PHOLIAGE

A Photosynthesis and Light Absorption model

Model Program Manual

Roelof Oomen

With Feike Schieving

Department of Plant Ecology and Biodiversity
Utrecht University, The Netherlands

February 2007, Utrecht NL

Introduction

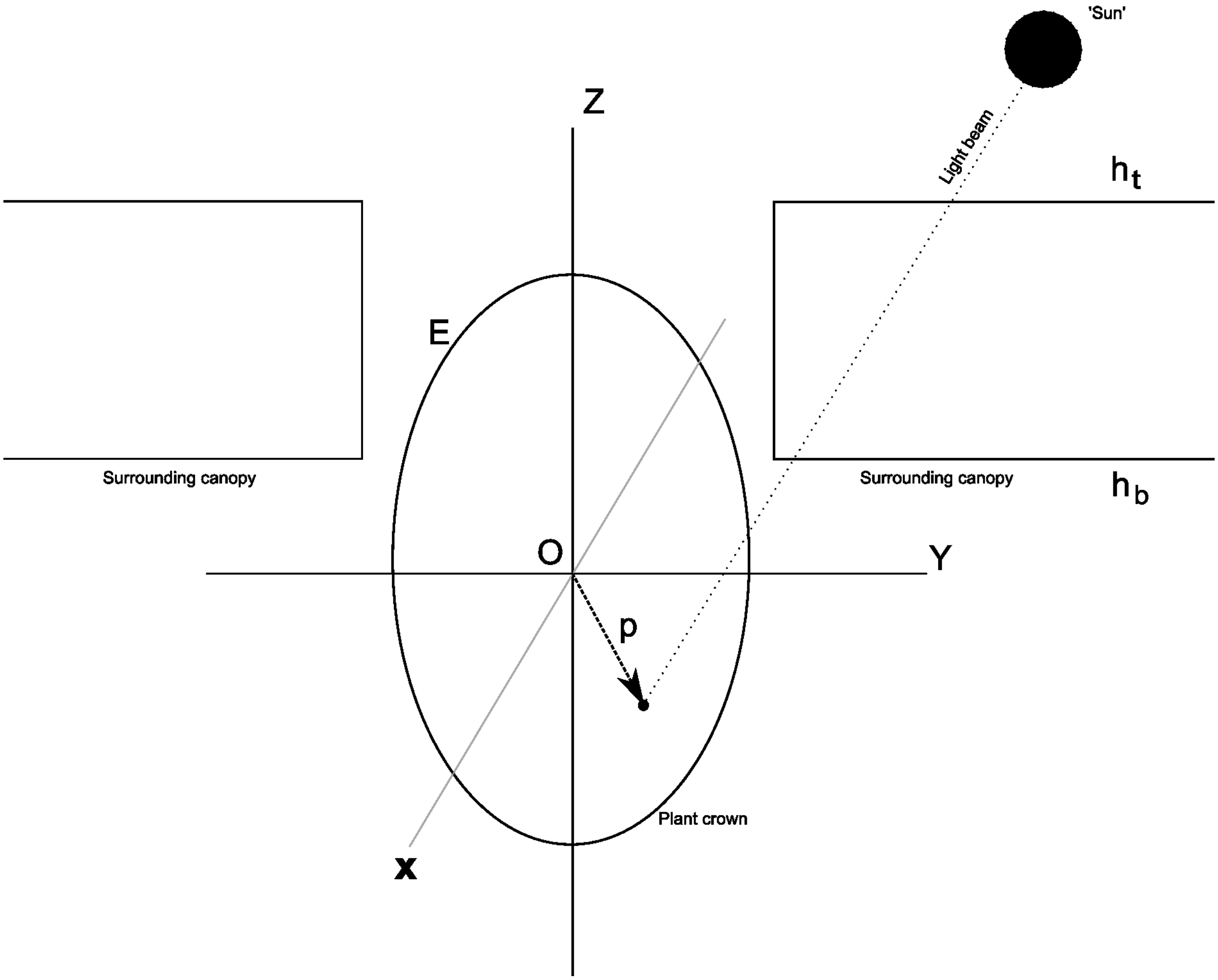
This document describes the PHOLIAGE computer program. The program is an implementation of the PHOLIAGE canopy light absorption model, as described in the accompanying paper “PHOLIAGE – A Photosynthesis and Light Absorption Model”.

This paper is intended to be:

- A description of the implementation of the model, some design considerations ,and the differences from the purely analytical structure of the model.
- A user’s manual.

Model overview

The PHOLIAGE model is a canopy light absorption and photosynthesis model designed to be used for analysing trees in enrichment planting projects. The model features an ellipsoidal crown placed in a surrounding vegetation (figure 1), possibly featuring a circular gap around the focus tree. Both the tree and the vegetation dimensions can be manipulated to a wide extend.



