



SpreadDEM

Centrifugal Spreading Simulation Software

www.compassis.com/spreaddem

USER MANUAL



Compass Ingeniería y Sistemas S.A.

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1. SpreadDEM Overview

The increasing concern of our society for the environment and the raise in the cost of labor, together with the most recent technological progress in all areas of knowledge is pushing the agriculture sector towards an ever increasing technification all over the world, gearing traditional farming towards precision agriculture.

The fertilizer industry represents a very substantial part of the business in agriculture. And while the use of mineral fertilizers is today indispensable in most industrial-scale agriculture, their high cost requires an optimized dosage. Furthermore, the damage that washed-away fertilizers can cause to the environment, including the contamination of wells and the eutrofizacion of natural water deposits, motivates the search for more accurate means of distribution.

One of the most common methods by which the fertilizer is distributed is the use of disc-shaped rotary spreaders. The discs normally come in pairs, fixed at the back of a tractor, oriented horizontally with respect to the ground and rotating at opposite angular velocities, so that their spread patterns overlap, forming, at every instant, a bean-shaped spread pattern on the ground, called the static spread pattern. The rectilinear motion of the tractor implies that the static spread pattern is extended in the longitudinal direction. The overlap of several of these extended patterns formed by successive, parallel trajectories on the field yields the resulting distribution of fertilizer on the ground. The objective is to have it distributed as uniformly as possible in as many conditions as may be encountered, including the effect of ground inclination, wind, different fertilizers and the vibrations induced by the ground irregularities.

This objective drives the design of a multitude of spreader systems. New prototypes are costly and time-consuming to produce, and testing them is also expensive as it requires large spreading halls and large amounts of fertilizer that become waste material. This means that trial and error must be very limited to a small set of alternatives and it is too risky to try out nonstandard designs.

1.1. What about SpreadDEM

SpreadDEM simulation software for centrifugal spreaders is a new powerful tool for spreader manufacturers and fertilizer producers. Being low-cost and time-saving, it opens the door to testing new designs easily and much more efficiently. SpreadDEM offers a very friendly and intuitive interface (Figure 1) with all the necessary ingredients for running a spreading simulation.

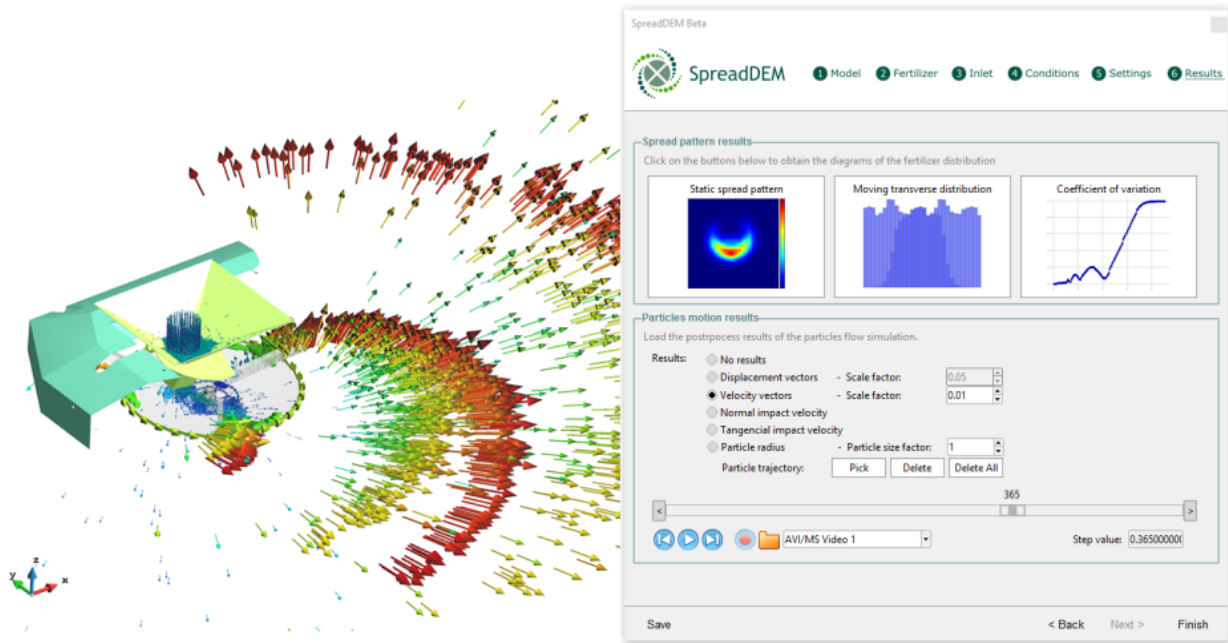


Figure 1. Screenshot of SpreadDEM user interface.

The program is based on the DEM (discrete element method), a numerical method which, in turn, is the core of an extensively validated software, the DEMPack, a software specially oriented to the simulation of particulate problems that has been extensively used in many national and international projects involving different disciplines.

This software is not only used to reduce the number of experiments required but also to enrich the understanding of the fertilization process thanks to the detailed information provided by the computing simulation. The trajectory of individual particles, their velocities and impact points can be closely analyzed to find the weak points in the design and generate optimized spreader geometries. Apart from that, SpreadDEM is capable of reproducing the most relevant results that are usually obtained from experimental tests, such as the spread pattern on the ground, the transversal distribution of fertilizer obtained after several passes of the spreader and the coefficient of variation graph, which gives an idea of the uniformity of the distribution. In addition, the effect of external conditions such as wind and slope of the ground can be virtually reproduced, giving the program a very attractive added value.

For all of these reasons, SpreadDEM brings the opportunity of optimizing the design of spreader machines through the transformation of the conventional engineering workflow into a more efficient one (Figure 2).

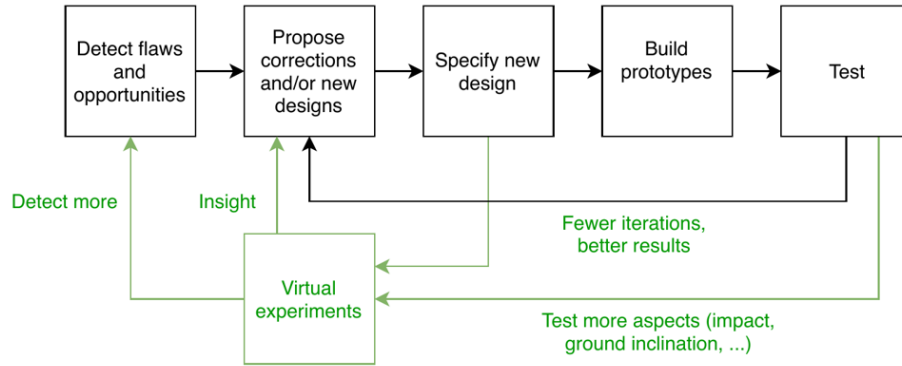


Figure 2. Conventional design workflow (in black) optimized with the use of SpreadDEM digital tool (in green).

1.2. Technical background: Discrete Element Method

There has been a substantial number of studies on the analysis of the spreading processes using numerical methods, especially in the later years. The Discrete Element Method (DEM) is the ideal technology for the analysis of this problem, since it is capable of capturing the dynamics of the fertilizer particles along the entire process.

The DEM is a computational model that calculates the trajectories of an arbitrary number of particles that move according to Newton's laws under the action of both external forces, such as their own weight, and of contact forces, which act between particles when they become close enough (Figure 3).

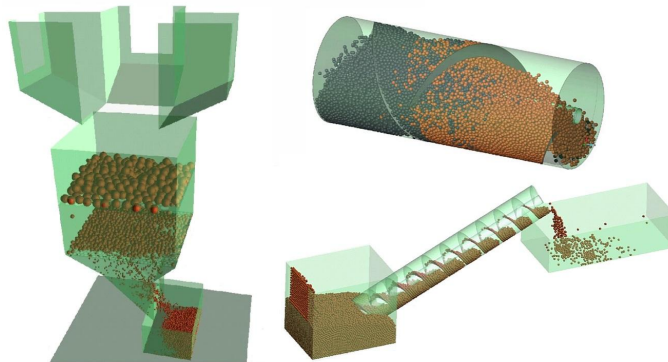


Figure 3. Application examples of the DEM technology.

In general, each particle is modeled as a sphere, and its movement is determined by the position of its center and its rotation vector, both of which evolve in time. The presence of bounding walls can in turn be modeled by a set of flat rigid triangles. The most popular variety of the DEM, and the one used in SpreadDEM, is called the soft-sphere method. In this version the particles are allowed to slightly overlap over each other and also penetrate the walls. There is a contact force and, sometimes, also a contact moment, to be added to the total actions being applied to the particles. These contact forces and moments are typically a function of the penetrations they undergo. The simplest version of this contact include a linear spring and dashpot

rheological model with no sticking, and which depends linearly on indentation, although the contact model can become much more complicated, often devised with a particular application in mind¹. Normally, there exists a number of free parameters that can be used to calibrate these micro-scale models by comparing the resulting macroscopic motion with experimental results.

Apart from the standard particle-particle and particle-walls contact forces, the analysis of the spreading process necessarily includes the aerodynamic actions on the particles when in flight. Those are, on one hand, the drag force, which acts opposite to the motion of the particles in the air and is mainly a function of their velocity and shape. On the other hand, the Magnus force, which arises from the spin of the particle. The importance of the latter is generally secondary when compared to the former, although in some cases it can become significant. The Magnus force is a function not only of the velocity and shape of the particles, but also of their spin. Taking into account the contribution of both forces is critical for an accurate analysis of the centrifugal spreading, as their effect in the final distribution of the fertilizer is considerable, both in distance (drag force) and direction (Magnus).

1.3. How to get SpreadDEM

These are the steps to get a one month trial version for free:

1. Download the latest version of SpreadDEM on our [website](#).
2. After installing it and launching the executable, you will find a dialog box with the information of the system (Figure 4).

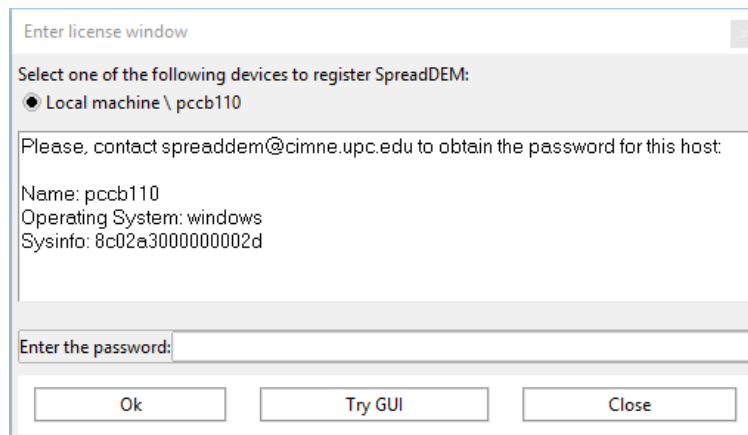


Figure 4. System information window.

3. Send this information to spreaddem@compassis.com and we will get back to you with the password as soon as possible.

If the trial period has been satisfactory, you can request an annual license on our [online shop](#).

¹ More details on this can be found on:

- Thornton, C., Cummins, S.J., Cleary, P.W., 2013. An investigation of the comparative behavior of alternative contact force models during inelastic collisions. *Powder Technology* 233, 30-46.
- Casas, G., Mukherjee, D., Celigueta, M.A., Zohdi, T.I., Onate, E., 2017. A modular, partitioned, discrete element framework for industrial grain distribution systems with rotating machinery. *Computational Particle Mechanics* 4, 181-198. References

2. User Workflow

SpreadDEM guides the user through a sequence of intuitive dialog boxes that prompt the user to fill in the essential input parameters required to perform a complete analysis of the fertilizer spreading process (Figure 5).

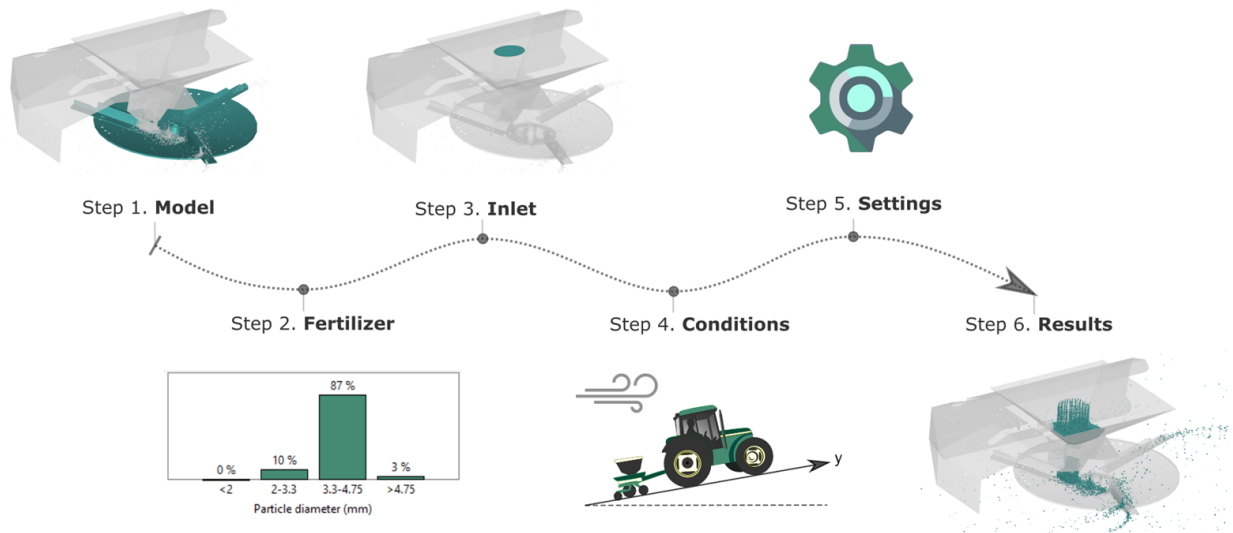


Figure 5. SpreadDEM workflow.

The whole process consists of six easy steps:

- **Step 1. Model** - Load the geometry of the rotating and fixed parts.
- **Step 2. Fertilizer** - Enter the fertilizer properties, such as density and granulometry.
- **Step 3. Inlet** - Define the particles' injection area and its mass flow rate.
- **Step 4. Conditions** - Specify the slope of the terrain and the wind speed and direction.
- **Step 5. Settings** - Set the computation parameters, such as the criterion to end the simulation.
- **Step 6. Results** - Analyze the results of the ended or ongoing simulation.

Apart from the information related to the spreader performance and the fertilizer properties provided by the manufacturer, it is also advisable to have some experimental results in order to calibrate the unknown fertilizer parameters. Otherwise, users can work with a range of possible values for the unknown properties and make a sensitivity analysis to quantify their influence on the final results.

This section will show you in more detail how to launch a spreading simulation, step by step, and how to analyze the subsequent results.

2.1. Starting window

Just after launching the executable of SpreadDEM, you will find a window with contact information and two starting options (Figure 6):

- **New project:** generate a new project from scratch.
- **Load project:** load a previously saved project. Choosing this option will open the interface at the exact step you were before closing the saved project.

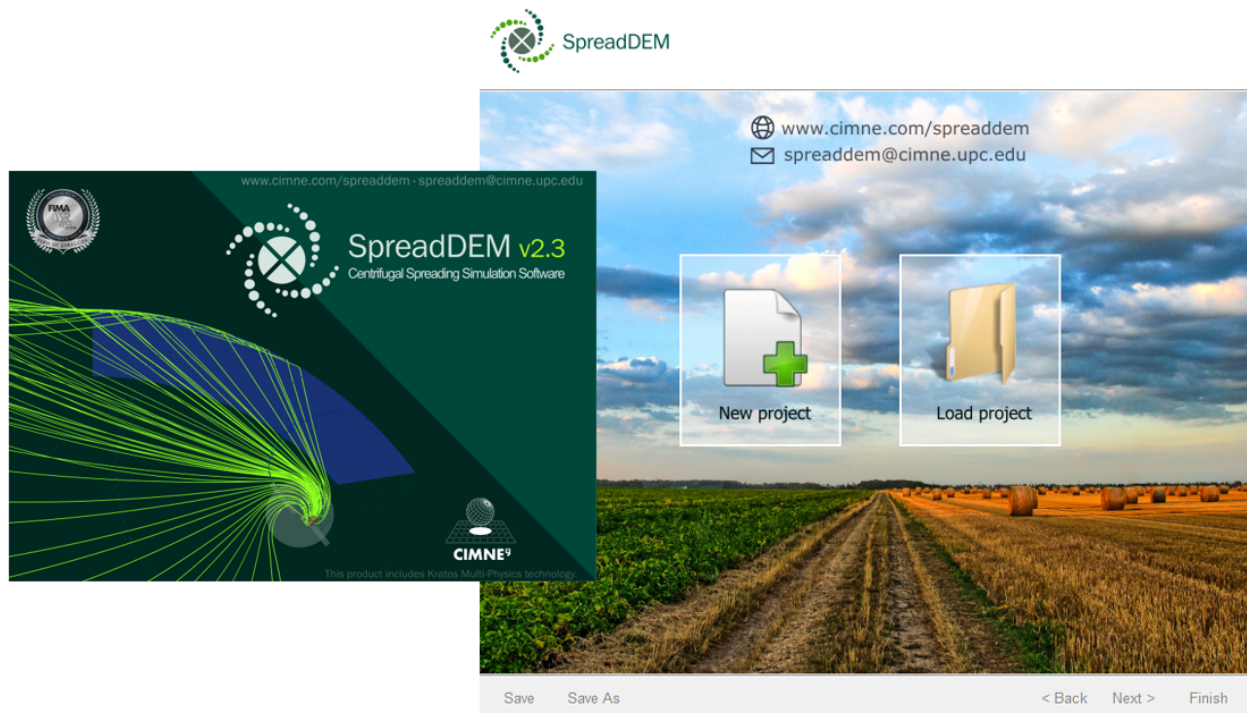


Figure 6. Start or load a project.

