ShadeMotion:
the analysis of tree shade patterns
tutorial

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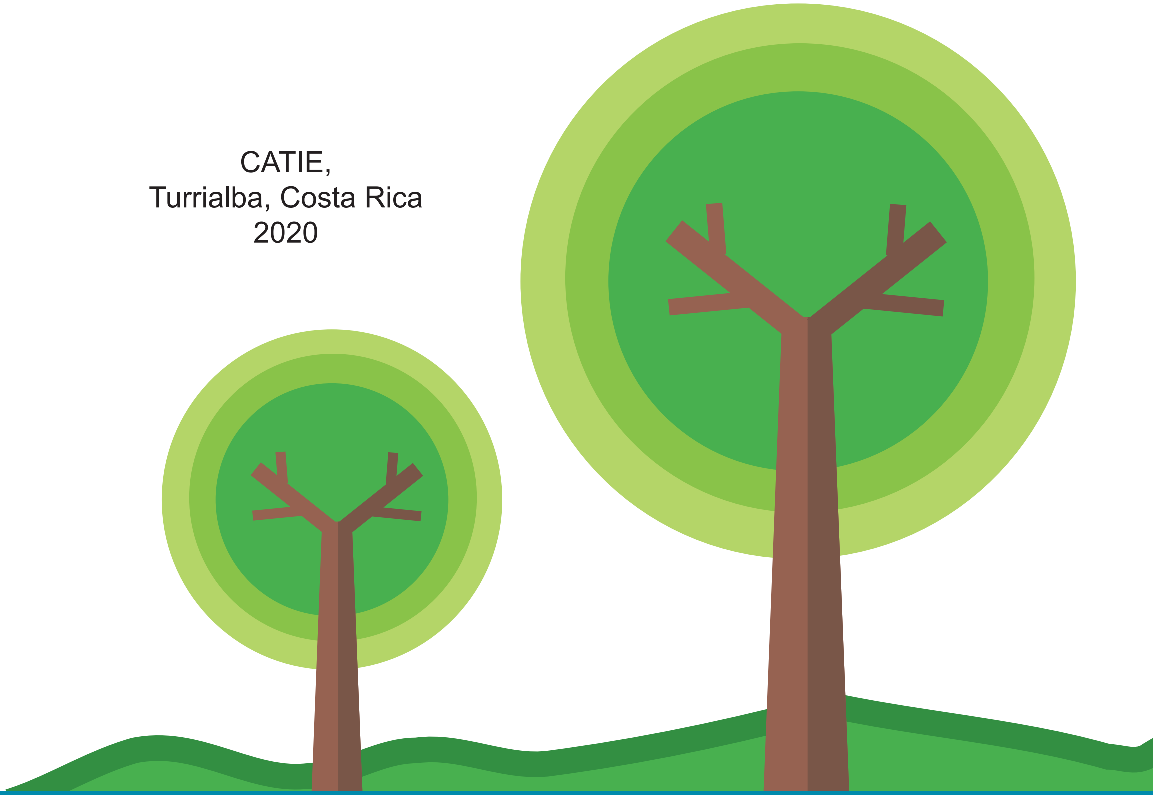

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Introduction

Plant physiologists have developed very complete models on the amount of radiation plants receive, most of them based on the morphological structure of plants.ShadeMotion approaches the issue from a different point of view and deals with the shade projected by the plants when they block the sun rays, based on merely geometrical considerations and taking advantage of the accuracy of the formulas that determine the position of the Sun at any time of the year and in any place of the Earth.

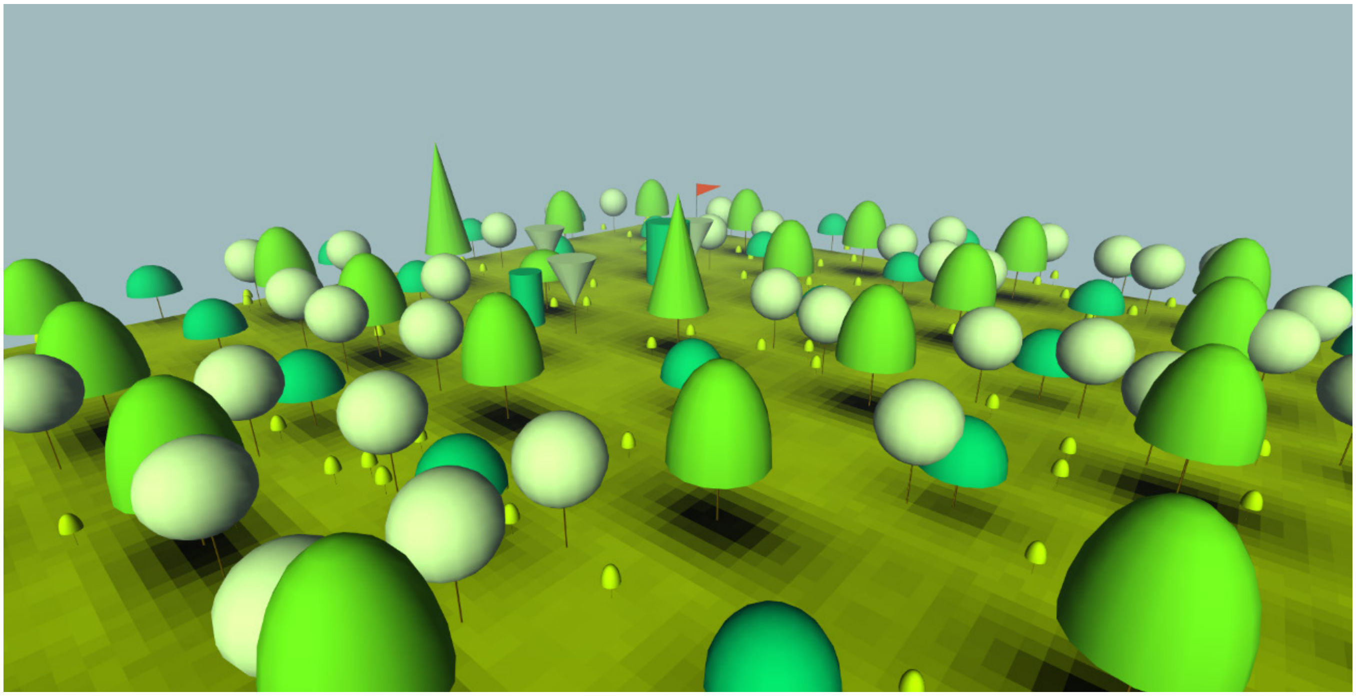
ShadeMotion allows keeping count of the shade hours stored at each "point" (cell) of a tree plot during a timeframe specified by the user.

Users have a wide range of options to elaborate simulations:

- The plot can be located at any geographical latitude of the planet.
- The plot can be flat or tilted with any degree of inclination, and the slope can be oriented in any direction.
- Any number of trees can be planted in any position on the grid representing the plot.
- Each tree can have its own characteristics regarding shape, crown size, and trunk thickness and height.
- The crown shape is limited to a range of basic geometric forms: spheres, semi-spheres, ellipsoids, semi-ellipsoids, cones, inverted cones, cylinders and umbrellas.
- Each crown can have its own degree of density or opacity, as well as its own monthly density variation due to the leaf fall and restitution of foliage.
- Each species can have its own pattern for crown and trunk growth.
- The software displays the results of simulations in a graphical way and through documents in several formats.
- Tri-dimensional views of the plot with the trees can be generated.

New features in Version 5.0:

- Trees can be planted in arrangements without the need of planting each tree individually.
- The development of the crop below the crown can be used to compute the shade map at the height of the crop plants.
- Trimmable species with regular expansion-contraction of the crown can be modelled.
- Shade reports are currently made by time intervals, without accruing the previous intervals.
- A considerable time reduction is achieved in the implementation of simulations.
- The software can be installed in your computer or you can run the simulations on-line from the website www.shademotion.net.
- The software currently runs in the three main platforms: Windows, OS or Linux.



Glossary

Raw files. Files that contain the most detailed information of a simulation, registering the amount of shade at each cell for each moment of the simulation.

Basal area. This is the sum of the cross-sectional areas of all the trunks measured at chest height, by area unit – usually per hectare.

Simple arrangement. Layout of the trees in vertically and horizontally aligned rows and columns, forming rectangular cells.

Complex arrangement. Layout of the trees obtained by overlapping two or more simple arrangements.

Random arrangement. Layout of the trees obtained by locating them randomly throughout the plot.

Flag. It is a mark placed on a cell to assess the amount of shade stored in a simulation.

Caducifolia. This describes a phenomenon that consists in the leaf fall of foliage of some trees during certain months of the year and the recovery of the foliage during other months.

Crown coverage. This is the area of shade projected by the tree crown due to the effect of sunrays falling perpendicular to the floor, subtracting the light “holes” due to crown density.

DAC. Abbreviation for “diameter at chest”. It refers to the diameter of a tree trunk at chest height.

Crown density. Percentage of opacity of the tree crown to light. A completely opaque crown will have a density of 100%.

Population density. This is expressed in number of trees per unit area. In ShadeMotion, the units by default correspond to the number of trees per hectare.

Frequency of solar movement. This indicates how often the Sun changes its position and how often the position of the shade is recalculated during a simulation.

Interval. Period of time during which the program performs a partial collection of data about shades and trees during the simulation.

Dynamic mode. This mode is activated to perform dynamic simulations.

Static mode. This mode is activated to perform static simulations.

Instantaneous mode. This mode is activated to perform instantaneous simulations.

Normal mode. This refers to the static or the dynamic mode.

Moment. In ShadeMotion the Sun does not change position continuously but rather in time step units called *moments.* If the value of moments is set in 1 hour, the Sun remains in the same position for one hour before changing to a new position. Saying that moments correspond to 1 hour is equivalent to saying that the frequency of solar movements is every hour.

Steps. These are time frames constituted by one or several *intervals.* In dynamic simulations, the user has the option for the simulation to stop in the steps in order to analyze the shade and eventually plant or remote trees.

Period. Moments in which – if the user has requested it – the program stops to show the condition of the plot and the shade. The periods are made up of one or several intervals.

Trimmable. This qualifies a species that is regularly trimmed.

Semiaxis. This refers to the positive half of any of the coordinate axis. For example, semiaxis Y+ is the positive half of the Y axis, which is always located to the left of the parcel plot and in ascending direction; that is, pointing towards the upper part of the screen.

Overlaps. These are phenomena that occur when two or more trees project shade over the same cell of the plot at the same moment.

Sampling zone. This is the zone the user has highlighted in yellow for the program to calculate shades only in the cells included in such zone.

2D. Is the view of the plot and the trees in two dimensions.

3D. Is the view of the plot and the trees in three dimensions.

Overview

1

Chapter

Graphic interface

The basic elements are involved in a ShadeMotion simulation: 1) the trees, 2) the plot and 3) the movement of the Sun. The user should provide information about these three elements through the interface described below:

Graphic interface zones and bars for ShadeMotion users

1. **"Shade Map" Zone.** It is located at the center of the interface, it is the yellow square were users plant the trees which shade is to be analyzed and where the amount of shade received by each cell of the grid is mapped. As will be seen later, there are several ways in which the user can plant the trees.
2. **"Tree" Zone.** It is located to the left of the plot. This is where the data of the trees to be planted in the plot are entered using the mouse pointer. The data the user can enter for each tree planted include: species, position (Cartesian coordinates) in the plot, crown shape and dimensions, trunk diameter and height, and crown density. The lower half shows information about the number of trees that have been planted, the density of the plantation, the crown coverage and the basal area.
3. **"Solar Movement" Zone and "Plot" Zone.** In this zone, located to the right of the plot, the user enters information regarding frequency and daily range for solar movement, the calendar timeframe of the simulation.
4. **"Plot" Zone.** In this zone, located in the lower right of the grid, the user enters the features of the plot: geographical latitude, degree of inclination and orientation of the plot, size of the plot and orientation of the coordinate axes. The zone includes a field for the growth of the crop that develops under the shade.