The model is described in more detail in the accompanying paper (see chapter 1), so here only the most important parts are described, especially in relation to the program.
The (internal) components the model can be divided into are:

1) Ellipsoid integration
2) Path length calculation
3) Light extinction
4) Light absorption
5) Photosynthesis

These components will be described more extensively below.

1. Ellipsoid integration

Here calculated light absorption speeds are integrated over the volume of the ellipsoid. This in fact means that the ellipsoid is divided in small volume units, for which the absorption speed in $\mu mol\ s^{-1}\ m^{-3}$ is calculated. When integrating, this speed is multiplied by the unit's volume, added to all other volume unit absorption speeds, yielding the total crown PPFD absorption speed in $\mu mol\ s^{-1}$.

2. Path length calculation

For any position in the crown ellipsoid (as determined by the ellipsoid integration) and every light direction, the path length of a light beam through the crown itself and through the vegetation can be calculated.

3. Light extinction

The light intensity at any point in the ellipsoid for a certain light direction is calculated with an exponential light extinction model, using path lengths through and extinction coefficients of the crown and the surrounding vegetation. The extinction coefficient of leaves is calculated using their leaf angle, generalised in three classes giving the fractions of the total leaf area density, the leaf area density and the direction of the light. The projection of leaves of all angles in a certain light direction is calculated and multiplied by the leaf light absorbance.

4. Light absorption

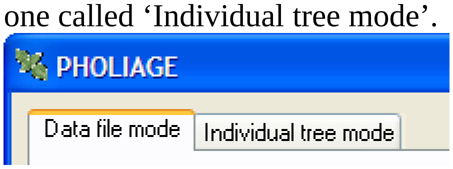
The light absorption per unit volume of any point in the ellipsoid is calculated by finding the projection of leaves of all classes in light of all directions (the entire sky dome). This is the light extinction. The light extinction is then multiplied by the leaf light absorbance, the light intensity at that point and the leaf area density.

5. Photosynthesis

Photosynthesis speed per unit volume is calculated by finding the incident light per unit leaf area from all directions on leaves of a certain inclination. The photosynthesis speed per unit leaf area is the calculated using that value and the light-dependent nitrogen content of these leaves. This speed is integrated over all leaf angles, yielding the photosynthesis speed per unit volume.

The PHOLIAGE model program

The PHOLIAGE model program is intended to be used for calculation the total light absorption and photosynthesis speed for large numbers of trees. Necessary input parameters can be measured in the field. The user interface exits of two tab sheets, one called 'Data file mode' and one called 'Individual tree mode'.



Data file mode

This is the main usage mode of the program. Plant parameters can be entered in an Excel file, a template is supplied with the program (PHOLIAGE_datatemplate.xlt). This template consists of a number of sections, which will be described hereafter.

The data template

	A	B
1	PHOLIAGE Model data	
2	Plot details	
3	Name	Location
4		

Here the name and the location of the plot can be entered. This is not mandatory, but useful for identifying your data file and especially your results file.

Light model	
Clouding const	Light on horizontal plane

Here the parameters of the light model for this model run are given (see section 'Light model', in the analytical description). Common values are 2 for the clouding constant and 1000 μmol m^{-2} s^{-1} for light on the horizontal plane.

Plants		Crown	Diameters...		Vegetation		
Plant ID	Height top	x	y	z	Gap radius	Top heigh	Bottom he

Here a plant identification (alphanumerical), top height (m), measured from the ground surface, and crown dimensions (m) can be given, with z being the vertical axis. The drop-down box right of 'Crown' is used to select whether the entered crown dimension represent diameters or radii. Vegetation parameters are gap radius, in meters van zero upwards, and top height and bottom height, both in meters, measured from the ground surface.

Plant	Angle fractions/counts				Vegetation	Angle fractions/counts			
Leaf Area	15	45	75	a_L plant	LAI Vegetat	15	45	75	a_L vegetatio

Here the leaf area and leaf distributions of the plant itself, and the surrounding vegetation can be entered. For the plant crown the total leaf area is given (in m^2), for the surrounding vegetation the LAI (Leaf Area Index, in m^2 leaves per m^2 ground surface). The leaf angles are given as either a count (will be transformed to fractions) or a fraction of leaves with their leaf angle in a certain class. The classes are characterised by their central leaf angle and are: 0-30, 30-60 and 60-90 degrees. When fractions are given they have to add up to exactly one, as the program does not distinguish between counts (not adding up to one) and fractions, and hence not warn for incorrect values. Leaf light absorption coefficient a_L is a value between 0 and 1, when 0, no light is absorbed, when 1 all light falling on a leaf is absorbed. This value influences both the total amount of light absorbed and the steepness of the light attenuation through the foliage.