2.2. Step 1: Model

The first step is to import the geometries of the spinning discs and the fixed parts of the spreader from any computer aided design (CAD) tool. Once the discs are loaded and set in their proper position, the user can assign the angular velocity and the rotation axis (Figure 7).



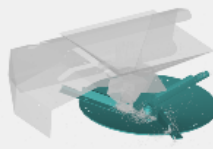
Units and axes convention
Select the units of the imported CAD geometry and check the axes convention before importing the geometry.
Model units: Axes convention:

Discs / rotating bodies
Import the geometry of the discs in .stl format. A maximum of two discs can be imported.

Disc1 Move

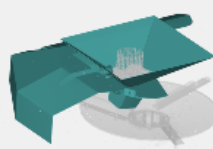
Kinematics Disc 1
Angular velocity: rpm
Rotation axis: Display vector
Disc center:
Axis node:
X m m
Y m m
Z m m

Duplicate disc:
Distance between discs: m
 Show duplicated disc



Fixed / rigid bodies
Import the geometry of the fixed/rigid bodies in .stl format. Different bodies such as hoppers, nozzles, deflectors, protectors, etc. can act as fixed bodies.

Rigid1 Move



Save Save As < Back Next > Finish

Figure 7. Step 1: Import the model.

- **Units and axes convention:** before importing any geometry, you have to set the units of the imported CAD geometry and be aware of the axes convention. You can see a scheme with the reference axes by clicking on the button "Show image" (Figure 8). The Y axis coincides with the direction of travel, Z is normal to the ground plane, and therefore the X axis follows the transversal direction of the field .

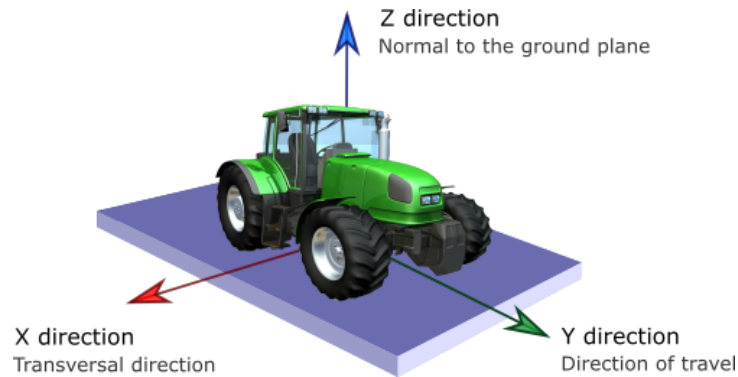


Figure 8. Axis convention.

- **Discs / rotating bodies:**

- **Import / erase bodies:** the model can be exported as a STL file format from any CAD software and imported to SpreadDEM. You can import the rotating bodies by clicking the “+” button, and erasing them with the “-” button. A total of two discs can be imported (Figure 9).

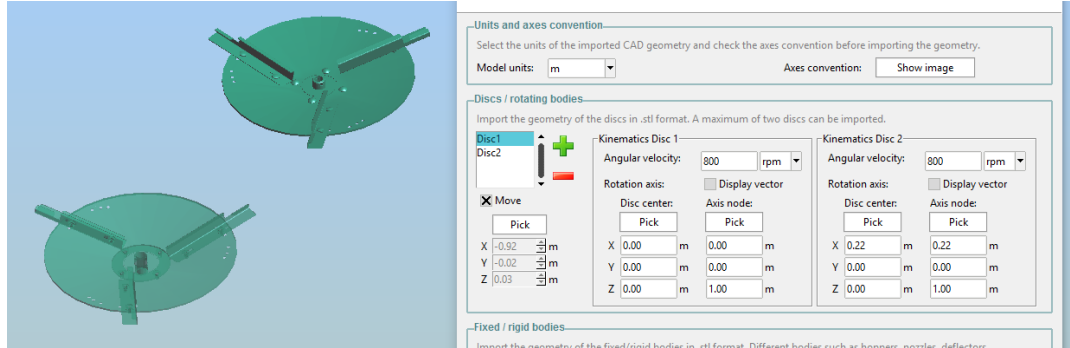


Figure 9. Two spinning discs imported.

- **Move option:** although it is highly advisable that the model parts are set on its proper position before importing them into SpreadDEM, you can translate parts following these steps (Figure 10):

1. Select on the list the object you want to move.
2. Click the "move" checkbutton.
3. Click the "pick" button and select an existent node on the object you want to move. You can see the nodes by clicking on the “mesh view option”, on the lateral menu.
4. Finally, use the *up and down arrows* below the pick button to move the object (or type the new coordinates for the selected node).

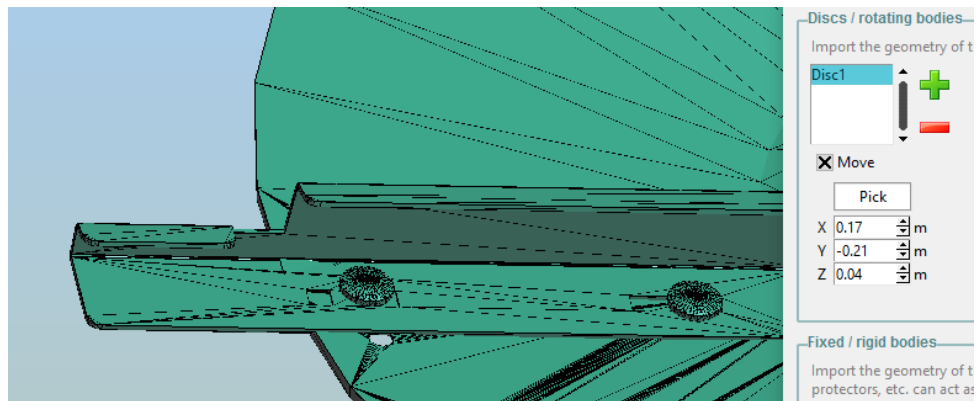


Figure 10. Move a model part once it has been imported.

At this moment, imported parts cannot be rotated on the SpreadDEM interface.

- **Angular velocity:** the desired disc rotation speed can be entered in rpm or rad/s. The direction of rotation is defined by the rotation axis. A negative value means that the direction of rotation is opposite to that defined by the axis of rotation.

- **Rotation axis:** it is defined by two points, the initial node should coincide with the center of the disc and the second node will define the rotation vector. Both nodes can be defined using the “Pick node” button and selecting the node on the model, or by entering its coordinates directly. First option implies that the nodes must exist on the model. Otherwise, coordinates should be introduced.
- **Display vector:** you can use this checkbox to make sure the rotation axis has been defined correctly according to the direction of travel and the configuration of the blades (Figure 11).

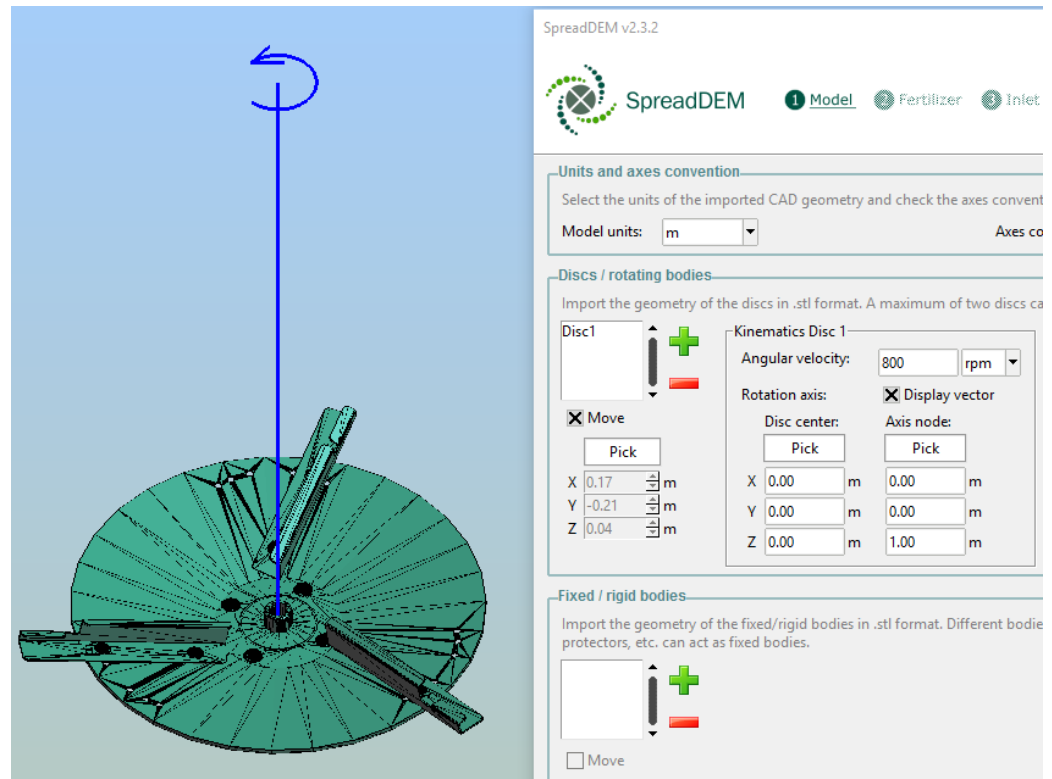


Figure 11. Rotation axis vector.

- **Duplicate disc:** for twin spreaders you can import and simulate both discs or do it with just one disc and use the “Duplicate disc” feature. This option does not duplicate the disc model but mirrors the results obtained for the simulated disc. That is, on animations you will see just one disc but you will see the contribution of both discs in the spread pattern, transverse distribution... In general, the higher the number of particles processed by the end of the simulation, the greater the cost will be. Therefore, it is very useful for symmetrical geometries because it can nearly reduce by half the computational time. When you use devices that make the model not symmetrical, such as deflectors on just one side, then you have to import the two discs and their respective rigid parts.

To define the mirrored disc, you have to specify on which side it is going to be duplicated -to the right or to the left side of the imported disc- and the distance between both axes (Figure 12). You can check if the mirroring is right by clicking on “Show duplicated disc”. Remember that the advancing direction coincides with the Y axis.

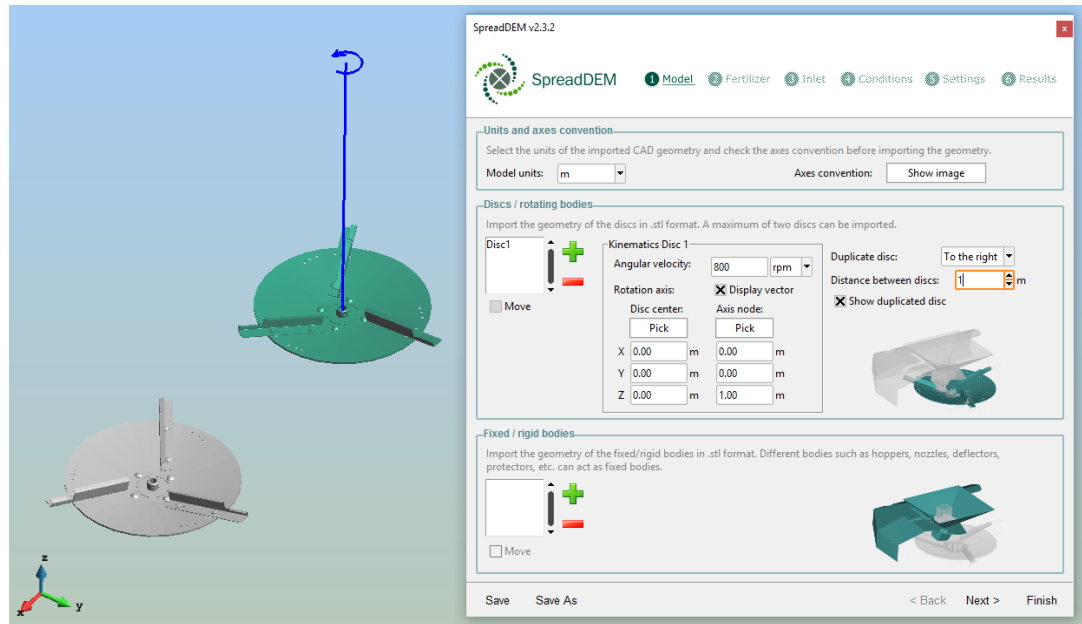


Figure 12. Duplicated disc (in gray) and imported disc (in green).

- Fixed / rigid bodies:** as well as rotating parts, you can import fixed parts such as hoppers, deflectors, protectors and opening levers, to correctly reproduce the experiment conditions (Figure 13). There is no limit in the number of fixed parts imported. The steps to import, delete and move rigid parts are the same as for rotating parts.

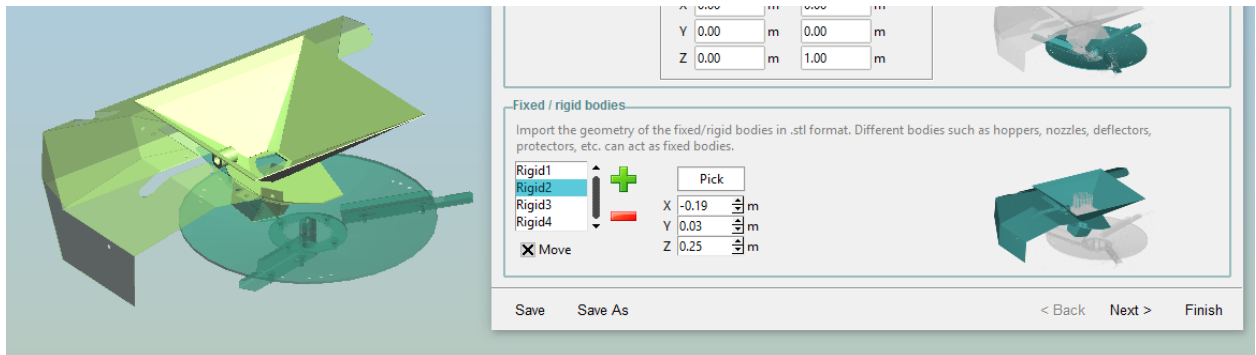


Figure 13. Rigid parts imported.

2.3. Step 2: Fertilizer

The performance of the spreader is highly dependent on the fertilizer properties, so the second step consists of specifying them (Figure 14). To guarantee the accuracy of the results, some parameters will require calibration to match the experiments. You can find more information about this calibration process in section 5.

SpreadDEM ① Model ② **Fertilizer** ③ Inlet ④ Conditions ⑤ Settings ⑥ Results

Material properties
 Enter customized fertiliser properties, or choose a predefined material for a first approach.

Material: Customized-fertiliser Advanced properties

Density:

- Particle density: 2000 kg/m³
- Bulk density: 1200 kg/m³
- Porosity: 40 %

Coefficient of friction particle-particle: 0.36
 Coefficient of friction particle-wall: 0.36
 Sphericity: Customized: 0.9

Particle Size Distribution
 Define the size of the fertiliser particles, either through its granulometry or through its probability distribution.

Granulometry Probability distribution

Diameter [mm]	Percentage [%]
<2	0
2-3.3	60
3.3-4.75	30
>4.75	10

Save Save As < Back Next > Finish

Figure 14. Step 2: Fertilizer properties.

- **Material properties:** there are some properties that are easy to obtain from fertilizer manufacturers, such as density, but there are some others whose value is more difficult to find out and also require advanced knowledge of the physical problem. This is the case of the coefficient of friction and sphericity.
 - **Material:** there is a small list of predefined materials, but in most cases it will be necessary to define a customized material.
 - **Density:** the user can enter either the particle density or the bulk density, which includes inter-particle voids and the porosity. If bulk density is used instead of the particle density, the porosity must be defined. It mostly affects the range of the particles' flight. Heavier particles will reach larger distances, while the smaller ones will not fly as far.

- **Advanced properties:** advanced properties can be also set, such as the coefficient of friction and the sphericity of the particles. These parameters are sometimes hard to guess from the fertilizer data sheets, but their value can be inferred from simulations if we can compare with experimental results available from older test campaigns.
 - **Coefficient of friction particle-particle:** this parameter is only relevant when you want to analyze in detail what happens during the hopper discharge. If the simulation does not include the computation of the hopper discharge, this parameter will not strongly affect the results.
 - **Coefficient of friction particle-wall:** it has a very pronounced influence on the time the particles take to slide along the vanes, causing the particles to be thrown out of the disc sooner for low coefficients and later for high coefficients. Therefore, it may cause a rotation of the spread pattern. Since its value is hard to guess, it can be obtained indirectly by comparing the numerical and experimental results and adjusting it if necessary.
 - **Sphericity:** it has a direct effect on the particle trajectory. Higher sphericities will offer less resistance on flight but will also be more vulnerable to the Magnus effect. This is especially critical in cases in which the particles tend to rotate instead of sliding through the disc vane. In the same way as the coefficient of friction, its value can be difficult to obtain and can be inferred in a calibration process. You can set the sphericity by selecting a set of similar shapes or by entering its exact value.

- **Particle size distribution:** the size of the particles affect the aerodynamic drag, and therefore the flight range. Smaller particles will produce less drag than bigger ones. However, if particles are scaled up maintaining density, bigger particles will land further than smaller ones. There are two ways to define the particle dimensions:
 - **Granulometry:** the size of the particles can be defined entering the granulometry with standardized sieve sizes, commonly used in the agricultural sector. A bar chart on the right allows the user to see more graphically how the distribution looks like. A warning message will appear before moving to another step if the sum of the percentages is not 100.
 - **Probability distribution:** dimensions can be also introduced using a probability distribution, normal or lognormal, entering the mean diameter and the standard deviation (Figure 15).

