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REFOLIATION OF *ERYTHROXYLUM COCA* VAR. COCA. I. MEASUREMENT TECHNIQUES

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Acock, M. C. *Refoliation of* Erythroxylum coca *var. coca. I. Measurement Techniques.* BIOTRONICS **28**, 87–95, 1999. Simulation models to estimate annual leaf yields of the coca (*Erythroxylum coca* var. coca) crop should be capable of describing seasonal fluctuations in yields. Knowledge of how the plant recovers from defoliation at each harvest is essential for model development. Coca plants were grown in a greenhouse and allowed to refoliate. The LI–COR Plant Canopy Analyzer[1], the Decagon Sunfleck Ceptometer, the CID Digital Plant Canopy Imager, and counting the number of leaves initiated on a growing point were used to track progress in refoliation Refoliation occurred in two flushes, both of which could be described as a logistic function of time. Plants began to refoliate in 10 d. By 17 d after defoliation, canopy cover was ≥50%. The second flush of leaf growth occurred at 40 d after defoliation and ended within about 10 d. The CID digitial plant canopy imager and the LI–COR plant canopy analyzer gave very different estimates of the extinction coefficient for light interception measured at five zenith angles. Extinction coefficient values from the CID digitial plant canopy imager were least affected by zenith angle. The number of leaves per growing point was highly correlated with leaf area index. When canopy analyzer instruments are unavailable or conditions are unfavorable for their use, the simple method of counting the number of leaves initiated on a growing point can give good information about coca refoliation.

Key words: narcotic, leaf yield, leaf area index, canopy cover, light interception, specific leaf area, yield assessment.

INTRODUCTION

When *Erythroxylum coca* var. coca is harvested, all the leaves of this perennial, tropical shrub are stripped from the plant. Typically this occurs every three months under favorable weather conditions (*1, 2, 4*) although harvests have been reported to occur every two (*5*) or four months (*7*) or five times a year (*6*). To accurately estimate an annual leaf yield for each of these harvest frequencies, it is necessary to define and monitor the conditions which influence the rate of recovery after each harvest.

The purpose of this study was to track the refoliation process of coca using the LAI–2000 plant canopy analyzer (LI–COR, Inc., Lincoln, NE, USA), the Digital

Plant Canopy Imager CI-110 (CID, Inc., Vancouver, WA, USA), the Sunfleck Ceptometer (SFC) (Decagon Devices, Inc., Pullman, WA, USA), and using a method for determining the increase in leaf number. Refoliation estimates from these various methods were compared to assess the accuracy and usefulness of each technique for making future refoliation measurements. Once the general shape of the refoliation progress was known, an equation to simulate the refoliation process was chosen and parameterized for the experimental conditions of this experiment.

MATERIALS AND METHODS

Experimental layout and cultural practices.

Forty-eight coca plants were repotted from 3.75 to 15 L containers using a potting mix consisting of 2 part coarse sand, 2 part sterilized soil, 1 part peat, and 1 part vermiculite by volume. All plants were defoliated and leaves were oven-dried at 70°C before weighing.

The plants were spaced 29.3 cm apart in four rows of 12 plants each, on a bench in a greenhouse. A drip irrigation system delivered 490 ml of water per pot daily. Twice a week, beginning 9 d after defoliation, plants were given 1000 ml of a fertilizer solution containing 200 $\mu g\ L^{-1}$ N in the form of 30N-4.37P-8.3K. The fertilizer solution contained a maximum of 7.0% Cl, 3% ammonium-N as ammonium phosphate, 27% urea, P as potassium phosphate and ammonium phosphate, K as potassium phosphate and potassium sulfate, B 0.02% as boric acid, Cu 0.07% as copper EDTA, Zn 0.07% as zinc EDTA, Fe 0.325% as iron EDTA, Mn 0.05% as Mn EDTA, Mo 0.0005% as sodium molydenate.