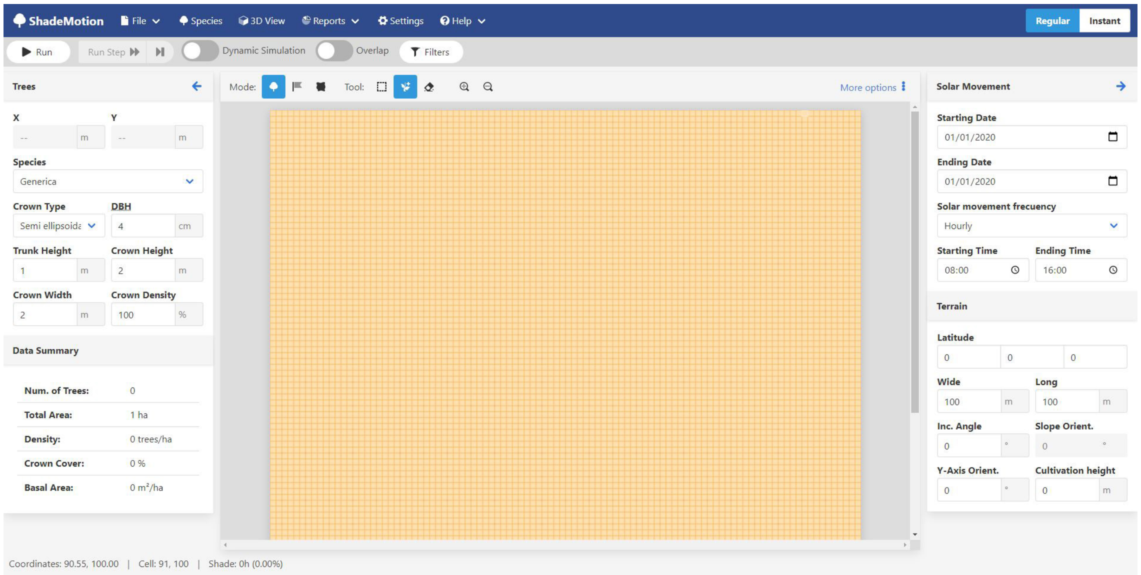


Figure 1. ShadeMotion 5.0 Graphic Interface with 4 zones and 4 bars.

1. **Menu Bar:** It contains some menus that are typical for most applications (File, Configuration, Help, etc.) and some specific menus (Species, Reports, among others).

2. **Simulation Bar:** It contains buttons to select the mode to run the simulation (static, dynamic, with shade overlapping or without it).

3. **Mode and Tool Bar:** It shows the three modes of action the user can choose (plant trees, plant flags and define the shade sampling area in the parcel) and their corresponding tools:

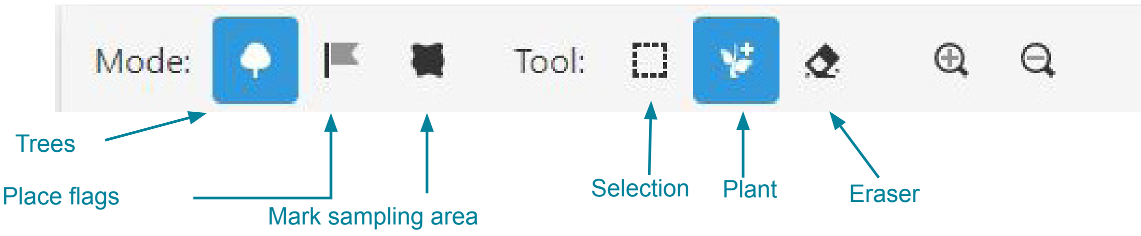
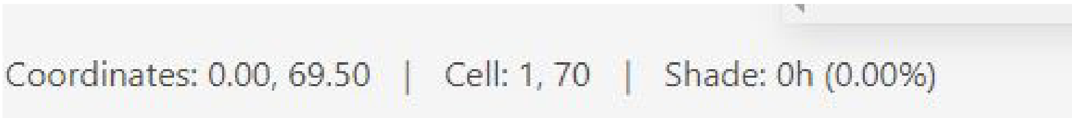


Figure 2. Bars of the interface window

Each mode can operate with the tools on the right (Selection, Plant and Eraser). For example, when the Tree mode – represented with a tree icon – is selected, it is possible to plant trees (Plant tool), erase trees (Eraser tool), or select trees (square icon).

4. **Status Bar.** It is located under the grid of the plot, at the bottom of the screen. It contains information about the amount of shade stored in the cell over which the cursor is placed when moving it over the shade map, after running the simulation. Example:



Time in ShadeMotion: frequency of solar movement, moments, daily solar range and simulation days

In ShadeMotion, the position of the Sun is calculated with a frequency selected by the user. If, for example, the user selects a **solar movement frequency** of one hour, ShadeMotion will calculate the position of the shades every hour. The hours will be the basic time units for the simulation, which we will call **moments** in the simulation. If a simulation has 1000 moments; that means that the position of the Sun and the shades was calculated 1000 times. We can think that all simulations imply a sequence of *moments* in each of which the position of the Sun and the shades of the trees have been recorded. The value of the solar movement frequency is determined in the field “Solar movement frequency”, in the “Solar Movement” Zone:

The options available are: Every 4 hours, Every 2 hours, Every hour, Every 30 minutes, Every 15 minutes. The value by default is “Every hour”. Evidently, the more frequent the calculation of the position of the Sun, the greater the accuracy of the results; but the simulation would last longer and the raw files, which can have up to 10^{10} entries, would be bigger and can only be analyzed with the appropriate software (Excel is not appropriate for this type of files because it can only take 10^6 entries).

In a simulation, in addition to the **frequency of the solar movement**, the user specifies a start date (day, month, year) and a final date for the simulation (to determine the **number of days of the simulation**), and the initial and final time for each day of the simulation (what we call **daily solar range**). This information, together with the definition of the **frequency of the solar movement** determines the **number of moments per day** in which the position of the Sun is registered. The total number of moments of a simulation (what we call “**total moments**”) is calculated as follows:

Total moments = number of days of simulation x number of moments per day

For example, if a user performs a simulation between January 1st, 2020 and December 31st, 2020 (365 simulation days) and observes the position of the sun every hour between 8 am and 4 pm (9 simulation moments per day), the total number of moments of the simulation will be 365 x 9 = 3285 moments. If we ran this simulation in a 1 ha plot, with a grid of 1 m per side, resulting in 10 thousand cells of 1 m^2 each, Shade-

Motion counts the number of simulation moments in which each cell of the plot received shade during the simulation. If one cell received 1354 moments of shade throughout the simulation, when placing the cursor over this cell, the percentage of shade displayed will be 41%, which is the result of $100 * (\frac{1354}{3285})$.

Geographical location of the parcel

The user should enter the geographical latitude of the parcel. The latitude shall be entered in degrees, minutes and seconds, in positive numbers to the north of the Equator, and in negative numbers to the south of the Equator. The geographical latitude is entered in the “Latitude” box located in the “Plot” Zone.

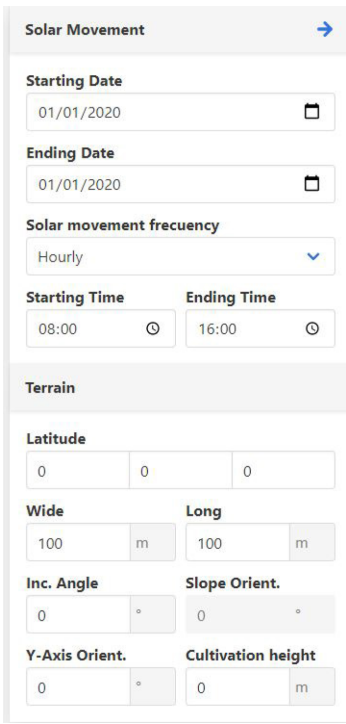


Figure 3. The “Plot” Zone is located to the right of the plot grid.

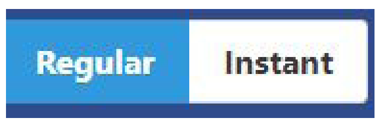
Dynamic, static and instantaneous simulations

Dynamic Mode. This mode takes into account the growth of the tree crowns and the trunk for each species, as well as the cyclic expansion and contraction of the crown for those trees that are regularly trimmed (“trimmable” species). A dynamic simulation can also have information about the growth of a crop under the trees, and the user might be interested in registering the shade at the level of the crop plants rather than at the ground level. In a dynamic mode, the user can remove or plant trees during the simulation. The dynamic mode is especially useful to study the shade in farms along several years; for example, during the whole life cycle of a crop that is managed under shade, like coffee or cacao.

Static Mode. This mode does not take tree growth into account: the crown and trunk dimensions remain constant, and it is not possible to plant or remove trees during the simulation. In the static mode, the simulation runs without stopping from start to end. However, the program takes into account the monthly variations in foliage density for tree species during the year (leaf fall). Although the static mode can be run for simulations of any length, it makes more sense to use it for simulations which duration does not exceed one year, since the following year the distribution of the trees and their dimensions will not vary and the shade counts will not vary either.

You can choose between the static or dynamic mode using the button at the left of the Mode and Tool Bar, the two modes are alternated:

Instantaneous Mode. This mode allows to see the shade map at a moment set by the user. The instantaneous mode option can be selected in the upper end of the “Menu Bar”. The option “Normal” enables the options of dynamic or static simulations.



Shade map of a simulation.

All simulations produce a shade map, in different tones of gray, of the shade-hours for each cell of the plot: the more the shade, the darker the tone of gray. If the cursor is placed over a cell, in the Task Bar, located below the grid of the plot, you will be able to see the value of coordinates of the cell followed by the number of shade hours and, in parenthesis, this value expressed as a percentage of the total moments of the simulation.

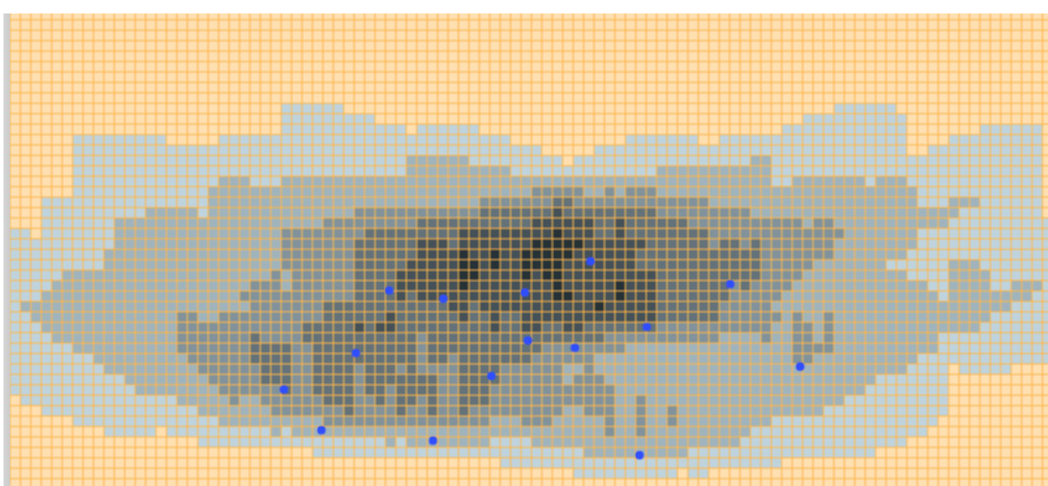


Figure 4. The shade map over the plot shows the zones with different levels of shade intensity. The blue dots indicate the places where the trees are planted.

Crown coverage of a set of trees

Crown coverage is defined as the area of the vertical projection of the crown (circular) over a horizontal plot, taking into account the density of the crowns (the crowns can let all, part of, or none of the sunrays pass). The crown coverage of a set of trees is the sum of the individual coverage of the trees that make up the set.

Example:

the crown coverage of a tree with spherical 10 m diameter and 100% density crown equals the area of a circle with 10 m diameter, which is calculated as: Area $= \pi(\frac{10}{2})^2 = 78$. If the density of the crown was 50%, the crown coverage would be half of the area mentioned. If there were 70 trees/ha of land, we would have to multiply the tree coverage by the number of trees per hectare, divide that result by 10 thousand square meters and, finally, multiply that result by one hundred in order to express the crown coverage in the plot as a percentage.

Population density (or just Density)

Population density is a figure that expresses the number of trees per surface unit in the plot. Normally, the density is expressed in trees per hectare (trees/ha). For example, if we have 20 trees in a plot of 5000 square meters (one half of a hectare, the density of this set of trees is $20 * \frac{10000}{5000}$ = 40 trees/ha.

Basal area of a set of trees on the plot

The cross-sectional area of the trunk at chest level is a measure of the tree size. This measure assumes that the trunks are cylindrical and the cross section is a circle. The sum of the areas of the cross-sectional areas of all the trees in a plot with known area (hectare, acre) is known as the ***basal area*** **(G)** of the plantation. Usually, G is expressed in square meters per hectare. For example, if we have 30 trees with 20 cm DAC in a plot of 0.6 ha, G would be 1.57 m^2/ha.

Saving a simulation

When a simulation is saved, the program stores all the data entered in the “Solar Movement” and “Plot” zones and in the “Configuration” window (which we will cover later on). The species defined by the user and their growing patterns are also stored. The simulations are saved in “json” format. When saving a simulation, the user will be able to run it again with the same parameters. If the user wants to save not only the parameters but also the results, he should do so at the end of the simulation. In dynamic simulations, some results can be saved during the simulation. The details about the results of a simulation are discussed in Chapter 4. To save a simulation, select the option “Save” in the “File” menu.

