

LEAF ORIENTATION IN HELIOTROPIC *CALATHEA* (MARANTACEAE)

BRIAN M. LAPPAS, ROBERT H. YANKER III, AND THOMAS J. LOBBEN

Faculty editor: Matthew P. Ayres

Abstract: Leaf movement in response to light, or heliotropism, should benefit plants where light intensity is a limiting factor. Heliotropic Marantaceae *Calathea* should exhibit one of three movement patterns. 1) Leaves could be perpendicular to the sun (diaheliotropic) to maximize light absorption and photosynthesis, 2) Leaves could be parallel to the sun (paraheliotropic) to minimize radiation and thermal damage, or 3) Leaves could move either diaheliotropically or paraheliotropically to optimize for changing light intensities. We found that at low light levels, plants had perpendicular leaf orientation to the sun, while at high light intensities; leaf orientation was parallel to the sun's rays. This movement suggests that *Calathea* tends to maximize photosynthesis when light is limiting, and minimize thermal damage when light is excessive. This ability to optimize at various light intensities could explain why *Calathea* can thrive in high-light gaps, and low-light understory.

Key Words: diaheliotropism, paraheliotropism

INTRODUCTION

Light availability in the tropical forest is a common limiting factor in plant distributions (Chazdon & Fletcher 1984). Consequently, plants have evolved various ways to optimize light exposure. One such adaptation is heliotropism, or the ability to orient leaves in response to the sun. Heliotropic plants specialize in one of three different movement patterns. 1) Leaves are perpendicular to the sun (diaheliotropic) to maximize light absorption and photosynthesis, 2) Leaves are parallel to the sun (paraheliotropic) to minimize radiation and thermal damage, or 3) Leaves move either diaheliotropic or paraheliotropic to

optimize changing low and high light intensities (James & Forseth 1980, Cronlund & Forseth 1990). A plant's ability to optimize light intensity may affect distribution ranges. We focused on the heliotropic genus *Calathea*, of the Marantaceae family, which occurred along forest edges and in light gaps in Corcovado National Park, Costa Rica. To determine the extent and nature of heliotropism in *Calathea*, we measured the vertical, rotational, and cupping angles of three plants over time, noting sun and shade.

METHODS

We surveyed two *Calathea* plants on either side of the airstrip 200 m south of the Estación

Biológica, Corcovado, Costa Rica (Plant 1, 2). On 8 Feb 2008 from 13:00 – 19:00, 9 Feb from 05:00 – 19:00, and 10 Feb from 05:00 to 11:00, we measured each plant every other hour. On 8 Feb 2008 from 05:00 – 19:00, we measured a 3rd plant in the same habitat that we artificially shaded with a sheet.

For each plant, we measured the topmost leaf representatives of each cardinal direction, for a total of four leaves per plant. For each individual leaf we took five measurements; leaf face's vertical angle (α) from horizontal (Fig. 1a), leaf face's vertical angle to the sun (β) (Fig. 1a), leaf face's rotation relative to horizontal (angle θ) (Fig. 1b), and the 'cupping' angle of a leaf face (γ) (Fig. 1c).

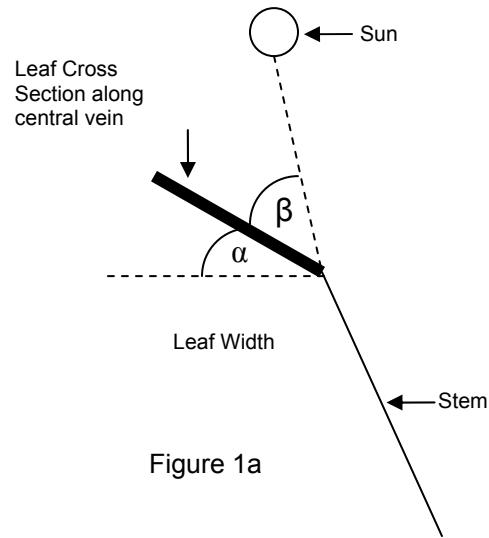


Figure 1a

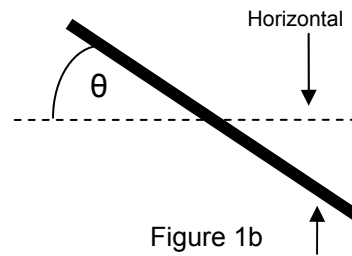


Figure 1b

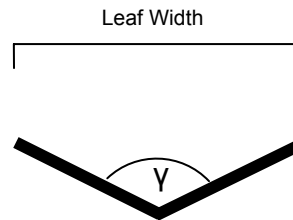


Figure 1c

Figure 1. A-C are diagrams of various angular measurements. A) Picture of a leaf cross-section taken along the central vein. The vertical angle between the leaf face and horizontal is pictured by alpha (α), while Beta (β) refers to the vertical angle between the leaf face and the sun. B) Graphical representation of leaf cross section (perpendicular to central vein). Theta (θ) refers to the rotational leaf angle relative to horizontal, in degrees. C) Gamma (γ) represents the angle of 'cupping' of each leaf. The smaller the γ value, the more 'cupped' a leaf is, and the less photosynthetic surface there is exposed.