Particle Size Distribution

Define the size of the fertiliser particles, either through its granulometry or through its probability distribution.

Granulometry
 Probability distribution

Probability distribution: normal ▾

Median diameter: 3 mm

Standard deviation: 0.2 mm

Figure 15. Probability distribution of the particle dimensions.

You can go to section 4 to know more about how each parameter affects the spread pattern.

2.4. Step 3: Inlet

The inlet of particles is the surface through which the particles will be injected during the simulation. In this step you can determine the number of inlets (one or two), their shape (circular or custom shaped) and their associated mass flow (Figure 16).

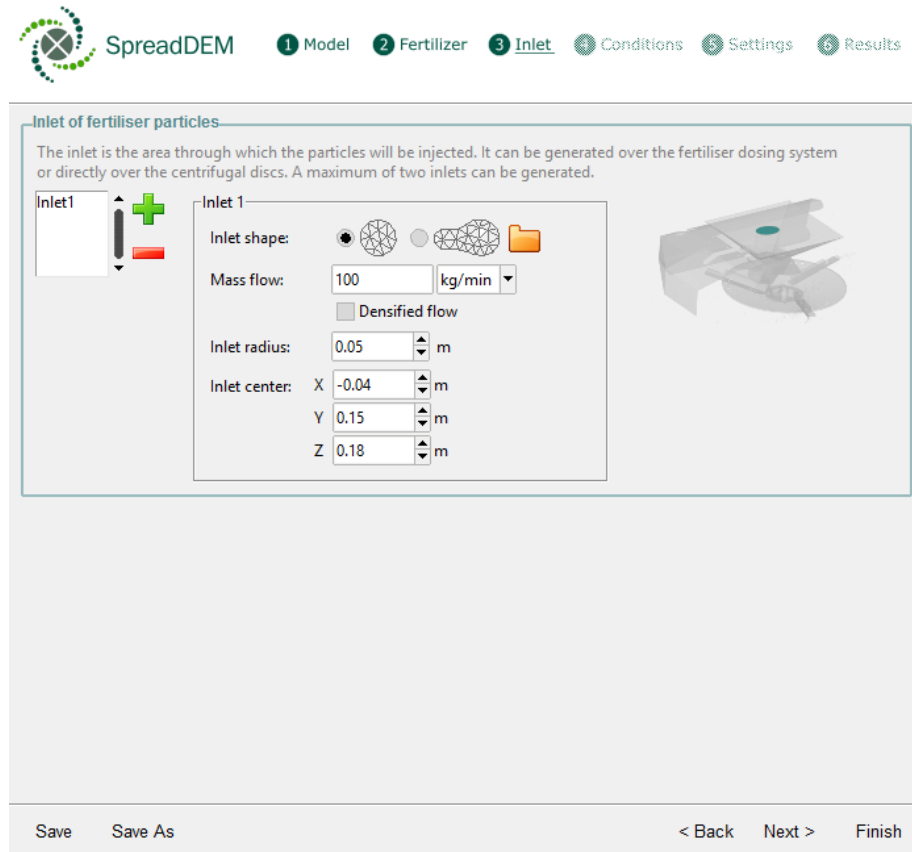


Figure 16. Step 3: Inlet of particles.

- **Create / erase inlet:** you can create a new inlet by clicking on “+” button, and erase it by selecting it and clicking on “-” button. A total of two inlets can be generated.
- **Inlet shape:** the inlet can be circular or custom shaped (Figure 17).

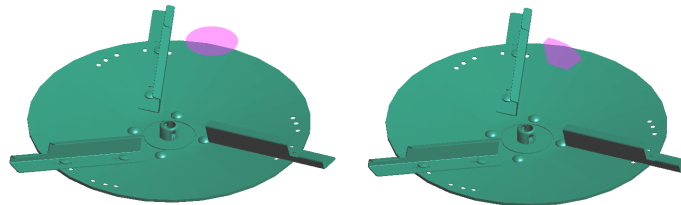


Figure 17. Circular and custom shaped inlet.

- **Circular inlet:** circular inlets are generated automatically, entering its radius and position (Figure 18).
 - **Inlet radius:** radius of the circular surface that will act as inlet.
 - **Inlet center:** coordinates, in global axes, of the circular inlet. Both in the case of the radius and the center of the inlet, you can change its value by entering a number directly or using the *up and down arrows*. Units match the model units set in Step 1.

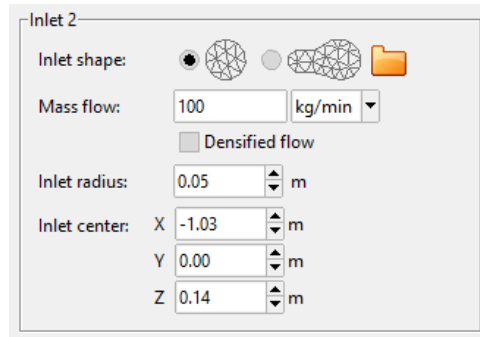


Figure 18. Definition of a circular inlet.

- **Custom shaped inlet:** in this case, inlet must be imported as a STL file format from any CAD software (Figure 19). It must be taken into account that the generated surface should be a planar surface. Otherwise, errors can arise when particles are generated, since they are injected into each of the mesh nodes and the spheres that generate them must not intersect.
 - **Move inlet:** you can translate the imported inlet by clicking on the "pick" button and selecting an existent node. You can see the nodes by clicking on the "mesh view option", on the lateral menu. After selecting a node, use the *up and down arrows* below the pick button to move the object (or type the new coordinates for the selected node).

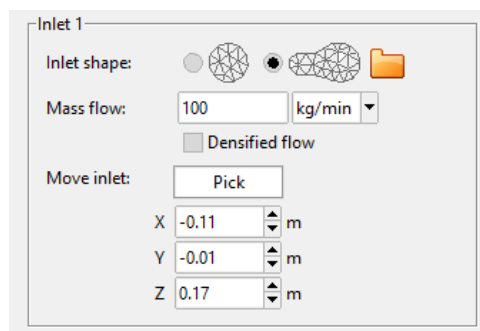


Figure 19. Definition of a custom shaped inlet.

- **Mass flow:** it is the mass or quantity of fertilizer particles per unit of time generated by the inlet.
 - The inlet flow can be indicated in kilograms per second (kg/s), kilograms per minute (kg/min) or particles per second (part/s).

- It is recommended to check that the value introduced corresponds to a single injector. If the experimental flow is used to feed a system with two discs then the introduced mass flow will be halved.
- By default, the inlet will inject particles at a certain speed. For very high mass flows, this may become a problem since the required injection speed can be very high. If the maximum speed allowed for the code to be stable is reached, the particles will be injected with a mass flow below the value entered by the user. If this occurs, a warning message will appear while the simulation is running, in Step 5 (Figure 20). To avoid this problem, the "densified flow" option is introduced.

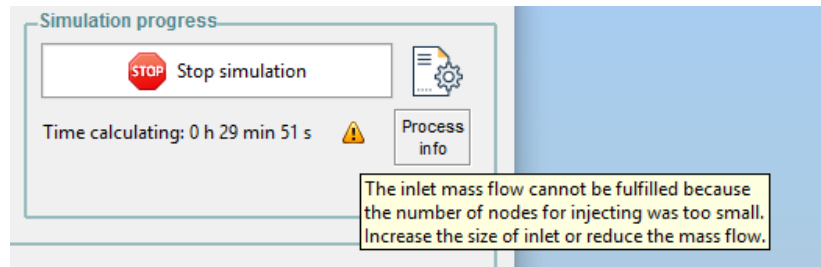


Figure 20. Warning message when the inlet mass flow cannot be fulfilled.

- Sometimes, the generated inlet is so small that it cannot inject as many particles as intended. In this case, as in the previous one, the mass flow will not be reached. It must be remembered that particles are injected from each node of the mesh. Therefore, fewer nodes will be able to inject fewer particles per unit of time (Figure 21).

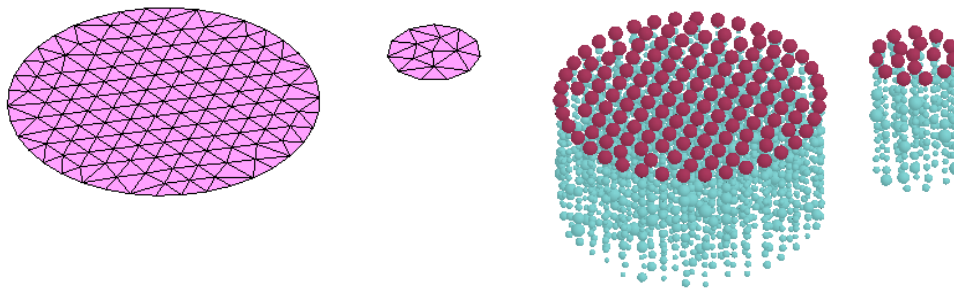


Figure 21. Injection of particles through two different sizes of inlet. Preprocess (left) and postprocess (right).

- **Densified flow:** when active, the injected particles will accumulate before entering a free-fall phase. When they cannot be accumulated anymore, the lower particles are released at the same flow rate that has been specified for the inlet (Figure 22).

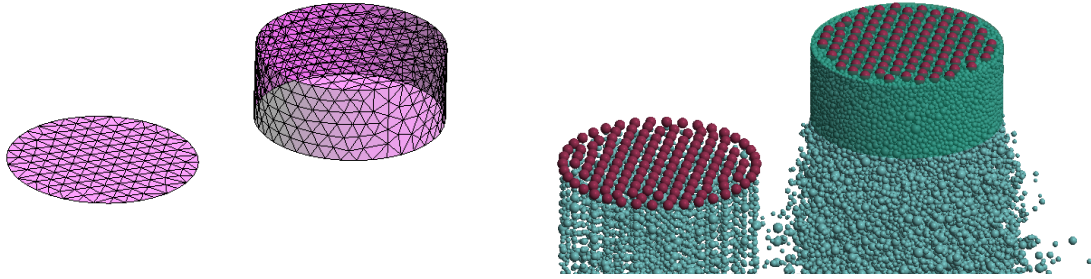


Figure 22. Injection of particles through a simple and a densified inlet. Preprocess (left) and postprocess (right).

This option not only solves the problems in which the desired mass flow is not reached, but also reproduces in a more realistic way the particle injection, since the particles do not leave the inlet in such a dispersed way (Figure 23). It becomes a fast way to simulate the contribution of the hopper without importing it. Since the particles do not accumulate as much, the calculation time is greatly reduced.

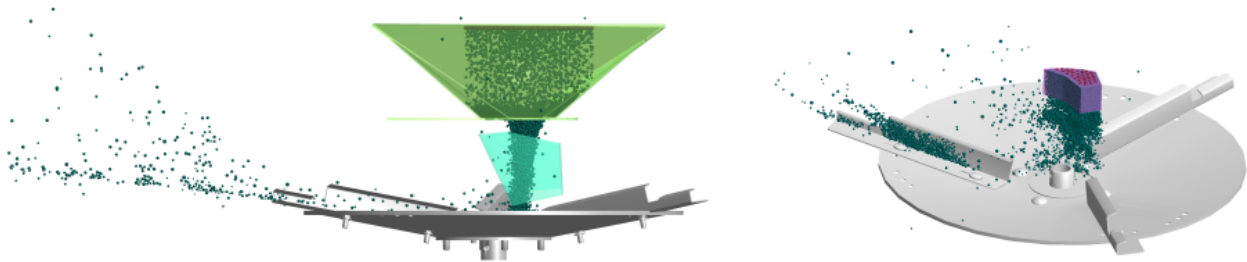


Figure 23. Simulation of the effect of the hopper importing it (left) and using a densified flow (right).

The most important factor driving computational time is the number of particles simultaneously present in the simulation (especially if they are in contact). So special care should be taken when deciding how to define the inlet, since the calculation time will depend considerably on it.

There are three possible approaches to raise the problem depending on the purpose of the current simulation (Figure 24):

- **Approach 1:** you can insert a circular inlet as a first approximation. This is the most simplified option and thus, the faster one, as there is no accumulation of particles upstream.
- **Approach 2:** you can import the inlet as an STL file with the exact shape and in the exact position of the aperture dosing system, in order to better reproduce the injection area. Moreover, you can use the densified flow option to get closer results to the hopper effect.
- **Approach 3:** you can import the fixed parts of the dosing system with the real aperture and put the inlet on the top of the geometry. This is the best way to reproduce the realistic problem as the mass flow is determined by the geometry. On the other hand, the particles will accumulate on the hopper and contacts among them will be calculated on each timestep. Therefore, this option will be, by far, the one with the highest computational cost.

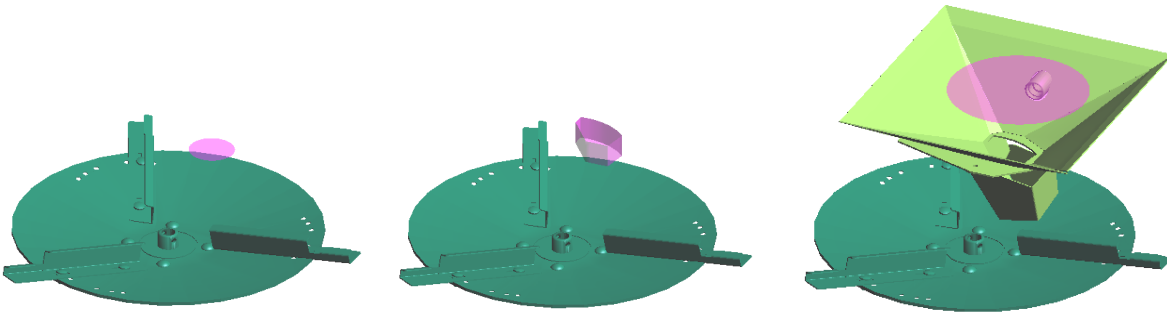


Figure 24. Different ways to raise a problem: approach 1 (left), approach 2 (center), approach 3 (right).

On the one hand, if you are mostly interested in the spread pattern, for example during the calibration process of the fertilizer parameters, you can launch a fast simplified simulation (approaches 1 or 2) and estimate its mass flow. On the other hand, if you want to know exactly what happens during the particles' discharge to evaluate the hopper design, for example, you can import the rigid parts of the dosing system (approach 3). This simulation, however, will take a considerable amount of time. You can also use this approach to check that the other approaches are giving good results.

That said, **if you don't know the exact flow rate of particles**, you can either use approach 3 or approach 2 (activating the "densified flow" option) by entering a reference parameter for the mass flow (150 kg/min, for example). The discharge of particles will adapt to the imported geometry, and the discharge will be close to the reality, provided that you have set a considerably high value for the mass flow (in such case, the only thing that can happen is that there is certain accumulation of particles in the hopper). If what you want is to estimate the value of the mass flow, you can gradually increase or decrease its value and check the level of accumulation of the particles in the hopper. If there are more and more accumulated particles, it will mean that the particle flow rate is too high. On the other hand, if the particles are discharged too quickly, it will mean that the flow rate introduced is too low.

2.5. Step 4: Conditions

Reproducing the external conditions in real service is actually one of the greatest advantages offered by virtual experiments with respect to the conventional ones, where reproducing these conditions is difficult or impossible. In the fourth step, you can provide details on the position and inclination of the ground, as well as the wind field conditions (Figure 25).



Ground plane

Define the relative position of the ground plane with respect to the imported geometry, as well as the slope of the terrain
Note that the disc should not be mirrored if the slope of the ground on X direction is non zero, as the results may not be symmetrical. Please import the geometry of the second disc manually if you want to compute the slope effect.

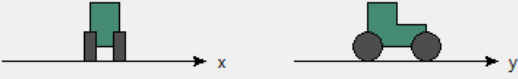
Ground position

Z coordinate: m Show ground plane

Slope of the ground

X direction: deg

Y direction: deg



Wind conditions

Specify the wind speed and direction according to the axes convention. Please note that the disc should not be mirrored if the transversal component of the wind (X direction) is non zero, as the results may not be symmetrical.
It is also inadvisable to compute the wind effect if you want to know the fertiliser distribution of a tractor whose traces are made in two-direction.

Wind speed: m/s

Wind direction: X

Y

Z

Figure 25. Step 4: External conditions.

- **Ground plane:** the distance between the discs and the ground, together with the terrain inclination, will affect the spread pattern.
 - **Ground position:** a virtual ground plane will be created at the position specified by the user. By default, it is generated 0.7 meters below the imported discs. This value can be modified by entering the Z coordinate of the plane, in global axes. The ground plane won't be displayed unless the option "Show ground plane" is active.

You can use the "Get coordinate" option on the lateral menu to obtain the coordinates of any node in the model, and thus check if the ground plane is positioned correctly with respect to the rest of the geometry (Figure 26).