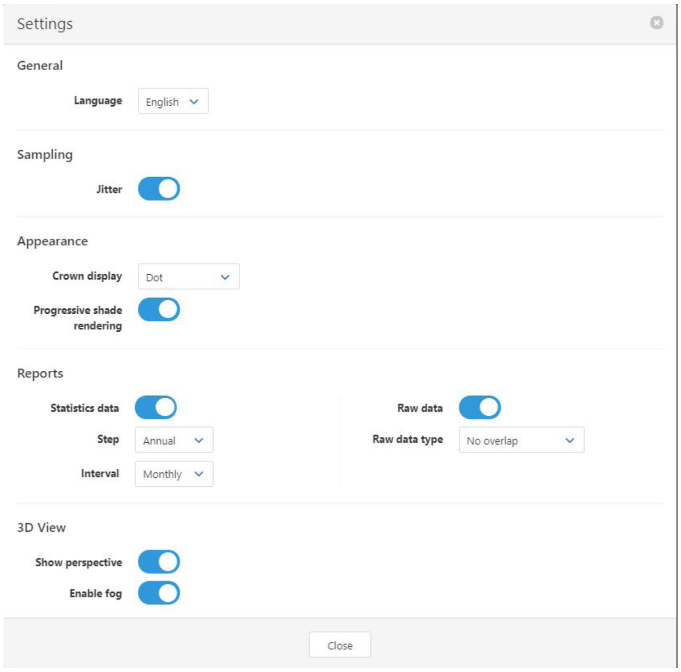


Figure 5. The Configuration window is displayed by clicking on the Configuration Menu.

Uploading a simulation

The files with ShadeMotion simulations have the extension ".json". A simulation is uploaded from the "File" menu, with the option "Open". It is also possible to upload a simulation by dragging the icon of the file and placing it over the grid of the plot or in any other part of the program window.

About the measuring units of trees and plot

The geometrical procedure for the projection of a tree crown shade over the plot has the feature of preserving the ratios between the measures of the trees and those of their shades, regardless of the measuring units used to measure the trees. This allows the users to enter the measurements of the trees (crown width and height, etc.) in their units of choice, subject to the condition that the plot size is interpreted in those same units. If, for example, the measurements of the trees are entered in yards, it is important to keep in mind that each cell with measure one yard per side.

The Trees

2 Chapter

Characteristics of the trees

The characteristics of the trees should be defined before planting them. Due to this, we will first discuss the characteristics of the trees and then move to the different ways of planting them.

Values that determine the characteristics of the trees

The following list describes the characteristics that a tree can have in ShadeMotion:

1. Position in the plot (cell in the grid)
2. Species
3. Crown type
4. Width (diameter) and crown height (Figure 5)
5. Diameter at chest height and height of the trunk to the base of the crown
6. Crown density
7. Monthly variation of crown density
8. Growth table of the four variables included in items 4 and 5 of this list
9. Trimming cycle table, in case of a trimmable tree.

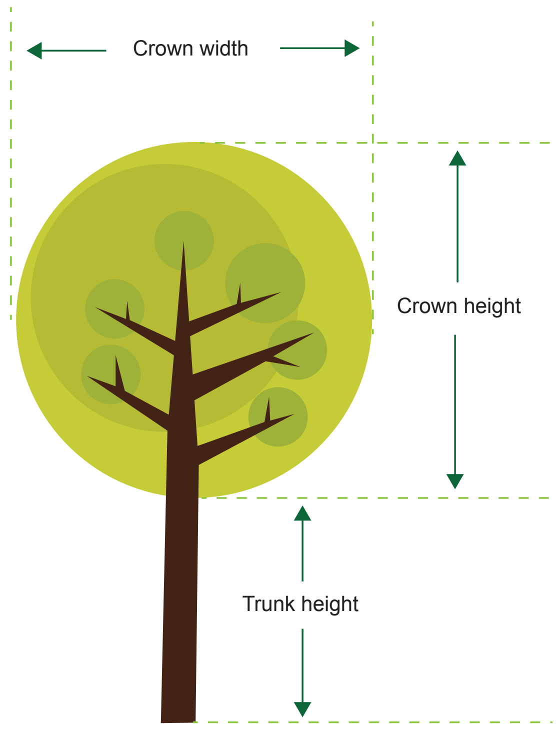


Figure 6. Dimensions of the tree (crown width, crown height, trunk height)

Monthly foliage change (leaf fall) and maximum crown density

Most tree species shed their leaves during the year; they do not remain unchanged. This phenomenon is known as *leaf fall*. ShadeMotion allows the user to assign any foliage monthly variation pattern to a species. In order to access the foliage variation table:

1. Click the “Species” menu located in the Menu Bar.
2. In the Species window, click over the option “Foliage Variation” and enter the maximum foliage percentage reached every month. A value of 0% indicates that the tree lost all the foliage and the crown let all the light pass. A value of 100% indicates that the crown has the maximum amount of foliage the species reaches during the year.

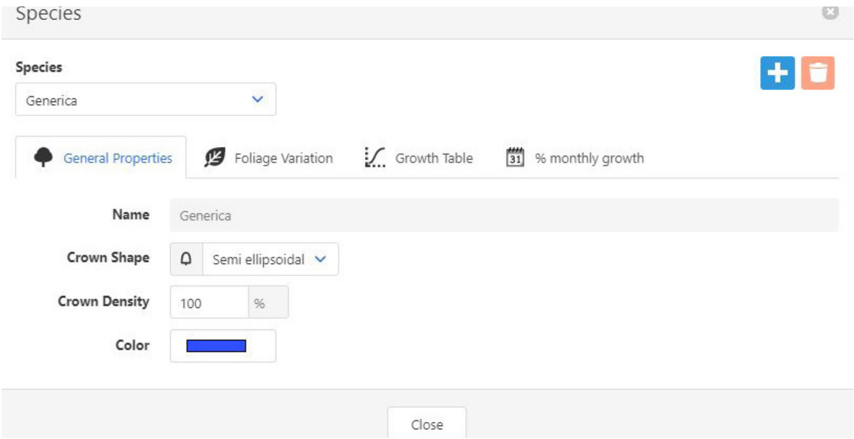


Figure 7.

The species differ in the maximum foliage reached during the months of the year. For example, an orange tree has a packed dense foliage crown, so the sunrays cannot pass. The crown of an orange tree (untrimmed) is practically a solid figure with a maximum foliage in crown density of 100%. A laurel tree (Cordia alliodora) reaches a crown density of 50% when it is in its greatest foliage period. ShadeMotion combines the crown density with the monthly leaf fall and randomly generates, for each crown, at each moment of the simulation, a number of “light holes”. While the crown density is entered in the “Tree” zone, the monthly foliage variation percentages of a species are entered in the “Foliage Variation” table, in the “Species” window of the “Species” menu.

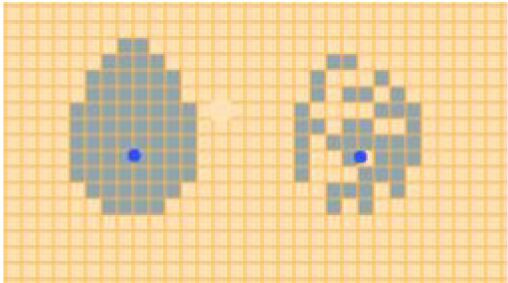


Figure 8. The crown on the left has a density of 100% and the crown on the right a density of 60% with 40% of light holes. The blue dots show the cells where the trees are planted.

In Figure 8, the crown on the left has a density of 100% and the crown on the right a density of 60% with 40% of light holes. The blue dots show the cells where the trees are planted.

Direction of the positive Y+ semiaxis

A Cartesian coordinate system is divided into four quadrants. We are only interested in the quadrant with positive coordinate values (first quadrant) to represent the coordinates for the position of each tree in the plot. Mathematically, the upper right quadrant of a system of Cartesian coordinates is defined by two positive semiaxes, one for the X (X+) and one for the Y (Y+).

The Y+ semiaxis of the plot (left side of the grid) points by default to the north as you move on it from the bottom up. However, when you want to simulate shade distribution in a horizontal plot of the real world, sometimes changing the direction in which such semiaxis points can facilitate the calculation of the coordinates of the trees in the field. When this is done, it is very important to register the new direction towards which Y+ is pointing, as we will explain later. To correctly interpret the position of the shade map with regards to the points of the compass, keep the following rule in mind:

> *The left side of the grid of the plot, as you go over it in ascending direction, always points towards the direction assigned to the Y+ semiaxis.*

Setting the orientation of the Y+ semiaxis should be done before planting the trees in the grid of the plot. If you do it after the trees are entered, this would be equivalent to a rotation of the parcel (including trees) and a different shade map will be generated, not corresponding to the situation before the change was made.

Example:

In Figure 9 (left) , the Y+ semiaxis is pointing north, and the left side of the plot runs from south to north as you go over it from the bottom up. The figure shows a tree with the shade over the point where the tree is planted, which means that the shade is projected to the north of that point. The fact that the shade is to the north of the plantation point is a geographical fact that cannot be changed by a shift in direction of the coordinate axes. In the right figure, we have the same tree at the same time and in the same day. Before planting the tree, the direction of semiaxis Y+ was changed, it is now pointing east (with φ = 90). The left side of the plot is now running from west to east as you go over it from the bottom up. The tree continues projecting its shade to the north of the point where it is planted.

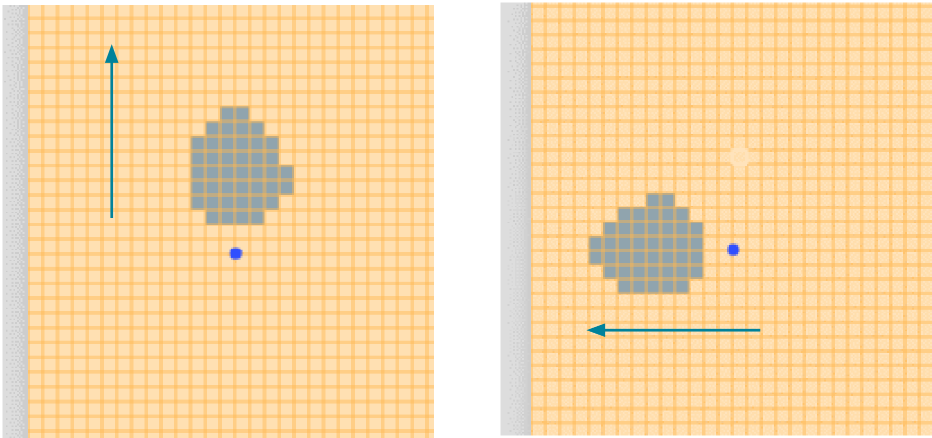


Figura 9.

Four ways of planting trees

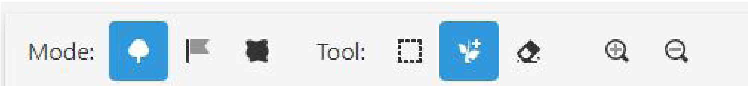
Once the user has assigned the correct properties to the trees, there are four ways of taking them to the grid of the plot:

- Manually with the mouse.
- Automatically through a regular or random arrangement.
- Preparing or importing an Excel file with data taken from the field.
    - Preparation in Cartesian coordinates.
    - Preparation through a GPS device.

Below is a more detailed explanation of each item from the previous list.

i. Manually

In the Modes and Tools Bar, choose the icon with the tree and then the one with the plant, as shown below:



Bring the cursor to the cell where you want to plant the tree and left click.

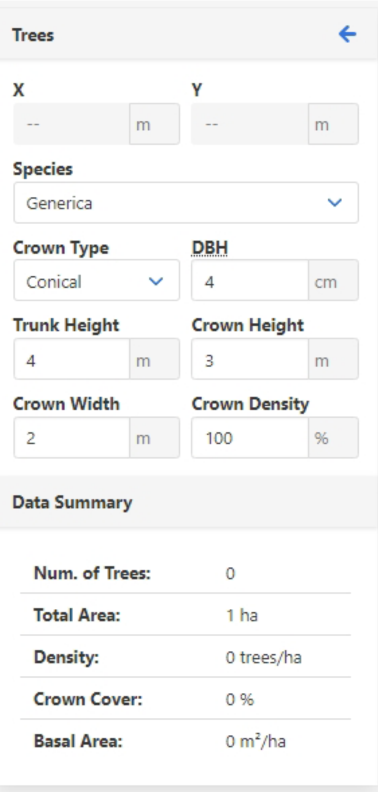


Figure 10. The figure shows the area to the left of the plot, where the "Tree" zone and the Global Panel are contained..

When planting the trees with the cursor, the users can modify (for each planted tree) the values of the Tree Zone windows. This should be done before the tree is planted. Boxes X and Y are used to move an already planted tree to a new position, selecting it before. "Summary Panel" is located at the bottom, and it shows the number of trees, the area of the plot and the estimations for density, crown coverage and basal area.

If the user wants to check the properties of a tree that is already planted, she should left click on it. A red circle will appear surrounding the tree and the values of its crown and trunk appear in the Tree Zone window.

ii. Plantation arrangements: systematic and random

It is possible to plant trees making very different types of arrangements.

