THE SEASONAL FLUCTUATION OF FLOWER PRODUCTION IN BIRD OF PARADISE AS AFFECTED BY LEAF COOLING PRACTICES IN HAWAII

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ABSTRACT

Eighty 1-year-old seedlings of bird of paradise, derived from siblings of 4 seed pods, were planted in the field in Waimanalo, Hawaii in 1982. Three treatments were applied: misting, 4 seconds in 10- to 15-minute intervals in the daytime in August-November 1984 and again in June-October 1985; shading, 30% black polypropylene continuous shade starting in August 1984; and control. Leaf emergence, flower emergence, and flower harvest were recorded from June 1983 to June 1986. The effects of leaf cooling treatments on the occurrence of seasonal fluctuation in flower production and in flower abortion were investigated.

Using air temperature and solar radiation measured at 10-minute intervals, a response surface regression for control leaf temperature accounted for 79% of variation. Regression analyses in mixed mode further indicated that, while mean air temperature 5 mm away from leaves was 31.3°C in sunny summer afternoons, control leaf temperature rose to 33.3°C, and misting and shading significantly reduced it from control by 4.6 and 3.2°C, respectively.

Since characteristics in branch development and inflorescence bud development until leaf emergence were determined to remain unseasonal, flower production patterns were studied by simulating them from leaf emergence. Time intervals in inflorescence growth after leaf emergence were estimated by leaf degree-minute models observed at 10-minute intervals.

The models satisfactorily predicted monthly flower production pattern by correctly indicating the occurrence of 4 peaks in the May 1985-May 1986 within 1 month. The use of leaf temperature enabled an estimation that a peak flowering period in July-September 1985 was extended by 1 month to October with misting in summer.

Although as many as 45% of emerged leaves including 3.4% non-producing leaves did not subtend flowers, flower abortion occurred all year without a seasonal fluctuation. Since leaf cooling by misting did not alter the number of flower abortion, flower abortion due to a high air temperature was judged unlikely to affect seasonal flower production pattern. Lack of available water and nutritional competition were suggested as possible causes of abortion.

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Abbreviations Used for Statistical Terms

Abbreviation	**Meaning**
ANOVA	Analysis of variance
CSS	Corrected sum of squares
CV	Coefficient of variation
DF	Degree of freedom
Diff	Difference
HO	Null hypothesis
Mult Factor	Multiplication factor
N	Number of observation
Pr	Probability
Pred	Predicted value
SD	Standard deviation
SE	Standard error of estimate
SS	Sum of squares
Std Err	Standard error
Tot	Total
USS	Uncorrected sum of squares
Var	Variance
x	Difference between actual and expected values

Names Used for Variables

Name	Dimension	Meaning
C	-	A level of discrete variable TRT
DAYS	day	Number of days of last-leaf emergence from December 31, 1982
FLLEN	mm	Inflorescence length
FX100-FM60	day	Sine function for LEINT with phase shifts
GEN	-	Branch generation number (1 for initial branch)
LEAF	fan^{-1}	Number of leaves produced by a fan
LEINT	day	Leaf emergence interval
LNFLLEN	ln(mm)	Inflorescence length in natural log
LNGEN	ln(GEN)	Branch generation number in natural log
M	-	A level of discrete variable TRT
MONTH	-	Month number starting 1 for January 1983
MSPL	day	Monthly mean of split interval
NSPLIT	-	Number of daughter fans produced by a split
PLANT	-	Discrete variable indicating plant identifications: 8, 20, and 24
RAD	$\text{J}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$	Solar radiation measured in the field
S	-	A level of discrete variable TRT
SEASON	-	Discrete variable indicating seasons: summer and winter
SET	-	Discrete variable indicating cloudiness condition: in the full sunlight (full-sun) and with clouds (all-sun)
SHEATH	-	Number of leafy sheath produced in flower stalk
SPLIT	plant^{-1}	Number of splits per plant
SPLITINT	day	Number of day between successive leaf emergences

Name	**Dimension**	**Meaning**
T1-T4	mV	Electrical potential measured for thermistors
T_{air}	°C	Air temperature near the leaf
TEMP	°C	Temperature
T_{field}	°C	Air temperature 18 m above the ground
TIME	day	Number of days from January 1, 1985
T_{leaf}	°C	Leaf temperature
$T_{leaf-air}$	°C	Temperature difference between leaf and air at 5 mm away from the leaf
$T_{leaf-field}$	°C	Temperature difference between leaf and air at 1.8 m above the ground
TRT	-	Discrete variable indicating leaf cooling treatments: misting (M), shading (S), and control (C)

Abbreviations Used for Models and Others

Abbreviation	**Meaning**
ALL-SUN	Leaf temperature model for all-weather condition
DDMAX	Heat unit accumulation model using daily maximum air temperature
DDMEA	Heat unit accumulation model using daily mean air temperature computed from 10-minute-interval measurements
DDMIN	Heat unit accumulation model using daily minimum air temperature
DM	Heat unit accumulation model using air temperature measured every 10 minute
DH	Heat unit accumulation model using air temperature recorded as hourly averages of 10-minute-intervals
DHI	Heat unit accumulation model using air temterature measured every hour
EPROM	Erasable and programmable read-only memory
FC	Stage of flower development at anthesis (flower cut)
FD	Stage of flower development at flower parts differentiation
FDFE	Time period between flower parts differentiation and flower emergence
FE	Stage of flower development at flower emergence
FEFC	Time period between flower emergence and anthesis
FI	Stage of flower development at flower initiation
FILE	Time period between flower initiation and leaf emergence
FULL-SUN	Leaf temperature model for clear-sky condition
IRT	Infrared thermistor
LDDMAX	Heat unit accumulation model using daily maximum leaf temperature

