Shademotion 4.0
Modeling the shading patterns of trees

Eduardo Somarriba, Randall Zamora, Jose Barrantes, Mathias Mallek, Eduardo Vargas, Francisco Quesada

CATIE, Turrialba, Costa Rica

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A central question:

How many hours (or any other time interval) of shade are cast over every coordinate point in a plot with trees?

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Background

- Very detailed radiation transmission models have been developed by other researchers
- We wanted to develop a simple, visual, exploratory model that could be used to quickly explore different planting patterns of trees on a plot and their effects on shading pattern
- User can then adjust the planting pattern of trees (e.g. thinning or planting) to achieve a specific shade pattern and shading level

Key Features

- Any number of tree species, any number of trees, large plot sizes can be modelled, trees may be planted in any spatial and temporal pattern, any Latitude, in plane terrains (horizontal and tilted)
- Tree populations change (recruitment, removal due to mortaliy or harvest), trees grow (height, crown), tree crowns can be pruned (growth, cut back, regrowth)
- -A rich palette of tree crown shapes
  - Sphere, hemi-sphere, conic, inverted conic, elipsoid, hemi-elipsoid, cillindric, umbrela, etc.
- Crown density
  - Opaque to fully open (0-1)
- Monthly leaf fall pattern

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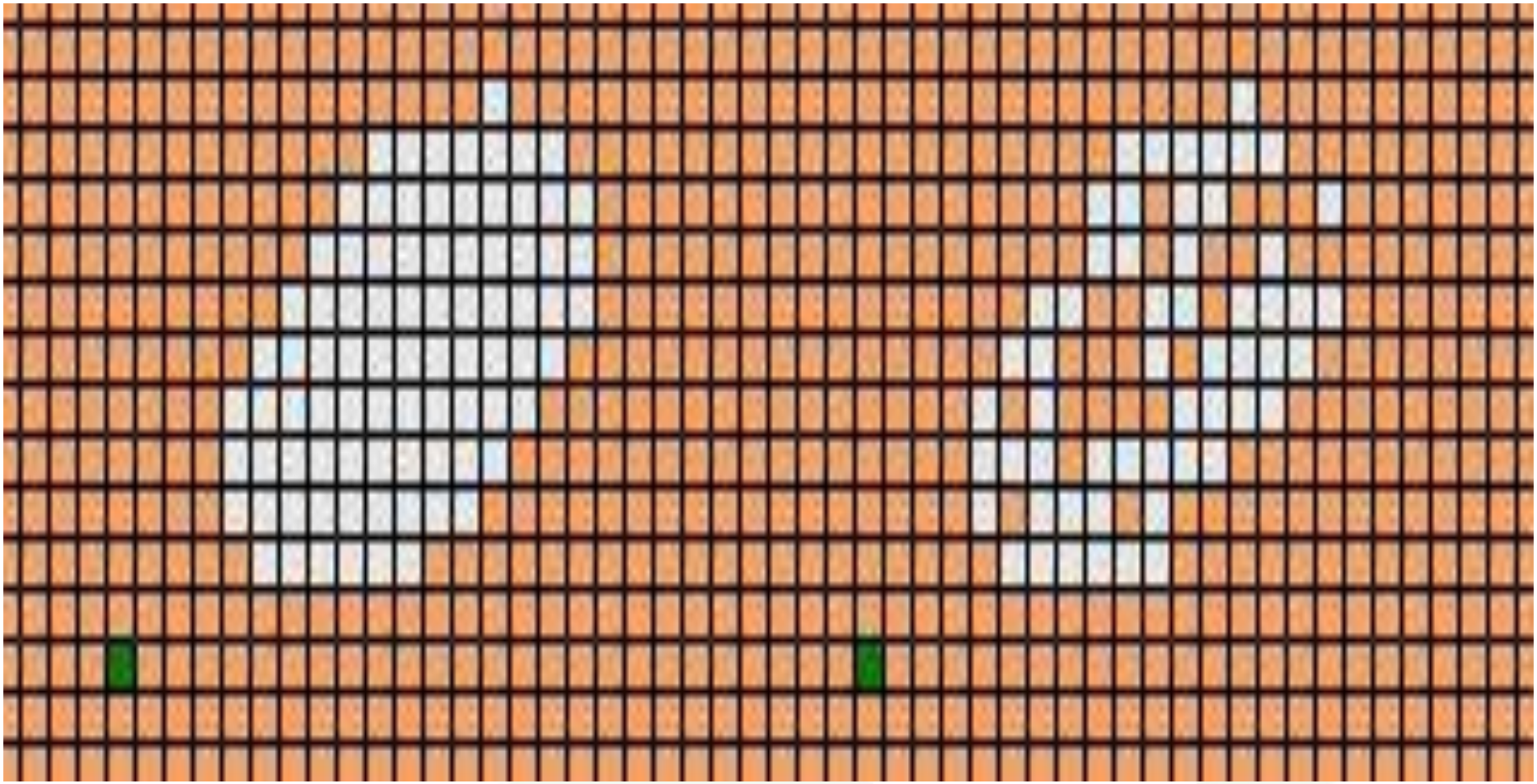


