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CANOPY ARCHITECTURE MODEL FOR COTTON

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Abstract

A mathematical model is described for specifying the size, location, and orientation of leaves in a cotton canopy. The model was developed based on established rules for plant branching and a methodology for affecting the probability of branching based on interplant competition. Aspects of modeled plant architecture were evaluated using data collected in a field study.

Introduction

RAYCOT is a mathematical model that uses ray tracing to produce a visual simulation of a cotton canopy [1]. To perform a simulation, the location, orientation, and size of each leaf in the cotton canopy must be specified, along with its reflectance characteristics. In previous applications of the model, the location, orientation, and size of each leaf was specified based on average values determined from a limited field data set collected at a single time during the growing season. It was not possible from this data set to model plants of different sizes and developmental ages. The objective of this study was to develop a general model of canopy architecture capable of specifying the location, orientation, and size of leaves for cotton plants of a wide variety of sizes and developmental ages. Results of this canopy architecture model can be used as the basis for RAYCOT simulations of cotton canopy visual and reflectance characteristics.

Field Study

A study was conducted during the 2003 growing season to collect data on the size, position, and orientation of leaves on field-grown cotton plants. The study was conducted in field plots located at the USDA-ARS Plant Stress Laboratory located in Lubbock, Texas. Measurements were made each week on five isolated cotton plants. Measurements included the number and length of nodes on the main stem and lateral branches, the angle between successive leaves and branches on the main stem, the dimension and angular orientation of leaves, and the length of leaf stems. Measurements were also made on three cotton plants growing within rows such that they experienced normal interplant competition (within-row plant spacing approximately 15 cm). All plants received sufficient irrigation during the growing season to prevent the occurrence of water stress.

Model Development

To produce a RAYCOT simulation, the user must build a "virtual cotton canopy" for which the location, orientation, and size of each leaf is geometrically specified. For computational simplicity, leaves in the virtual canopy are assumed to be circular, flat, and of negligible thickness. With these assumptions, any leaf in the virtual canopy can be completely specified by its radius and six parameters; three of the parameters (*CenterX*, *CenterY*, and *CenterZ*) specify the 3-dimensional location of the center of the leaf, while the other three parameters (*AFactor*, *BFactor*, and *CFactor*) describe the 3-dimensional plane equation passing through the leaf. For a modeled cotton plant consisting of a main stem and lateral branches, these six parameters can be determined for any leaf from the values of seven variables associated with the size, location, and orientation of the leaf and the structures supporting it on the plant. These seven variables are described in Table 1, and are shown diagrammatically in Figure 1.

Table 1. Seven variables describing the size, location, and orientation of leaves on the virtual cotton plant (see Figure 1).

Plant Height	*PH*
Stem Position (measured from the top of the plant)	*SP*
Stem Rotation Angle (measured clockwise from the perpendicular to the row direction)	*RA*
Stem Length (measured as the distance from the leaf to the main stem)	*SL*
Stem Angle (measured from vertical)	*SA*
Leaf Radius	*LR*
Leaf Angle (measured from vertical)	*LA*

The first step in building a virtual cotton plant is to simulate the branching structure which ultimately determines the number and locations of leaves on the plant. Most higher plants (including cotton) have characteristic branching regimes involving a hierarchy of primary and lateral branches resulting from the repetition of a simple "shoot-unit." The basic simplicity of the branching process has allowed the successful simulation of plant architecture for a wide variety of species, including cotton [2, 3, 4, 5].

In this study, the basic "shoot-unit" consists of an internode, an associated leaf, and the stem connecting the leaf to the internode (see Figure 2). Repetition of this leaf-stem-internode unit produces both the main stem of the simulated cotton plant and its lateral shoots. The presence of an apical meristem at the distal end of the internode potentially allows repetition along the axis of the existing internode. The presence of a meristem in the axil of the leaf potentially allows the formation of a new branch.. The formation of a new shoot-unit either along the existing stem or as a branch off of the existing stem is governed by probability. In the simulation, the formation of a new shoot-unit is determined by generating a random number x (in the range 0-1) and comparing this number to a value a (also in the range 0-1) established for the particular location on the plant. If $x \leq a$, then a new shoot-unit is allowed to form. For simplicity, $a = 1$ for the formation of new internodes on the main stem up to the maximum number of main stem internodes, which currently is an input to the model. The value of a is less than 1 for the formation of branches. Thus, two simulated cotton plants will have the same number of main stem internodes, but may have different numbers of branches, and the branches may be in different positions relative to the main stem internodes.

Once the branching structure of the simulated cotton plant is established, the spatial architecture of the plant is determined by assigning lengths to internodes and leaf stems, along with the angles that the leaf stems and axillary branches make with their associated internodes. These values were estimated from the field data. By applying these values to the branching structure, the position and orientation of each leaf on the simulated plant can be determined.

It is commonly observed that isolated cotton plants tend to produce more and longer branches, as compared to plants experiencing competition with neighbors in the plant community. This observation was verified by the field data collected in this study. A competition factor was employed to account for the effects of interplant competion on branch formation. In evaluating this factor, the horizontal area influenced by a plant was assumed to be a circle of radius equal to the horizontal projection of the longest axillary branch on the plant. The overlap of this "zone of influence" with those representing neighboring plants was used to compute the value of the competition factor [6]. In Figure 3, a simulated cotton plant with its center at point "C" competes with another plant with its center at point "N1," as indicated by the overlap of the circles representing the zones of influence of the two plants. To facilitate computation of the overlap, the plant at point "C" is represented by a grid of squares. In this example, 4 grid squares lie within the zone of influence of the neighboring plant. Thus, the degree of competition experienced by this plant, defined as the "competition factor" *COMP*, would be approximated by

$$COMP = [17(1) + 4(0.5)] / 21 = 0.905$$

For any simulated plant, the value of *COMP* can range from 1 (no interplant competition) to 0. Representation of the circular zone of influence by a grid of squares greatly simplifies the computation of *COMP* in situations involving multiple overlaps of zones of influence for plants of various sizes. To account for the effects of interplant competition on branch formation, the value of a described earlier is multiplied by the value of *COMP*. This reduces the probability that new branches and new internodes on branches will be formed under competitive conditions. The net effect is to produce simulated plants with fewer, shorter branches.