Abbreviation	**Meaning**
LDDMEA	Heat unit accumulation model using daily mean leaf temperature computed from 10-minute-interval measurements
LDDMIN	Heat unit accumulation model using daily minimum leaf temperature
LDM	Heat unit accumulation model using leaf temperature measured every 10 minute
LDH	Heat unit accumulation model using leaf temperature recorded as hourly averages of 10-minute-intervals
LDHI	Heat unit accumulation model using leaf temterature measured every hour
LE	Stage of flower development at leaf emergence
LEFC	Time period between leaf emergence and anthesis
LEFD	Time period between leaf emergence and flower parts differentiation
LEFE	Time period between leaf emergence and flower emergence
PPFD	Photosynthetic photon flux density
RTD	Metallic resistance thermistor

CHAPTER 1

INTRODUCTION

Bird of paradise, *Strelitzia reginae* (Ait.), is a common ornamental plant in Hawaii often used in subtropical landscapings for its exotic appearance. The plant is also grown in the field for cut flower markets, local and export. In 1986, the wholesale value of the cut flowers totaled $325,000 for the state of Hawaii which was 560% of the sales for 1981 ($58,000, Davis, 1986). The number of farms producing the cut flower also increased 150% (30 to 46 farms) and The number of flowers sold increased 460% (17,000 to 78,000 dozens) in the period. Growers in Europe have reduced production of the flower due to the high cost of greenhouse heating (Fransen, 1977). Since bird of paradise is grown in the field in Hawaii, growing bird of paradise costs less and it has an economic potential for this state.

A problem associated with bird of paradise flower production. One of the problems with field plantings of bird of paradise for flower production is difficulty in controlling the main flowering period. Geographic location of the planting showed considerable differences (Halevy, et al., 1976; Criley and Kawabata, 1984): the peak flowering periods were observed in June-September in Waimanalo, Hawaii; in October-December and March-May in San Diego, California; in March-April and September in Israel; and in fall-winter-spring in South Africa.

Factors contributing to difficulty in controlling main flowering period are an existence of seasonality in the flower growth (Kawabata, et al., 1984) and a slow growth and development of the plant (Kawabata and Criley, 1984). This research was intended to enable an estimation of the seasonality of flower production of bird of paradise and to modify the peak flowering period in Hawaii.

Review of previous work in bird of paradise modeling. The fluctuation of flower yield of bird of paradise is a dynamic system; a time-dependent regression analysis of the flower yield in Waimanalo, Hawaii for 7 years (Kawabata, et al., 1984) identified 2 trends in the system (Fig. 1), a long term increase (A) and annual fluctuations (B). These trends represented different characteristics. The long term trend (A) reflected the rate of plant growth and the adaptation of plant to the environment. The slope would vary according to the environment and the yield for a given time after planting may differ from one location to the other. On the other hand, annual trend (B) reflected the intensity of the seasonality (or the amount of fluctuation relative to the mean yield). The total yield for an annual cycle would not be affected by the strength of the seasonality for a specific location. Since the trends, a long term increase and annual fluctuations, represented different aspects in the flower yield, it was necessary to model these trends separately and to estimate the flower yield as a sum of the 2 trends.

Strategies for modeling bird of paradise flower production. For the long term trend, this dissertation research focused on quantifying the branch characteristics. Bird of paradise showed a dichotomous branching pattern (Fisher, 1976): a compressed underground stem usually split into 2 stems at the apical meristem (Fig. 2), and leaves from the new stems formed fans, clusters of leaves in a distichous arrangement which resembled a fan (Fig. 3), above the ground. Since a leaf normally subtended a flower stalk, the possible maximum flower production could be computed by multiplying the number of leaves produced per fan and the rate of occurrence of the branch split. By determining branch characteristics such as the rate of split occurrences, number of leaves produced by a fan, and leaf emergence intervals, it was possible to model the long term trend in flower production.

For the annual trend, the effect of flower abortion on the flower production was determined first. The flower abortion occurred when the flower bud was approximately 2 cm long and the flower parts were being differentiated at the apical meristem. The magnitude of abortion was estimated to be up to 50% of the annual yield in Waimanalo, Hawaii (Criley and Kawabata, 1984). The apparent loss of the flowers on flower production plots starting in a high temperature period in summer (Kawabata, et al., 1984) was suggested for shifting yield peaks.

Differential rate of the flower stalk elongation was modeled as sigmoidal curves since the seasonal fluctuation in the flower production could be the result of temperature environment (Kawabata, et al., 1984): high temperature in warm season increasing the rate of flower stalk elongation and low temperature in cool season delaying the flower development. The combined effect would create peaks and valleys of flower production.

By determining the effect of flower abortion and the rate of flower growth affected by the environment, the seasonality of flower production can be modeled.

Consideration of the environment and its modification. Although previous studies have provided information on the yield growth over years and the seasonality in the past, they may not be appropriate in predicting future occurrences. This is because the time-dependent regression analyses showed only the statistics of the yield in the past, and the environmental factors, varying year to year and affecting the plant growth, were not incorporated in the model. A long development period for the flower, estimated for 17-25 weeks from 2-cm stage to anthesis (Kawabata, et al., 1984), makes the growth readily influenced by the seasonal change of environment. For a dynamic system such as the flower yield of bird of paradise, therefore, it was desirable to make a model which included environmental variables so that the flowering time could be predicted.