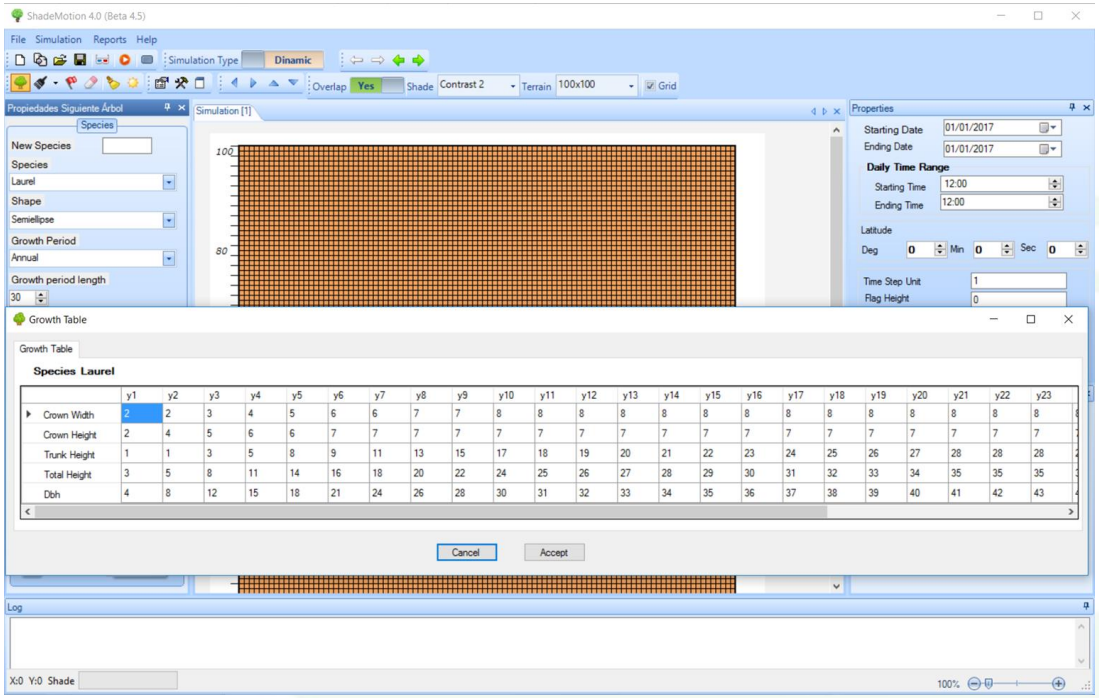
Crown density: 100% and 60%, respectively

Monthly leaf fall pattern

Growth table

- It allows the program to change the crown and trunk dimensions over time, it improve the simulation accuracy. It´s done based on the a growth table values.

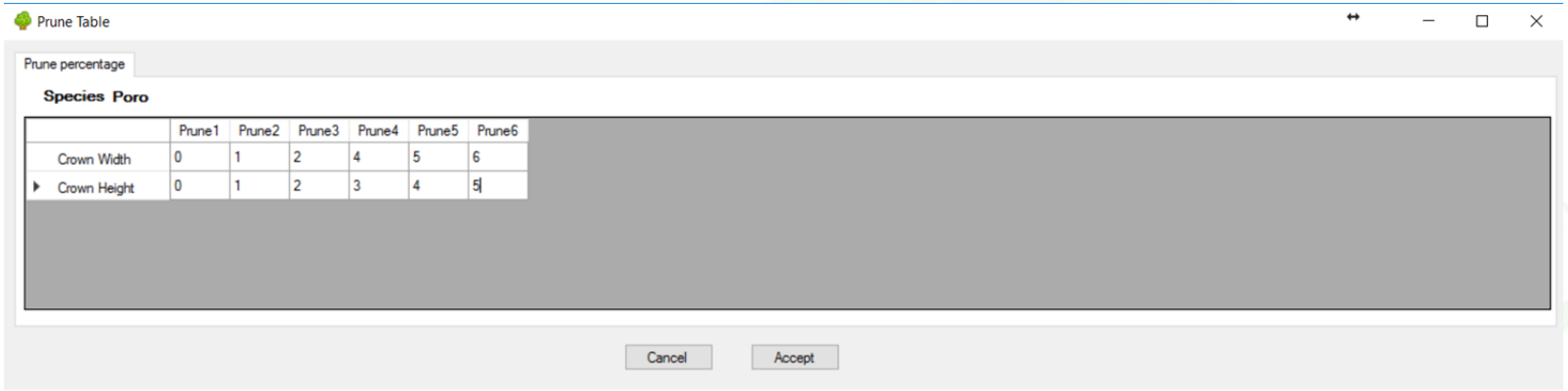
- The growth table represents the species growth values.



ShadeMotion4
Growth Table

Prune simulation

- This new feature allows to includes tree prunes into the simulation.
- Similar than growth table a prune table is used to know the crown and trunk dimension after a prune.