Simple arrangements

Systematic arrangements are constructed from *simple arrangements*. A simple arrangement is made up by horizontal rows and vertical columns that limit square or rectangular patterns. A simple arrangement should contain trees of the same species and identical characteristics. To plant a simple arrangement:

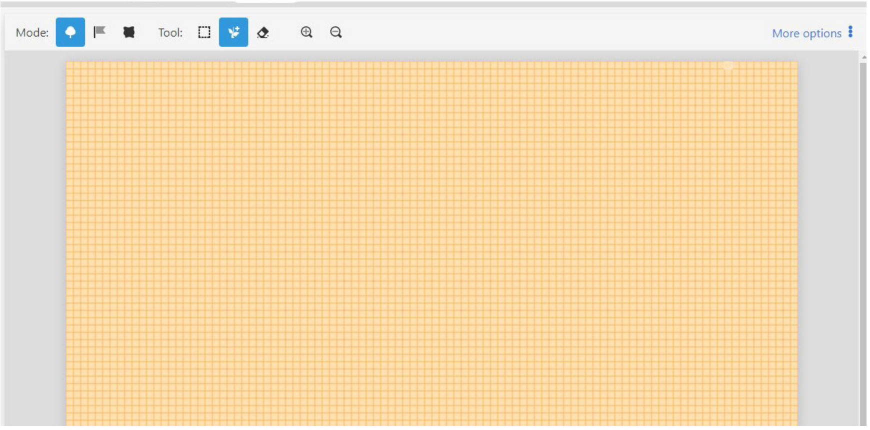


Figure 11. The figures shows the button "More Options" located in the upper right corner of the grid.

1) In the "More options" window, to the right of the plot, choose the option "Systematic Plantation Pattern" and enter the following information in the corresponding pop-up window.

a) Enter the distance between trees in the same row or *horizontal distance*.

b) Enter the distance between trees in the same column or *vertical distance*.

c) Enter the coordinates of the tree located in the lower left corner of the arrangement (lower row, left column)

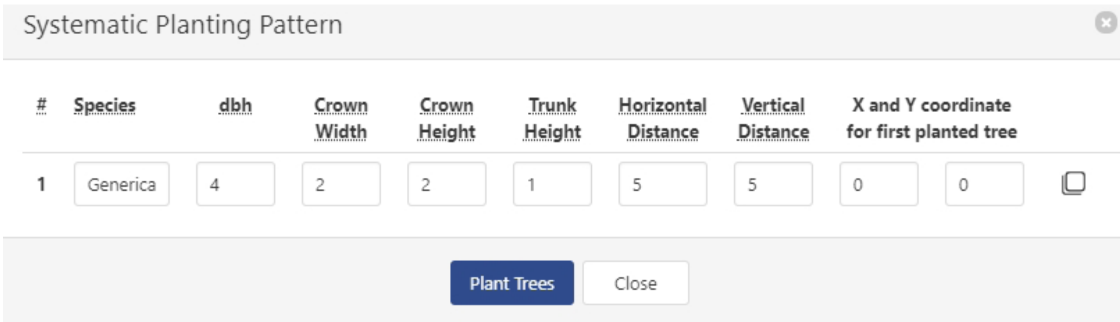


Figura 12.

Figure 12 shows the window "Systematic Plantation Pattern" of a simple arrangement where the horizontal distance is 12 meters and the vertical distance is 4 meters, and the coordinates of the tree located in the lower left corner are (0, 0). Figure 13 below shows a portion of this arrangement.

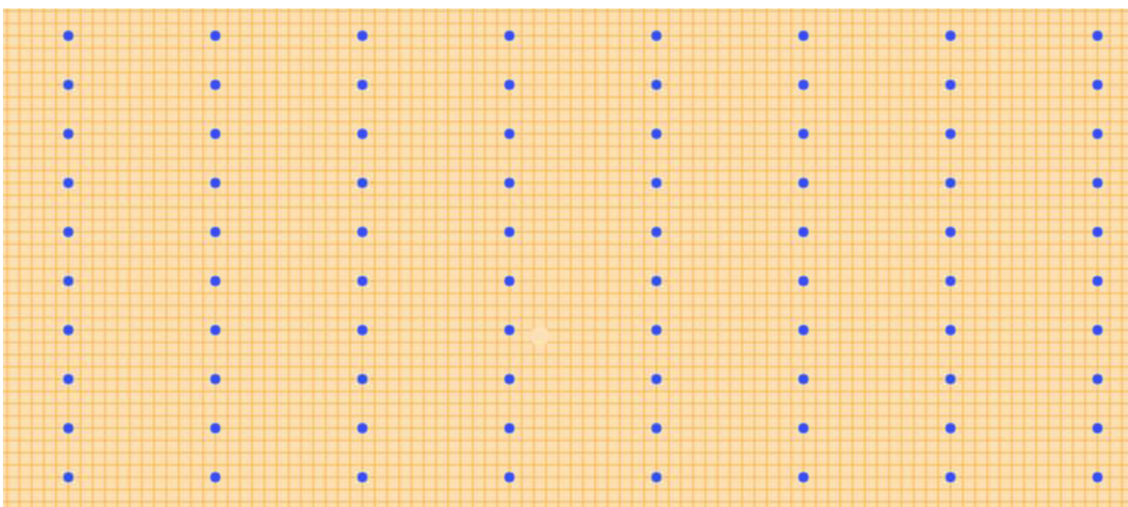


Figure 13. Systematic arrangement with distance of 4 cells between rows and 12 cells between columns.

Complex arrangements

By overlapping two or more simple arrangements we can construct *complex arrangements*, which basic cells are not necessarily rectangular. Figure 14 shows a complex arrangement (trails with double rows of trees and triangular plantation) formed by overlapping two simple arrangements: a timber species in blue and a fruit species in green. Timber species appear in blue with a vertical distance of 6 m, horizontal distance of 18 m, and coordinate of the first tree (0, 0). Fruit species appear in green and were planted with a vertical distance of 6 m, horizontal distance of 18 m, and coordinates of the first tree (3, 3).

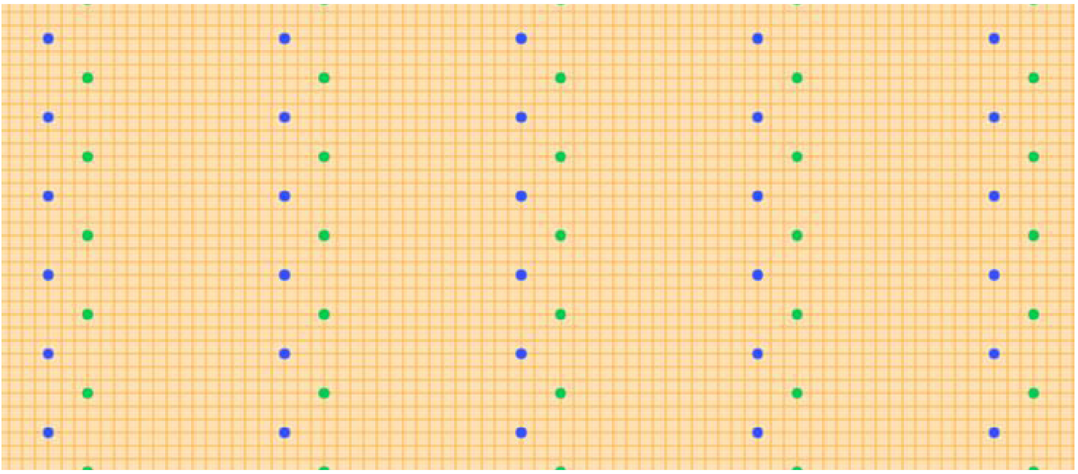


Figure 14..

Attention: ShadeMotion does not allow to plant two trees in the same position of the plot. In case of tree conflict, the first one planted would prevail. This rule applies in all the tree planting modalities, including systematic or random arrangements.

Random arrangements

In a random arrangement, the trees are planted in randomly chosen positions. To plant a random arrangement, in the "More options" menu, choose "Random Planting Pattern". The number of trees in the arrangement is defined by indicating the density of the plantation in trees per hectare of plot. ShadeMotion has a mechanism to avoid – as much as possible – that two or more trees are planted too close from one another.

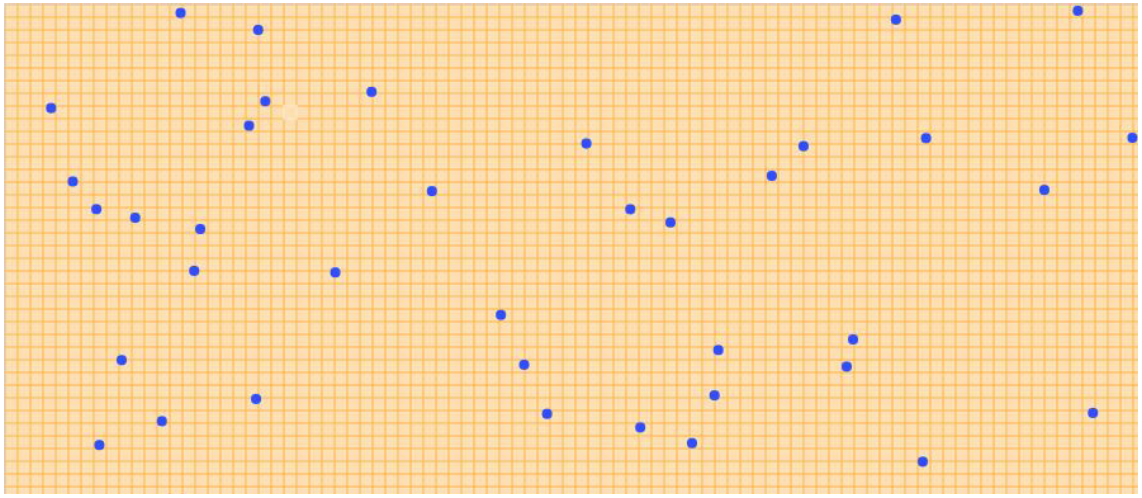


Figure 15. The figure shows a sector of a 100x100 plot with 100 trees planted at random.

iii. Preparation of an Excel file by collecting data in the field.

a. In Cartesian coordinates

ShadeMotion accepts Excel files with tree data if they have the appropriate structure. Users can go to the website www.shademotion.net to download the model file:

Árboles_SMv5.xlsx, which they can fill out with their own data for the simulation.

In order to record the position coordinates of a set of trees in the field, it is necessary to improvise a Cartesian coordinate system in the parcel. In order to do this:

1. Choose a point of the parcel as the origin of the coordinates, from which two strings will come out forming the X+ and Y+ axes. This will be the point to which the system will assign coordinates (0, 0) as the origin of the coordinate system. The strings will form a pair of perpendicular axes. It is important for the strings to enclose the first quadrant of the region where ALL the trees are located. To accomplish this, there should be no trees to the left of the string selected as the Y axis or under the string chosen as the X axis. Ideally, choose the origin in such a way that the center of the "cloud of trees" is located approximately at the center of the plot. If this is no possible due to practical reasons, ShadeMotion has the capacity of "centering" the trees in the shade map (see next section).
2. When installing the improvised coordinate system, it is very important to register, the direction towards which the Y+ semiaxis of such system is pointing. This angle should be measured clockwise from the north; clockwise corresponding to a positive angle. When uploading the file with the field data, the value for this angle should be entered in the box "Y axis orientation". If you decided to direct semiaxis Y+ to the north, it is not necessary to enter any value in such box, since the system will work with the default value 0. It is very important to keep in mind that once the tree file is loaded, the orientation of semiaxis Y+ should not be changed.
3. Use a measuring tape or a laser devise to measure the distances between two points and, thus, determine the coordinates for each tree.
4. Save the file in a folder under an appropriate name.
5. To upload the file in ShadeMotion, select the option "Open" in the "File" menu.

If the user uploads a simulation prepared in the field by a team he has not been part of, he/she must ensure that such team entered the direction of the Y+ semiaxis of the system used in the field to register the coordinates.

b. In GPS coordinates

To prepare an Excel files with the GPS coordinates of the trees, users should structure the file in the appropriate way. This task can be simplified by downloading the model file ÁrbolesGPS_SMv5.xlsx. This file has two pages; one for the GPS coordinates of the point chosen as the origin, and another page for the GPS coordinates of the trees.

To prepare the file, follow the steps below:

1. Renaming the model file with a name that describes your model is recommended.
2. Select a point of the plot as the origin of coordinates. Choose the point of origin so that all trees are located to the left of an imaginary line from the origin pointing north and above another imaginary line from the origin pointing east (these two lines will become the X+ and Y+ axes when the GPS coordinates are transformed to cartesian coordinates). The fact that the Y+ semiaxis points north cannot be changed when working with GPS coordinates.
3. Enter the GPS coordinates of the point of origin chosen in item 2. GPS coordinates are registered in the "Origin" tab of the model file (first delete the example coordinates that appear as a guide in the Origin page of the model file).
4. Open the tab "Trees" and register the GPS coordinates of the trees; one tree in each row of the page.
5. When you finish entering all the trees, upload the Excel file in ShadeMotion from the "File" menu, option "Import GPS Field Data". The trees should appear on the ShadeMotion plot and the program will have converted your GPS coordinates to Cartesian coordinates.

