the image acquisition area, and adjust the image clarity;
3) Take a particle of organic fertilizer and place it at the top of the guide rail. Pay attention to ensuring that the cylindrical surface of the particle contacts the surface of the guide rail to ensure that the particle falls in a rolling process. When shooting, release your fingers and let the particle fall freely to the bottom of the guide rail.
4) Repeat the experiment 8 times for each organic fertilizer particle with a moisture gradient, and after the experiment is completed, replace the guide rail material and repeat the above steps. 2.5

Test results

The test results are shown in Fig . 4 and Fig . 5

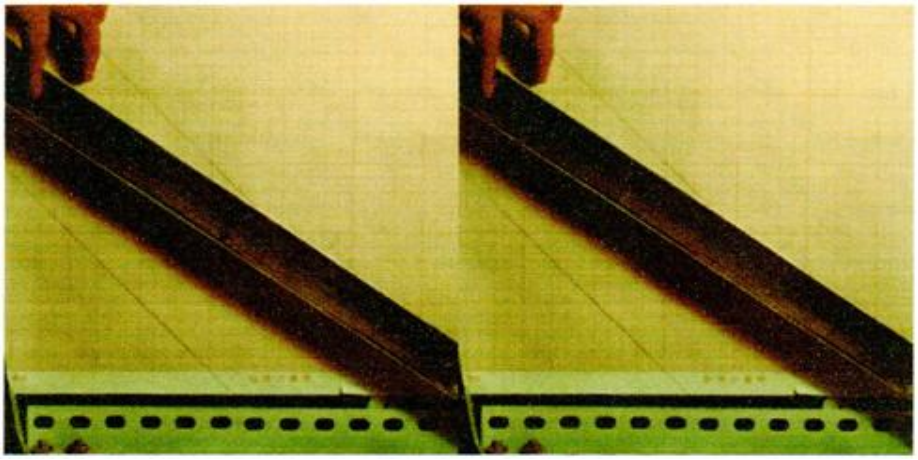


Figure 5 Rolling friction coefficient test between fertilizer particles –Steel Static

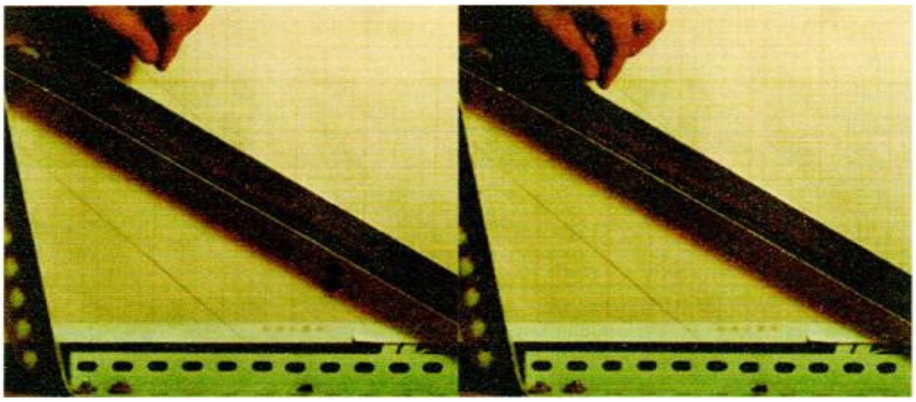


Figure 5 Rolling friction coefficient test between fertilizer particles –fertilizer particles

Results and discussion

Test results

Each group of experiments was repeated 8 times under each moisture content gradient, with the experimental data between organic fertilizer particles and organic fertilizer particles shown in Table 1, and the experimental data between organic fertilizer particles and steel plates shown in Table 2.

Table 1 Rolling friction coefficient test between fertilizer particles –fertilizer particles test Results

Moisture content	Rolling friction coefficient								Mean value	Standard deviation
1%	0.179	0.100	0.273	0.153	0.166	0.148	—	—	0.150	0.028
4%	0.184	0.135	0.117	0.209	0.151	0.183	0.143	0.148	0.158	0.035
8.5%	0.182	0.151	0.158	0.223	0.124	0.169	0.206	—	0.173	0.033
17.4%	0.273	0.234	0.219	0.290	0.292	0.295	0.273	0.251	0.266	0.028