Prune Table

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Key Features

- Various options for data entry and storing outputs
  - Mouse/screen
  - GPS, cartesian coordinates
  - Excell, others
- 3-D visualization of trees in plot
- Shading recorded
  - With or without shade overlap
- Shade evaluated at variable heights
  - ground level or above crop canopy

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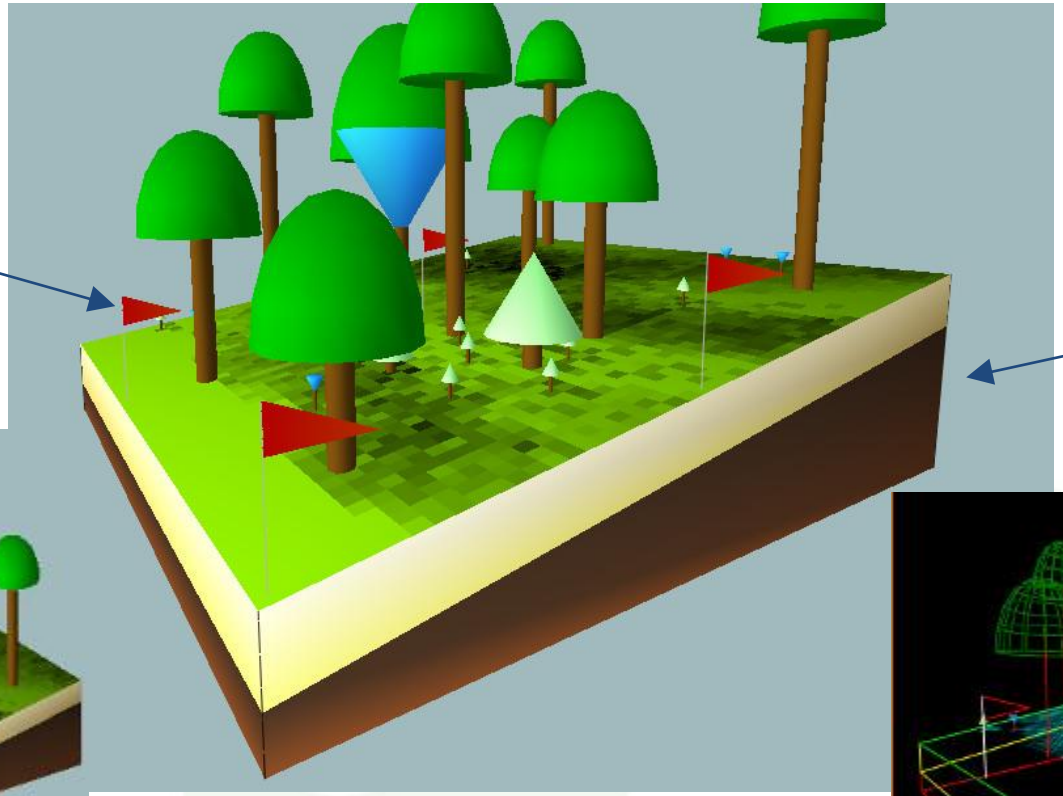
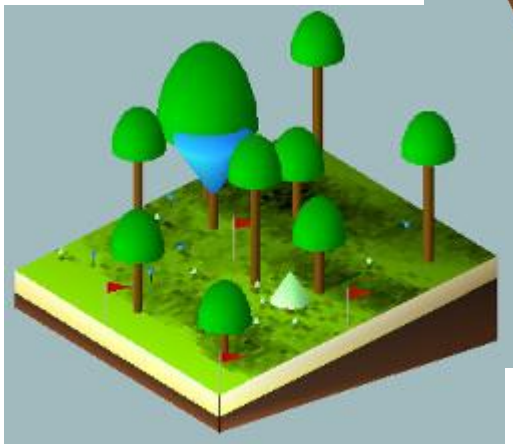
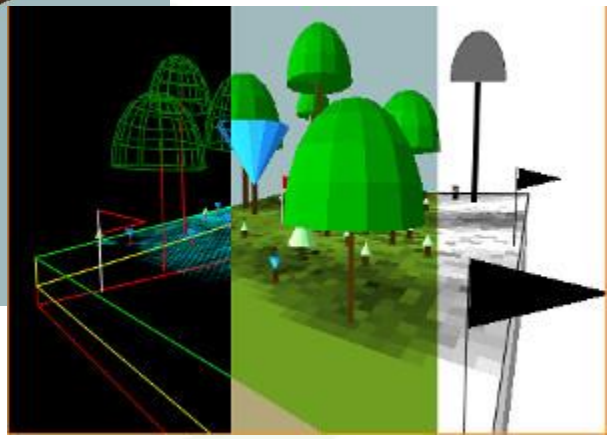