Centering a set of trees in the plot

When trees are imported through a Cartesian or GPS coordinate file, it is possible that the set of trees is completely decentralized; sometimes very close to the limit of the plot or even with trees outside the first quadrant. Centering the trees is very important because if they are too close to the coordinate axis, at certain hours of the day, their shade will probably be projected outside the plot. To center the trees, choose the option "Center trees" in the "More options" menu located in the extreme right of the "Mode and Tool" Bar.

Deleting trees, deleting shades or cleaning the plot

Removing trees, shades or both is usually a need that emerges frequently when constructing simulations. By opening the "More options" menu, the following options can be found in the upper right of the plot:

Delete shade, delete trees, delete shade and trees

It is also possible to delete trees individually or in sets, keeping the other trees on the plot. There are two ways of doing this:

1) Select the icons “Plant” and “Eraser”, both located in the Mode and Tool Bar:

and left click over the trees you want to remove.

2) Select the icons “Plant” and “Select” located in the Mode and Tool Bar

Using your mouse, enclose the region that includes the trees you want to remove. You will see that the trees are surrounded by a small circle when you enclose them in a selected area. You can delete them by clicking the “Del” key or by pressing the right click of the mouse and selecting “Remove”.

Definition of new species and filling out their tables

In addition to the species that are pre-installed in the system, the user can define his/her own species. If the user wants to define a new species, he/she should click the option “Species” in the Menu Bar. In the pop-up window, click “+” in the upper right corner, as shown in Figure 16:

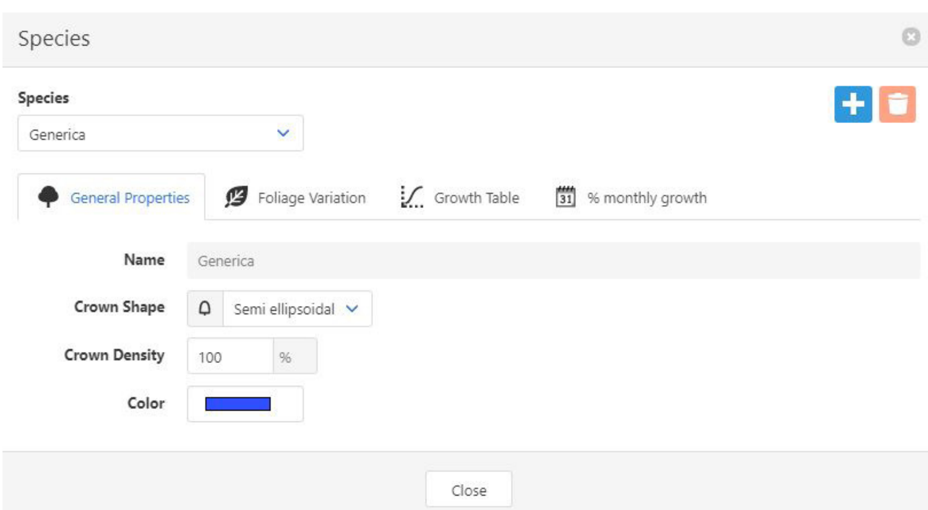


Figura 16

Enter the name of the species in the field “Name” and fill out the fields with the data from the species. The growth is described through annual increments. If the number of years of the simulation is greater than the number of years in the growth table, ShadeMotion will use the values of the last year of the table until it completes the number of years of the simulation. If you want a static simulation where the species does not grow, it is enough to fill out the row of the first year. New rows of the grow tale can be generated by clicking the “Duplicate” icon to the right of the row you want to duplicate or edit with new values.

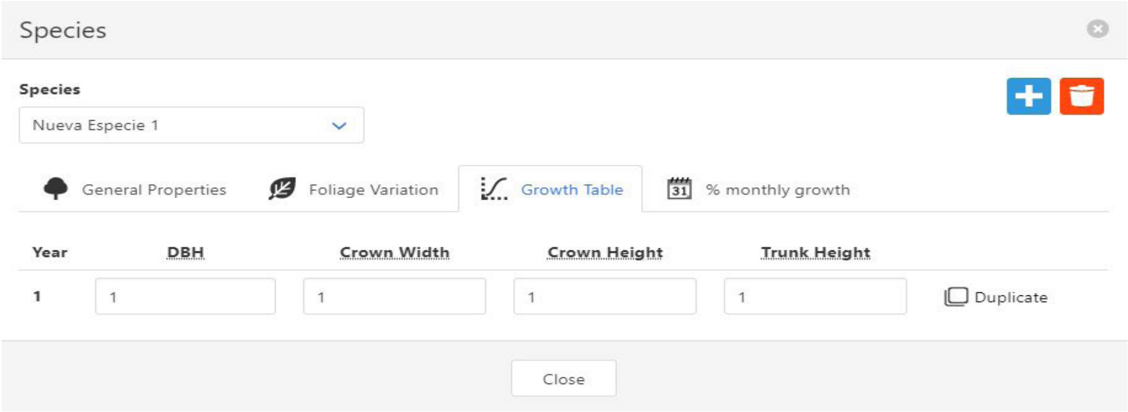


Figura 17.

If you want to eliminate the species, click over the garbage bin icon, to the right of the “+” symbol. When a simulation is saved (“Save as” option), the species defined by the user, their tables included, are saved as part of the initial data of the simulation.

Trimmable species

Trimming the crown of the trees (to let light pass, or to harvest biomass and use it as organic coverage for the soil or as forage for animals, etc.) is a common management practice. Trimming reduces the size of the crown, and the growth of the tree re-establishes it. In Shade Motion, any species can be defined as trimmable. The growth of the tree occurs in two time scales: 1) it changes its total size every year as it increases its age, and 2) the dimensions of its trimmed crown change every month. The growth table reflects the dimensions of the tree at each age and in times of lack of trimming. Trimming is represented, in ShadeMotion, as percentages of the crown dimensions in the growth table for a given year.

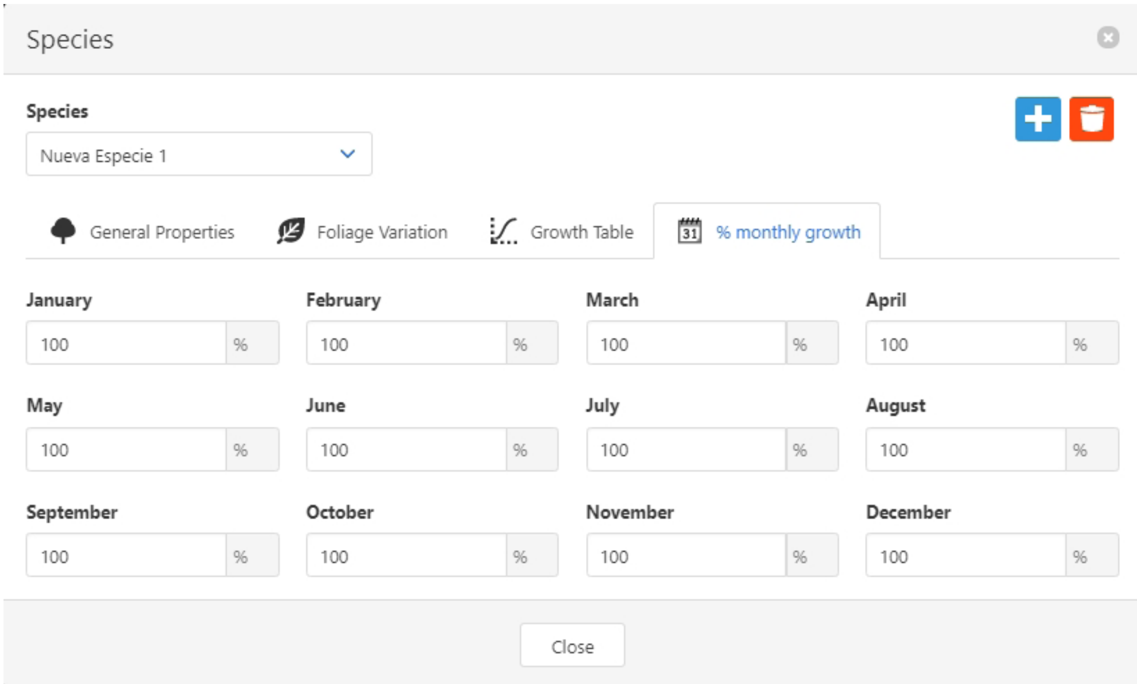


Figure 18. Table for the monthly percentage variation.

Overlaps, flags, sampling zone and tilted plots

3
Chapter

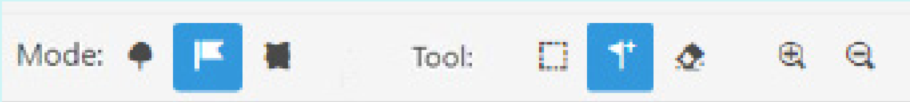
Shade overlaps

Two or more trees can project shade simultaneously (what is called overlapping) over a cell of the plot during some moments of the simulation. Upon the request of the user, ShadeMotion counts the number of shade-hours received by each cell of the plot including or not including the overlaps. For example, if in a moment of simulation, and with solar movement frequency of one hour, a cell receives shade simultaneously from 3 trees, ShadeMotion counts 1 hour of shade in the file WITHOUT overlaps and 3 hours in the file WITH overlaps. The definition of with or without overlaps is important in the interpretation of the percentage of shade reported for the cell and in the statistical values we will observe in the results (see next chapter of this tutorial). If the option WITHOUT overlaps is chosen, the percentage of shade will vary between 0 and 100% because the number of shade moments that can be counted in a cell is equal or lower than the total number of moments of the simulation. If the option WITH overlaps is chosen, the percentage of shade can be more than 100%. The number of shade moments with overlaps is a measure of the "amount" of shade received by each cell. Obviously, if several trees project shade simultaneously over a cell, the shade will be greater than if it was only one tree projecting it.

By default, the simulations run on the "without overlaps" mode. To change the mode, the <<Overlap>> button located in the second row of the Tool Bar should be activated or deactivated.

Crops that grow under the trees

ShadeMotion allows measuring the shade at the ground level or at different heights; for example, foliage height or at the height of the canopies of the crops under the trees. The software also allows placing flags in specific sites of the plot where we want to observe the shade.

1. **Crop height in a static simulation.** Click the "Crop height" box located in the "Land" zone and enter the height information for the crop. Take the following restriction into account: the height entered cannot be equal or greater than the value of the lowest height trunk of the shade trees.
2. **Crop growth in a dynamic simulation.** Enter the crop height data through time (steps).
3. **Flag placement**. To place a *flag*, click over the icon of the flag in the Mode and Tools Bar, right over the plot. The program will pace red dots in the cells that have been flagged.
4. 

When clicking on the flag, the axe icon is automatically selected, to the right of the flag (the flag and the axe are both in blue in the figure). The flag is placed by bringing the cursor to the cell you want to flag and clicking on it.

Deleting flags. To delete a flag, with the flag selected, select also the icon of the eraser, to the right of the axe, and click on the cell that has the flag you want to delete. You can also erase all the flags in a region by doing the following:

1) Enclose the region with the selection tool.
   a. Right click the mouse and choose the option "remove"
   b. Or press the "Del" key

Selecting a sampling zone in the parcel

Several reasons can motivate the ShadeMotion user to count the shade in only part of and not in the whole plot.

- 'For example, because due to the population of trees the shade is not distributed throughout the plot but only in part of it (see figure below). If the user does not specify the area of interest, ShadeMotion will compute the shade percentages and the descriptive statistics of the shade in the parcel considering ALL the cells of the plot, which will include many cells with number of shade moments in zero; and this will artificially lower the averages and other statistical indicators.