SFC readings.

The SFC consists of a series of 80 PAR sensors spaced at one cm intervals along a probe. The probe was positioned horizontally between eight plants for each below canopy measurement and the average PAR reading from all the sensors was recorded. There were 11 such positions within the group of plants. The average incoming radiation reaching the probe was measured before and after the series of 11 measurements taken below the canopy. If there was a substantial difference between the incoming radiation at the beginning, end, or during the series of measurements (>10%), those data were discarded.

Data from the SFC were used to calculate canopy cover, C, over time using the following formula:

$$C = 1 - T$$

Where, $T = (I_u/I_o)$, I_u is the unintercepted PAR at the bottom of the crop canopy and I_o is the incoming PAR measured before it passes through the canopy. A shade cloth was pulled just underneath the outer skin of the plastic (acrylic-) paneled greenhouse to diffuse the incoming radiation.

The following equation was used to describe the change in cover with each new flush of growth as a function of time:

$$C = C_{fn}/[1+(t_{0.5}/t)^{a}]$$

Where C_{fn} is the value of canopy cover at the end of flush n, $t_{0.5}$ is the number of days required for C to reach 50% of its value at the end of flush n, a indicates the rate of increase in canopy cover during the flush, and t is time (days). Values for C_{fn}, $t_{0.5}$, and a were determined using Sigma Plot 4.16 for the Macintosh iterative curve fitting routine.

LAI–2000 readings.

Canopy transmittances were calculated from measurements taken above and below the canopy using a fisheye sensor which projects a hemispheric image onto five separate silicon detectors arranged in concentric rings. The sensor is filtered to disregard radiation above about 490 nm. Each detector receives light from a different part of the sky, the midpoint of the segments being 7, 23, 38, 53, and 68° from the vertical. Twelve measurements were taken with the LAI–2000, one measurement above and three below the canopy between the rows of plants, repeated three times to give one estimate of Leaf Area Index (L). The sensor was always placed so that there were at least two plants between the sensor and the edge of the canopy. Measurements using the LAI–2000 and the SFC were made every day near solar noon. The field of view on the LAI–2000 was restricted to 270° to block out changes in transmission caused by the presence of the operator.

CI–110 readings.

A CI–110 consists of a fisheye image capturing device, software, and a palmtop computer. The software digitizes and manipulates the captured CCD images at a resolution of 1.3 million pixels, then calculates the solar beam transmission coefficient, $T(\phi)$, or the fraction of the sky visible from beneath the plant canopy, for each of five segments of the sky with the mid–points of the segments at 7, 23, 38, 53, and 68°. The gap–fraction inversion procedure (*3*) was used to calculate L and extinction coefficients, $K(\phi)$, for the block of coca plants. The part of the image showing operator interference or edge of the canopy was excluded from the analysis and a threshold was set to maximize contrast. The CI–110 operates with a wavelength range of 320–490 nm and a radiation rejection $<1\%$ for 490–650 nm and $<0.1\%$ for 650 nm. The lens is coated with MgF_2 for improved transmission at high oblique angles.

Extinction coefficients, $K(\phi)$, were calculated using the equation:

$$K(\phi) = -\mathrm{Log}_e[T(\phi)]/L$$

where L is the leaf area index.

Leaf initiation rate.

Beginning 15 d after defoliation, the number of leaves present on five growing points selected at random on each plant was recorded every two to three days. Measurements were made less frequently as leaf initiation slowed.

The leaves of coca plants are rolled when they first begin to emerge from the bud. They can reach almost full size before they unroll and present a flat surface. Leaves were counted from the day they unrolled.

All plants were defoliated 104 d after the first defoliation. Ten plants were randomly chosen for subsampling for specific leaf area (m^2 leaf area kg^{-1} leaf). Up to 2000 cm^2 were measured using an AAM–8 (Hayashi Denkoh Co. Ltd., Tokyo, Japan) leaf area meter. Fresh and dry (oven–dried at 75℃) weights of leaves were recorded.