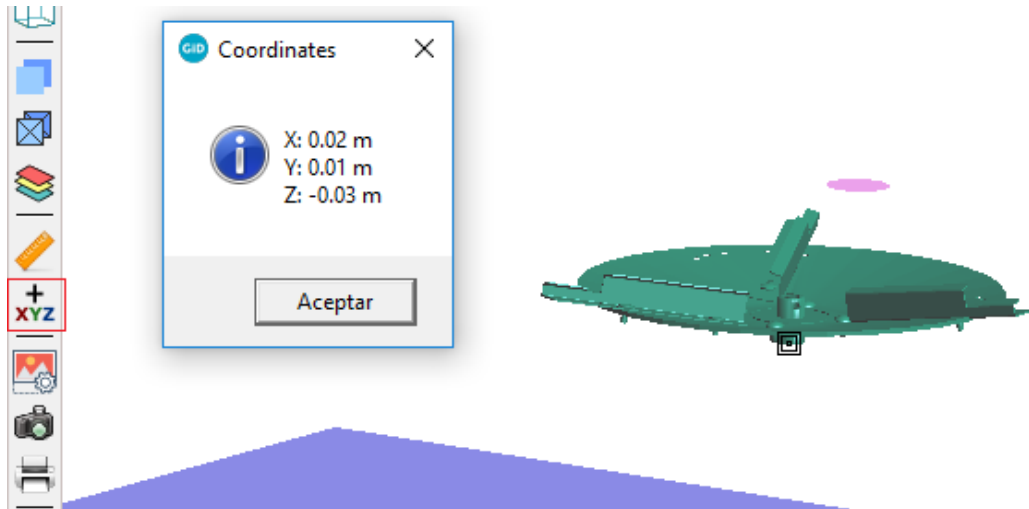


Figure 26. Getting a coordinate of a mesh node.

- **Slope of the ground:** optionally, the user can specify the inclination of the terrain, in degrees, with respect to the horizontal plane (XY). A representation of the entered inclination will appear on the left of the X and Y direction entries (Figure 27). You can remember the axes convention by clicking on the correspondent button.

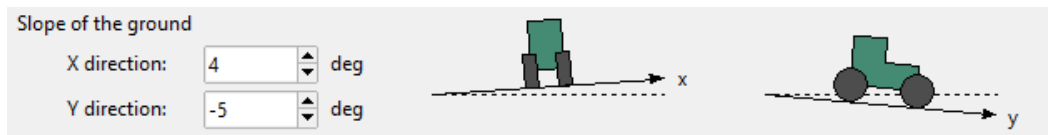


Figure 27. Representation of the slope of the ground.

The user will not notice the effect of the slope on the model, even when the ground plane is displayed, because the discs and rigid parts would be inclined as well.

You should be careful using this feature if you are simulating a double-disc spreader mirroring the results of a single disc. If the slope of the ground in X direction is non zero, the results may not be symmetrical. In such cases, you should import the geometry of the second disc if you want to compute the slope effect.

- **Wind conditions:** the wind will have an effect on the flying trajectories of the particles.
 - **Wind speed:** enter the module of the wind speed in meters per second (*m/s*), kilometers per hour (*km/h*), miles per hour (*mph*) or feet per second (*ft/s*).
 - **Wind direction:** specify the components of the wind direction, with respect to the global axes convention. This vector will be converted into a unit vector.

Again, you should take special care if you are mirroring the results of a single disc to obtain the contribution of a double-disc spreader. When the transversal component of the wind (X direction) is non zero, the results may not be symmetrical. In these cases, you have to import both discs.

It is also inadvisable to compute the wind effect if you want to know the fertilizer distribution of a tractor moving back and forth. In such cases, you should sum up the contribution of isolated traces separated by the working width.

2.6. Step 5: Settings

Finally, the user can set up the calculation settings, launch the calculation and analyze the first results of the ongoing simulation (Figure 28).

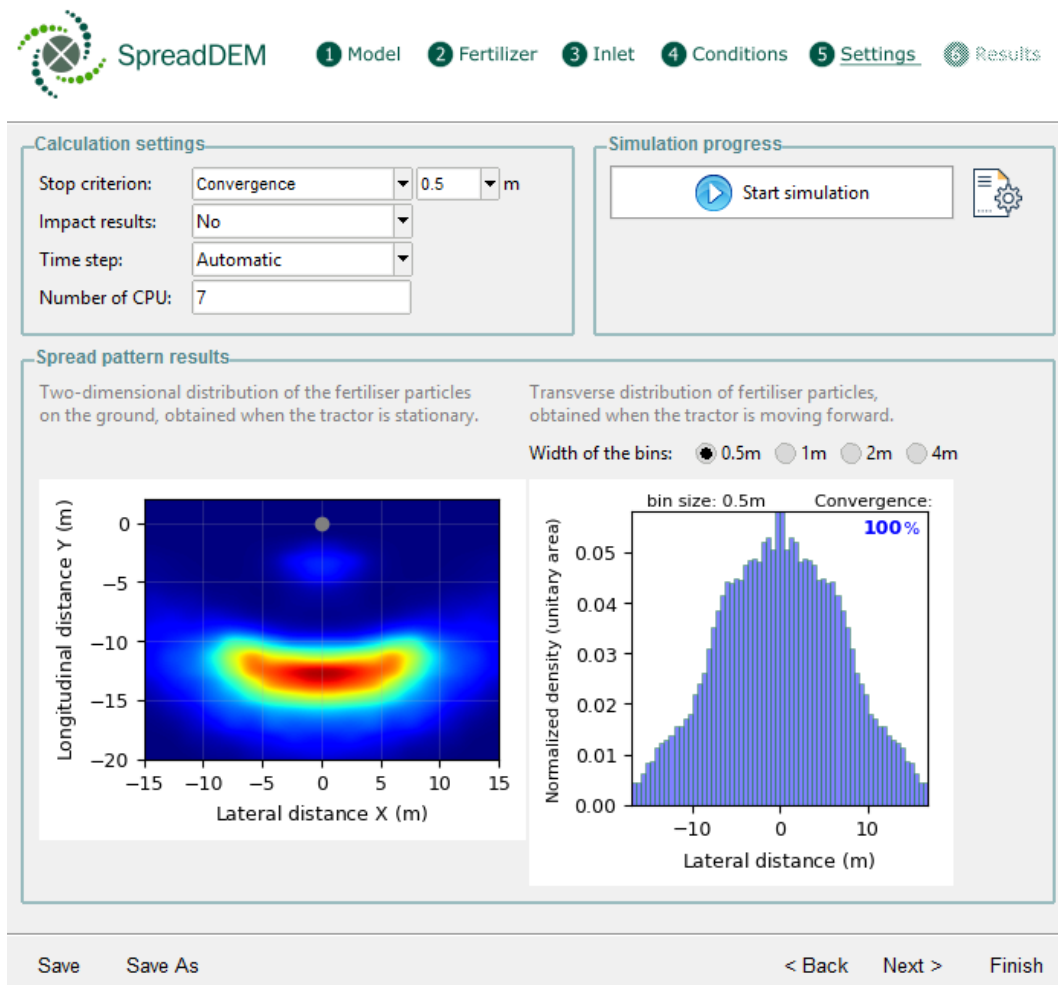


Figure 28. Step 5: Calculation settings.

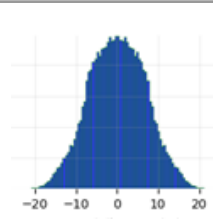
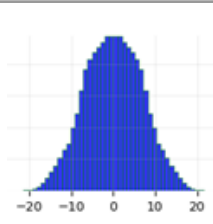
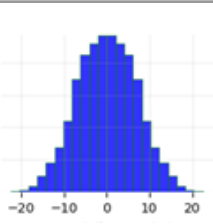
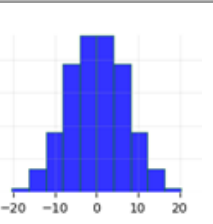
- **Calculation settings:** some parameters related to the numerical calculation must be defined.
 - **Stop criterion:** the calculation will stop automatically according to the selected option. These are the different methods available:

- **Convergence:** the calculation will end when the 100% of the statistical convergence of the transverse distribution is reached, that is, when the diagram of the lateral distribution does not vary its shape significantly over time.

The user must specify the width of the bins, meaning the width of the columns of the transverse distribution graph. This is a measure of the accuracy of the results. The wider the bins we select, the faster the diagrams converge at the expense of less precision in the results.

Next table shows an example of the calculation time to reach the 100% of convergence of a simulation, depending on the specified column width.

Table 1. Computation time (in hours, h) in function of the bin width (in meters, m).

Bin width: 0.5 m	Bin width: 1 m	Bin width: 2 m	Bin width: 4 m
			
71 h	6 h	2 h	2 h

- **Total mass of fertilizer:** stops the simulation when the mass specified by the user is reached. The fertilizer mass must be set in kilograms.
- **Total time simulated:** the simulation will end after a specific simulation time, in seconds. Do not confuse the calculation time with the simulation time. While the first one is the real-time that it takes to run a simulation, the latter refers to the seconds of the numerical simulation.
- **Total disc turns:** simulates just the disc turns specified by the user. After that, the inlet will not inject particles anymore and the calculation will continue until the last particles that have been injected reach the ground.
- **Inlet stop time:** the inlet will inject particles up to the specified time. As in the previous case, the calculation will continue until all the particles in the domain reach the ground.

Whatever the end time criterion selected, the user can stop the simulation at any point depending on the required accuracy. In the first iterations of a design process, the trend of the results may be analyzed at an earlier stage of convergence., by stopping the simulation manually.

- **Impact results:** activating this option allows you to register the normal and tangential impact velocity of the particles colliding with each other and with the rigid bodies such as the discs or deflectors. Not activating this option does not mean that collisions will not be calculated, but that the results will not be saved.

The computational cost of this feature is considerably high, so we only recommend it for simulations that have the sole purpose of analyzing collisions.

- **Time step:** increment of time between each step of the simulation. A default value can be used by selecting the “Automatic” option, or a personalized value can be entered by advanced users using the “Customized” option.

If the time step is too high, the simulation may become unstable. If the value is too low, the simulation will be stable but the computation time will be much higher. The value must be a compromise between stability and computation time.

- **Number of CPU:** SpreadDEM uses a multithreading method to run a simulation. A primary thread is divided into a specified number of sub-threads, allocating threads to different CPUs (Figure 29). The number of dedicated CPUs while running in parallel must not exceed the total number of available CPUs in the system. It is recommended to leave at least one cpu free for other system processes.

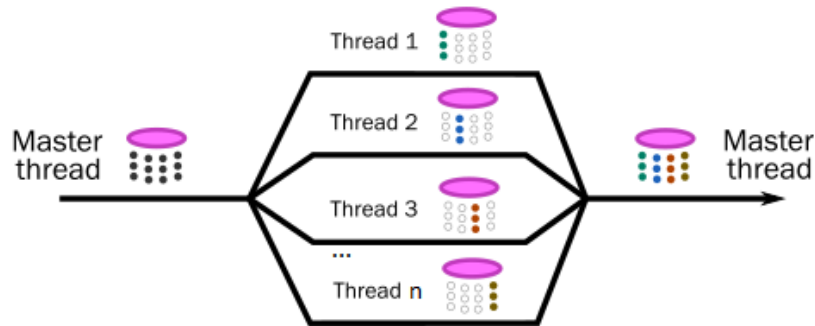


Figure 29. Multithreading process.

- **Simulation progress:** this area of the user interface will show some information about the calculation progress (Figure 30).

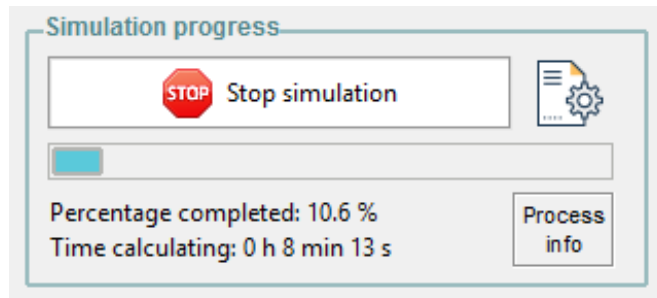


Figure 30. Information about the simulation progress

- **Start/Stop simulation:** the simulation will start after clicking on “Start simulation”. This button will turn into “Stop simulation” just after the beginning of the simulation.
- **Project parameters report:** the button to the right side of “Start/Stop simulation” allows the user to save a summary of the parameters of the project, such as the project name and date, the angular velocity of the disc, the material properties, the mass flow or the external conditions (Figure 31). This report can be saved in formats TXT or CSV.

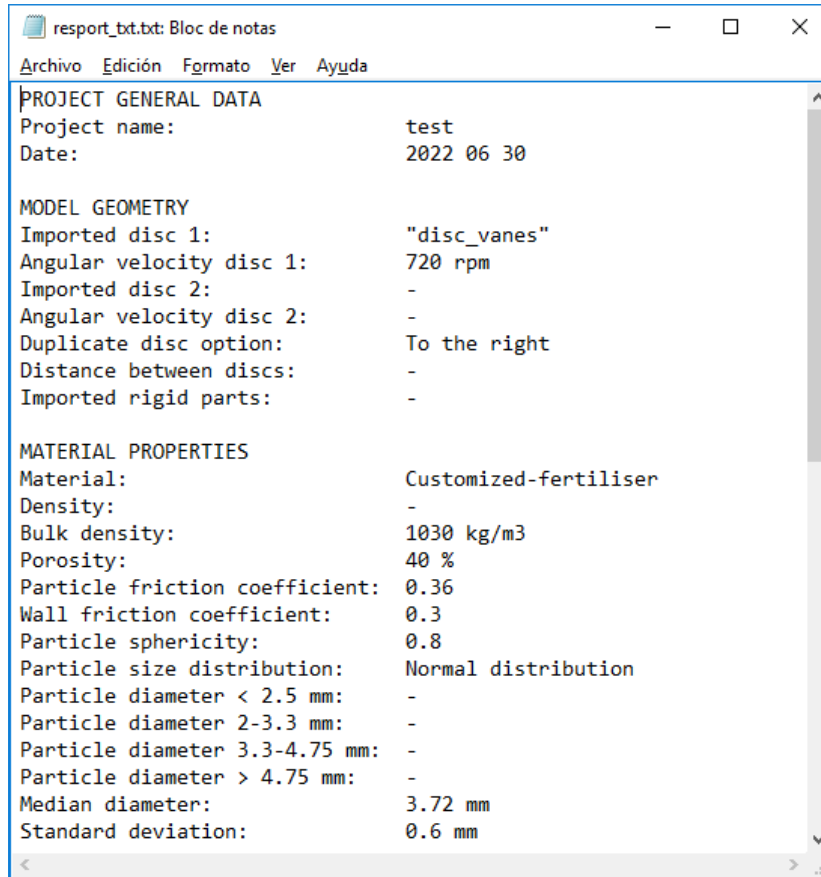


Figure 31. Information about the simulation progress

- **Process info:** during the simulation, it will appear some information about the progress of the simulation, such as the time calculating up to that moment or the percentage completed (only available if the stop criterion is “Total time simulated”). For more detailed information you can click on “Process info” and the complete report will pop up (Figure 32).

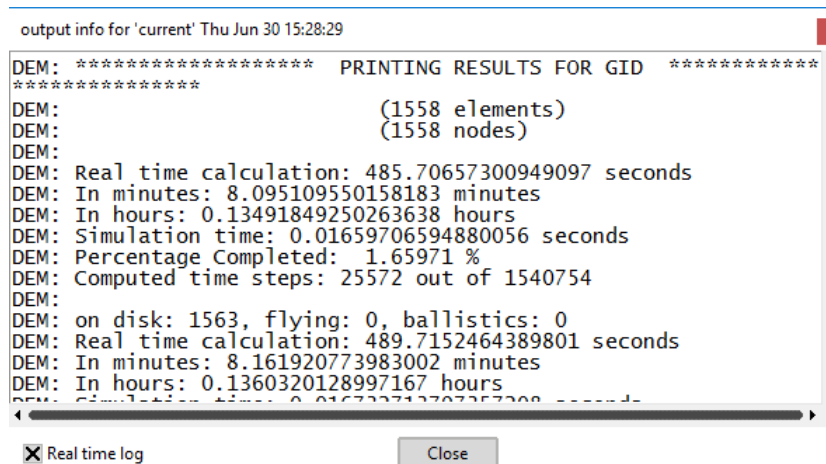


Figure 32. Output information of the simulation.

A warning icon will appear in this area of the interface if the mass flow specified by the user cannot be reached (Figure 20). At this point, you should check that the mass flow value is right and, if so, you can try using a “densified flow” option in the inlet definition (see section 2.4 for more information).

- **Spread pattern results:** the spread pattern and the transverse distribution graph will be displayed and updated all along the simulation (Figure 33). The first results may take some time to appear, as it requires a significant number of particles to have reached the ground plane.

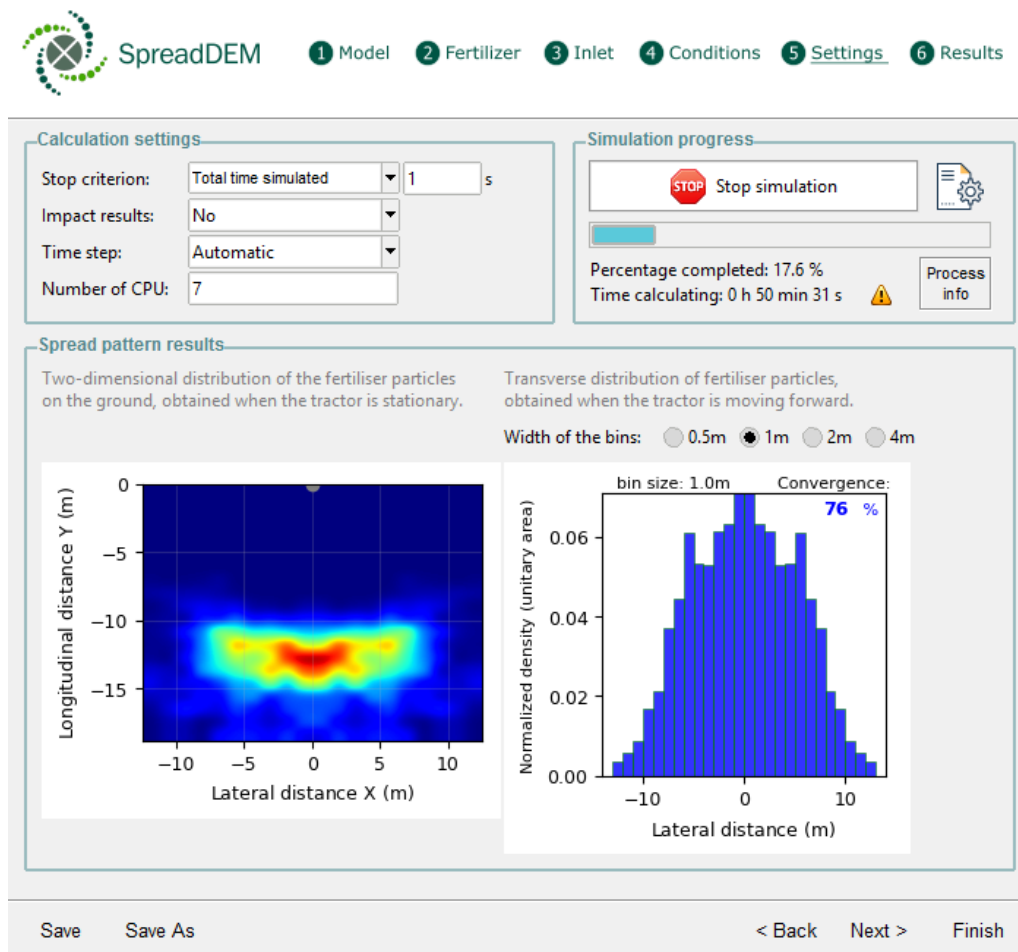


Figure 33. Results of the ongoing simulation.