No effort has been made previously to modify plant environment for field plantings of bird of paradise. Since high temperature in summer has been linked to flower bud abortion, lowering maximum plant temperatures in summer (Geiger, 1950) may reduce the number of flowers aborted. Two cultural practices, shading plants with a cover and wetting leaves with water, are practical and economical methods to modify the plant environment. Shading plants can reduce leaf temperature by limiting incoming solar radiation and misting leaves can lower leaf temperature by increasing evaporative cooling. These cultural practices, in addition to having a short term effect on flower abortion, can modify branching characteristics and plant growth rate and further increase the long term yield.

Objectives. The problem to be investigated in this research was the occurrence of seasonal fluctuation pattern in flower yield of bird of paradise in Hawaii and the objective was to build a model which would estimate the peak flowering period. The successful resolution of the objective will enable us to predict the flower production pattern of bird of paradise in Hawaii and to predict the shift in peaks of flower harvest modified by cultural practices.

In Chapter 2, regression models using environmental variables were developed for leaf temperature of bird of paradise under leaf cooling practices. In Chapter 3, the effects of leaf cooling practices on the flower production and the abortion rate were determined. In Chapter 4, long term plant growth was determined by estimating the parameters for branch characteristics. In Chapter 5, inflorescence growth before leaf emergence was modeled and the morphological state of the flower bud development before the 2-cm stage was investigated microscopically. In Chapter 6, seasonality in the flower growth in leaf emergence to anthesis was modeled with leaf temperature and the leaf cooling practices. In Chapter 7, flower production in Waimanalo, Hawaii was simulated using the parameters estimated.

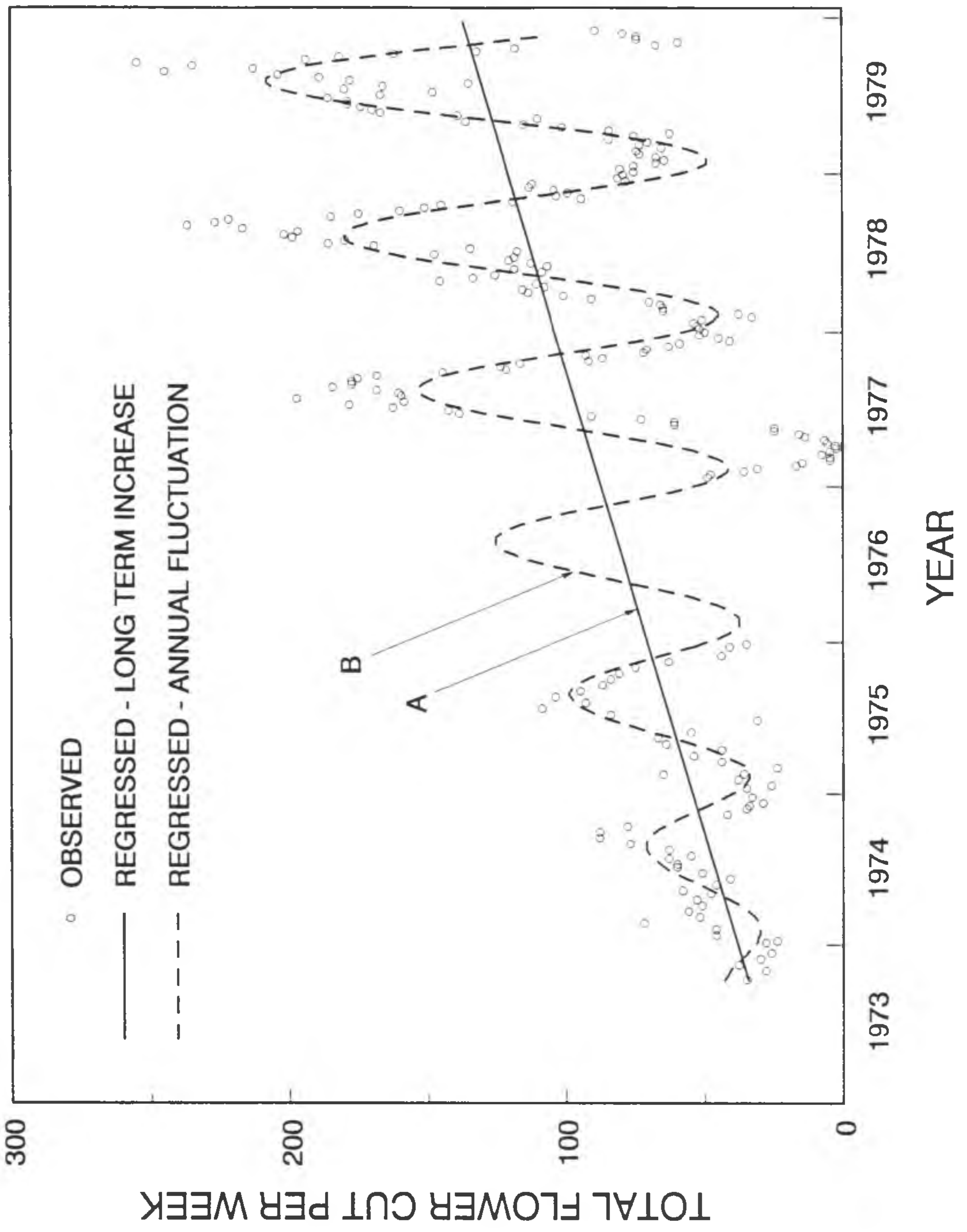

Figure 1. Bird of paradise flower yield from 108 seedlings planted in 1969-1970 in Waimanalo Experimental Farm, Waimanalo, Oahu. A, a long term increase due to the increase of plant size; B, annual fluctuations due to environmental change.