Greenhouse temperature environment.

The daily mean temperature over the whole refoliation period was 21.7± 0.2℃. Air temperature in the greenhouse was recorded every 15 minutes. The values for these 15 minute intervals ranged from a minimum of 15.6℃ to a maximum of 44.4℃. The mean daily minimum was 18.1±0.2℃ and the mean daily maximum was 27.2±0.4℃.

RESULTS AND DISCUSSION

Leaf initiation.

The first major unrolling of leaves was observed 10 d after defoliation (Fig. 1A). The average daily temperature between the time of defoliation and the start of refoliation was 23.7±0.3℃.

The average number of leaves per growing point rose quickly to 3. The growing points went through a short rest period which lasted about one week before continuing to produce new leaves at a linear rate until there were approximately 6 leaves by d 70. After this time, the growing points went into a prolonged rest phase. Canopy cover was>0.5 in only 17 d from defoliation when the average number of leaves per growing point was 3.0.

LAI–2000.

The most rapid increase in L (as calculated by the LAI–2000 and shown in Fig. 1B) began 10 d after defoliation, the time when leaves were first observed to unroll. L reached a value of 3.60 on d 104 from the first defoliation (Fig. 1B).

The number of leaves initiated on a growing point, and L calculations from the LAI–2000, are closely related (Fig. 1C). This close association means that measuring the number of leaves per growing point can offer a means of monitoring changes in L when suitable equipment is not readily available or cannot be used in a given situation. In a structured environment such as a greenhouse where reflective surfaces may exist, the use of the LAI–2000 can present problems. Producing a uniform light environment over the whole hemisphere is difficult and the structural components of the greenhouse may interfere because they are so close.