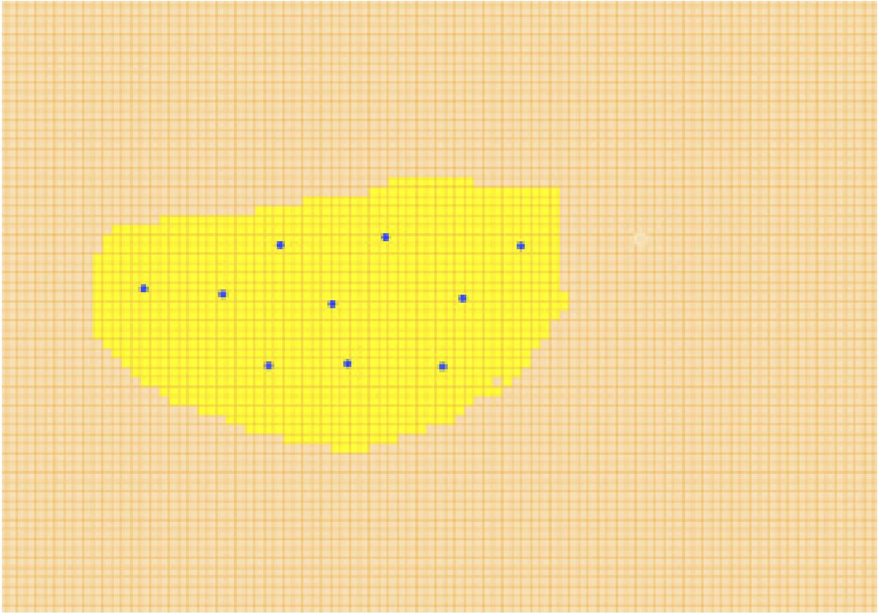
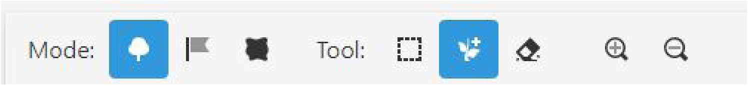


Figure 19. The figure shows 10 trees with an outlined mapping zone.

- Because, although the trees are homogeneously distributed in the plot, the cells that are close to the borders of the plot receive less shade than those located to the center of the plot. Again, if a central representative area to count the shade is not specified, ShadeMotion will compute the percentages of shade and other statistical results considering ALL the cells of the plot, and this will affect the accuracy of the averages. In this case, the user should run two simulations; the first one to visually determine the pattern of shade to identify and paint the sampling area, and the second one asking ShadeMotion to only count the shade in that sampling zone.
- Because the user wants to accelerate the time it takes to run a simulation with many trees, in very large plots and with long simulation cycles.

ShadeMotion allows the user to "paint" the part of the plot he is interested on to count the shade. No cell outside the painted area will be evaluated for shade counts. However, it is important to take into account that <u>the program will also count the shade projected inside the sampling area by those trees located outside such area.</u> Several sections of the plot can be painted, and the sections can be separated from each other.



A sampling zone is marked by moving the brush with the cursor through the plot. If you want a thicker brush, select another thickness in the field “Brush thickness” in the “Tree” zone to the left of the plot:

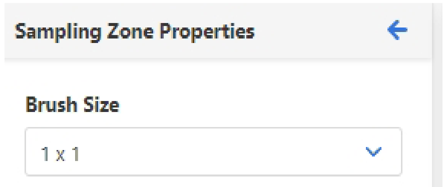


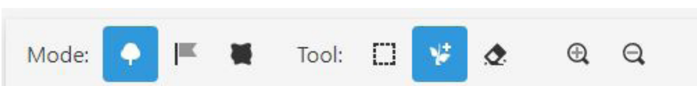
Figure 20.

A rectangular sampling zone can be painted by using the selection tool and the right button of the mouse instead of the brush. Take note that the window that allows to select the thickness of the brush (last figure) only pops up when the sampling zone icon is selected. It is possible to paint sampling zones that have different separated regions.

Deleting the sampling zone

There are two ways to delete the sampling zone painted in yellow.

1) Select the icons “Sampling zone” and “Eraser”, both located in the Mode and Tools Bar:



move the eraser with the mouse over the areas you want to delete. You can set the thickness of the eraser in the field “Bush thickness” mentioned above.

2) With the selection tool, enclose the sampling area or the section you want to delete, right click and choose the option “Delete sampling zone”. With this option, there is no need for the icon of the eraser to be selected.

2D and 3D views of the plot and the trees

2D View

The trees planted on the grid of the plot can be viewed in the following three ways:

1) Punctual mode: as a filled in dot showing the position of the tree in the plot.
2) Circumference mode: as a dot surrounded by a circumference with a diameter equal to the crown width.
3) Lateral view mode: a lateral outline of a tree showing the type of crown and the height of the trunk, in proportion with their measures.

The option by default is “Punctual”. In the three cases, the different species are painted with different colors. The 2D option for the trees is selected in the window of the “Configuration” menu, in the “Crown painting” field.

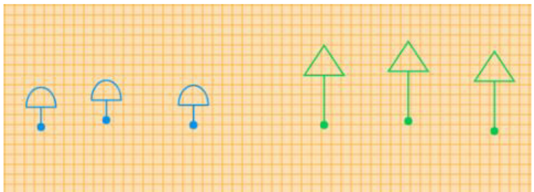


Figure 21. Trees of two species using “lateral view” painting mode.

3D View

It is possible to have a 3D view of the trees in the plot at any moment during the preparation, during and at the end of the simulation, by clicking the “3D View” option in the Menu Bar. By using the following elements:

1) The roller of the mouse
2) Using the mouse to drag
3) The arrows in the keyboard

it is possible to zoom in, zoom out, transfer or rotate the plot to get different views of the parcel with the trees.

Tilted plots

When setting up a simulation in a tilted plot, it essential to provide the program with two angles describing the degree of inclination and the orientation de slope is facing:

- Angle σ of maximum inclination, also called gradient angle.
- Angle δ that measures the azimuth of the slope (the direction towards which the maximum slope “points”). This angle is measured from the north, clockwise and in descending direction of the plot. For example, if the slope, in descending direction, is “pointing” east, the angle δ would measure 90°.

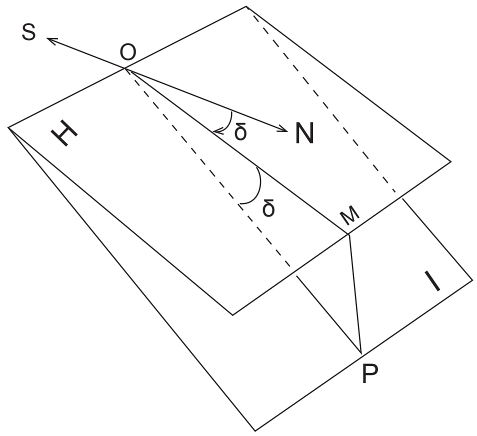
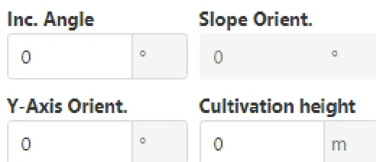


Figure 22. The figure shows a horizontal plane H, a tilted plane **I** and the angles σ = <MOP and δ = <NOM that respectively determine the slope of the plot and the direction the slope is facing. Both angles are entered in the Plot zone, located to the right of the plot grid.



Orientation of Y+ axis in tilted plots

In tilted plots, it is not possible to change the direction of the Y+ axis, which coincides with the maximum inclination lines in descending direction. This direction is automatically assigned by the program. The following precautions must be observed:

1. Positive semiaxis Y+ should point in the direction of the maximum inclination and in descending mode.
2. The origin of the coordinates should be placed in a point of the plot so that the trees are located inside the first quadrant.

Once the improvised coordinate system is placed in the field, the angle formed by the positive semiaxis Y+ (or, what is equivalent, a maximum inclination line in descending direction) with the geographical north should be measured. The angle is measured with positive sign clockwise, and the information is entered in the “Slope direction” box in the “Plot” zone.

Filters

Let us suppose that once a simulation is run, you want to see the shade map that corresponds to the trees located inside a height range, or the map that corresponds only to some species of the tree population, or perhaps determine the zones of the plot where shade is found within a certain range of shade hours. This is the type of results filters allow us to get. There are three types of filters that can be applied:

1. By number of shade hours
2. By species
3. By tree height

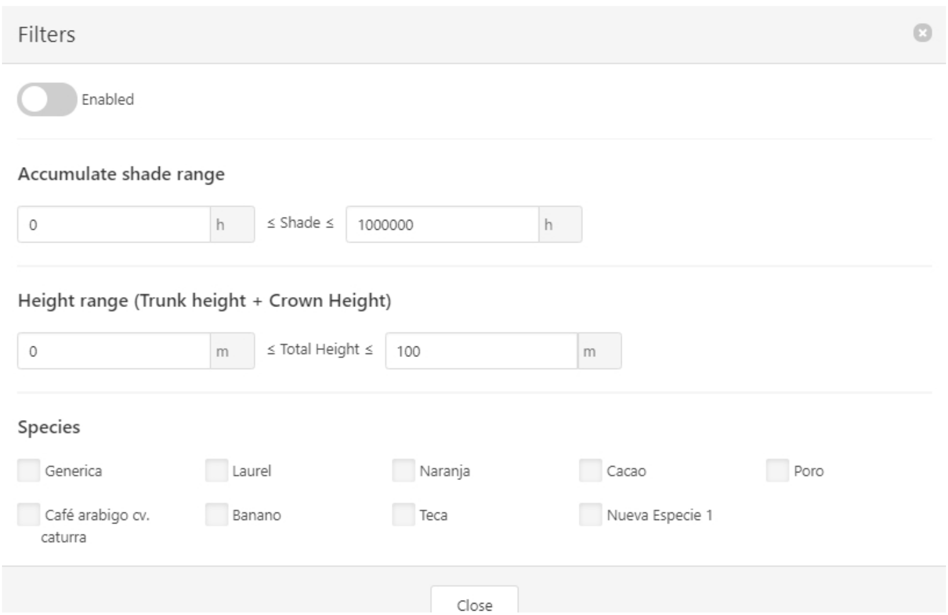


Figure 23. Type 2 and type 3 filters require to rerun the simulation after the filter is applied; this is not the case for Type 1 filters.

Steps and intervals

A ShadeMotion simulation is a sequence of moments where you count whether or not there is shade (with or without overlaps) in each cell of the plot or in the sampling zone marked by the user. The user can observe the number of total shade hours in two types of time periods; a long one (STEP) that contains one or more periods of equal or lower duration than the step called *intervals*. For example, we can run a dynamic simulation of 30 years with results of shade observed in 30 annual steps, and each of the steps is broken down into 12 monthly intervals. We are interested in seen the changes in the shade results in monthly intervals because the leaf fall pattern of the trees is monthly, and because there are trimmable species that change the crown dimensions every month due to monthly trimming.

The user chooses between the options to define the duration of the *steps* and the *intervals* in the “Configuration” menu in the fields indicated below:

Figure 24

The values to choose from are: annually, every six months, monthly, weekly and daily.

Two ways of running a dynamic simulation

In dynamic simulations, the users can choose to stop the simulation at the end of each *step* to analyze the shade and decide whether it is convenient to plant or eliminate some trees in the plot before starting the next *step*. For this reason, it is possible to run a dynamic simulation *step by step*, or all at once (if we do not want to inspect the shade, plant or eliminate trees throughout the simulation cycle).

A dynamic simulation can be run in two possible ways:

1) From start to end without the simulation stopping in any *step* by pressing the button “Run”.
2) Making the simulation stop in each step, for which you will have to resume the process pressing the button “Next step” every time the program stops in order to advance to the next step. If, in a given step, the user does not want the program to stop any more and rather run the program all the way to the end, the user should press the icon to the right of “Next Step” shown in the figure below:

The “Configuration” menu

Some of the options that determine the initial configuration of a simulation are found in the “Configuration” menu, which is shown in the figure below. Some of these options have been mentioned above and some do not require any explanation.

