Investigation of the impact interaction of pelleted seeds with the soil environment

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Abstract. The issues of studying the impact interaction of seeds with the soil environment by the method of discrete elements are considered. The main parameters of the used virtual stand are described and a brief description of the interaction model is given. As a result of the study, the depth of penetration of the seed, its displacement in the horizontal plane and the greatest depth of the crater were obtained. Analysis of the data showed that on unbound and loosely bound soils, a penetration rate of 50 m/s is sufficient for almost 100% penetration into the surface layer without noticeable displacement of the pelleted seed. On medium cohesive soils at a speed of 50 m/s, stable seed penetration is not ensured. The probability of its release is about 10%. At speeds of 75 m/s, almost 100% penetration into the surface layer is provided without noticeable displacement of the coated seed. On cohesive soils at speeds of 25 m/s, the seed is always ejected from the crater over a considerable distance. At a speed of 50 m/s, the probability of seed ejection is reduced to 30% and at 75 m/s to 10%.

1. Introduction

Currently, an increasing number of researchers are turning to the topic of reforestation using aeroseeding. The revival of interest in this topic is associated with an increase in the rate of deforestation and the intensive development of unmanned aerial vehicles (UAV). The main advantages of using UAVs are the possibility of reforesting hard-to-reach and difficult-to-pass areas, as well as high technology productivity with relatively low labor and material costs.

For sowing, pelleted seeds are used, most often conifers with a small seed size. In this case, the pelleted seed receives additional acceleration in the sowing unit. This is required for the seed to penetrate the surface soil layer and increase the accuracy and rate of seeding. The result of the interaction of the seed with the soil environment (the amount of deepening, rebound) largely determines the further development of the plant.

At the same time, the issue of mathematical modeling of the impact interaction of the seed with the soil surface, depending on such factors as soil connectivity and speed of movement, remains insufficiently studied. The depth of seed penetration into the soil environment, the probability of rebound and its value depend on these factors.

To study the processes of soil interactions with working organs and seeds, the method of discrete elements is now most often used. The following groups of studies can be distinguished. The most significant group is the study of the interaction of passive working organs with the soil environment [1]. Quite a lot of works studying the interaction of active working organs [2,3]. There are also
separate studies that simulate the interaction of sown seeds and soil [4,5], fertilizer granules and soil [6] (figure 1). In other industries, there are similar studies of the impact interactions of objects with granular media, for example, the processes of formation of craters on the surface of planets, the movement of projectiles in granular media, etc. This is a whole series of experimental studies.

In the study [7], glass balls of different diameters from 65 to 500 µm were used, and steel balls with a diameter of 2 to 14 mm were the impact objects. The process was filmed with a high-speed camera with a frequency of up to 2000 frames per second.

Similar experiments were carried out with vertically directed spherical impact objects falling without rotation [8]. The targets were glass balls of three sizes: 200-425, 180-300 and 106-212 µm. The impact objects were ten different spheres ranging from 4 to 20 mm and densities from 2500 – glass to 15000 kg·m\(^{-3}\) – tungsten carbide. The drop height ranged from 30 to 350 mm, depending on the density of the target layer.

In the study [9], impact objects were dropped into a discrete medium from a height of 10 to 2500 mm with final impact velocities from 0.4 to 7 m/s. Used strikers of various shapes and bulk materials.

This study desperately needs high-speed X-ray imaging [10]. A steel ball with a diameter of 12 mm was used as an impact object, dropped from a height of 340 mm into a layer of boron carbide (B4C) particles 85 mm thick. Also, for a more uniform packing of the layer of target particles, its additional aeration was carried out.

All these practical studies have a number of common features: a predominantly spherical impact object with different masses is dropped from a variable height without additional acceleration and rotation; the target object is predominantly formed from spherical particles; in all studies, the particles were not additionally bound, which is not typical for soil particles.

Numerical discrete models were also used [11–14]. However, their results cannot be used because of very significant differences in the properties of the simulated environment and interaction modes.