Figure 2. The apical meristems of bird of paradise which resulted from dichotomous branching. The leaves were removed in order to view the split.

Figure 3. Two fans of bird of paradise resulted from dichotomous branching.

CHAPTER 2

ESTIMATING LEAF TEMPERATURE OF BIRD OF PARADISE BY AIR TEMPERATURE, SOLAR RADIATION, AND LEAF COOLING PRACTICES

The temperature environment in Hawaii affects the flower production of bird of paradise. Low air temperatures (20°C was the lowest weekly average of daily means) have been shown to be the most influential environmental factor for the yield fluctuation among high and low air temperatures, daylength, and solar radiation. An air temperature of 27°C was proposed as an upper threshold for aborting the flower bud (Kawabata, et al., 1984). Air temperature has also been used to compare the flowering behavior of bird of paradise in 4 production sites in the world (Halevy, et al., 1987)

Although air temperatures measured in a meteorological shelter are useful, they do not precisely represent the plant temperature itself. Leaf temperature in the field, in general, is higher than the surrounding air in the day (Geiger, 1950) and air temperature near the ground fluctuates greater than in the shelter (Hannan, 1984). Therefore, direct monitoring of plant temperature is more desirable than monitoring air temperature for estimating the effect of thermal environment on the flower yield of bird of paradise.

Roots and stems of bird of paradise remain underground where temperature fluctuation is minimal. Only leaves and flowers emerge above the ground. With thin and wide structures in the air, the plant probably will experience the largest temperature change in its leaves. This study was designed to estimate the leaf temperature of bird of paradise in the field so that the temperature effect on the flower production can be evaluated more precisely.

2.1 Literature Review

Leaf temperature. Leaf temperature is used for managing cultural practices such as determining the irrigation scheduling in snap beans (Bonnano and Mack, 1983), corn (Geiser, et al., 1982), and soybean (Carson, et al., 1972), and yield estimation in wheat (Diaz, et al., 1983). Raschke (1960) discussed plant temperature as a result of energy balance system in which heat was transferred by convection, conduction, latent heat of energy, and radiation. He listed major factors affecting plant temperature: air temperature, longwave and shortwave radiation, relative humidity, mesophyll diffusion resistance, boundary layer resistance, and wind. Although all those factors affect leaf temperature, in practice only a small number are ordinarily used for its estimation: leaf temperature was estimated by air temperature in snap bean (Bonnano and Mack, 1983), by vapor pressure deficit and air temperature in soybean (Carson, et al., 1972), and solar radiation in cotton (Wiegand and Namken, 1966). These studies indicate that it is not necessary to measure all variables for a satisfactory estimation of leaf temperature since high correlations were found for each with leaf temperature.

Modifying temperature environment. Tanner (1974) explained micro climatic modification of temperature by an energy balance system: shading and pruning change light penetration, mulching and painting modify reflectance of soil surface, sprinkling modifies latent heat of energy, irrigation of soil changes thermal properties of soil, and greenhouses and other structures reduce air movement.

Numerous examples of reducing air temperature by evaporative cooling have been reported: a 5-10°C reduction in pear orchard (Lombard, et al., 1966), a 21°C reduction in alfalfa field (Robinson, 1970), a 3.5°C reduction in apple orchard (Unrath, 1972), and a 4-6°C reduction in apple field in spring (Stang, et al., 1978). Soil temperature was also reduced for 3.3°C by sprinkling in a potato field (Peterson and Weigle, 1970).

Reducing leaf temperature by evaporation. A direct approach for reducing temperature stress is to wet the plant itself. Water molecules evaporating from the plant surface will remove thermal energy from the surface and plant temperature is reduced. The effectiveness of this evaporative cooling was summarized (Table 1) for horticultural crops. All plants were sprinkled or misted in summer to reduce high temperature stress except for flower buds in apple and pear in which plants were sprinkled in spring to delay flowering. As temperature reductions were observed for all the plants listed, it is probable that wetting bird of paradise leaves would also reduce the leaf temperature.

There was no guideline to determine how much and how often water should be applied for evaporative cooling as it varied from experiment to experiment in the previous studies. Using sprinkling, water was applied from 2-min-on/2-min-off in apple (Anderson, et al., 1975) to 5/15 in pear (Lombard, et al., 1966) or continuous in the day time in prune (Even-Chen, et al., 1981) and potato (Peterson and Weigle, 1970). Using misting, which provides finer droplets than sprinklers, water was applied 1/5 in apple (Stang, et al., 1978) to continuous in plum (Gay, et al., 1971) and grape (Matthias and Coates, 1986).

It is undesirable to over-wet leaves because excess water drips down to the ground and only a portion of water applied contributes for evaporative cooling. This is important in an experiment since water evaporated from or absorbed by soil also may change soil temperature and soil water status and may interfere with the control condition of the ground. Since misting provides a smaller droplet size than sprinkling and is less susceptible to dripping, misting is preferred to sprinkling, although wind can more easily modify the distribution pattern of mist droplets.

The change in leaf temperature has been shown to lag behind changes in air temperature. When fleshy leaves of *Rheo discolor* under shade were brought into the full sunlight, 5-10 min were required before the leaf temperature reached the high temperature equilibrium (Geiger, 1950). When sprinkling grape leaves with water was stopped, 15 min were required before the leaf temperature returned to the temperature before sprinkling (Gilbert, et al., 1971). Therefore, the most appropriate method for a leaf cooling experiment by evaporation would probably be to mist just long enough to wet the leaves thoroughly at 10- to 15-min intervals, so that the leaf temperature would remain reduced and excess water loss would be minimal.