Orthographic Projection



Different display modes

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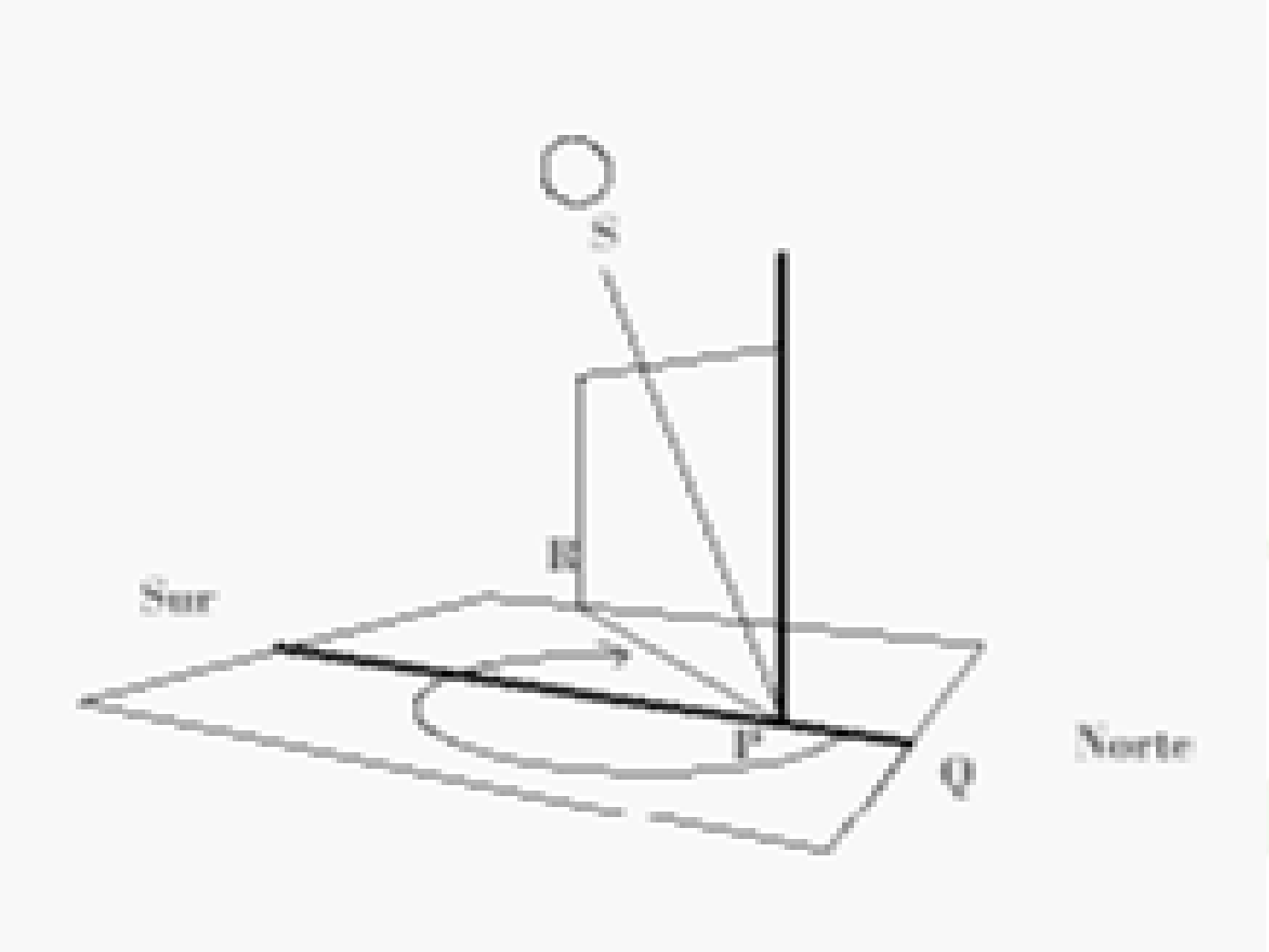
How Shademotion 4 Works!!!!

The position of the Sun is defined in terms of two angles, which in turn depend on Latitude, day of year, time of day



Elevation: angle SPR; Azimuth: angle QPR (in this figure this angle is greater than 180º)

The Sun's position is computed according to the following equations

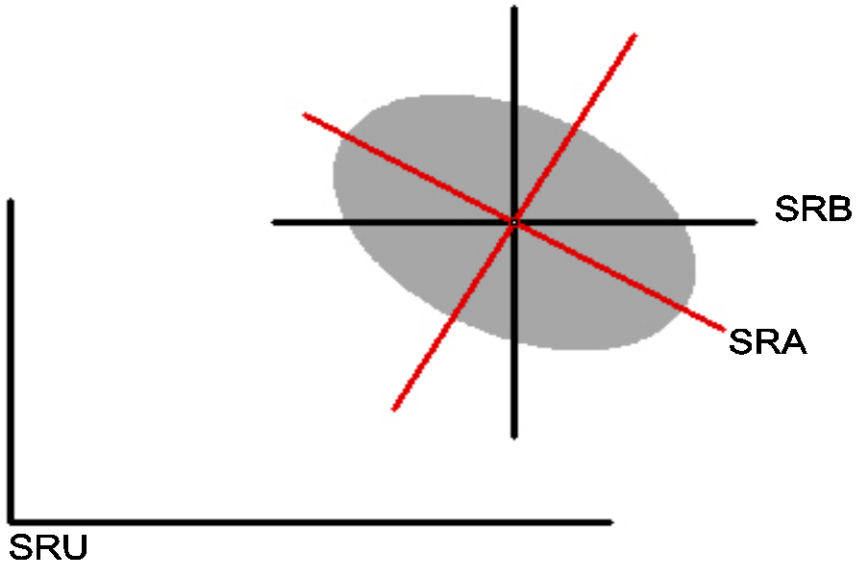
$$hor = 15\,(hora - 12)$$

$$decl = 23.45\,sen((360/365)\,(d + 284))$$

$$elev = sen^{-1}[cos(lat)\,cos(decl)\,cos(hor) + sen(lat)\,sen(decl)]$$

$$azim = cos^{-1}\left[\frac{cos(lat)\,sen(decl) - sen(lat)\,cos(decl)\,cos(hor)}{cos(elev)}\right]$$