![Figure 1. Modeling the soil environment by the discrete elements method (DEM).](image-url)

The key external factor that determines both the surface location of the pelleted seeds and their position relative to the soil surface is the interaction with the soil environment. Current studies are
considering an interaction case that does not involve seed penetration into the soil layer, assuming that the soil particles are highly adhesive and form a hard surface.

The aim of the research is to study the impact interaction of pelleted spherical seeds with the soil environment, taking into account different degrees of connectivity of soil particles and speeds of seed movement using the DEM.

2. Material and methods

2.1. Description of the virtual stand for studying the parameters of the interaction of the pelleted seed with the soil environment

The DEM allows you to study in detail the process of penetration of pelleted seeds into the target surface (soil, snow cover). Mathematical modeling of these processes requires an adequate description of a complex set of physical processes, which include severe deformations and discontinuity of materials.

To carry out the research, a plot of the soil surface with a size of 100×100 mm was modeled (figure 2). The radius of soil particles in various series of experiments was taken to be 1 mm, and an exclusively spherical shape was used. The density of particles was taken to be equal to the density of the solid phase of the soil 2500 kg·m⁻³, weight 0.011 g. When filling with soil particles during the experiment, the formed soil layer will have a lower density, corresponding to the density of natural forest soils.

The radius of the pelleted seeds was taken equal to 2.5 mm, while the spherical shape was also used. The density of the pelleted seed was taken equal to 1900 kg·m⁻³, weight 0.124 g.

The target soil plot was formed using filling an area of 100×100×100 mm, followed by grouping of particles under the action of gravity. The resulting soil layer with a particle radius of 1 mm consists of 64,547 particles. The height of the reservoir is at least 50 mm, respectively, its volume is 0.0005 m³ and the total mass of particles is 0.676 kg. The density of the soil layer is 1352 kg·m⁻³, which corresponds to the density of forest soils.

![Figure 2. Virtual soil plot for seed introduction research.](image)

2.2. Description of the virtual stand for studying the parameters of the interaction of the pelleted seed with the soil environment

When soil elements come into contact with each other and the seed, elastic forces arise, and forces of dry and viscous friction (figure 3).
Figure 3. Schemes of force contact of soil elements: (a) – forces arising from the contact of two discrete elements; (b) – forces arising from the contact of the soil element and a solid surface;  $F^Y$ – elastic forces; $F^C$ and $F^B$ – dry and viscous friction forces.

The motion of discrete elements under the action of these forces is calculated according to the laws of classical dynamics.

Modeling is done in 3D Cartesian space (x, y, z). The state of each element $E_i$ is specified by six variables: the coordinates of its center ($x_i$, $y_i$, $z_i$) and the velocity components ($v_{xi}$, $v_{yi}$, $v_{zi}$). A more detailed description of the mathematical model is given in another work of the author [15].

2.3. Monitoring the simulation process

For visual control of the simulation results and assessment of the displacement of soil particles, we used color diagrams of particle velocities (figure 4). Zero particle speed corresponds to blue color, speed of 1 m/s red color, intermediate values – shades of green.

Figure 4. Monitoring the simulation process.

The control of the geometric parameters of the interaction of the pelleted seed with the soil was carried out by the depth of penetration and displacement in the horizontal plane in the case of rebound. In this case, the depth of penetration is fixed at the lower point of the sphere of the seed shell. The
maximum depth of the crater was also measured, since the pelleted seed with a high probability will occupy the lower position under the influence of external factors (precipitation, etc.) if it remains within the crater.

3. Results and discussion

3.1. Seed penetration into loosely cohesive soil

Figure 5 shows color diagrams of the central cut of the soil, demonstrating the process of penetration pelleted seed into loosely cohesive soil at flight speeds of 25, 50 and 75 m/s.

Analysis of the data shows that at speeds of 25 and 50 m/s, the depth of the crater is slightly greater than the depth of seed penetration. This is due to the fact that the entry of the seed into the soil does not occur vertically downwards, but at a slight angle due to the significant speed of the aircraft. Therefore, there is a slight longitudinal displacement of the change upward along the wall of the formed crater. At a travel speed of 75 m/s, on the other hand, the penetration depth is greater than the depth of the crater, which means that the seed is completely covered with soil.