Other factors reducing leaf temperature. Shading is used to cool horticultural crops. Natural shading by its own leaves reduced plum fruit temperature by 4°C (Gay, et al., 1971). It is possible to reduce leaf temperature of bird of paradise by providing a shade if the reduced light intensity does not affect the plant growth. In South Africa, a low light intensity caused by tree shade reduced the flower production of bird of paradise (van de Venter, et al., 1980).

Wind is another environmental factor which may reduce leaf temperature. In a growth chamber experiment, a leaf-air temperature difference of sorghum leaves of 4°C was reduced to zero by 2 $m \cdot s^{-1}$ air movement (McCree, 1984). Umbel-air temperature difference in onion also was a function of wind speed and predicted within 2-3°C (Tanner and Goltz, 1972).

Sensors for measuring leaf temperature. There are many temperature measurement instruments: thermocouples, thermistors, mechanical and liquid expansion thermometer, infrared thermometers (IRT), metal resistance temperature detectors (RTD), and others (Geiger, 1950; Hannan, 1984). Although any of these methods can be used for leaf temperature sensing, only thermocouples, thermistors, IRTs, and RTDs are suited for unattended operation with computerized data logging equipment.

Thermocouples are by far the most frequently used sensors for plant temperature measurement. Copper-constantan thermocouples were used in apple (Anderson, et al., 1975; Stang, et al., 1978; Unrath, 1972), in peach (Bauer, et al., 1976), in plum (Gay, et al., 1971), in grape (Gilbert, et al., 1971), in pea (Howell, et al., 1971) and in onion (Tanner and Goltz, 1972). The advantages of this sensor are 1) the size is small that it can be implanted in the plant tissue, and 2) it can be used in a wide range of temperature fluctuation (-270 to 400°C with copper-constantan thermocouple). The disadvantages are 1) it needs a reference point which may be difficult to maintain in the field, and 2) the electric potential it creates is small (10-40 microV$\cdot$°C^{-1}) so that a large error is introduced in the amplification process.

Thermistors are not commonly used in plant temperature measurement probably due to their large size, typically 1-10 mm in diameter. But thermistors have some desirable characteristics: 1) high accuracy, within ±0.1°C; 2) high sensitivity, generally 30 mV$\cdot$°C^{-1}; and 3) high resistance which requires less power for the measurement.

RTDs function similar to thermistors except the sensing substance is usually a fine platinum wire instead of thermistor's compacted powder of metallic oxides. RTDs are suited for surface temperature sensing as the sensor can be formed in a plane. However, its low resistance, 50-100 ohm per sensor, requires a large power source, and sensor itself generates heat from the electrical excitation, adding a source of error.

IRTs have been often used to measure canopy temperature in agronomic crops: in soybean (Carson, et al., 1972), in wheat (Diaz, et al., 1983), in corn (Geiser, et al., 1982), in cotton (Wiegand and Namken, 1966), and in snap bean (Bonnano and Mack, 1983). The advantages of this method are 1) it can sense temperature from a distance without touching the object and 2) the existence of sensors does not influence the temperature. Disadvantages are 1) measurement is not precise as changes in leaf orientation, aiming angle, and solar azimuth cause error (Nielsen, et al., 1984), 2) it is difficult to measure the same spot of the leaf as leaves flutter with wind, and 3) the expense of instrumentation is greater than for other systems.

Therefore, the most suitable temperature measuring method for bird of paradise leaves in the field would be the use of thermistors because of their high precision, low energy consumption, high electrical potential output, and easiness of interfacing with data-logging equipment. The only shortcoming is that they are not small enough to be implanted in the leaf. If the power source is not restricting, thermocouples and RTDs can be better sensors because of the smaller size (thermocouples) or the flatter shape (RTDs).

The duration and interval for the temperature measurement. One of the earliest attempts for a continuous measurement of temperature was done by Geiger (1950). He monitored air temperature and leaf temperature of *Bilbergia* continuously for 2 days by resistance thermometers. The leaf temperature was approximately 10°C or higher than air in the middle of the day, and the leaf temperature fluctuated more than the air temperature.

In recent studies, the interval of leaf temperature measurement was continuous in grape (Gilbert, et al., 1971), at 10 min interval in plum (Gay, et al., 1971), at 15 min interval in grape (Matthias and Coates, 1986), and at 1 hour interval in apple (Anderson, et al., 1975) and in pea (Howell, et al., 1971). The duration of monitoring in these studies was less than 2 days except for grape (Matthias and Coates, 1986) in which leaf temperature and solar radiation were recorded throughout a summer. These researchers reported the means or the maximum differences of air and leaf temperatures for the observation periods, and no one attempted to model the plant growth modified by the temperature difference.

If air temperature is related to the temperature difference (of leaf and air), information such as the mean or the maximum temperature difference would not be adequate for modeling plant growth since air temperature fluctuates daily and over the plant growth period. Therefore, it is desirable to measure temperature environment continuously or in short intervals for the entire plant growth period so that a leaf temperature model (or the temperature difference model) can be used for estimating plant growth.

Statistical methods. Since the discovery of the method of least squares by C. F. Gauss in the beginning of the 19th century (Stigler, 1981), the development in the method of linear regression has been steady but slow due to the intensive computation required. Many of the procedures became usable only after high-speed processing power of computers made a wide use of the methods possible approximately 25 years ago. Recent developments are in the areas of residual analysis, collinearity problem, data transformation, stepwise regression, ridge regression, nonlinear regression, criteria for the model selection, and the use of graphics (Hocking, 1983).