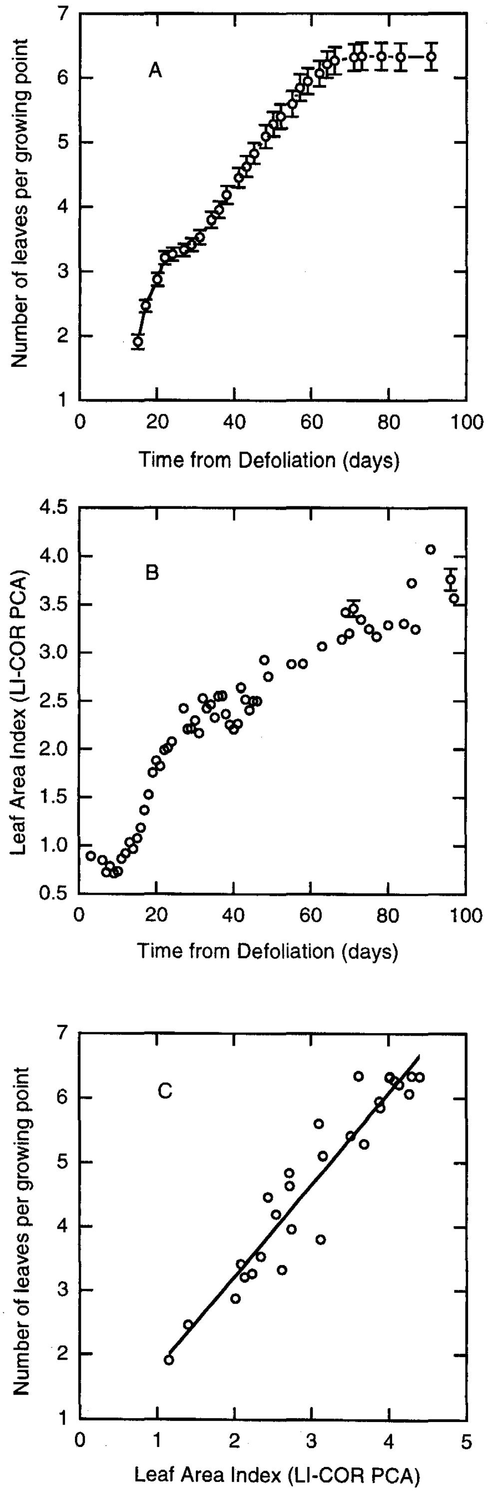

Fig. 1. Graphs showing (A) the mean number of leaves per growing point as a function of time after defoliation, (B) leaf area index as calculated by the LI–COR plant canopy analyzer as a function of time, and (C) the relationship between the number of leaves per growing point and leaf area index as calculated by the LI–COR plant canopy analyzer.

SFC.

A graph of the progression of canopy cover with time as calculated with SFC data is presented in Fig. 2. Two equations were used to describe the

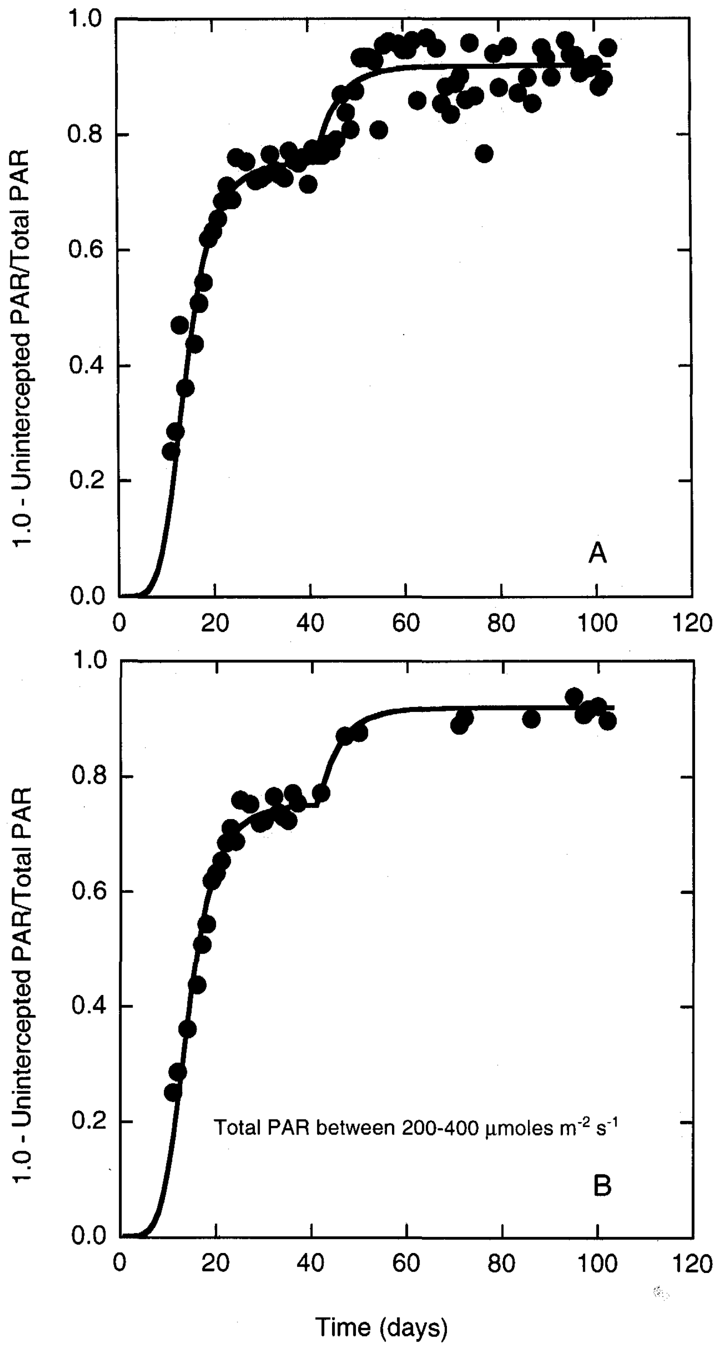

Fig. 2. Canopy cover calculated from measurements of total incoming PAR and PAR at the bottom of the crop canopy made by the Decagon Sunfleck Ceptometer. Graph A shows all calculated values of canopy cover. Graph B shows calcutated values of canopy cover when the total incoming PAR was between 200–400 μmoles $m^{-2} s^{-1}$.