3.2. Seed penetration into medium cohesive soil

Figure 6 shows color diagrams of the central cut of the soil, demonstrating the process of penetration pelleted seed into medium cohesive soil at flight speeds of 25, 50 and 75 m/s.

Analysis of the data shows that at speeds of 25 m/s, the seed is ejected from the crater outside the modelling zone in all experiments. At a speed of 50 m/s, the probability of seed ejection is reduced to 10%. The depth of the crater at speeds of 50 and 75 m/s is also slightly greater than the penetration depth of the seed.
3.3. Seed penetration into cohesive soil

Figure 7 shows color diagrams of the central cut of the soil, demonstrating the process of penetration the pelleted seed into the cohesive soil at flight speeds of 25, 50 and 75 m/s.
Analysis of the data shows that at speeds of 25 m/s, the seed is ejected from the crater outside the modelling zone in all experiments. At a speed of 50 m/s, the probability of seed ejection is reduced to 30% and at 75 m/s to 10%. The depth of the crater at speeds of 50 and 75 m/s is also slightly greater than the penetration depth of the seed.

In addition, figure 8 provides a summary of average crater depths and average penetration depths on different soil types.

Thus, the following high-speed operating modes of the seeding devices can be recommended.

On loose and loosely cohesive soils (sandy soils), an entry speed of 50 m/s is sufficient for almost 100% penetration into the surface layer without noticeable displacement of the pelleted seed. Even at a speed of 25 m/s (in fact, it is achieved with a free fall from heights of more than 30 m), there is a slight displacement practically without carrying out beyond the boundaries of the formed crater.

On medium cohesive soils at a speed of 50 m/s, stable seed penetration is not ensured. The probability of its release is about 10%. At speeds of 75 m/s, almost 100% penetration into the surface layer is ensured without noticeable displacement of the seed.

On cohesive soils at speeds of 25 m/s, the seed is always ejected from the crater over a considerable distance. At a speed of 50 m/s, the probability of seed ejection is reduced to 30% and at 75 m/s to 10%.

It should also be noted that penetration into the soil layer is observed only on loosely soils, that is, the seed is covered by soil particles from the sides and top. In the case of penetration of medium cohesive and cohesive soils, there may be only slight lateral coverage of the seed with soil particles or being on the surface, but within the formed crater.

4. Conclusions

The data obtained as a result of the study showed that on unbound and loosely bound soils, a penetration rate of 50 m/s is sufficient for almost 100% penetration into the surface layer without noticeable displacement of the pelleted seed. On medium cohesive soils at a speed of 50 m/s, stable seed penetration is not ensured. The probability of its release is about 10%. At speeds of 75 m/s, almost 100% penetration into the surface layer is provided without noticeable displacement of the coated seed. On cohesive soils at speeds of 25 m/s, the seed is always ejected from the crater over a considerable distance. At a speed of 50 m/s, the probability of seed ejection is reduced to 30% and at 75 m/s to 10%.

The data for unbound soils are in good agreement with the experimental and numerical studies of other authors. This is because the additionally unbound soil particles behave like bulk materials used in other studies. All the main stages of the process of crater formation and particle ejection are also similar. With an increase in the degree of soil connectivity, the differences with the previously obtained data increase.
In further studies, in order to increase the reliability of the model, the angles of deviation of the trajectory of the seed flight from the vertical arising from sowing from a moving unmanned aerial vehicle should be taken into account. Also, the speed of rotation of the seed should be taken into account, especially when its shape differs from the spherical one and the granulometric composition of the soils. Another important feature that requires study is the possibility of destruction of the pelleted seed shells, which is associated with their limited strength. Additionally, cases of interaction with media with physical properties uneven in depth should be investigated. For example, the presence of a more durable surface layer, the presence of forest floor on the surface, etc.

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