We graphed α , θ , and γ angles over time (Figure 2) to show absolute motion for Plants 1 & 2. We determined how many degrees (θ) off of horizontal the leaf face was, and attributed a +/- value to right or left rotation respectively. We also noted whether the plant was in shade, sunlight, or darkness.

From the theory of diaphototropism, we inferred that maximal absorption for a leaf would be at a perpendicular vertical angle to the sun ($\beta=90^\circ$) and open flat (uncupped; $\gamma=180^\circ$). We calculated the difference from maximal absorption for each leaf by taking the

difference from β angles and 90° (Figure 3).

RESULTS

Calathea leaves showed a wide range of motion in vertical, rotational, and horizontal angles (Figure 2). Their similar ranges suggested more than just random motion throughout the day (Table 1). For both vertical and cupping angles we fit a general linear model including day (1 or 2), hour (0500-1900), Plant (1 or 2), all interactions, and leaf (nested within plant).

	Plant 1	Plant 2	Plant 3 (Shade Treatment)
Vertical			
Mean Vertical Angle \pm SE	37.3 \pm 2.6	56.4 \pm 2.5	42.8 \pm 4.17
Min. Vertical Angle	-25	4	0
Max. Vertical Angle	70	90	85
Rotational			
Mean Rotational Angle \pm SE	.83 \pm 1.2	.92 \pm 1.6	-.68 \pm 1.6
Min. Rotational Angle	-25	-25	-30
Max. Rotational Angle	70	90	85
Cupping			
Mean Cupping Angle \pm SE	148.2 \pm 5.4	154.3 \pm 4.5	156.2 \pm 7.2
Min. Cupping Angle	45	55	70
Max. Cupping Angle	180	180	180

Table 1: Means and ranges of motion for the three angle vectors (vertical, rotational, & cupping) for each of the 3 plants.

Plants 1 and 2 showed similar repeating patterns; leaves stood up straight at midday (higher β) and were folded at the central-vein (smaller γ), while they flattened out during the morning and afternoon (Figure 2). Vertical angles were more parallel to the sun at midday (large difference from 90 degrees), and

more perpendicular to the sun during the morning and afternoon (small difference from 90 degrees; Figure 2). This daily pattern was reflected in highly significant effects on vertical and cupping angles of hour ($F > 17$, $df = 7,90$, $p < 0.0001$) and hour*plant interactions ($F > 12$, $df = 7,90$, $p < 0.0001$) (Figure 2). In

contrast, leaf rotation to horizontal was invariant with respect to hour and hour*plant ($F < 1.36$, $df = 7,90$, $p > 0.22$).

Whether Plant 1 or 2 was in direct sunlight or shade had little effect on the overall pattern of vertical movement (Figure 2a). However, Plant 1 had lower vertical

angles when shaded than Plant 2 did in the sun. The shaded treatment (Plant 3) showed similar patterns of vertical and horizontal movements, with the highest vertical angles, and lowest cupping angles occurring at midday (Figure 2a, 2b).