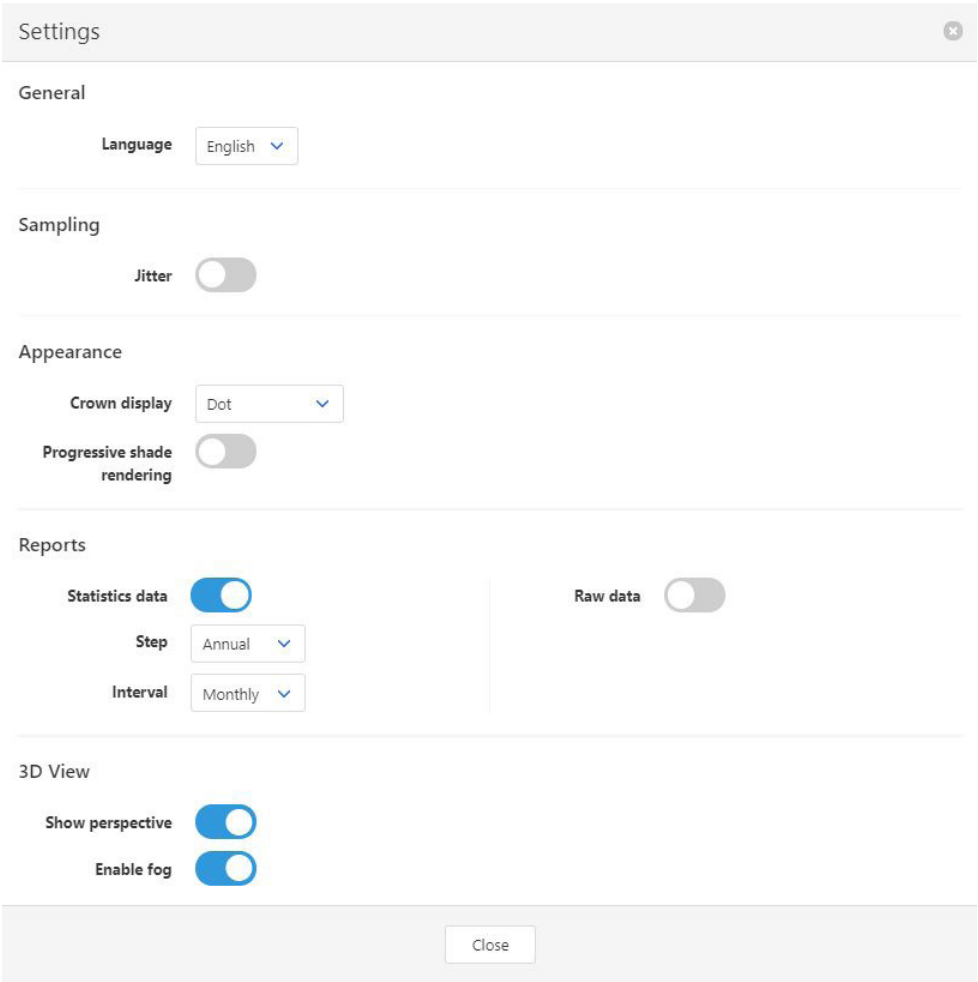


Figure 25. Chart of the "Configuration" menu

Among the options shown in the window that have not yet been discussed we have:

<u>Jitter</u>. When this option is selected, the calculation of the shade does not take place in all the moments at the exact time, but in some moments the time is either advanced or delayed a little. The idea of this is to avoid the presence of zones without shade produced by the leap in shade position between one hour and the next, an effect that is more notorious in simulations with few trees and for short periods.

<u>Progressive shading</u>. This button activates the "progressive shading", which allows observing how the shade map changes during the simulation. When progressive shading is deactivated – default state – the final shade map appears at the end of the simulation.

The central part of the window contains the reports, which detailed discussion will be left for the next chapter.

Examples of simulations

4
Chapter

After introducing the basic elements needed to construct a simulation, we will show some examples with some of the situations we can face, together with the elements to pay attention to in order to construct the corresponding simulation.

Example #1: an instantaneous simulation

Objective: To evaluate the shade projected by 10 trees of *Citrus sinensis* (orange), 5 years old, planted with the mouse in a 1 ha horizontal plot, at 10 degrees latitude north, at 10 am on October 25th.

Actions to be taken:

1) Select instantaneous simulation.
2) Choose the species *Citrus sinensis* (orange) and assign the corresponding dimensions for the age of 5 years in the "Tree" zone (in instantaneous and static simulations, the growth tables are not taken into account).
3) Select the date and time of the simulation to observe.
4) Review the values of the parameters in the zones of the interface.
5) If you want to change the orientation of semiaxis Y+, this should be done before planting the trees.
6) Plant the trees manually.
7) Choose between the options of with or without overlaps.
8) Check if all the values of the "Plot" zone are correct.
9) Run the simulation.
10) Check the results: 1) inspect the tree plantation map.

Example #2: a static simulation

Objective: To evaluate the shade projected by 70 trimmed “terminalia” (Terminalia ivorensis) trees and 140 trimmed “poró” (Erythrina poeppiggiana) trees. The trees are planted in a systematic way, with square arrangement of 12 m x 12 m both species. We need to analyze the shade at the height of the coffee plants, which in the year of the study have 2-0 m height. The simulation will last one year, from January 1st, 2020 to December 31st, 2020, with a daily solar range of 9 simulation moments, every hour between 8 am and 4 pm each day, in the Earth equator, at cero degrees latitude. The plot is horizontal.

Actions to be taken:

1) Verify that the active type of simulation is static simulation.
2) In the Tree zone, define the species Terminalia ivorensis and *assign values for the crown and the trunk, crown density and fill out the “Foliage variation” table.*
3) Review the values of the parameters in the “Tree” zone and the “Plot” zone.
4) If you want to change the direction of semiaxis Y+, this should be done before planting the trees.
5) Define the corresponding systematic arrangement, introduce the coordinates of the first Terminalia tree and the first “Poró” tree.
6) The steps and intervals are left with their default values: annual and monthly, respectively.
7) Enter the height of the crop.
8) Decide whether to run the simulation with or without overlaps.
9) Run the simulation.
10) Review the results: 1) inspect the tree plantation map, 2) analyze the statistical results by steps and intervals, 3) analyze the development of the trees throughout the steps and intervals, and 4) save the result files if you want.

Example #3: a dynamic simulation

Objective: To study the space-time distribution of the shade in a coffee plantation with shade from *Cordia alliodora* (laurel) – a timber species – and Erythrina poeppiggiana ("poró") a species that is trimmed every 6 months and which function is to provide shade for the coffee. The simulation will be run for a 30 year period in a 1 ha parcel located at 10° latitude north.

Actions to be taken.

1) Select the option for dynamic simulation.
2) Leave the default option "without overlaps".
3) Set the start and end dates, and the daily solar range.
4) It is not necessary to define the species because they are already pre-defined and they have their own tables.
5) Select the annual steps and the monthly intervals.
6) Enter the dates and times, and check that the values in the Tree zone and the Plot zone are correct.
7) If you want to change the orientation of semiaxis Y+, this should be done before planting the trees.
8) Plant a systematic arrangement of laurel trees with a separation between rows and columns of 12 meters, and a systematic arrangement of "poró" trees with a separation between rows and columns of 6 meters (which requires thinking about how to accommodate both species to avoid some "poró" trees from mounting over the laurel trees, and still have an acceptable space between both species).
9) Decide whether or not to run the simulation step by step.
10) Decide whether or not to request the generation of a raw file.
11) Run the simulation
12) Check the results: 1) inspect the tree plantation map, 2) analyze the statistical results by steps and intervals, 3) analyze the development of the trees throughout the steps and intervals, and 4) save the result files if you want.

Results

5
Chapter

All simulations generate maps, statistical results and raw data.

- There are two types of maps: 1) showing the location of each tree on the plot, and 2) showing a 3D view of the trees on the plot. At the end of a simulation, the shade map of the last moment of the simulation is shown, but the statistical results show maps by steps and intervals.
- The statistical results about the amount of shade-hours in all or part of the plot, by steps and intervals, include:
  - Descriptive single variable statistics: minimum, maximum, average, mode, median, asymmetry and kurtosis
  - Relative frequency histogram and cumulative frequency distribution of the shade-hours in the plot.
- There are two types of files: statistical results files and raw data files
  - Statistical results are compiled in a file that can have html, Excel and Json format.
- If the user requests so before running the simulation (in the Report menu) it is also possible to obtain text files without format, called “raw files”, which contain the state of the shade in each cell for each moment of the simulation.

The statistical results file contains the following tables:

1. “General Data” table.
2. “Shade by Step” table.
3. “Shade by Interval” table.
4. “Species” table.
5. “Monthly growth table”.
6. “Monthly leaf fall development” table

Regarding the crop:

7. “Crop growth” table.
8. “Crop height development” table.

Table “General data”.

This table contains general information on the initial configuration of the simulation.

General Data

Summary		Global Properties	
Start Date:	2020-01-01	Version:	5.1.42
End Date:	2024-12-31	Latitude:	10
Start Hour:	08:00	Terrain Inclination:	0°
End Hour:	16:00	Slope Orientation:	0°
Solar movement frecuency:	Every hour	Terrain dimension:	100 m × 100 m
Step:	Annual	Sampling Region:	10000 m²
Interval:	Monthly		

Figure 26. Table with General Data

Table “Shade by Steps”

This table shows the main statistical information associated to each step: medium, standard deviation, minimum, maximum, mean, asymmetry and kurtosis. In the extreme right of each step’s line, there are two words in blue-purple (explanation below).

The next figure contains information about the shade in each step.

Shade by Steps

Step	Mean	StdDev	Min	Max	Median	Mode	Skewness	Kurtosis	Cumulative Frequencies
1	7.77	43.42	0	842	0	0	10.03	132.03	Chart SVG
2	25.68	117.63	0	1318	0	0	6.74	53.66	Chart SVG
3	41.50	142.88	0	1006	0	0	3.98	15.85	Chart SVG
4	60.53	179.88	0	1033	0	0	3.38	10.85	Chart SVG
5	64.26	166.38	0	983	0	0	3.10	9.40	Chart SVG

Figure 27. Table with information by Steps

By clicking on the Word “Graph”, the window will show two graphs: a frequency histogram related to the shade hours versus the number of cells, and a cumulative frequency distribution graph with those two variables for each step, as shown in the figure below:

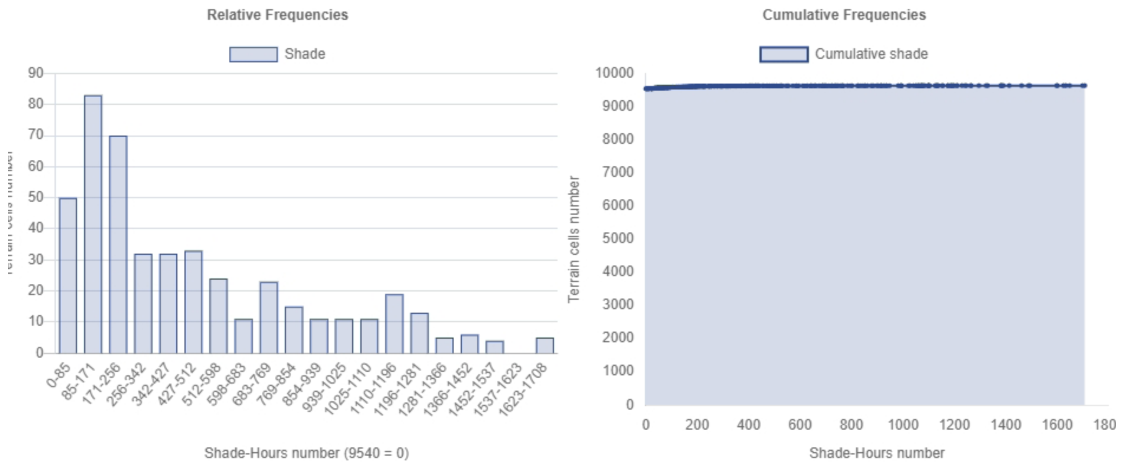


Figure 28. The figure shows the Graphic for step No. 5

The term "SVG" opens a shade map in three layers, showing: the shade without the trees, the trees without the shade and the trees with shade, as sown below:

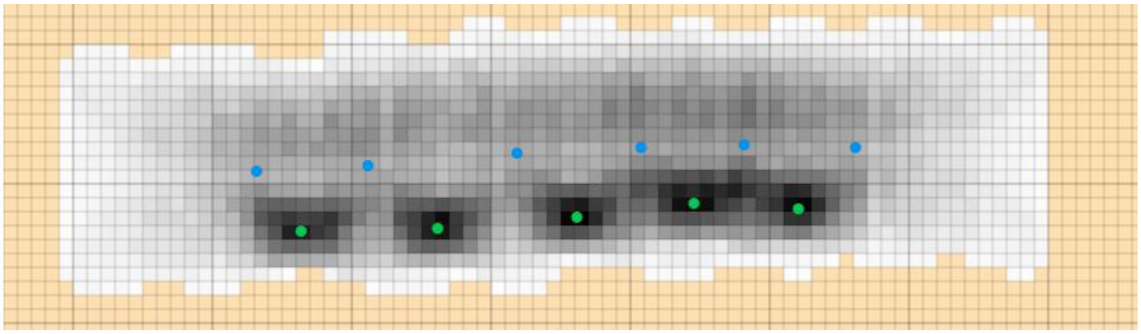


Figure 29. The figure shows a view of the plot with the trees at the end of step No. 5

The plot maps with shade and trees for each step, although they do not show the value of the shade in each cell, they do constitute a visual guide to decide when to eliminate or plant trees in some parts of the plot.

Table of “Shade by Intervals”

This table shows, for each Interval, the same statistical descriptions of the previous chart. Since each step can have several intervals, the size of this table can be considerably bigger than the one for the steps. In the example, we have 5x12 = 60 intervals. The figure shows the 12 intervals (monthly) of the first step and the first three intervals of the second step.