Results and Conclusions

An example of the simulation of leaf positions and orientations using this model is shown in Figure 4. This model is capable of simulating cotton plants of various sizes and developmental ages. It will be incorporated into the RAYCOT model to facilitate the simulation of cotton canopy visual and reflectance characteristics.

Acknowledgment

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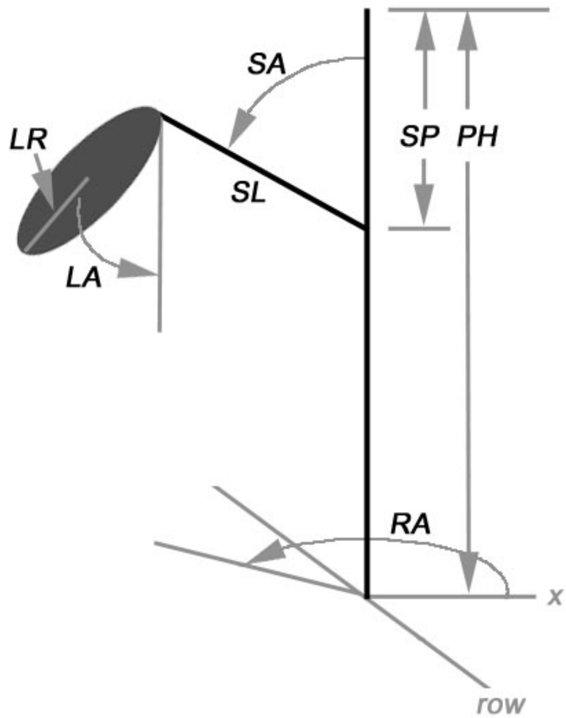

Figure 1. Diagrammatic representation of the seven variables needed to describe the size, location, and orientation of a leaf on the virtual cotton plant (see Table 1 for meaning of symbols).

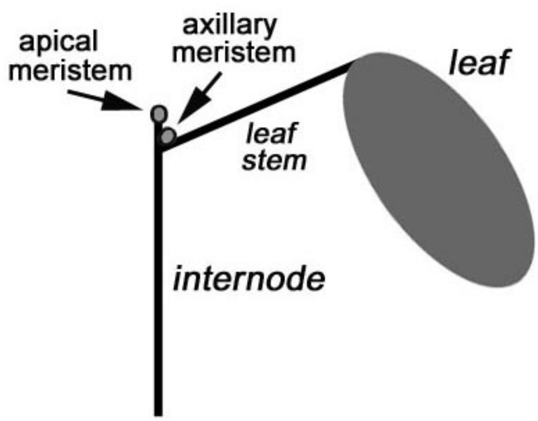

Figure 2. Diagrammatic representation of the basic leaf-stem-internode unit used to construct the virtual plant. The locations of the apical and axillary meristems are indicated.

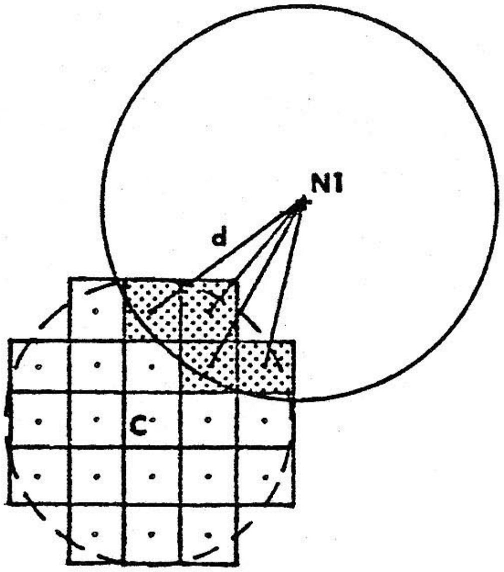

Figure 3. Determination of the competition experienced by an individual plant located at point "C" (approximated by a grid of squares) by a neighboring plant located at point "N1." Grid squares with centers within the circular zone of influence of the neighbor, as determined by the distance "d" being less than the radius of the neighboring zone of influence, are shown shaded.

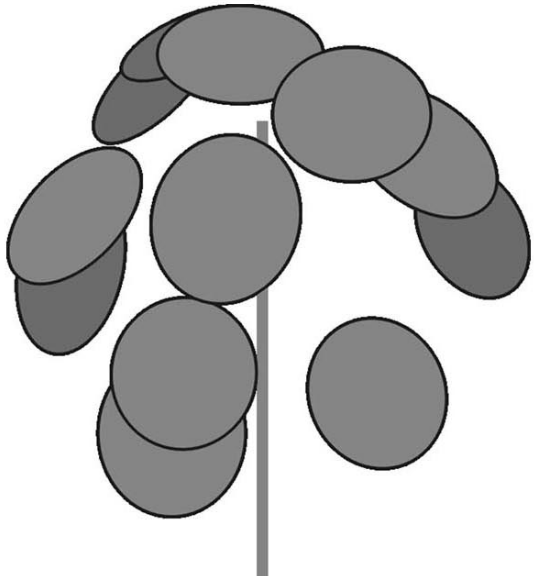

Figure 4. Example of simulated positions and orientations of leaves on a virtual cotton plant, viewed obliquely.