Table 1. Parameter values ± standard errors to describe the two flushes of leaf growth (f1, f2) in terms of changes in canopy cover over time.

Parameter	Units	Values for f1	Values for f2
C_{fn}		0.755±0.001	0.919±0.001
$t_{0.5}$	days	14.1±0.016	35.7±0.312
a		4.95±0.031	10.3±0.477

Table 2. Estimation of extinction coefficient for each of five zenith angles for the LAI-2000 (± standard error) on 104 d and for the CI-110 plant canopy analyzer on 98 d from defoliation.

Zenith Angle (°)	LAI-2000	CI-110
7	0.63±0.02	1.22
23	0.64±0.03	1.00
38	0.62±0.01	0.98
53	0.61±0.02	0.97
68	0.38±0.003	0.97

change in canopy cover with time, t, because of the two flushes of growth. Parameter values for the equations are given in Table 1.

The difference between predicted–observed values for canopy cover declined systematically with increasing PAR (data not shown). To eliminate this bias, data points were chosen if the incoming PAR radiation was between 200 and 400 μmoles m^{-2} s^{-1} because the average mean error of the difference between predicted and observed was near zero (Fig. 2B). This selected reduction in observations did not require a change in parameter values. The same equations fit the observations in Fig. 2A and Fig. 2B.

Extinction Coefficients.

Extinction coefficient values for the five zenith angles for the LAI-2000 and CI-110 instruments were substantially different (Table 2). A K value of 0.63 should be used, according to the LAI-2000, for calculating the fraction of foliage intercepting a direct beam of radiation except for very low angles, when a much smaller fraction of the foliage intercepts the beam of radiation. On the other hand, the CI-110 software calculated values for K very nearly 1.00 for all angles except the highest angle where the fraction of foliage was computed to be 1.22.

Leaf Area Index.

The leaf canopy just before defoliation covered a ground area of 5.564 m^2. Both CI-110 and the LAI-2000 gave higher L values compared with the standard leaf dry weight and leaf area sampling technique, using a leaf area meter. CI-110 gave an L value closer to the standard method than the LAI-2000 (Table 3).

Table 3. Calculations of L (± standard error), K, and/or T from light measurements from various sources just before the second defoliation [98 d from first defoliation for the CI-110 and SFC and 104 d for the LAI-2000 and the LFDW and SLA method (leaf area index from leaf dry weight and specific leaf area)].

Method	L	Extinction Coefficient $K=-\mathrm{Log}_e(T)/L$	T
LFDW and SLA	2.35±0.09		
LAI-2000	3.60±0.001	0.466	0.187
CI-110	2.72±0.12	0.994	0.083
SFC			0.105

The large L calculated by the LAI-2000 is a consequence of the lower K values. The higher transmission values recorded by the LAI-2000 were not enough to compensate and bring the result closer to the standard value for L.

CONCLUSIONS

The number of leaves on a growing point can be used to monitor L when plant canopy analyzers are not readily available or environmental conditions do not favor their use.

Regeneration of canopy cover was rapid, beginning 10 d after defoliation and reaching >0.5 by 17 d after defoliation.

Based on the data from this experiment, it is impossible to define an appropriate extinction coefficient for coca that can be used to equate transmission coefficients and L.

A logistic equation can be used to describe progress in coca refoliation with time, t.

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DISCLAIMER

[1]Company and trades names are given for the benefit of the reader and do not imply an endorsement of the product or company by the USDA.

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