- **Static spread pattern:** stationary distribution of the particles on the ground level.
- **Transverse distribution:** normalized transverse distribution of the particles over the ground.

The percentage of the statistical convergence is shown in blue, on the upper right corner. Above it, the user can select the width of the columns of the bar graph (*width of the bins*). Remember that the percentage of convergence gives us information about how much the graph is changing over time. Most of the time it is not necessary to wait until the 100% convergence of the narrower column, when the precision required is not so high. In that case the simulation can be stopped in an earlier step.

2.7. Step 6: Results

In this step you can obtain and analyze the results of the simulation (Figure 34). It is not necessary to wait until the calculation is finished, since you can load the results at any moment of the simulation process.

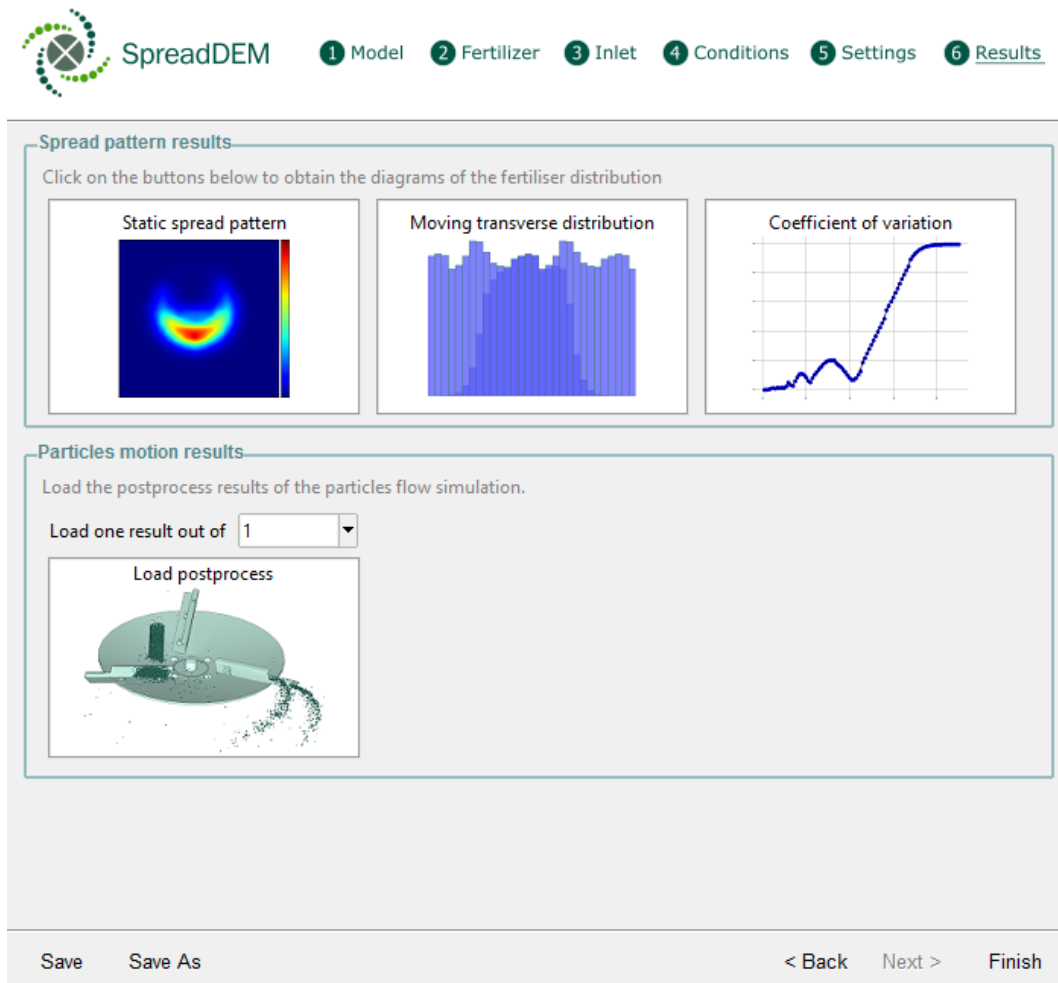


Figure 34. Step 6: Results.

The results are divided into two sections: one with the most important graphs of the fertilizer distribution and another related to the movement of fertilizer particles.

- **Spread pattern results:** the distribution graphs that are commonly obtained from experimental results can also be generated with SpreadDEM:
 - **Static spread pattern:** it shows the distribution of the accumulated fertilizer particles on the ground, usually bean-shaped, considering a static disc position (Figure 35). It can be used to estimate the maximum flying distance and the zones with higher density.

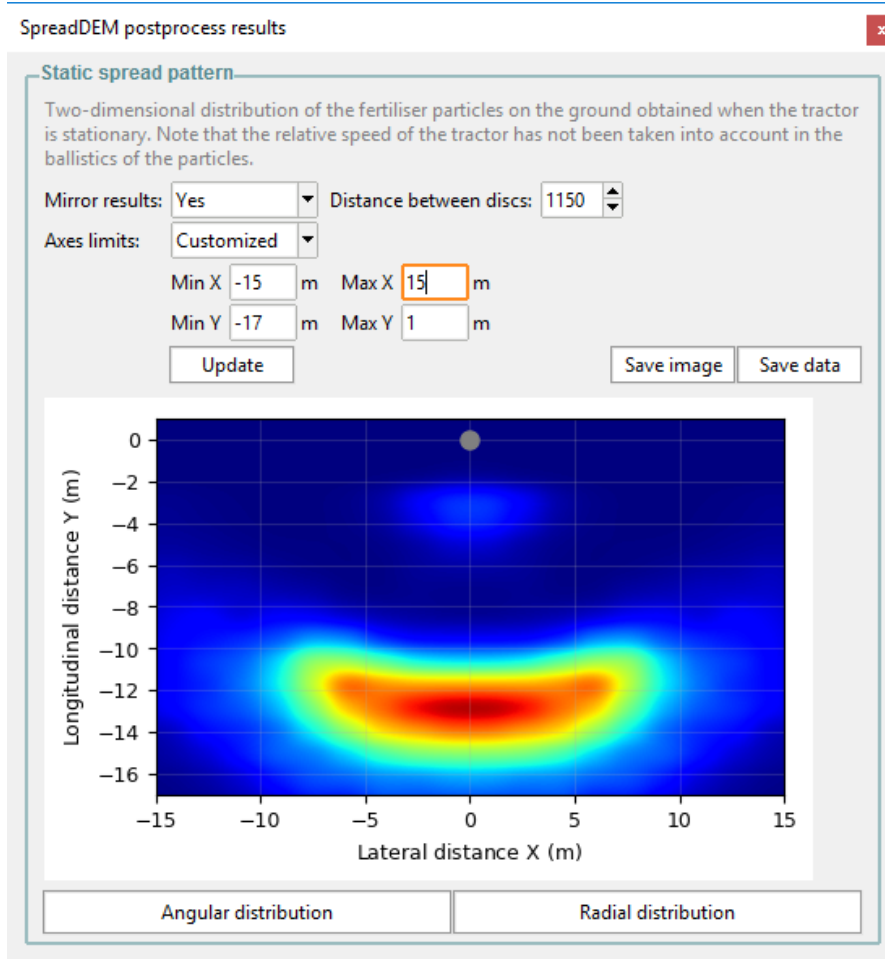


Figure 35. Static spread pattern

- **Mirror results:** in double spreaders, when just one disc has been simulated, you can deactivate or activate the mirror effect to see the contribution of a single disc or both discs. Distance between discs can be modified too.

Remember that this option will only make sense for symmetrical problems, that is, without wind in the transverse direction and without devices such as deflectors in just one side of the spreader.

- **Axes limits:** the printed area containing the spread pattern will be dimensioned automatically. However, the user can customize its size by entering the minimum and maximum X and Y distances, considering the origin of the coordinate system centered on the disc (represented by a gray dot).
- **Save image and save data:** the image and the raw data can be exported in several formats, PNG for the image and TXT, CSV and JSON for the data.

- **Angular and radial distributions:** these two graphs can be also generated based on the static spread pattern (Figures 36 and 37). They are useful to better analyze the average flying distance and the angular interval with higher densities. Again, the images and data of these graphs can be exported.

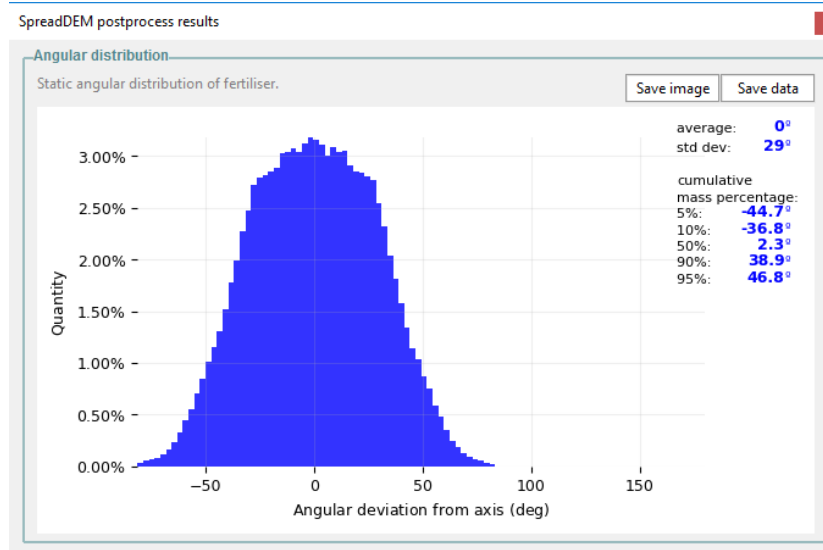


Figure 36. Angular static distribution.

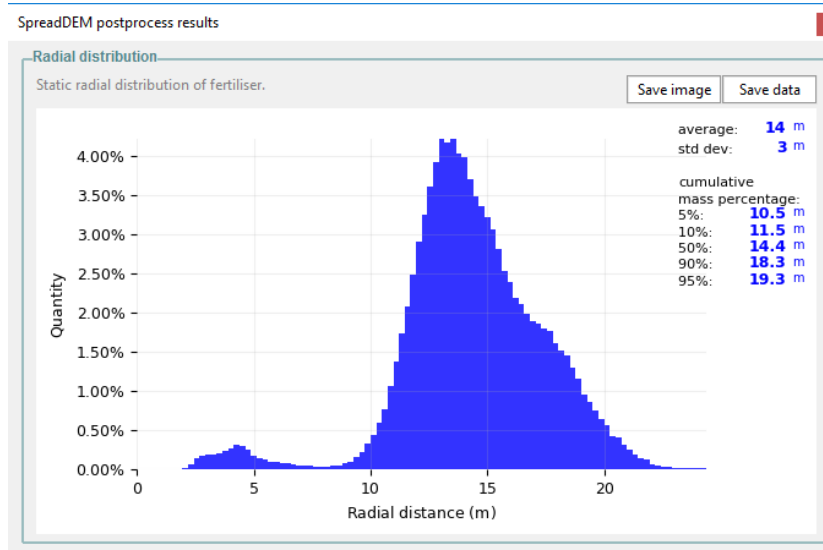


Figure 37. Radial static distribution.

- **Moving transverse distribution:** this graph is obtained from the summation of all the amounts of fertilizer deposited while the tractor is moving forward at a certain speed, and makes different passes at a certain working width (distance between passes). The aim of the transverse distribution is to estimate the dose of fertilizer distributed and how uniform it is. Figure 38 represents how this graph is obtained from the static spread pattern.

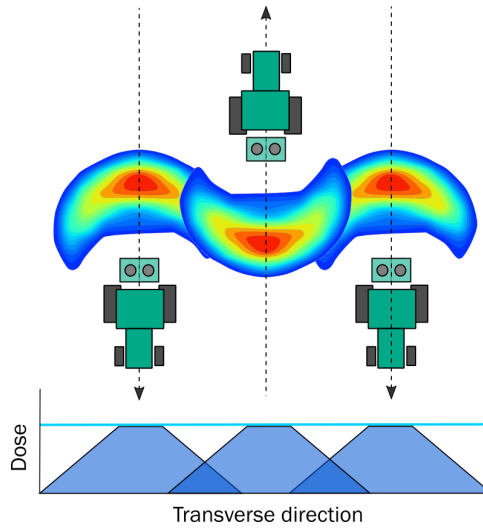


Figure 38. Generation of the transverse distribution graph.

In SpreadDEM, the transverse distribution represents the index of irregularity across the field, where the 100% corresponds to the average density, expressed in kilograms per hectare (Figure 39).

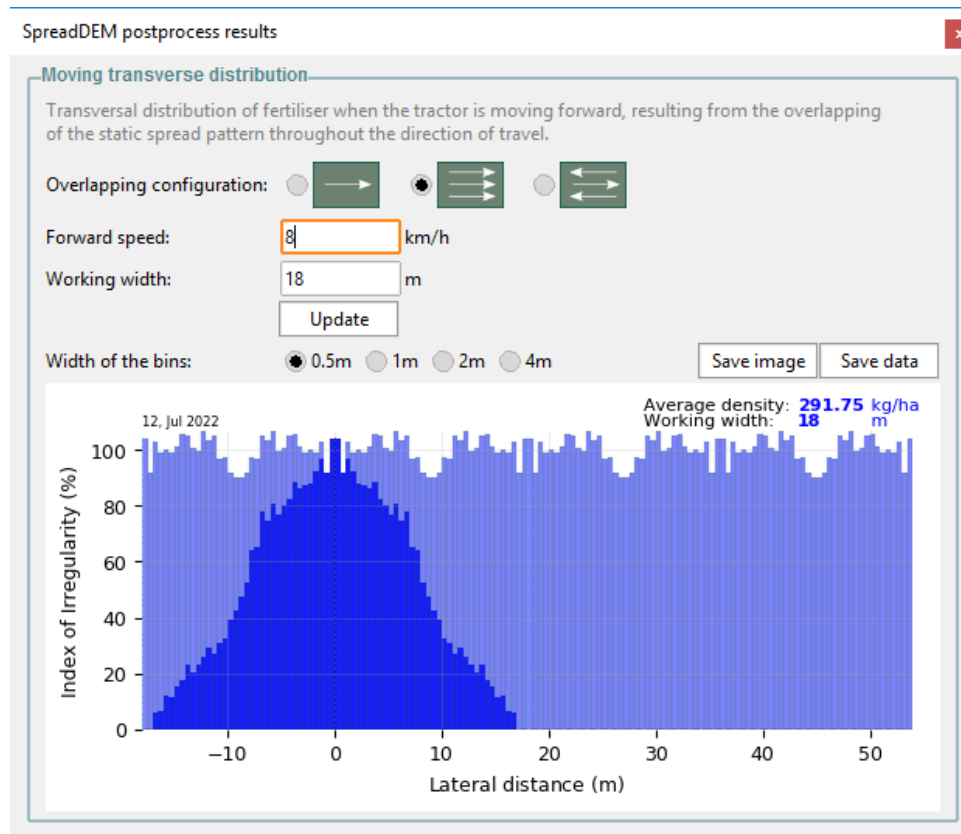


Figure 39. Moving transverse distribution.

- **Overlapping configuration:** there are three possible ways in which the tractor covers the entire range of the field through its tramlines: considering a single pass of the tractor or considering several passes with its subsequent overlapping of results, in the same direction or in opposite directions. When the problem is symmetrical, the distribution will be the same for direct and inverse overlapping.
 - **Forward speed:** it refers to the speed of the tractor. Higher moving speeds will reduce the amount of fertilizer mass distributed in the area.
 - **Working width:** this is distance separating two successive tramlines.
 - **Save image and data:** the image and the raw data can be exported in several formats, PNG for the image and TXT and CSV for the data.
- **Coefficient of variation (CV):** the uniformity of the dose on the field can be analyzed by calculating and representing the dispersion of the transverse distribution for different working widths (Figure 40). So with this information the user can estimate the best working width for optimum overlapping. The lower the value of the CV, the more evenly the fertilizer is spread. Generally, a 15% variation of the field dose is considered acceptable.