Three coordinate systems (SRA, SRB and SRU) needed for analysis



Analytic expression of the shade, rotations and translations

- Three steps to develop the analytical expression of the shade projected by a tree on the ground
  - First calculate anaytic expression of the shade with a coordinate axis centered in the shade (SRA)
  - Second, we rotate SRA to align it with SRU. We call this SRB
  - Third, we traslate the origin of SRB to SRU

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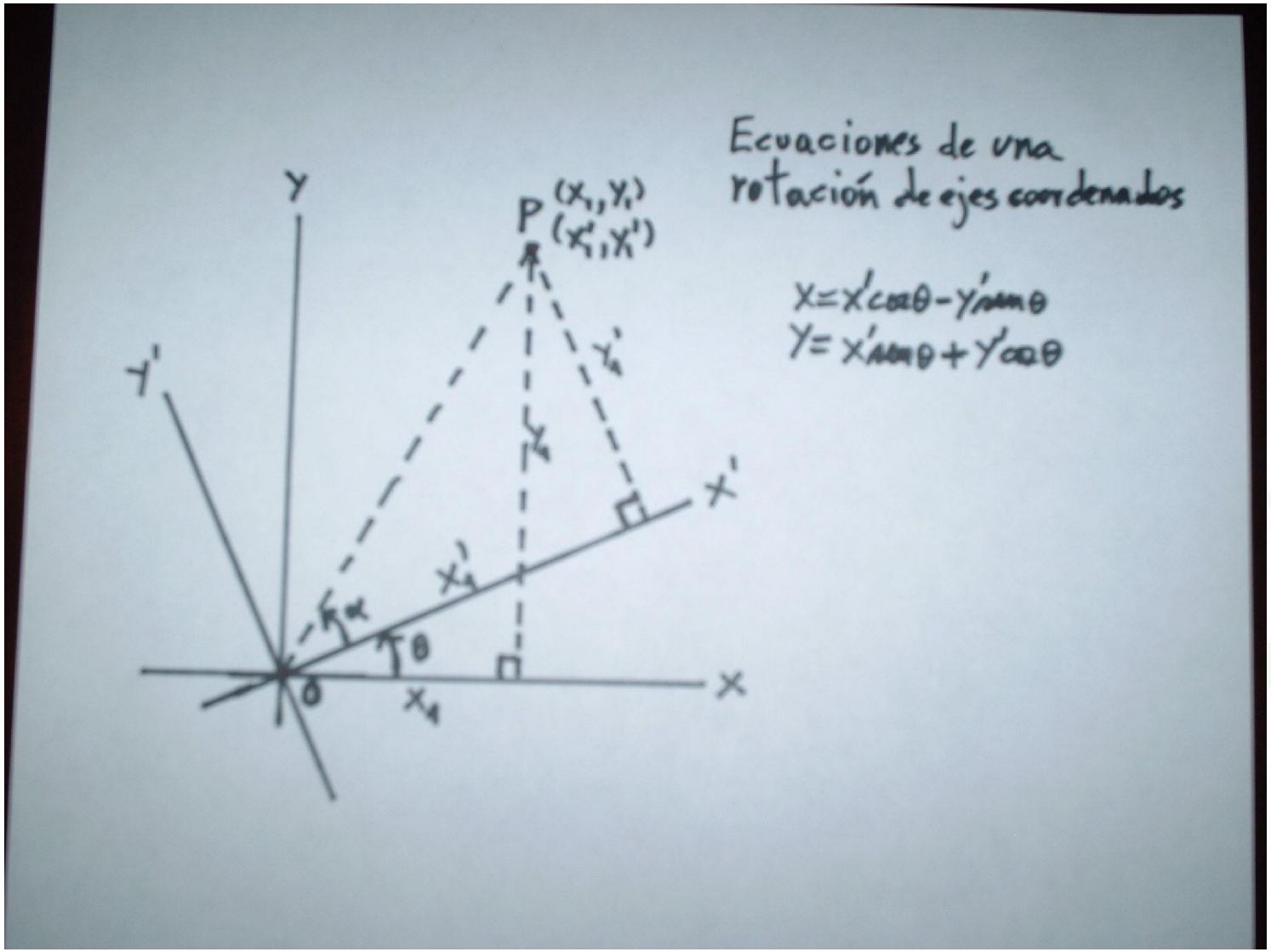
Rotation of axes