Shade by Intervals

Step	Interval	Mean	StdDev	Min	Max	Median	Mode	Skewness	Kurtosis	Cumulative Frequencies
1	1	0.67	5.79	0	112	0	0	10.76	132.41	Chart SVG
1	2	0.53	4.87	0	96	0	0	11.29	146.07	Chart SVG
1	3	0.36	3.65	0	100	0	0	13.16	208.70	Chart SVG
1	4	0.20	2.72	0	81	0	0	20.72	489.65	Chart SVG
1	5	0.35	3.72	0	98	0	0	14.08	237.39	Chart SVG
1	6	0.53	5.43	0	127	0	0	12.38	177.21	Chart SVG
1	7	0.55	5.69	0	141	0	0	13.04	199.81	Chart SVG
1	8	0.54	5.56	0	132	0	0	12.92	192.44	Chart SVG
1	9	0.55	5.53	0	104	0	0	11.94	156.67	Chart SVG
1	10	0.60	5.59	0	133	0	0	11.73	162.79	Chart SVG
1	11	0.65	5.72	0	115	0	0	10.84	133.78	Chart SVG
1	12	0.68	5.92	0	127	0	0	11.02	142.94	Chart SVG
2	1	2.04	13.21	0	172	0	0	7.58	62.24	Chart SVG
2	2	1.61	10.92	0	158	0	0	7.95	68.97	Chart SVG
2	3	1.26	9.25	0	162	0	0	9.61	109.19	Chart SVG

Figure 30. The figure shows that each interval has a graphic and a SVG figure of the plot with the trees.

Table for "Species"

This table contains information about the crown and the trunk of each shade species. Each interval shows the information of each species plus a figure that corresponds to the total of all the species. For example, since we have two species, the table will have 3 entries per interval and a total of 12x5x3 = 180 entries.

Species

Step	Interval	Species	Coverage %	Trees/ha	Basal Area (m²/ha)	DBH (cm)	Trunk Height (m)	Crown Height (m)	Crown Width (m)
1	1	Total	0.10	13	0.06	6.77	1.92	1.08	1.08
1	1	Laurel	0.10	7	0.01	4.00	1.00	2.00	2.00
1	1	Poro	0.00	6	0.05	10.00	3.00	0.00	0.00
1	2	Total	0.08	13	0.06	6.77	1.92	1.54	1.54
1	2	Laurel	0.05	7	0.01	4.00	1.00	2.00	2.00
1	2	Poro	0.02	6	0.05	10.00	3.00	1.00	1.00
1	3	Total	0.12	13	0.06	6.77	1.92	2.00	2.00
1	3	Laurel	0.02	7	0.01	4.00	1.00	2.00	2.00
1	3	Poro	0.09	6	0.05	10.00	3.00	2.00	2.00

Figure 31. The figure shows the first 3 intervals of the detailed species table

Growth charts

The last four charts provide information about growth: the first two concern the growth of the species and the last two concern the growth of the crop.

Monthly growth variation

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Laurel	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Poro	0%	50%	100%	100%	100%	100%	0%	50%	100%	100%	100%	100%

Foliage Variation

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Laurel	100%	90%	50%	20%	50%	100%	100%	100%	100%	100%	100%	100%
Poro	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Cultivation

Growth Table

Edad	Cultivation Height
1	0

Cultivation monthly variation

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

The numerical information contained in the statistical data file can be saved in an Excel file, if requested in the "Reports" menu, although without the graphics. This can be useful to export to other applications.

In the case of a static simulation, the statistical data file contains the same tables as the dynamic simulation but, since the species do not grow, this type of simulations are usually run for short periods of time and the tables are smaller.

Structure and contents of the raw files

There are three types of "raw files". These files should be requested by the user before running the simulation in the corresponding field of the "Configuration" window. These are text files without format, big files, which contain information about the amount of cumulative shade in each cell of the plot at each moment of the simulation. There are three types of raw files:

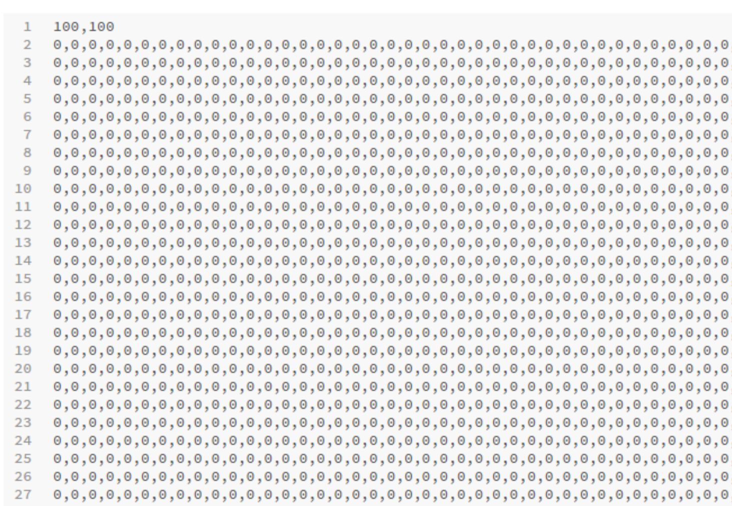
a. Cumulative shade without overlaps

b. Non-cumulative shade with overlaps

c. Cumulative shade with overlaps

The term "cumulative" refers to the fact that the total amount stored in previous moments is added to the amount of shade that corresponds to a given moment. The "non-cumulative shade without overlaps" files can be generated by the users, if needed, through a very simple process that consists on replacing, in all cells of type a. files the shade values greater than 1 for the value 1. This can be done with a statistical analysis tool like R, SAS or Python, just to mention some options.

The three raw files have the same structure by blocks. Each block is a representation of the plot and has rows and columns of numbers that we call "positions", separated by comas. The number of positions coincides with the number of cells of the complete plot, even when a sampling zone has been defined.



```
100,100
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
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0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
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```

Figure 32. Fragment of the first block, which begins with the dimensions of the plot.

The block shown in the figure moves towards the right and downwards until it completes – out of the first row mentioned – a total of 100 rows and 100 columns.

There is a block for each moment of the simulation. The blocks are separated by a white line and begin with the date and time of the moment. If the user has painted a sampling zone, the first block will have 1's in the positions that correspond to such zone. If no sampling zone has been marked, the program assumes that the sampling zone is equal to the whole plot (the 10.000 cells if the plot is 100 x 100) and, in this case, all the first block will have only zeroes.

The following blocks, the shade blocks, contain the moments of the simulation: one block for each moment. Using the case of the file "cumulative without overlaps", in the block that corresponds to a given moment, we would only see umbers different from zero in the positions of the cells that have received shade. The number in that position should be equal to the amount of shade without overlaps that the cell has received, including that moment (in the case of "cumulative"). This format allows to reduce the amount of memory required to store these big files. The following example, in miniature, will finish clarifying the structure of the raw files.

Example, in miniature, of a raw file

Let us suppose that we make a very small simulation, in a 10x10 plot (with 100 cells) and painting a sample area of 3 cells. These will be the only cells where the program will examine if there is shade or not. We run a very short static simulation: from January 1st, 2020 from 10 am to 12 at noon (this is equivalent to 3 moments of 1 hour each). The moments are defined by the hours 10, 11 and 12. The plot only has two trees very close from one another, in order to produce the overlap of the shades at some moment. Under these conditions of the raw file, which is of the "non-cumulative overlaps", the format will look as the one below, where we highlighted the cells in the sampling zone in bold:

10,10	2020-01-01T10:00:00	2020-01-01T11:00:00	2020-01-01T12:00:00
0,0,0,0,0,0,0,0,0,0	0,0,0,0,0,0,0,0,0,0	0,0,0,0,0,0,0,0,0,0	0,0,0,0,0,0,0,0,0,0
0,0,0,0,0,0,0,0,0,0	0,0,0,0,0,0,0,0,0,0	0,0,0,0,0,0,0,0,0,0	0,0,0,0,0,0,0,0,0,0
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0,0,0,0,0,0,0,0,0,0	0,0,0,0,0,0,0,0,0,0	0,0,0,0,0,0,0,0,0,0	0,0,0,0,0,0,0,0,0,0
0,0,0,**1,1,1**,0,0,0,0	0,0,0,**0,1,2**,0,0,0,0	0,0,0,**0,0,1**,0,0,0,0	0,0,0,**0,0,0**,0,0,0,0
0,0,0,0,0,0,0,0,0,0	0,0,0,0,0,0,0,0,0,0	0,0,0,0,0,0,0,0,0,0	0,0,0,0,0,0,0,0,0,0
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0,0,0,0,0,0,0,0,0,0	0,0,0,0,0,0,0,0,0,0	0,0,0,0,0,0,0,0,0,0	0,0,0,0,0,0,0,0,0,0

Figure 33. Blocks of the raw file "Non-cumulative overlaps"

We can see that the file has 4 blocks: the first bock describes the shape of the plot and the location of the sampling zone, and the remaining blocks describe the shade in the three moments of the simulation. In the first block, the first row indicates the dimensions of the plot, the remaining blocks of the first row indicate the date and time of the moment to which the block corresponds. The sampling area is marked in the first block and it is made up by the positions marked with 1's. If the user does not mark a sampling zone, then the first block will only have 0's, but the sampling zone will be considered as the whole plot. In this example we can see that the sampling zone only has 3 cells. From the second block on, we have the "shade blocks". There will be a shade block for each moment of the simulation, which, in this miniature example, has three moments. The first row of each shade block indicates the date and time of the moment. The first shade block (second block of the file), which corresponds to hour 10, shows that there was shade in two of the three cells of the sampling zone. The presence of a 2 in one of the cells shows that there has been overlap of the shade projected by two trees. The next block, which corresponds to 11 am, shows a reduction in the shade with respect to the previous hour.

Note about the aspect of the raw files. The raw files are text files without format and, depending on the text processor used to open them and on the configuration of the computer (or the operative system), sometimes are not shown in blocks but as a long row. This can be corrected by changing the configuration of the text processor or by changing the processor. Text processors aimed to programming, like Brackets, usually show the file in blocks and even add a column to the left of each block to number the rows. Such column can be used as reference for the programmers and is not considered part of the file..

Acknowledgements

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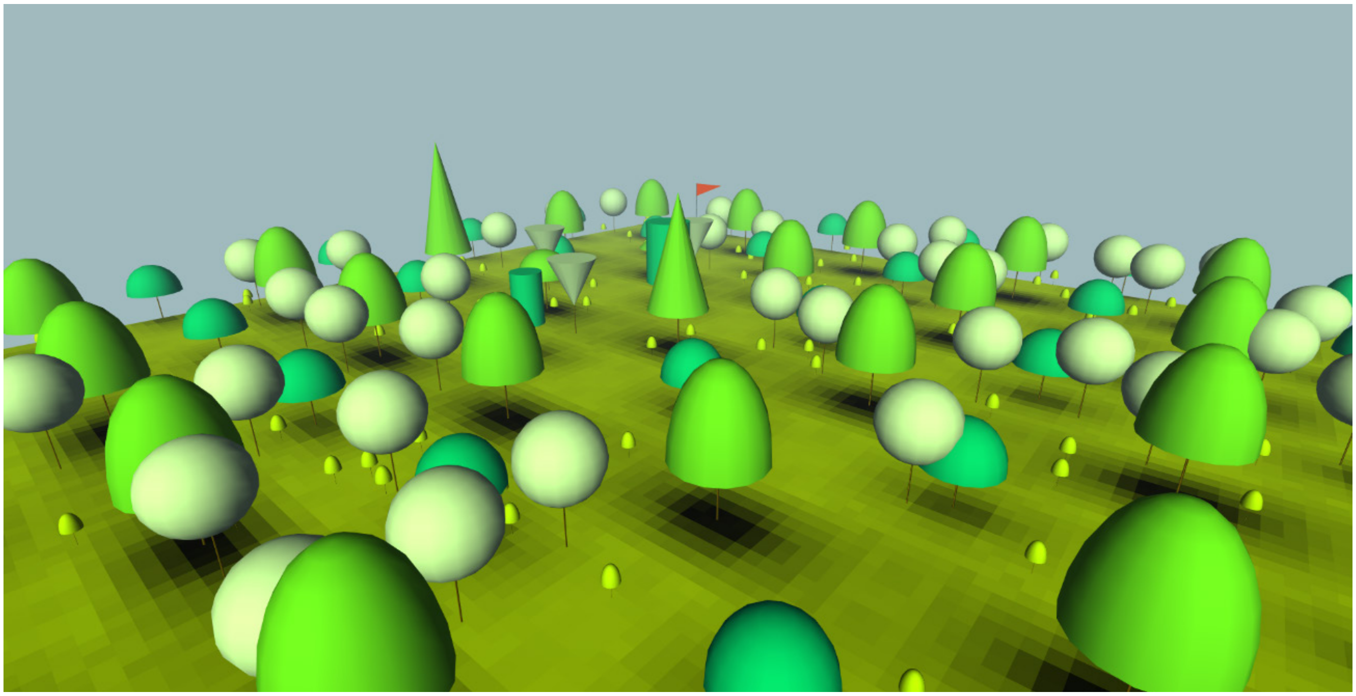

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Solutions for environment and development
Soluciones para el ambiente y desarrollo

Headquarters, CATIE
Cartago, Turrialba, 30501
Costa Rica
Tel. + (506) 2558-2000

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