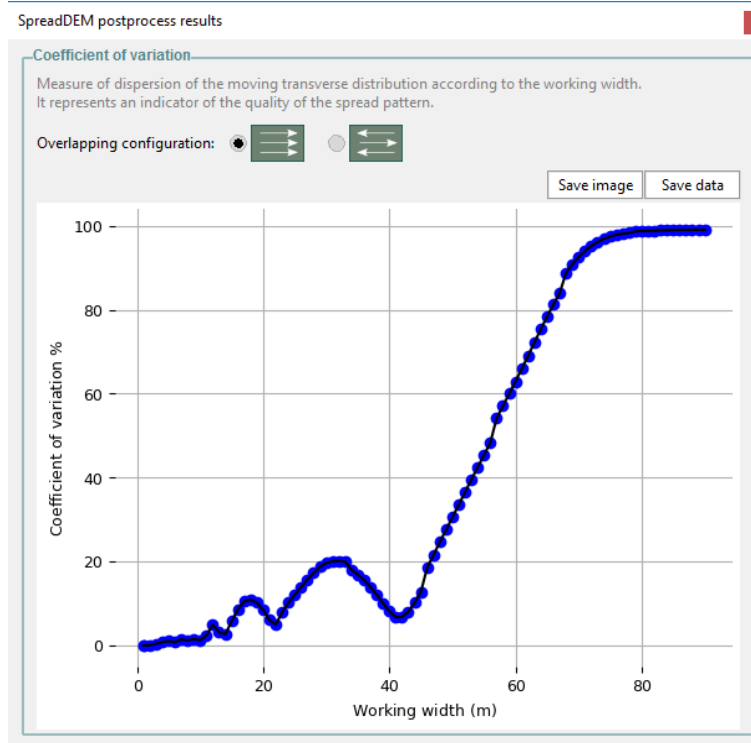


Figure 40. Moving transverse distribution.

- **Overlapping configuration:** as in the previous result, you can choose between two configurations of overlapping results, depending on whether the passes of the tractor are made in the same direction or in opposite directions.
- **Save image and data:** again, the graph can be exported in PNG format and the raw data in TXT and CSV formats.

- Particle motion results:** in this section you can load the postprocess results and track every single fertilizer particle traveling from the hopper to the ground. All the impact points and velocities of the particles are recorded, as well as their exact trajectory during their acceleration on the disk, for any subsequent detailed inspection. Weak points in the design can be located by analyzing unexpected particle behavior that may cause potential problems during their injection and ejection.
 - Load postprocess:** the postprocess can be loaded either one simulated step by one, or one out of 5, 10, 20, etc. This is because some cases can become too big to be loaded. Once you have selected the correspondent option on the drop-down list, you can proceed by clicking on “Load postprocess” button (Figure 34). After loading the simulation results, the same window will be updated to show the new options available (Figure 41).

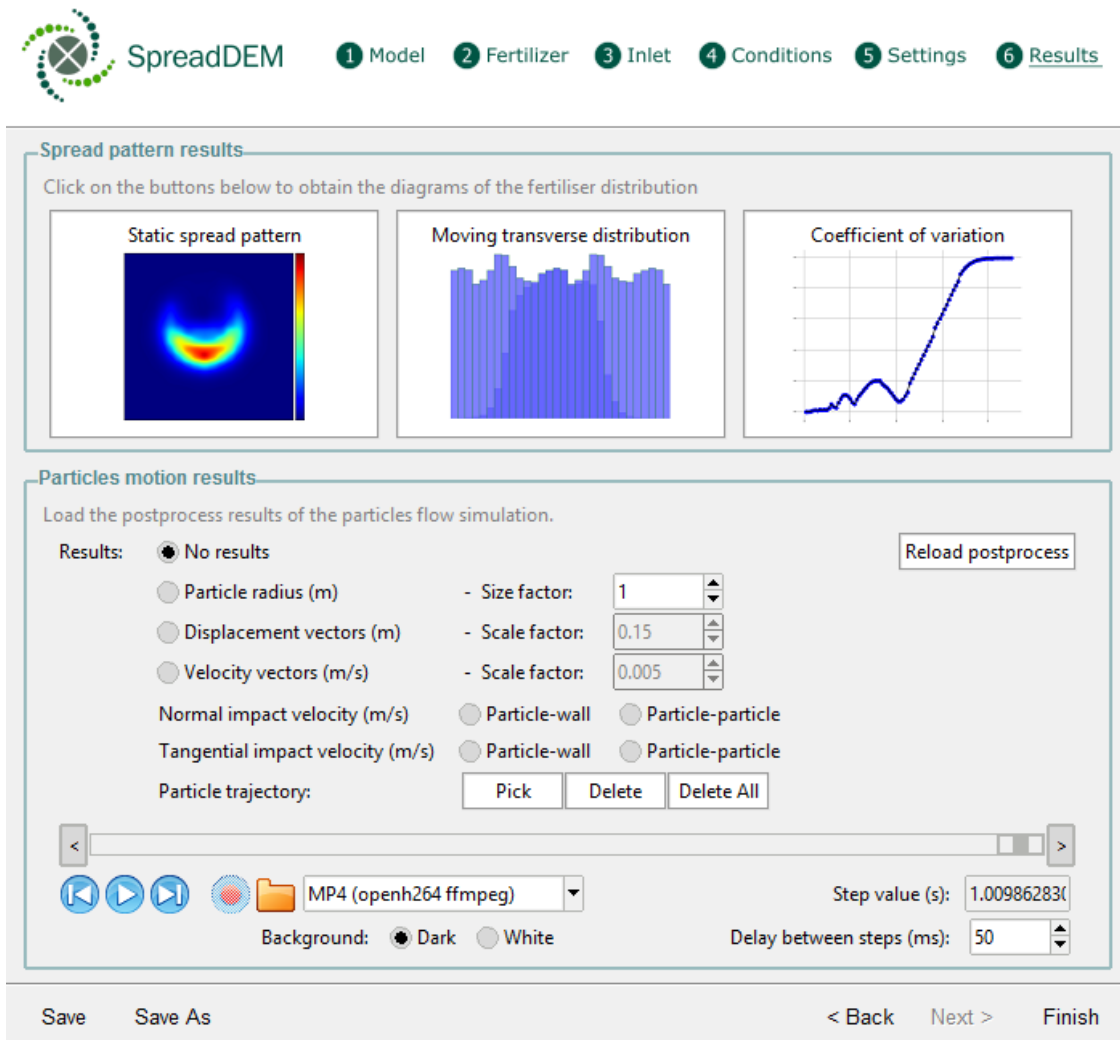


Figure 41. Postprocess results window.

- Results:** postprocess results can be loaded at the end of the simulation or during the simulation. If the results have already been previously loaded, you can reload and update them by clicking on “Reload postprocess” button, at the upper-right corner of the section.

The possible results to be displayed are:

- **No results:** erases all the results displayed before.
- **Particle radius:** radius of the particles, in meters (Figure 42). The legend with the color scale is always displayed in the down-right corner of the working area.

The user can change the size factor of the particles, to scale them up/down in order to better visualize and compare the different particle sizes.

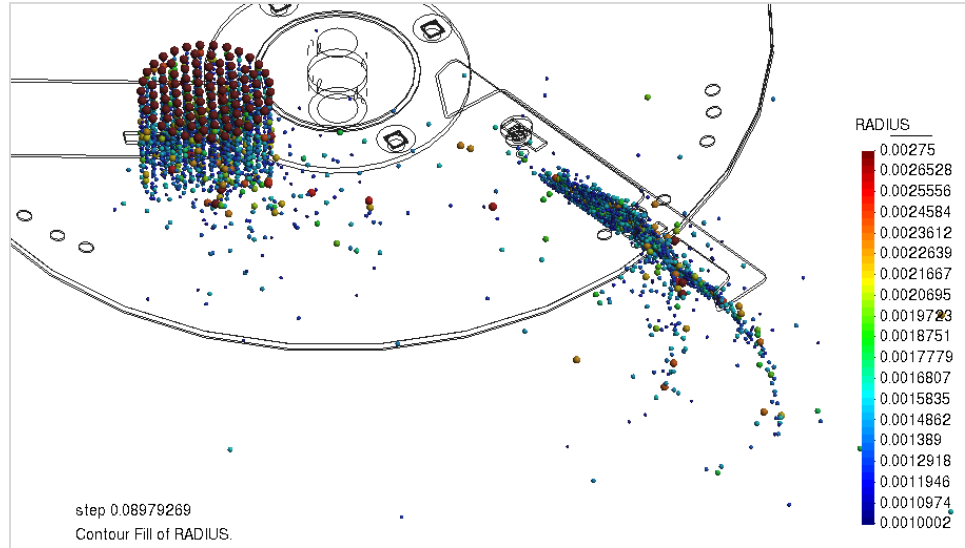


Figure 42. Particle radius.

- **Displacement vectors:** module of the displacement vectors of the fertilizer particles, in meters, represented by a color scale (Figure 43).

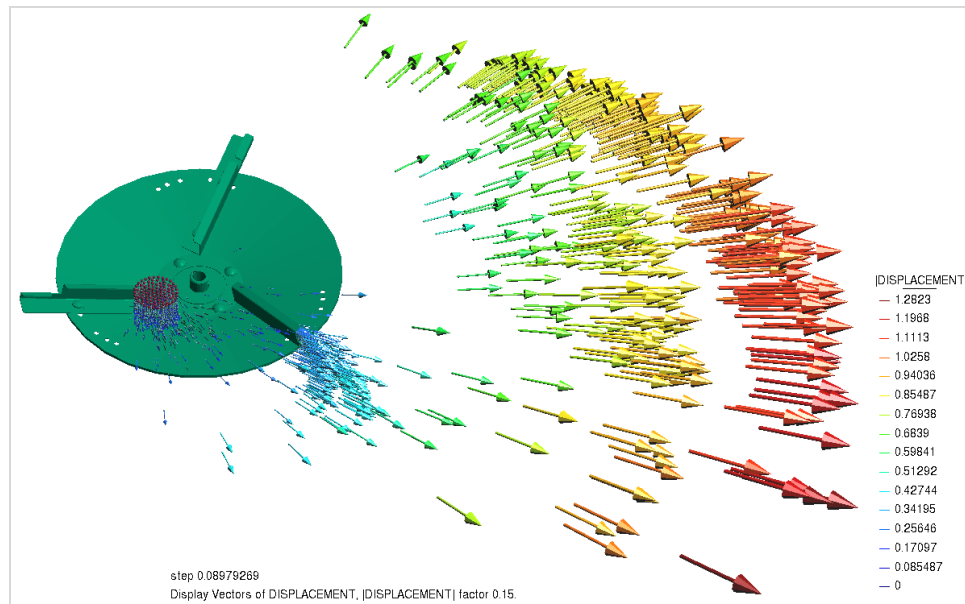


Figure 43. Displacement vectors.

- Velocity vectors:** module of the velocity vectors of the fertilizer particles, in meters per second, represented by a color scale (Figure 44). It may be useful, for example, to estimate the ejection velocity of the particles when they leave the disc vane.

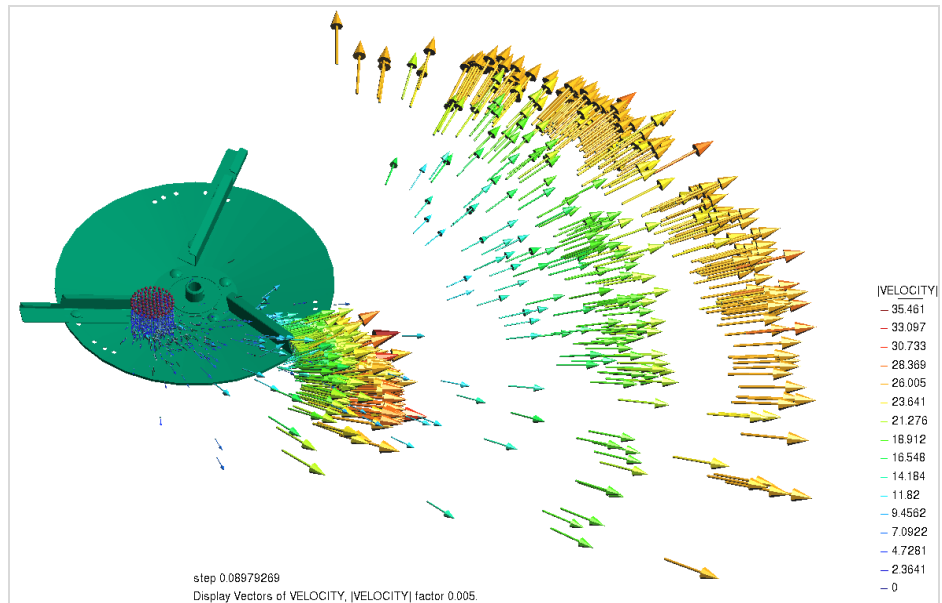


Figure 44. Velocity vectors.

- Normal and tangential impact velocities:** velocity components of the particles colliding with each other (*particle-particle*) or with the rigid bodies such as the disc vanes or deflectors (*particle-wall*) (Figure 45). Units are meters per second. This result may help in the design of the dosing system to avoid the breakage of the fertilizer particles into fines.

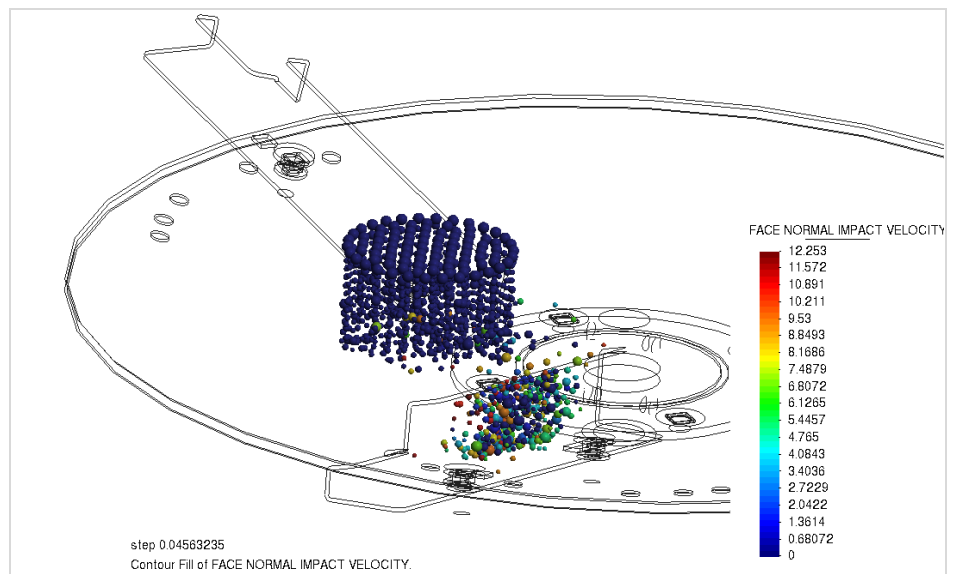


Figure 45. Normal impact velocity

- **Particle trajectory:** traces of the fertilizer particles from their injection until they reach the ground (Figure 46). This can help in the design of rigid parts such as deflector, or simply to detect unexpected movements of the particles. In order to display the trajectories lines you can use the "Pick" button and select one fertilizer particle or a group of them. You can also delete one single trace ("Delete" button) or delete all of them ("Delete All" button).

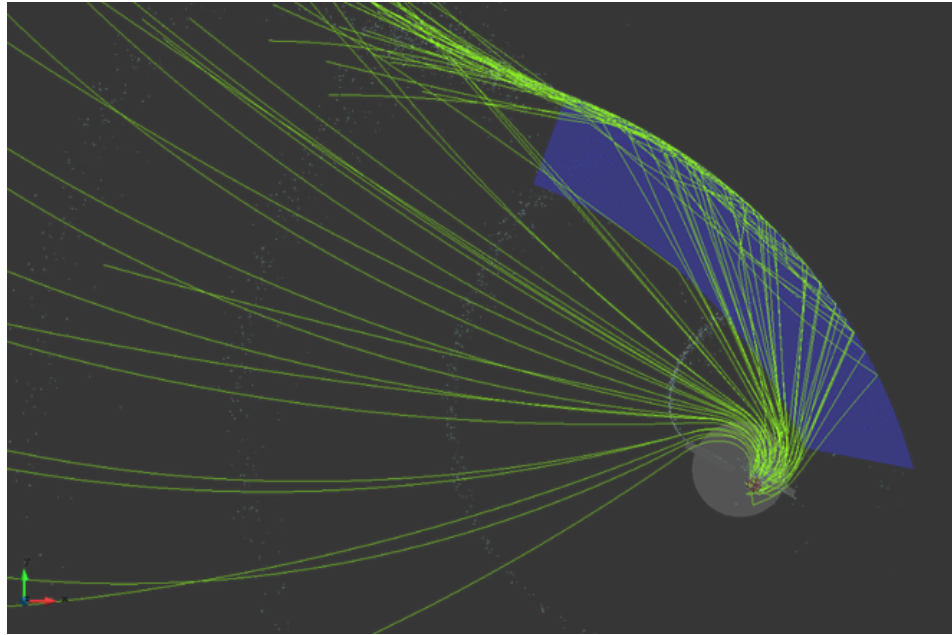


Figure 46. Individual trajectories of every single particle (right)

- **Animation:** using the animation progress bar and the standard animation buttons (Figure 47) you can analyze the dynamic behavior of the fertilizer particles for each time step.

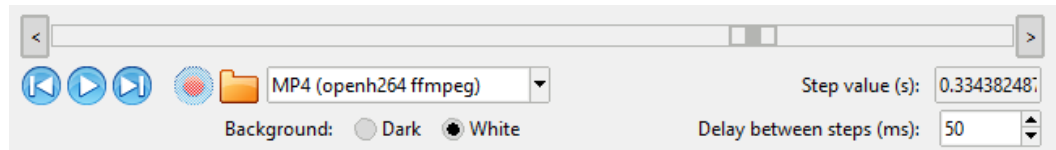


Figure 47. Animation frame.