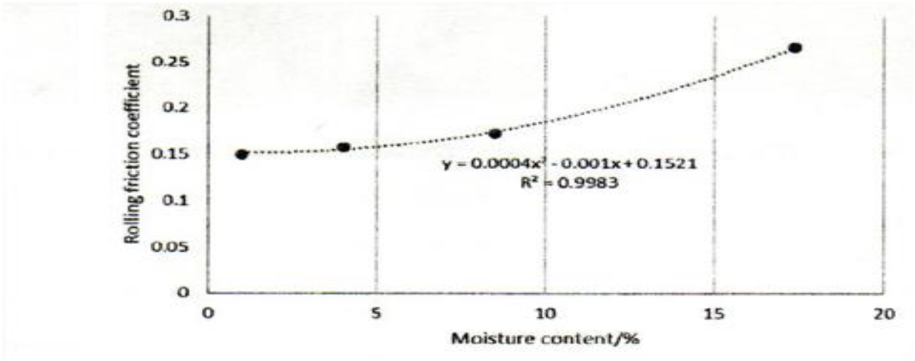
Note: "—"The rolling friction coefficient cannot be calculated due to the severe particle bouncing in this experiment, as the effective displacement change cannot be read.

Table 2 Rolling friction coefficient test between Fertilizer particles -steel static test Results

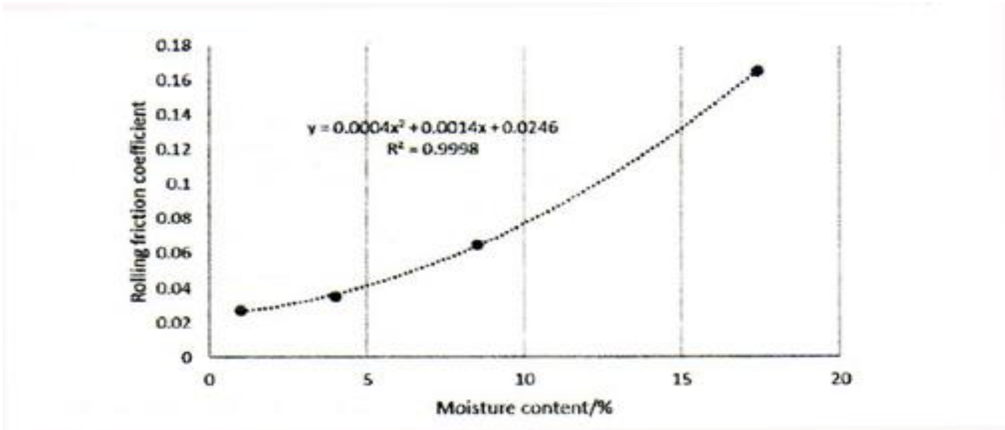
Moisture content	Rolling friction coefficient								Mean value	Standard deviation
1%	0.014	0.027	0.025	0.030	0.023	0.047	0.025	0.027	0.027	0.009
4%	0.025	0.03	0.047	0.045	0.036	0.041	0.034	0.023	0.035	0.008
8.5%	0.034	0.078	0.036	0.046	0.087	0.026	0.045	0.088	0.065	0.025
17.4%	0.182	0.169	0.078	0.158	0.162	0.165	0.175	0.233	0.165	0.042

Test analysis

Based on the above experimental results, the functional relationship between the rolling friction coefficient and particle moisture content between organic fertilizer particles and between organic fertilizer particles and steel plates can be obtained as shown in Fig . 6. The fitting equation is obtained through linear regression: y = $0.0004x^2 - 0.001x + 0.1521$ ^{2} = 0.9983 between particles, y = $0.0004x^2 - 0.0014x + 0.0246$ $R^2 = 0.9998$, between particles and steel plates.



(a) Relationship curve between rolling friction coefficient and moisture content of organic fertilizer particles and



(b) Relationship curve between rolling friction coefficient and moisture content of organic fertilizer particles and steel plates

Figure 6 Rolling friction coefficient and water content relationship curve

CONCLUSIONS

From Fig 6, it can be seen that the rolling friction coefficient between particles increases with the increase of water content, and the increase is not proportional to the increase in water content. When the moisture content is below 10%, the contribution of the decrease in particle moisture content to the decrease in rolling friction coefficient weakens; When the water content is higher than 10%, the increase in water content contributes more and more to the increase in rolling friction coefficient. According to the analysis of particle appearance, when the moisture content of the particles is below 10%, the color of the particle appearance is lighter, the surface moisture content is extremely low, and the surface performance is similar to that of a metal surface without stickiness; When the moisture content is higher than 10%, the surface moisture content of particles increases, and the surface begins to have a certain degree of viscosity, leading to a rapid increase in its rolling friction coefficient. This viscosity becomes more apparent with the increase of moisture content.