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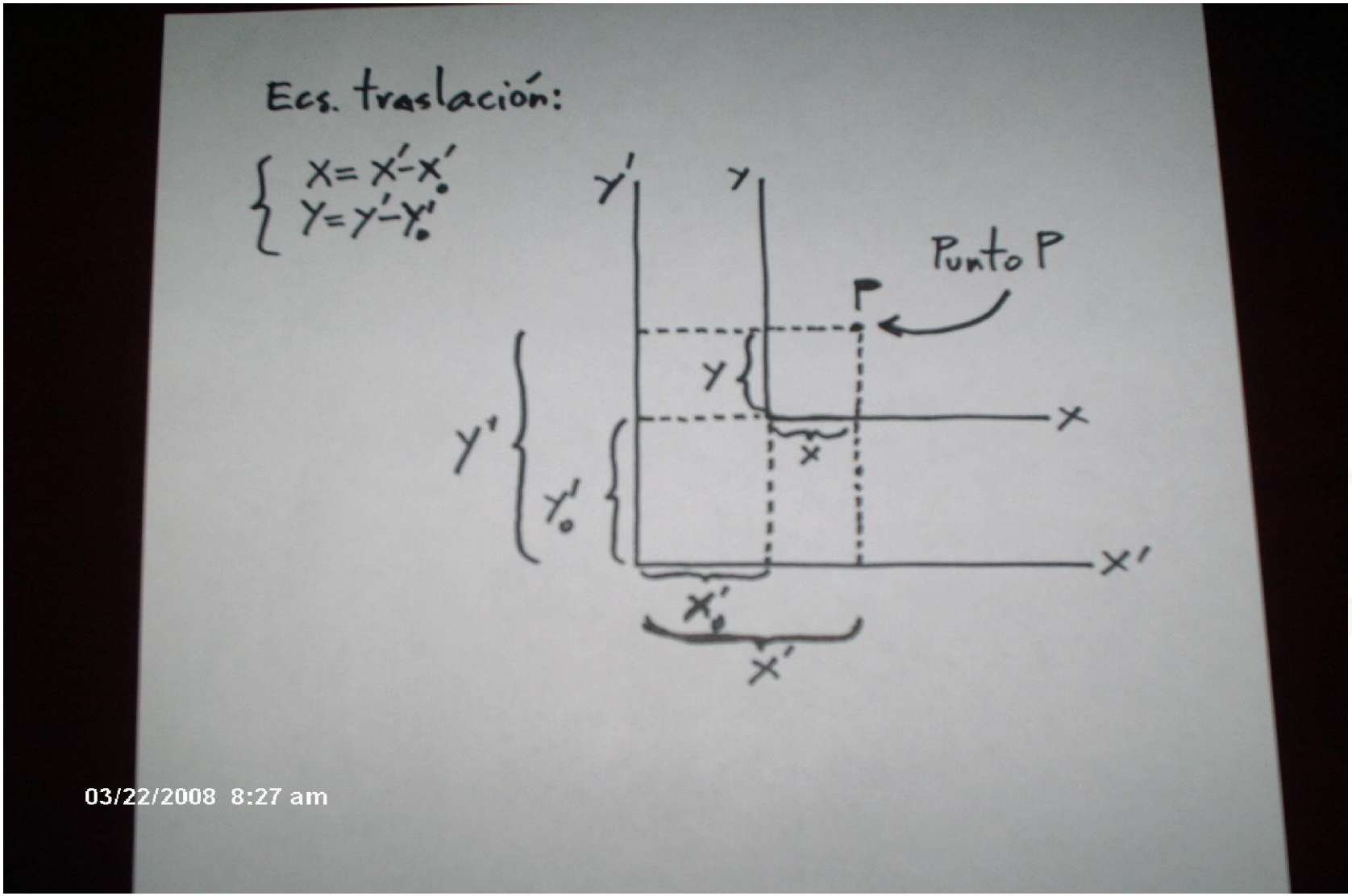
Equations to rotate axis

$$x = x' \, cos(\theta) - y' \, sen(\theta)$$

$$y = x' \, sen(\theta) + y' \, cos(\theta)$$

Translation of origin of a Cartesian coordinate system



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Moving the origin of the coordinate system

$$x' = x'' - x_0$$

$$y' = y'' - y_0$$

- An example with ellipsoidal shade
- The analytical expression of an ellipsoidal shade in SRA

$$\frac{x^2}{a^2} + \frac{y^2}{(bcotan(elev))^2 + a^2} < 1$$

- This is modification of the equation of an ellipse with origin centered at its center of the ellipse

$$(x/a)^2 + (y/b)^2 = 1.$$

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The equation of the ellipse with axes rotated (SRB)

$$\frac{((x' \cos(azim + 180) - y' \operatorname{sen}(azim + 180))^2}{a^2} +$$

$$\frac{x' \operatorname{sen}(azim + 180) + y' \cos(azim + 180))^2}{(b \operatorname{cotan}(elev))^2 + a^2} < 1$$