You can start the animation by clicking the "Play" button, which in turn will become a "Stop" button to pause the animation. You can also navigate through the different time steps using the "Forward" and "Rewind" buttons or the arrows on the sides of the progress bar.

- **Recording option:** it is possible to record the animation following these steps:
 1. Select the format from the drop-down list (MP4, AVI, GIF...).
 2. Use the "Folder" button to define where the file will be saved.
 3. Click on the "Record" button. It will turn green.
 4. Click on the "Play" button to start recording the animation.
 5. To stop the recording, click on the "Stop" button or wait until the end of the animation.

- **Step value:** current step value displayed in the working area, in seconds. The delay between steps is the time-step defined before launching the simulation, in Step 5.
- **Delay between steps:** time, in milliseconds, elapsing between one step to the next one during the recorded animation.
- **Background:** background color of the working area. This color will be preserved in animations.

2.8. Visualization and navigation options

In this section you will find an explanation on how to interact with the user interface, to change the visualization options and to navigate through the different steps of the program, among other useful features.

The different visualization and navigation options can be divided in three main areas, as shown in Figure 48: the navigation menu (1), the working area (2) and the lateral menu (3).

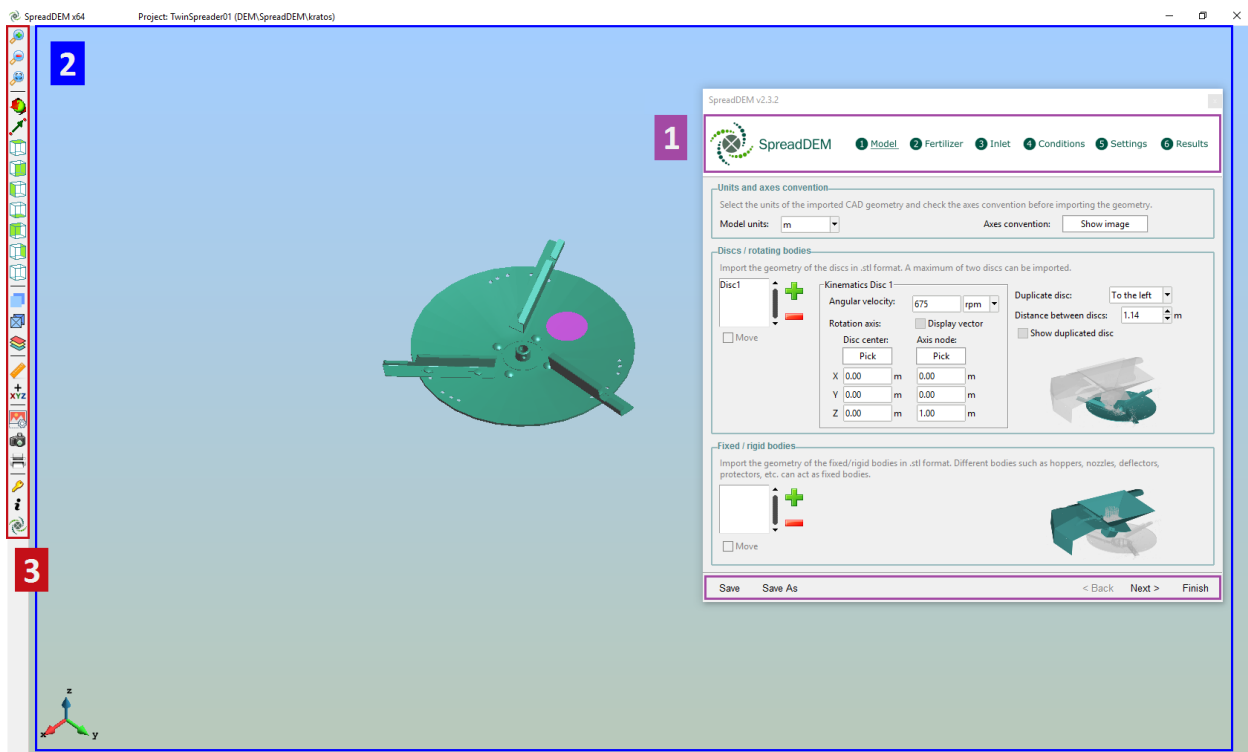


Figure 48. Different areas of the SpreadDEM user interface.

- **Navigation menu (1):** it consists of two different areas, containing this features:
 - **Save:** saves your work progress by updating the last saved version of the file.
 - **Save as:** saves your work as a file with a different name.
 - **< Back and > Next:** it allows you to go one step forward or backward.

- **Finish:** closes the current project and starts a new one. You will be asked if you want to save the project or not.
- **Steps navigation area:** above the main window, there is a link to each step of the interface, to quickly navigate among them. Each link will be enabled once you have already visited that step.
- **Working area (2):** the model will be displayed here. There are some ways of zooming and scrolling through this area: using the options displayed with the right button of the mouse, using hotkeys or using the options in the lateral menu. The first two options will be summarized below:
 - **Right mouse click:** the pop-up menu that appears with the right mouse click offers three different features (Figure 49).

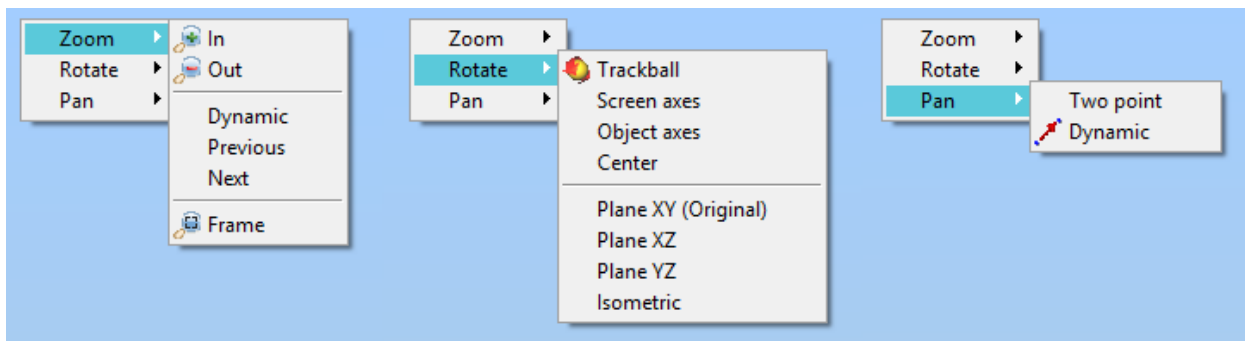


























Figure 49. Different areas of the SpreadDEM user interface.

- **Zoom:** you can zoom in and out by selecting an area (“In”, “Out”) or by scrolling the mouse (Dynamic). You can go to the previous or next zoom configuration (“Previous”, “Next”), and you can also frame the model in the center of the screen (“Frame”).
- **Rotate:** there are different ways of rotating the model. You can do it by scrolling the mouse (“Trackball”), rotating separately each axis using (“Screen axes”, “Object axes”), set the center of rotation (“Center”) or visualizing specific planes (“Plane XY”, “Plane XZ”, “Plane YZ”, “Isometric”).
- **Pan:** used to translate the view, maintaining the current visualization plane. You can do it by selecting two points on the screen (“Two point”), or by scrolling the mouse (“Dynamic”).
- **Hotkeys:** the same -but simplified- functions that can be made using the *Right mouse click* can be done using these keyboard shortcuts:
 - **Mouse wheel / Shift + center mouse click:** to zoom in/out with respect to the cursor position on the screen.
 - **Shift + Left mouse click:** to rotate.
 - **Shift + Right mouse click:** to pan.
 - **Esc / Central mouse click:** to finish any operation.

- **Lateral menu (3):** some useful general options are provided in this area, mainly related to the visualization of the model on the working area.

	Zoom in	Zooms the project in selecting a rectangle.
	Zoom out	Zooms the project out selecting a rectangle.
	Zoom frame	Adjusts the visualization to comprise the whole model.
<hr/>		
	Rotate view	Rotates the model dynamically using the mouse as 'spaceball'.
	Pan view	Translates the model dynamically.
	Plane view	Rotates the model to screen axes (XY, XZ, YZ, -XY, -XZ, -YZ and isometric view).
		
		
		
		
		
		
		
<hr/>		
	Smooth render	Mesh is not drawn to represent geometry in a smoother way.
	Mesh render	Mesh coming from the imported model is drawn.
	Layers	Opens layers menu, which allows you to change colour, transparency and visibility of each layer (Figure 50).
<hr/>		
	Measure distance	Reports the distance between two nodes selected by the user.
	Get coordinates	Reports the X, Y, Z coordinates of the selected node.
<hr/>		
	Capture settings	Changes page and capture settings: margins, image size, resolution, background colour and transparency (Figure 51).
	Take a snapshot	Takes a picture of the current view, using the capture settings.
	Print snapshot:	Prints the current view, using the capture settings.
<hr/>		
	Register	Opens the dialog-box containing the system information required to ask for a license.
	User manual	Opens a PDF with the user manual.
	About us	Opens a window with some information about the software and its developers.

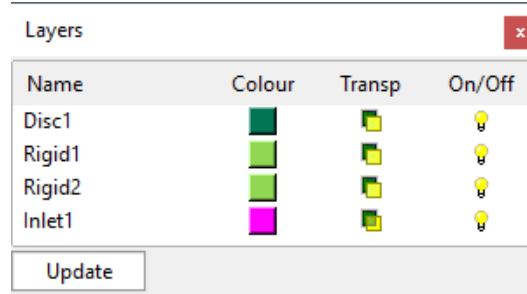


Figure 50. Layers window.

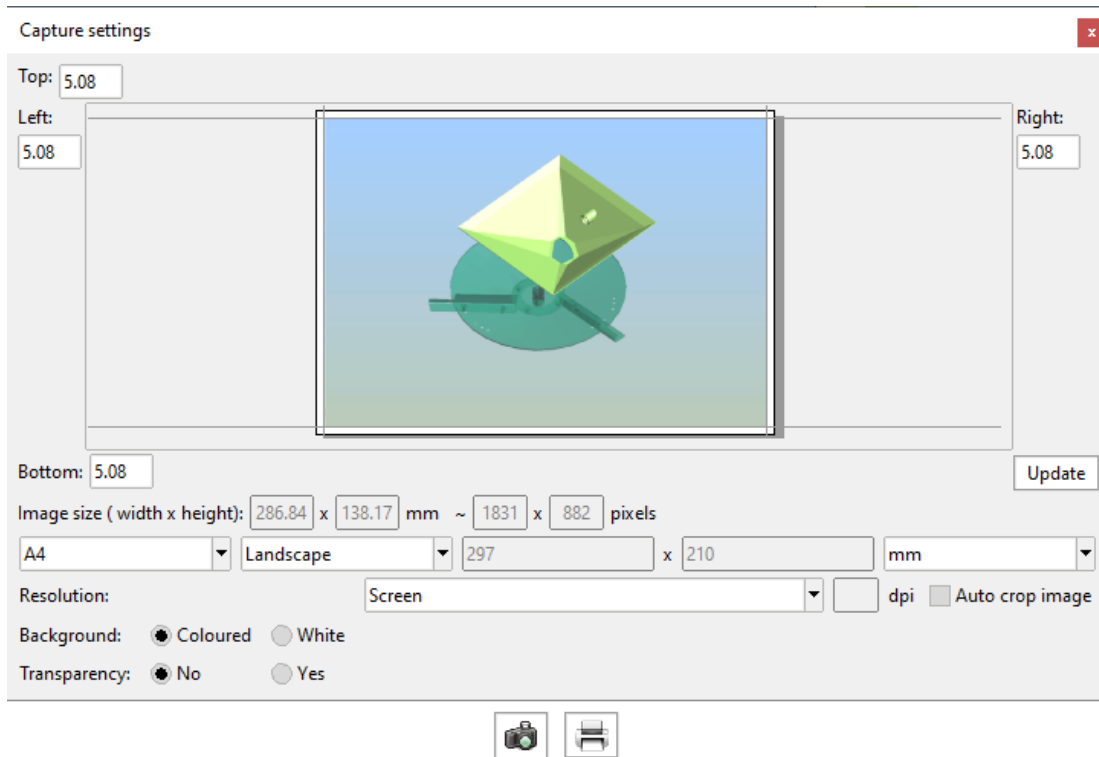


Figure 51. Page and capture settings.

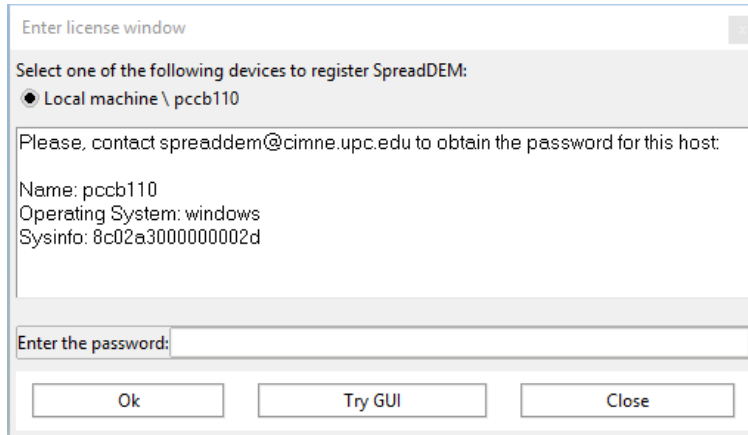


Figure 52. System information window.

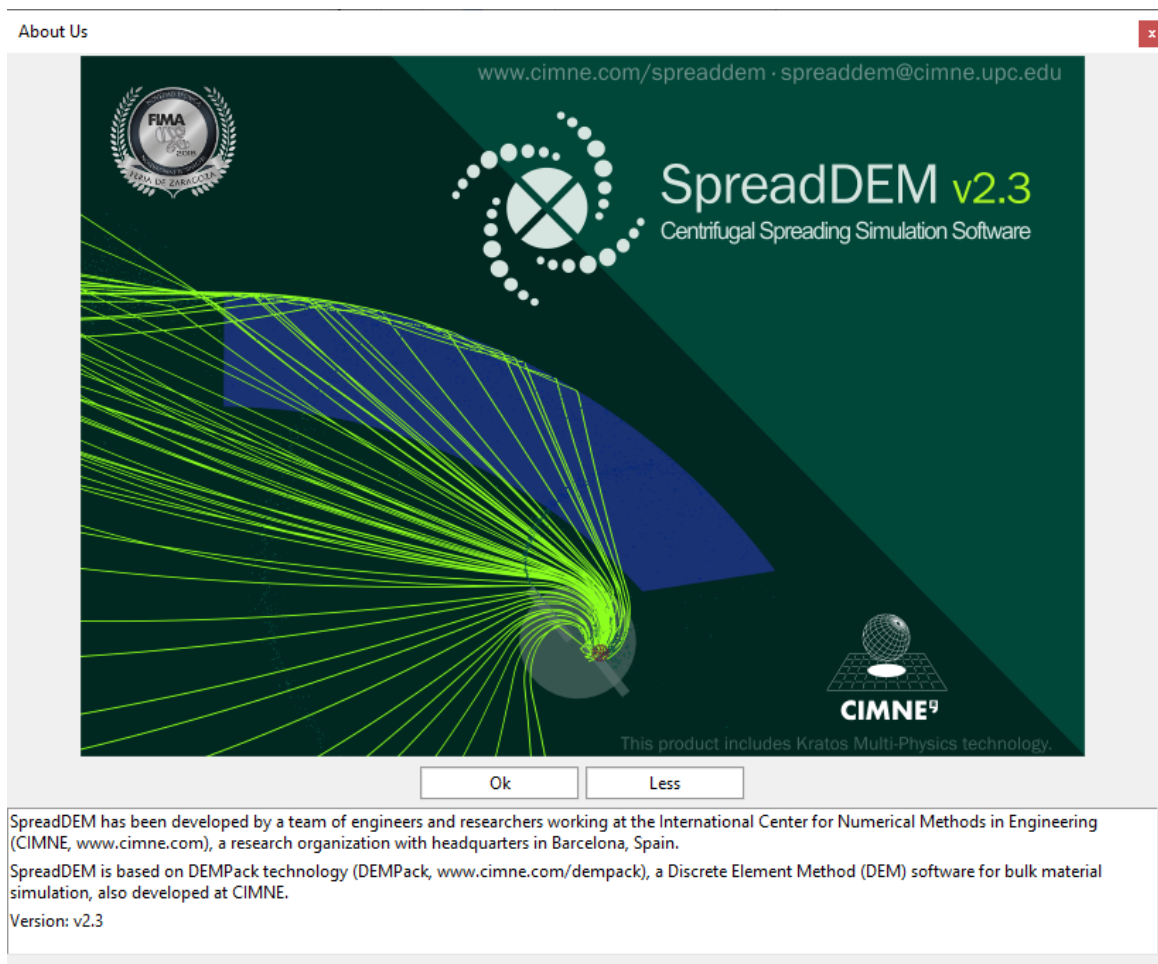


Figure 53. About Us window.

3. Computation time

The first aspect to check related to computation time is to know if our workstation meets the minimum system requirements specified in section XX.

Simulations can be launched one by one, or can be launched simultaneously opening several SpreadDEM windows. Which is the best option?

- The fastest option is to run several cases simultaneously, opening different SpreadDEM windows, and distributing the processors among them.
- There comes a point when increasing the number of CPUs does not imply a significant reduction of the simulation time and can even be counterproductive if we are close to occupying all available processors. This point will depend on each singular case.