One of these developments prompted by the use of computers is response surface analysis, a variation of multiple regression analysis. The number of days to flower in chrysanthemum 'Bright Golden Anne', for example, was regressed by day temperature, night temperature, and 3 levels of radiation (Karlsson and Heins, 1986). Such a multiple regression analysis approach is desirable in plant response studies since the plant interacts with more than 1 environmental factor.

One of the newest developments in the statistics is the sequential fitting of linear models, a computational procedure known as "the Sweep Operator" (Goodnight, 1979) or "the Abbreviated Doolittle Loop" (Allen and Cady, 1982). This procedure brings explanatory variables into the model one at a time, converts them into a variable orthogonal to the variables already in the model, and computes the additional sum of squares explained by the additional variable. The significance of variables sequentially added in the model can be verified by the *t* test at each step when a variable is added. With the creation of indicator variables (Allen and Cady, 1982), this regression procedure also can process an analysis of classification variables (ANOVA) as a special case of linear regression. Thus, most of the existing statistical models can be approached by one "generalized and unified" linear model (Allen and Cady, 1982). The use of this sequential linear model fitting procedure is well documented for computer applications (Freund, et al., 1986; Allen, 1984).

A practical benefit of using this statistical approach for the experimental design is that it makes the mixed mode data analyses easy. A covariate analysis is the simplest example of the mixed mode data analysis: a covariate variable (a numeric variable) is used to reduce the error sum of squares in an analysis of means (of a discrete variable). Using the sequential model fitting, an additional interaction (between the numeric and the discrete variables) can be added to the model which further reduces the error term and enables the test of the homogeneity in regression coefficients (slopes). This method greatly reduces the computational complexity involved in the comparison of slopes explained in the conventional covariate analysis (Snedecor and Cochran, 1967).

For this research, modeling the bird of paradise leaf temperature can be viewed as a multiple regression in terms of numeric variables (leaf temperature and solar radiation) and an analysis of variance in terms of discrete variable (leaf cooling practices). With the sequential model fitting, these models become a response surface regression model, and the significance of differences in treatment means, slopes, curvatures, and the interactions among discrete and numeric variables can be computed and tested.

Determining the leaf temperature of bird of paradise was necessary. The reasons were 1) improving the precision of the flower growth model was possible with the use of leaf temperature as the characteristics in the flower production pattern were related most closely to the air temperature in Hawaii (Kawabata, et al., 1984) and leaf temperature would reflect the plant growth better than air temperature. 2) The estimation of leaf temperature was also required to determine the effect of misting and shading on the flower production. Therefore, this study was intended to answer following questions in order to model the flower production pattern of bird of paradise under control and leaf cooling treatments in Hawaii:

1. Do shading and misting treatments reduce the leaf temperature of bird of paradise?
2. If they do, how much can the temperature be lowered?
3. Is it possible to make a leaf temperature prediction model?

2.2 Materials and Methods

Plant material. Sibling seeds of bird of paradise from open-pollinated seed pods from one mother plant were sown in Spring 1981, transplanted in 10-cm pots in Fall 1981, and 80 seedlings were planted in the field at Waimanalo Experimental Farm, Waimanalo, Oahu, in November 1982. The field was scheduled for watering with 25 mm per week by overhead sprinklers. An irrigation system was installed in July 1984 using a public water line for a dependable scheduling. Each plant was watered by a nozzle which formed 90° fan-shape spray. The spray was aimed at the base of plant from 30 cm away. No water was sprayed on the leaf. The amount of water applied to a plant was 34 liters a day and 3 days a week in summer. If an effective area of watering was 1 m^2, then the application of city water is equivalent to 10 $mm \cdot wk^{-1}$.

Location. The experimental site, Waimanalo Experimental Farm, Waimanalo, Oahu, is at an altitude of 25 m, and has a photoperiod between 10 hr 50 min and 13 hr 26 min, solar integral between 2 and 26 $MJ \cdot m^{-2} \cdot day^{-1}$, average annual rainfall of 1000-1300 mm, and average northeasterly wind of 9 $m \cdot s^{-1}$ (Armstrong, 1973).

Treatments. The field consisted of 3 blocks, 24 plants per block, and they were treated with misting, shading, or control (no leaf cooling treatment).

Misting was applied in summer, August 22-November 14 period in 1984 and again June 14-October 2 in 1985. A plastic mist nozzle (Fig. 4) with a circular spray shape, delivering 0.057 liter per second, was placed on the north-east side of the canopy on each of the plant. The misting system was set to turn on approximately 4 sec in every 10-15 min controlled by an electric mist controller, SolaSpray (Fig. 5; Model 3, Append A). The total amount of water applied (Table 2) through the misting system was reduced as the SolaSpray increased the time intervals between on-times when the water environment was judged less than extremely stressful by its own sensors for air temperature, light than extremely stressful by its own sensors for air temperature, light intensity, and humidity. Misting was automatically turned off at night.

A 30% shade was provided by black polypropylene shadecloths placed 3 m above the ground (Fig. 6). They were installed on August 1, 1984, and left in the field until the end of the experiment, June 1986.

Equipment used for the data collection. A Datapod, a 2-channel electric potential recorder (B, Fig. 5; model DP-211, Append. A), was used for recording air temperature with a thermistor sensor (TP-10V, Append. A) and radiant flux density with a pyranometer (LI-200S, Append. A). The unit operated on AA-size batteries and the data collected were stored in an erasable and programmable read-only memory (EPROM). The recording interval was set to 10 min which enabled the unit to operate for 1 week without replacing EPROMs.