REFERENCES:

1. Ye, L.; Zhao, X.; Bao, E.; Li, J.; Cao, K. Bio-organic fertilizer with reduced rates of chemical fertilization improves soil fertility and enhances tomato yield and quality. Sci. Rep. 2020, 10, 177.
2. Prasuna, R.; Ch, P.R.; Kumari, A.L.; Rao, P.J.; Prasad, P.R.K. Yield and fiber qualities of cotton (Gossypium hirsutum) as influenced by long-term manures and fertilizers on cotton MonoCropping. Agric. J. 2017, 64, 120–122.
3. Wei, H.; Zan, L.; Li, Y.; Wang, Z.; Saxén, H.; Yu, Y. Numerical and experimental studies of corn particle properties on the forming of pile. Powder Technol. 2017, 321, 533–543.

4. Tao, R.; Tang, C.; Li, R.; Tan, L.; Chu, G. Effect of partial replacement of chemical fertilizer with organic fertilizer on nitrogen transformation and nitrogen content of different forms in drip irrigated cotton field. Soil Fertil. China 2015, 1, 50–56.10.
5. Li, R.; Tao, R.; Wang, D.; Chu, G. Effects of nitrogen reduction and organic fertilizer application on soil biological properties and aggregate properties in cotton field with drip irrigation. J. Appl. Ecol. 2017, 28, 3297–3304.11.
6. Li, S.; Liu, X.; He, P. Analyses on nutrient requirements in current agriculture production in China. J. Plant Nutr. Fertil. 2017, 23,1416–1432.
7. Kokoshin S N, Kirgintsev B O. Modernization of the Drying drum Design for Organic Fertilizers .J. International Journal of Engineering Research and Technology, 2021, 13(12): 4646-4652.
8. Bhowmik A, Bhunia S, Debsarkar A, et al. Development of a Novel Helical-Ribbon Mixer Dryer for Conversion of Rural Slaughterhouse Wastes to an Organic Fertilizer and Implications in the Rural Circular Economy.J. Sustainability, 2021, 13(16): 9455.
9. Naswir N, Hasman E, Irwan A. Rotary Electrical Controlled Drum Dryer for Organic Fertilizer Production.J. Journal of Applied Agricultural Science and Technology, 2019, 3(2): 319-326.
10. Yuan, Q. Parameter calibration of discrete element model of organic fertilizer particles for mechanical fertilization. Trans. Chin.Soc. Agric. Eng. 2018, 34, 21–27.
11. Xiang,W. Calibration of simulated physical parameters of clay loam based on accumulation test. Trans. Chin. Soc. Agric. Eng. 2019, 35, 116–123. Yu, S.; Bu, H.
12. Dong,W.; Jiang, Z.; Zhang, L.; Xia, Y.Calibration of Physical Characteristic Parameters of Granular Fungal Fertilizer Based on Discrete Element Method. Processes 2022, 10, 1564.
13. Adilet, S.; Zhao, J.;Sayakhat, N.; Chen, J.; Nikolay, Z.; Bu,L.; Sugirbayeva, Z.; Hu, G.; Marat, M.;Wang, Z. Calibration Strategy to Determine the Interaction Properties of Fertilizer Particles Using Two Laboratory Tests and DEM. Agriculture 2021, 11, 592.
14. Yuan, F.; Yu, H.;Wang, L.;Shi, Y.;Wang, X.; Liu, H. Parameter Calibration and Systematic Test of a Discrete Element Model (DEM) for Compound Fertilizer Particles in a Mechanized Variable-Rate Application. Agronomy 2023, 13, 706.
15. Ma D, Liu C, Zhao Z, Zhang H. 2014 Rolling friction and energy dissipation in a spinning disc. Proc. R. Soc. A 470: 20140191.
16. Wang J W, Tang H, Wang J F, Jiang D X, Li X. Measurement and analysis of restitution coefficient between maize seed and soil based on high-speed photography. Int J Agric & Biol Eng, 2017; 10(3): 102–114.