Apart from the computer specifications, the total time depends on various factors that vary from case to case. The most important are (roughly in order of importance):

- Total number of particles to be simulated.- In general, the higher the number of particles processed by the end of the simulation, the greater the cost will be. It usually takes only a few minutes to see the first results with the motion of the particles over the disc. It takes longer for the spread pattern to be displayed, as it requires a significant number of particles to have reached the ground plane.
- Granulometry.- The smaller particles are problematic because 1) it is likely that there is a greater number of them and 2) they require a greater number of computational time steps per particle than bigger particles.
- Mass load.- Higher feed rates imply more particles in the domain, which in principle means greater costs. However, note that if the statistical convergence or the total mass criteria are used, lower feed rates will imply larger simulated time. Thus, having a very small feed rate can lead to very long computation times, as it takes very long to process all the particles.
- Connectivity.- More contacts per particle implies a higher computational cost, all other things being equal. Thus, the accumulation of particles in structures such as funnels and hoppers leads to higher costs.
- Impact results.- Checking the impact results option activates a number of operations that increase the cost of the simulation considerably.
- Speed of the discs.- Higher impact velocities require more steps to be appropriately resolved. The program will detect this and use smaller time steps, increasing the cost of the simulation.

While the calculation is running, a diagram showing the statistical convergence of the transverse distribution on the present time of the simulation will appear in Step 5: Settings window (it will be displayed once after a significant number of particles have reached the ground). Above this graph, there are some options to choose the width of the bins, meaning the width of the columns of the graph. This is a measure of the accuracy of the results. The wider the bins we select, the faster the diagrams converge at the expense of less precision in the results. If the end time criterion is Statistical convergence, the calculation will end automatically with the 100% of convergence for the narrower bins (0.5m). Whatever the end time criterion selected, the user can stop the simulation at any point depending on the required accuracy. In the first iterations of a design process, we recommend comparing the results at an earlier stage of convergence, by stopping the simulation manually.

Results can be loaded at any moment of the calculation in Step 6: Results.

Keep in mind that the Discrete Element Method, on which the SpreadDEM is based, is intrinsically an expensive numerical technique due to the level of detail that it captures.

3.1. How to reduce computation time

There can be several reasons for this. Here are the most likely candidates and some actions that can be taken to reduce the simulation time:

1. The total number of particles present in a simulation at any particular time is too high. The simulation costs grow roughly like the number of particles. Generally, The larger the number of particles, the greater the cost. The most common reasons for having a large number of particles are:
 - a. The granulometry contains a great number of fines. - The smaller particles are normally a small percentage of the total mass and reducing their number will not greatly affect the final results while having a great impact upon the simulation cost. Consider lowering it if possible.
 - b. There is a great deal of accumulation in the system due to peripheral structures such as funnels or hoppers. - Check the feed rate and friction coefficient of the surfaces: if there is a great deal of accumulation it means that the numerical feed rate you have imposed cannot be attained by the funnel leading to excessive accumulation. The DEM computes every single particle-particle as well as particle-wall interactions, so having accumulated particles implies a high time consumption. For a first approximation, consider doing without the peripheral structures such as funnels.
 - c. Two discs are being simulated. - The simulation time is nearly doubled if two discs are simulated instead of one as the number of particles is duplicated. For twin spreaders and symmetrical problems, it can be imported just one disc and duplicate the other one activating the Duplicate disc option. This feature does not increase the simulation time, as the results are mirrored when printing results. This is not recommended if the transverse slope of the ground is non zero or if the transverse wind is activated, as the results may not be symmetrical.
2. The speed of the moving parts is too great. This can happen with very fast spinning discs. The reason is that numerical resolution of the impacts has to be broken down into smaller time steps, leading to larger total simulation time.
3. The Impact results option is active in Step 5: Settings. The computational cost of this kind of results is high, to the extent that disabling this feature can reduce approximately by half the simulation time. Our recommendation is to activate it just in case it is strictly necessary. Most of the time, the impacts of the particles on the rigid faces are sufficiently characterized during the firsts turns of the disc. In such cases, the problem can be divided into two simulations: a first one with the Impact results option active, that can be stopped after a few turns of the disc, and another complete simulation with this option turned off.

In addition, the SpreadDEM team is putting all its efforts in upgrading the version of the software to reduce by half approximately the calculation time.

Actions that do not increase the simulation time:

- Rigid parts that do not involve an accumulation of particles, such as deflectors, do not sensibly increase the simulation time.
- The simplification of the imported geometries almost does not affect the simulation time.

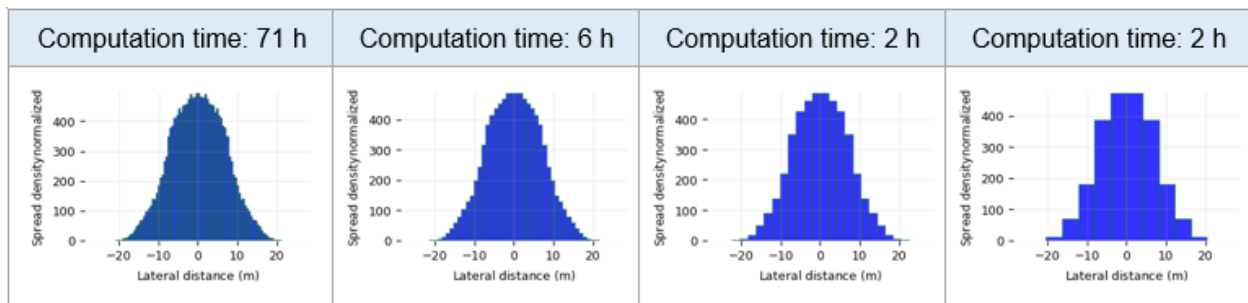
3.3. Convergence

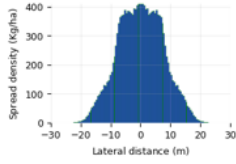
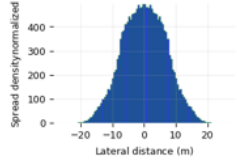
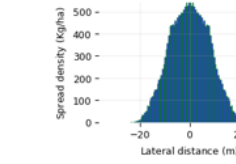
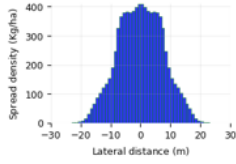
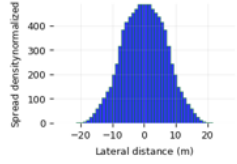
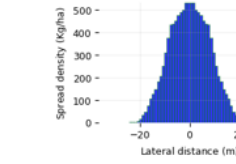
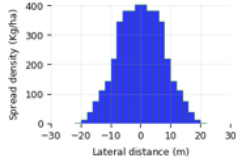
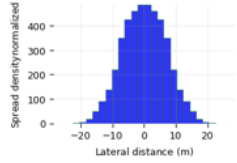
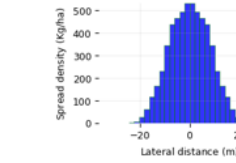
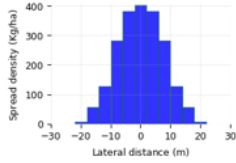
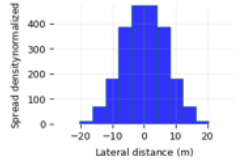
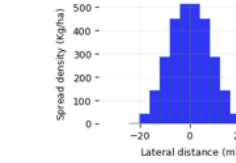
While the calculation is running, a diagram showing the statistical convergence of the transverse distribution on the present time of the simulation will appear in Step 5 window.

The wider the selected bins (width of the column of the graph), the faster the diagrams converge at the expense of less precision in the results.

If "Statistical convergence" is chosen as the end time criterion, the calculation will end automatically with the 100% of convergence for the narrower bins (0.5m).

In general, it is not strictly necessary to leave the simulation running for such a long time unless you need a very high accuracy.



Scenario 1	Scenario 2	Scenario 3
Computation time: 86 h	Computation time: 71 h	Computation time: 6 h
		
Computation time: 14 h	Computation time: 6 h	Computation time: 51 min
		
Computation time: 5 h	Computation time: 2 h	Computation time: 16 min
		
Computation time: 5 h	Computation time: 2 h	Computation time: 16 min
		

4. How the fertilizer parameters affect the results?

The numerical results obtained with SpreadDEM strongly depend on the parameters used to run the computation. This is an explanation on how the different parameters affect the results:

- **Granulometry:** The dimensions of the particle affect the drag, and thus, the landing range. The drag generated by a particle is directly proportional to its area. Thus, bigger particles produce more drag than smaller particles. However, if particles are scaled up maintaining the density, their volume and mass is increased by the cube of the multiplier. So for the same density, bigger particles land farther than smaller ones.
- **Density:** It mostly affects the range of spread patterns, since lighter particles lose their momentum before larger ones, due to the air resistance.
- **Sphericity:** It is used in the expression of the drag force in the ballistic flight, so it mostly affects the range of the spread pattern. Spherical shapes generate less drag than non-spherical shapes. For high disc speeds, the sphericity can also affect the Magnus effect due to the spinning particles leaving the disc.
- **Coefficient of friction particle-particle:** It may have an influence in the hopper discharge rate mainly, since the on-disk dynamics are more strongly affected by the particle-wall friction, not by the particle-particle friction. If the simulation does not include the computation of the hopper discharge, this parameter is not so relevant.
- **Coefficient of friction particle-wall:** It has a very pronounced influence on the time the particles take to slide along the vanes, causing the trajectories to start at different phases of the disk rotation and, ultimately affecting the ejection direction. Its variation causes a rotation of the spread pattern, so even though its value is unknown, it can be obtained indirectly by comparing the numerical and experimental results and adjusting it if necessary.

Parameters such as sphericity, coefficient of friction, and even the density, are sometimes not provided by the fertilizer producer and become hard to guess. To guarantee the accuracy of the results, the use of new fertilizers may need calibration to match the experiments. Once a material has been calibrated, you can change geometries, feeding position and rate, discs speed, wind, slope and terrain height, and the results should be reliable.

In order to help you in the calibration process, here are some examples of the influence of the most important parameters affecting the results:

5. Calibration process

In order to compare the experimental spread pattern with the simulations, a small calibration process is required to guarantee the accuracy of results.

Parameters that are usually easy to obtain: <ul style="list-style-type: none"> • Granulometry • Density 	Parameters that usually need calibration: <ul style="list-style-type: none"> • Sphericity • Coefficient of friction
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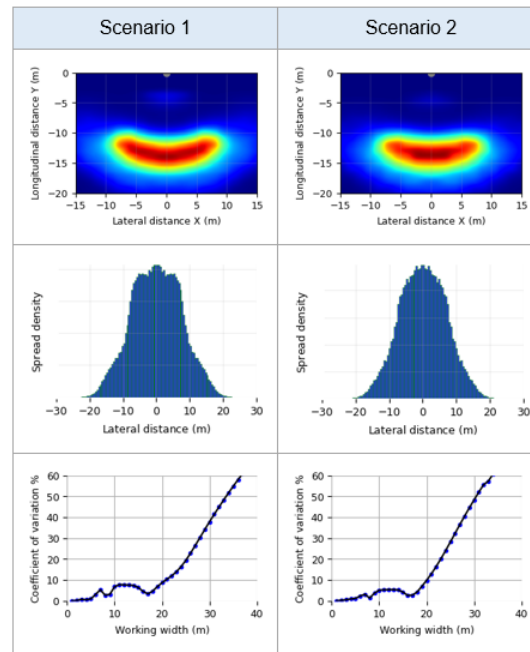
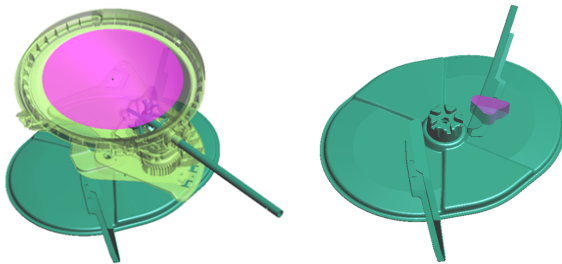
Once all the material parameters are known, changes can be made in geometries, feeding position and rate, discs speed, wind and height, and the results should be reliable.

5.1. STEP 1. Preliminary simulations

To see which situation reproduces best the experiments and help us decide how much a simulation can be simplified to give reliable results. Reference values are taken for the calibration parameters.

- Simulation 1: hopper discharge is actually simulated.
- Simulation 2: simplified inlet (dense flow may help).

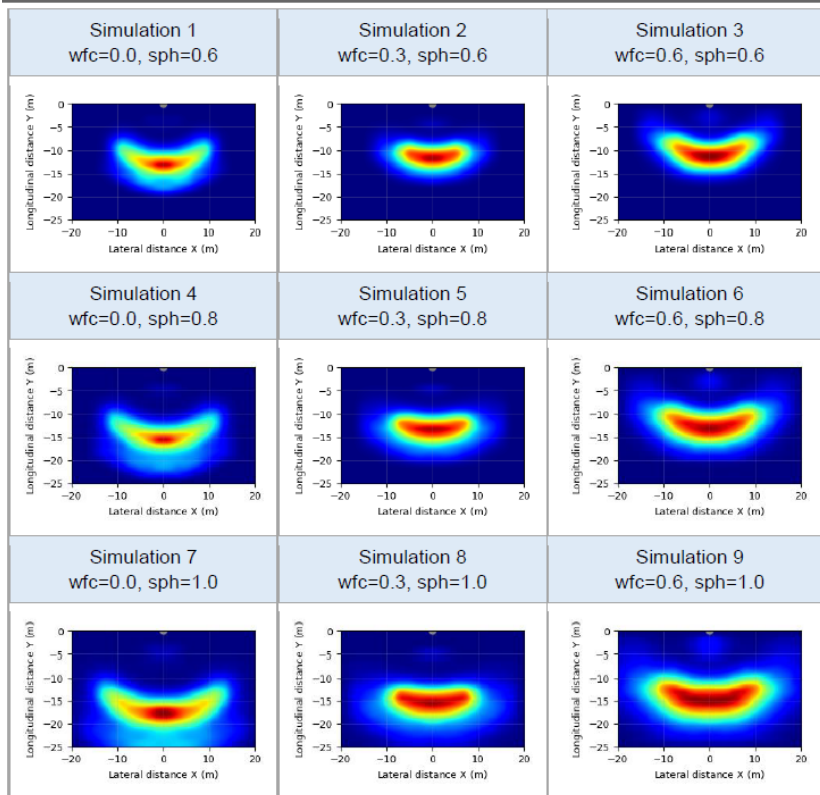
If the results are similar enough, we can proceed with the simplified approach.



5.2. STEP 2. Sensitivity analysis

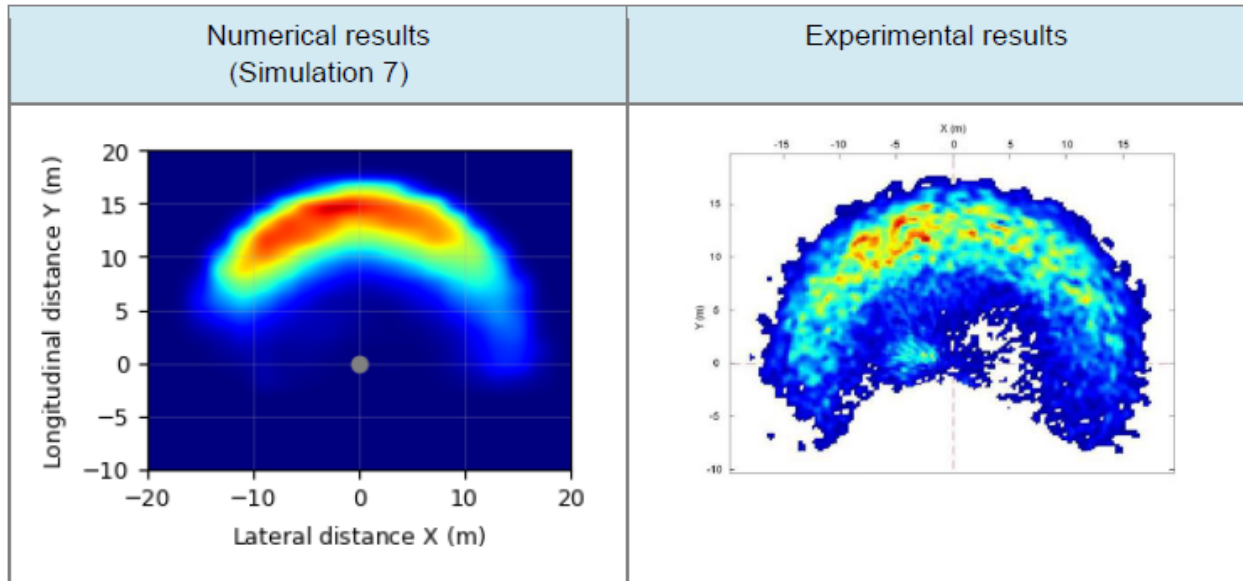
This step consists in launching a set of cases considering a range of values for the unknown physical properties. It is not necessary to wait until full convergence.

	Sph = 1.0	Sph = 0.8	Sph = 0.6
FC = 0.7	Simulation 1	Simulation 2	Simulation 3
FC = 0.5	Simulation 4	Simulation 5	Simulation 6
FC = 0.3	Simulation 7	Simulation 8	Simulation 9



5.3. STEP 3. Compare numerical and experimental results

Compare the simulation results from step 2 with the experimental ones, and decide which is the value of the calibration parameters that works best. Iterate if necessary going back to step 2.



5.4. STEP 4. Launch a more accurate simulation

Once the material has been calibrated, if one requires very precise results, an additional simulation can be launched importing all the rigid parts, such as the hopper. This will serve to confirm the results as well.

5.5. STEP 5. Make any changes

With the final material parameters, it is possible to make changes to the geometries, feeding position and rate, discs speed, wind and height with reliable results.