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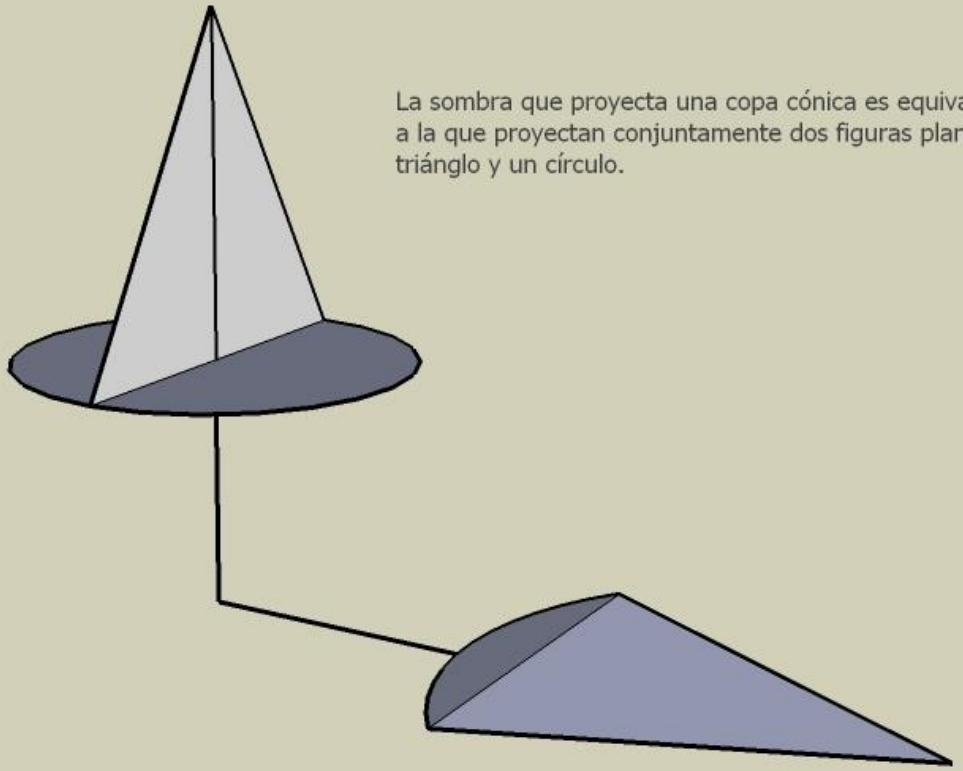
A final translation of the coordinate axes to the left-lower corner of the plot produces the final expression of the shade with respecto to SRU:

$$\frac{(((x'' - x_0)\, cos(azim + 180) - (y'' - y_0)\, sen(azim + 180))^2}{a^2} + \frac{(x'' - x_0)\, sen(azim + 180) + (y'' - y_0)\, cos(azim + 180))^2}{(b\, cotan(elev))^2 + a^2} < 1$$

A cell covered by the shade should satisfy this expression in the variables x'' and y''

Conic crowns require more analysis because the shade is expressed by a set of inequalities for both the base of the crown and the crown itself



La sombra que proyecta una copa cónica es equivalente a la que proyectan conjuntamente dos figuras planas: un triánglo y un círculo.

The analytical expressions for shades in tilted planes are far more complex than in horizontal planes because the shade is “deformed” by the specific orientation of the shade respect the changing slope of the terrain.

Adjustments for the “deformation” of the shade are mathematically complex.

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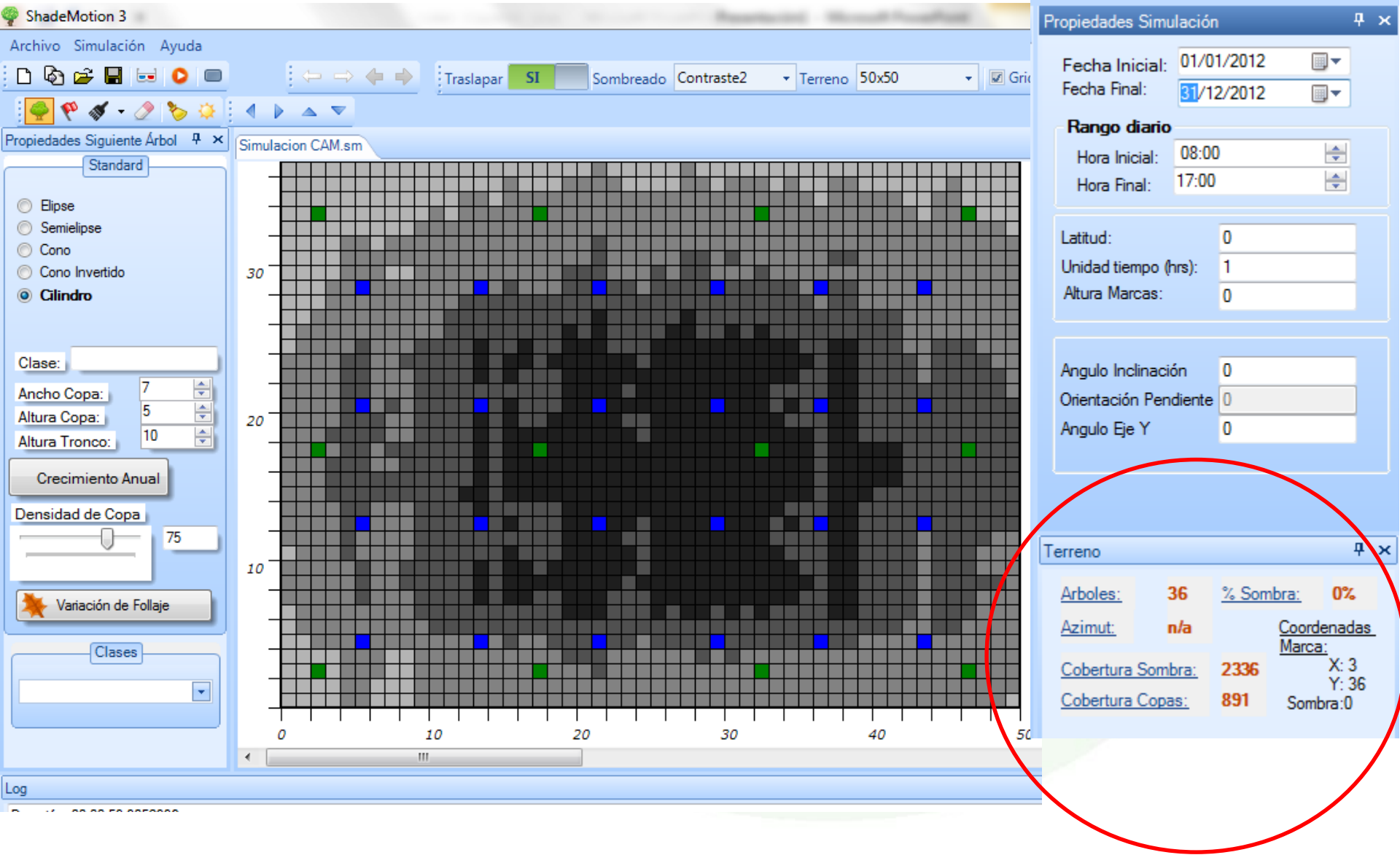
Applications