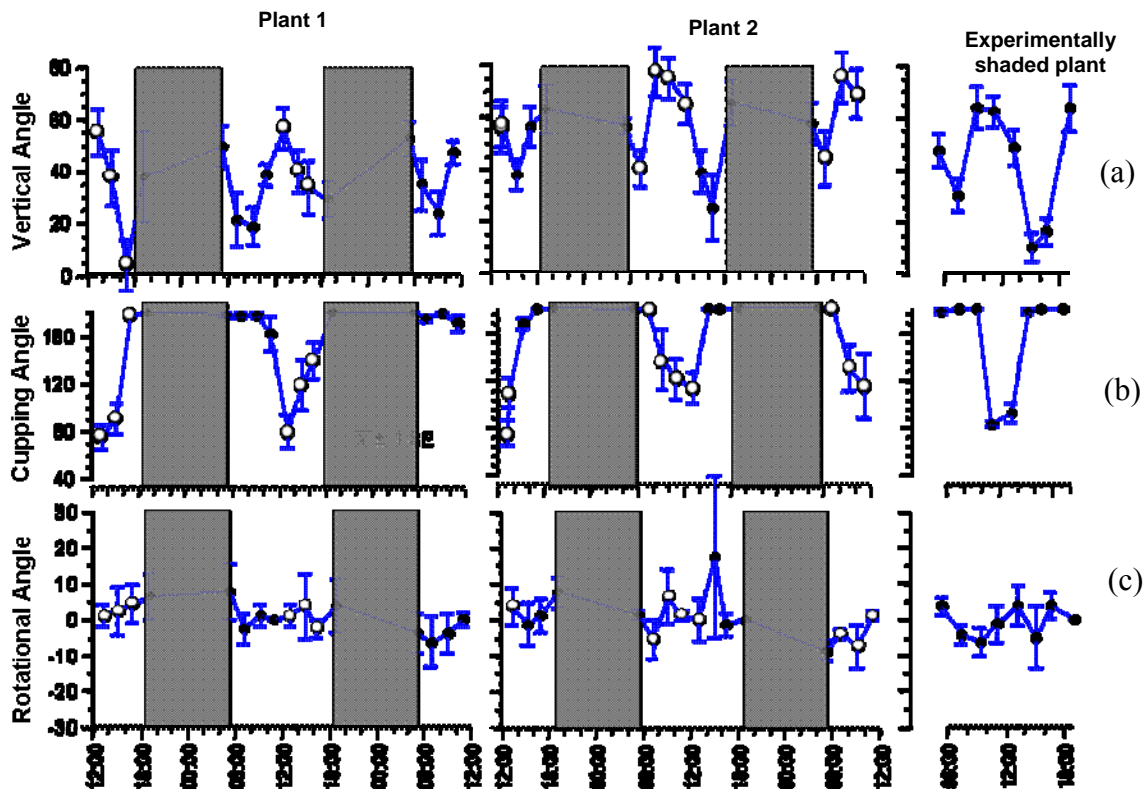


Figure 2 A-C: Temporal patterns in leaf angles (Vertical to horizontal, Cupping, and Rotation to horizontal respectively) over time for Plants 1, 2, & 3. Gray bars indicate nighttime, while filled and open circles represent times that plants were in the shade or sun respectively; Error bars show ± 1 SE based on leaves within plants.

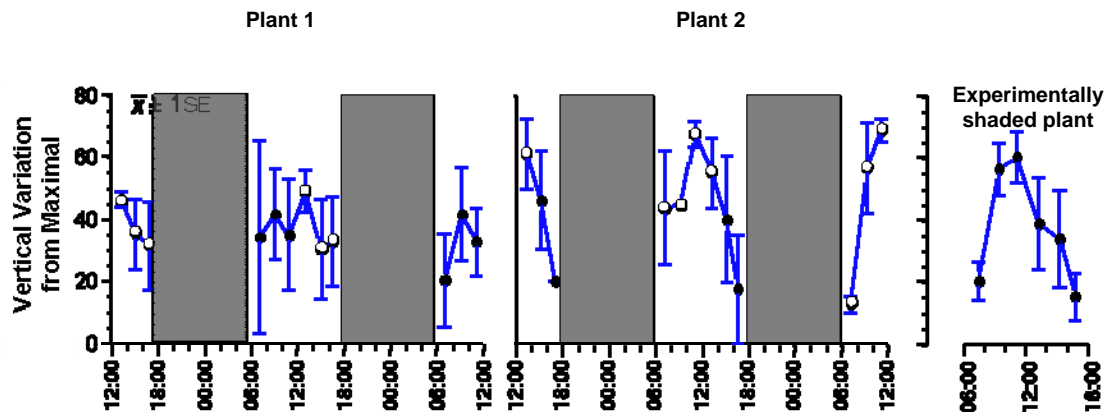


Figure 3: Graphs of vertical distance away from 'maximal' absorption angle for each plant over time. Gray bars indicate night, while filled and open circles represent times that plants were in the shade or sun respectively; Error bars show ± 1 SE based on leaves within plants.

DISCUSSION

Calathea leaves moved significantly in response to direct sunlight. Leaf movement was both paraheliotropic and diaheliotropic. Paraheliotropic movement occurred at midday when the light intensity was greatest, suggesting that the plant was under light, heat, and desiccation stress. Because of the high solar flux at midday, it is likely that photosynthesis of *Calathea* was well above light saturation, and was physically responding to prevent light damage.

Conversely, diaheliotropic movement occurred in the morning and afternoon when light levels were low. During these times, the plants could maximize photosynthetic activity without reaching their maximum light saturation points. The ability of *Calathea* to act both paraheliotropically and

diaheliotropically depending on light levels could explain its distribution and success in both gap and understory habitats. Further studies could compare *Calathea* distribution and light capturing efficiency with a similar non-heliotropic plant, such as *Heliconia*, to evaluate if there is a quantifiable benefit to heliotropism in the tropics.

Interestingly, the pattern of vertical leaf movement in Plants 1 and 2 were not affected by time in the shade. This result was supported further by the similar vertical leaf patterns of Plant 3, despite being artificially shaded all day. Both of these results suggest the possibility of an established circadian clock in *Calathea*. If light and temperature stimuli establish a circadian clock, even after the stimulus is removed, the pattern of leaf movements will continue for a certain amount of time. Future studies could modify

light and shade treatments for longer periods of time, to quantify how new stimuli would affect this circadian clock. Abrupt light changes may occur in the tropics with the abundance of tree falls, and the *Calathea's* ability to respond could be noteworthy.

LITERATURE CITED

- Chazdon, R.L., and N. Fletcher. 1984. Photosynthetic Light Environments in a Tropical Rain Forest in Costa Rica. *The Journal of Ecology* 72:553-564.
- Cronlund, S.L., and I. N. Forseth. 1995. Heliotropic Leaf Movement Response to H⁺/ATPase Activation, H⁺/ATPase Inhibition, and K⁺ Channel. Inhibition in Vivo. *American Journal of Botany* 82:1507-1513.
- James, E., and I. Forseth. 1980. Solar Tracking by Plants. *Science* 210:1094-1098.