An Easylogger, a multi channel recorder (A, Fig. 5; EL824-GP, Append. A), was used for collecting leaf, air, and soil temperatures. The unit operated similarly to the Datapod except the Easylogger had a larger EPROM memory capacity, more channels, and more flexibility in storing data.

Leaf temperature was measured by 4 thermistors (ON-909-44008, Append. A). The thermistor was selected for its high resistance (30K ohms at 25°C) for power conservation, flat metal surface for a better contact with a leaf, water resistance, and a high accuracy (interchangeable at ±0.2°C). A temperature sensing assembly, an electric bridge (Fig. 7), was constructed for each sensor to record the temperature change, and 5 V excitation was applied by the Easylogger.

Each sensor assembly was calibrated (Fig. 8) with a mercury thermometer (Chicago Surgical and Electrical, Append. A) on a slide warmer by warming it with electric heat and cooling it with an ice. A quadratic regression was performed for each of the sensor assembly (Table 3). The regression coefficients estimated by the regressions were registered in the Easylogger program so that the Easylogger would recorded actual temperature measurement instead of the electrical potential reading.

To standardize leaf temperature readings, the youngest expanded leaves facing south were chosen for the measurement. Sensors were attached to the leaf in the center of the blade on the abaxial surface to avoid exposure to direct radiation. A coil spring was used to apply a pressure on the sensor so that the leaf did not receive physical damage but permitted enough contact with the sensor for the measurement. Air temperature near the leaf was recorded by placing a thermistor approximately 5 mm away from the leaf (Fig. 9).

Data collected. Air temperature and radiant flux density were recorded January 1, 1984, through June 30, 1986, in 10 min intervals using the Datapod. The sensors, representing the weather shelter readings, were located 1.8 m above the ground.

Leaf temperature of control (in the full sunlight) and the air temperature near the leaf were recorded August 2, 1985, through

February 10, 1986, in 10-min intervals using the Easylogger. Leaves to which sensors were attached were changed 12 times in the period to represent leaves generally and to avoid the deterioration of leaves. Leaf temperature of the misting treatment was recorded August 2 through August 18 in 1985, and shading treatment was recorded 2 through 18 in August 1985 and again December 3, 1985, through January 15, 1986. The Easylogger was synchronized with the Datapod to have simultaneous recordings among the measured variables.

The following variables were taken as additional measurements:

a. *Leaf temperature of young and old leaves.* Although leaf temperature was measured on the youngest fully expanded leaf, the majority of the leaves consisted of older leaves which might show a different temperature response than the young leaves. The young leaves were represented by a leaf which emerged on June 26, 1985, and the old by a leaf which emerged on February 27, 1985. The old leaves had 3 leaves prior to the emergences of the young leaves.

b. *Leaf temperature with different orientation.* A cross section of southerly facing leaf of bird of paradise had 2 sides in a V-shape arrangement, an east half facing westerly and a west half facing easterly. The difference in temperature response of these halves to the daily movement of the sun was sought by comparing them with a southerly facing half since the leaf temperature measurement could be affected by the location of the sensors.

c. *Soil temperature.* Fluctuation in soil temperature was sought since it was not included in the search of explanatory variables for the seasonal fluctuation in flowering of bird of paradise (Kawabata, et al., 1984), and it could affect flower bud development at the 2-cm stage when flower bud abortion often occurred (Criley and Kawabata, 1984). The sensors were inserted 5 cm below the soil surface next to the stems where the flower buds were located. The measurements were taken in summer and winter for a comparison, and the soil temperatures under misting in summer and under shading in winter were also recorded.

Data analysis. The raw data stored in EPROMs of the Datapod were retrieved by the Easyreader program (Program 1), an application program written in BASIC language. The solar radiation reading, stored as millivolts (mV), was converted to an energy unit (LI-COR, 1982), $J \cdot m^{-2} \cdot s^{-1}$, by multiplying the Datapod reading with 1000/7.1 as the LI-200S pyranometer generated 7.1 mV for 1000 $J \cdot m^{-2} \cdot s^{-1}$ (by the manufacturer's calibration). The Easyreader program also converted the date and time records to the SAS (Appendix A) datetime format for further data analysis. Daily summaries for the maximum and minimum air temperatures 1.8 m above the ground, and the daily solar radiation integral were computed for the entire data collection period. The instantaneous readings of the sensors in 10-min intervals represented the weather condition for the previous 10-min period.

The temperature readings of the Easylogger were retrieved by a commercial communication program, and the corresponding air temperature 1.8 m above the ground and solar radiation values recorded by the Datapod were added to this data.

The cloud cover changes the solar spectra observed on the earth surface (Gates, 1965), and the experimental site was frequently overcast most of the day. Since leaf temperature is dependent partly on the heat from solar radiation, the leaf temperature estimation would contain an undetermined amount of error if the solar radiation did not have a straight-line response to the cloudiness (or the leaf temperature response to solar radiation changed with the cloudiness). Although the cloud cover measurement was not recorded, two subsets of the data, FULL-SUN and ALL-SUN, were derived from the original to test the effect of cloudiness on the leaf temperature models.

FULL-SUN data. The FULL-SUN data set was selected for representing the clear-sky-only condition in the field: days with high solar integral values were chosen from August 1985-January 1986 period graphically on the daily plots. Relatively constant intervals between the dates selected were maintained to enhance an equal representation of the air temperature range in the site. The data before 11:00 and after 14:00 were deleted because the direct sun could hit the thermistors, one side of the leaf blade could shade the other, and light angle was low. The low radiation instances occurring in these days were identified from the daily plots and deleted individually.