- Designing appropriate planting designs to achieve a required shading level and pattern
- Using shade levels estimated by ShadeMotion as covariable in competition studies (e.g. in systematic spacing designs)
- Estimation of solar radiation by linking ShadeMotion estimations with radiation flux at particular localtions, date and time of year

One year simulation (08:00-17:00)

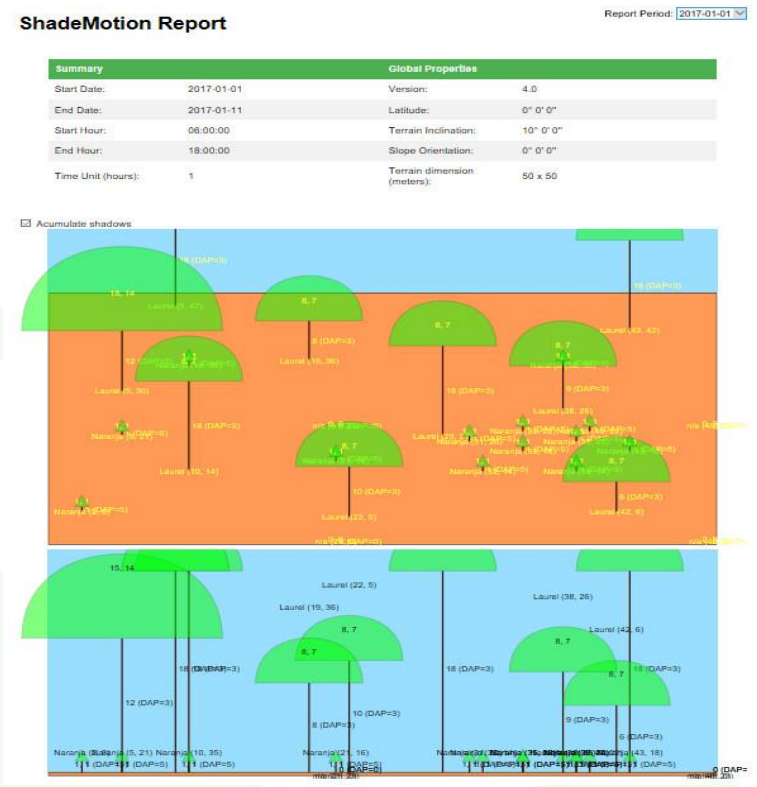


Comparing shading patterns of various tree planting designs
2500 m2 plots, one year, 07:00-17:00

Cacao and tree spacings (m x m)	% Cover	Hours shade				
		Mean	std	Max	Min	% shade
cacao(4x4)-laurel(8x8)	20	822	192	1245	288	22,51
cacao(4x4)-laurel(12x12)	10	366	102	577	10	10,04
cacao(4x4)-laurel(12x12)-casha(8x8)	22	1042	240	1493	198	28,54
cacao(4x4)-laurel(12x12)-casha(8x12)	18	800	206	1207	120	21,91
cacao(4x4)-laurel(16x16)-casha(8x8)	14	670	225	1146	0	18,37

Dynamic Reports

- Dynamic reports include the simulation results in standard format: JSON suitable for further processing.
- The report uses D3.js to create interactive charts.
- The date selector allow the viewer to navigate to different moments in the simulation.



Date Selector

Further improvements, Shademotion 4.1

- New screens, more user friendly
- Crops grow in height = the floor (where shade in recorded) can be lifted according to the height growth pattern of crops
- A new module included to help researchers to manipulate tree populations over time


Thank you