Nitrogen	
N_0	a_N

Here the parameters of the nitrogen distribution are given. N_0 is the nitrogen content of leaves at the top of the plant (μmol m^{-2}), a_N is the exponent of the nitrogen attenuation in relation to the light distribution.

Pmax			Dark respiration		Photosynthesis	
a	b	c	a	b	phi	theta

Here the parameters for the photosynthesis relations have to be entered. The p_{max} relation of the program is a hyperbolic one if c is entered and a linear one if c is left empty. If the a of the dark respiration function is zero or empty the dark respiration will be constant b. The photosynthesis curve is a non-rectangular hyperbola, characterised by quantum yield phi (ϕ, mol per mol) and curvature theta (θ).

Running the model

The data file is selected using the ‘Select file’ button. The file name and the number of plants read by the program are shown.

All integrals of the model are evaluated numerically by the Gauss-Legendre method (Press et al. 1989). An integral is calculated using a number of abscissas, which can be individually set. Default 6-point integration is used, however higher numbers yield more precise results, but result in longer calculation time. As can be seen the number of points for Kf theta and P theta appear to be multiplied by the number of leaf angle classes. This is in fact not true; these integrations over the theta angle are divided in three separate integrations over the respective leaf angle classes, because the transitions between these classes are not continuous.

Integral	Gaussian points
Ellipsoid z	6
Ellipsoid r	6
Ellipsoid psi	6
I theta	6
I psi	6
I_0 theta	6
Kf theta (*LACla	2
Kf psi	6
I_L theta	6
I_L psi	6
P theta (*LAClas	2
P psi	6

The model is executed run by clicking the ‘Run’ button, and a progress bar and a seconds counter show track the progress of the execution. When the run is finished the results can be saved to an Excel file using the ‘Save’ button, which opens a dialog allowing to enter a file name or select an existing file. When the box before ‘Open file after saving’ is checked Microsoft Excel is launched after saving, showing the results.
The results for both light absorption and photosynthesis speed are in μmol s^{-1}.

Individual tree mode

In this mode all possible parameters of the model can be individually varied. The main use of this mode is validating the model results by experimenting with all possible parameters.
The differences for the plant and vegetation parameters with the input template of the ‘Data file mode’ are: the x, y and z semi-radii of the ellipsoid are called a, b and c in accordance with the model description, H_t and H_b are measured relatively to the centre of the ellipsoid instead of to the ground, crown and surrounding vegetation leaf area are both given as a density (m^2 m^{-3}).
In his mode also all integration intervals can be altered, for reference of the intervals, see the analytical model description. All intervals, except ellipsoid Z, represent angles in radians. The intervals for integrals where f^{Ω} is used cannot be set, as they are dependent on the

Integral (min/max)	Value
Ellipsoid z (min)	-1
Ellipsoid z (max)	1
Ellipsoid psi (min*pi)	0
Ellipsoid psi (max*pi)	2
I psi (min*pi)	0
I psi (max*pi)	2
I_0 theta (min*pi)	0
I_0 theta (max*pi)	0,5
Kf psi (min*pi)	0
Kf psi (max*pi)	2
P psi (min*pi)	0
P psi (max*pi)	2
I_L theta (min*pi)	0
I_L theta (max*pi)	0,5
I_L psi (min*pi)	0
I_L psi (max*pi)	2
Crown AzWidth f_ome	2
Veg AzWidth f_omega	2
AzWidth i_omega_0 (*	2

chosen leaf angle classes, hence are in this case (in degrees) 0-30, 30-60 and 60-90, totalling 0-90 degrees or 0-0.5π radians. The three AzWidth values are the azimuthal 'widths' (or angles) of functions f^{Ω} and i^{Ω}_{0}, where, instead of integrating over the azimuth, a multiplication by the azimuth angle is done (set to the full circle 2π in the model description).
There also is an option for choosing other leaf angle distributions than the three-class measured fractions used normally. They are:
Spherical: $f^{\Omega}(\vartheta_L)=\sin\vartheta_L$
Uniform: $f^{\Omega}(\vartheta_L)=\frac{2}{\pi}$

Future model extensions

-Daily absorption/photosynthesis values.
-Better nitrogen distribution (see analytical description).
-Elongated ellipse-formed gap for cutting lane simulation.
-Directional light (with direct sunlight instead of only diffuse light)

Acknowledgments

The development of this model would not have been possible without the invaluable support of Feike Schieving. Many long and inspiring talks and a lot of constructively critical comments have shaped both this model and my mathematical perception. Furthermore, I want to thank Niels Anten and Marijke van Kuijk for providing the ecological research background.

Literature

Numerical recipes in Pascal, par. 4.5, Press et al. 1989, Cambridge: Cambridge University Press.