Using measurements of solar radiation, air temperatures near the leaf and 1.8 m above the ground, a response surface regression model for leaf temperature was developed for the clear-sky condition for the site. The temperature difference between the leaf and air near the leaf, and the temperature difference between the leaf and air 1.8 m above the ground were also modeled for comparison.

ALL-SUN data. The ALL-SUN data were selected for representing the average weather condition at the experimental site: the daily records between 11:00 and 14:00 from August 2, 1985, to February 10, 1986, were included in this data set regardless of the solar radiation level.

A response surface regression model for the ALL-SUN leaf temperature was developed for the comparison with the FULL-SUN model. The cloudiness was represented by 2 data sets, FULL-SUN and ALL-SUN, consisting a set of indicator variables. The possible interactions between the explanatory variables and the cloudiness on the leaf temperature were searched by blocking the sum of squares into separate means, slopes, and curvatures for the 2 response surfaces and tested with F tests with 1 degree of freedom (*t* tests).

Leaf cooling practices. Response surface regression models for the leaf temperature under misting and shading treatments were developed using the same procedure as the FULL-SUN model. The effectiveness of the leaf cooling practices was tested by comparing each treatment with the control for the different characteristics of the response surfaces.

Following computers and computer programs were used for the data analysis: statistical models were developed and compared with sequential model fitting incorporated in the PC SAS (SAS, Append. A) and the STAN (Statistical Consultants, Append. A) running on the IBM

PC/AT (IBM, Append. A); data modifications were handled by the PC SAS and the Quick BASIC (Microsoft, Append. A); and graphic outputs were plotted by the Zeta plotter (Nicolet, Append. A) with the SAS running on the IBM 3180 (IBM, Append. A) mainframe computer at the University of Hawaii Computing Center or printed by the LaserJet printer (Hewlett Packard, Append. A) with the GRAPHWRITER and the FREELANCE programs (Lotus Development, Append. A) running on the IBM PC/AT.

2.3 Results

2.3.1 Description of Variables Measured

The characteristics in annual and daily fluctuations of air temperature 1.8 m above the ground and solar radiation at the experimental site were studied before building leaf temperature models. The effects of leaf age and orientation on the leaf temperature, and soil temperature fluctuation were also investigated.

2.3.1.1 Annual Fluctuation of Air Temperature 1.8 M above the Ground

The daily maximum of air temperature 1.8 m above the ground ranged 21.5-40.5°C, and the daily minimum ranged 10.5-25.0°C in the January 1984-May 1986 period (Fig. 10). Days with a high maximum tend to have a low minimum probably due to a greater loss of heat to the long wave radiation to a clear sky than to a cloudy sky.

A metal cabinet placed in the field to hold the sensor could have raised the temperature reading when there was not enough air movement to remove the hot air surrounding it. This was observed occasionally as abnormally high temperature in the morning when the sun hit the side of the cabinet.

2.3.1.2 Annual Fluctuation of Solar Radiation

The daily sum of solar radiation ranged 1.3-26.0 $MJ \cdot m^{-2} \cdot day^{-1}$ for the same period as air temperature 1.8 m above the ground (Fig. 11). Plots of high radiation sums generally followed a sine curve fluctuating 10-25 $MJ \cdot m^{-2} \cdot day^{-1}$, and the presence of large and frequent deviations from the sine curve indicated large day-to-day variations existed due to cloud covers. Fifteen days with high radiation sums were visually determined (arrows, Fig. 11) for the FULL-SUN data representing clear-sky weather in the experimental site (Table 4).

2.3.1.3 Daily Fluctuation among the Variables Measured

The relationships among measured variables were represented by the records on August 22, 1985 (Fig. 12). The solar radiation showed a peak at noon with sharp depressions caused by occasional passing clouds. The air temperature 1.8 m above the ground followed the pattern of the solar radiation reaching the maximum of near 30°C in the morning and remaining at that level for the most of the afternoon. Contrary to the air temperature, the leaf temperature continued to increase in the afternoon until 15:00. The air temperature near the leaf was between the air temperature 1.8 m above the ground and the leaf temperature. The short-term fluctuations (at 10-min intervals) in temperature measurements corresponded well to the solar radiation and correlated well with each other. The soil temperature showed a small and smooth fluctuation following the solar radiation.

The readings of leaf temperature and the air temperatures at night were almost identical which assured valid comparisons among readings from different sensors and data recording devices.

2.3.1.4 Graphic Comparison of Leaf Cooling Practices

The leaf temperatures under misting, shading, and control were compared with each other and with the air temperature near the leaf using the records on August 15, 1985 (Fig. 13). While the air temperature near the leaf remained 30-33°C in the 11:00-16:00 period, the control leaf temperature constantly exceeded the air temperature peaking after 15:00 at 36-37°C. The misted leaves started showing the cooling effect about 10:30 and leaf temperature remained within 25-30°C most of the afternoon. The shaded leaves also showed a temperature reduction, remained within 28-33°C, although it was not as effective as the misting.

The large short-term fluctuations in the day were caused by the reduced solar radiation by passing clouds, and the high temperature readings before 10:30 were probably caused by the direct irradiation of sensors by the morning sun.

2.3.1.5 Comparison of Leaf Temperature of Young and Old Leaves

The leaf temperature records of September 29, 1985, shows a typical difference between young and old leaves (Fig. 14). The leaf temperature of the old leaf increased at a higher rate than the young leaf reaching the maximum at 9:00 in the morning, while the leaf temperature of young leaf reached the maximum after the noon. This could indicate that the transpiration system in the old leaves became less efficient than the young as the leaves aged. The cloud cover reduced the leaf temperatures after 13:00.

2.3.1.6 Comparison of Leaf Orientation

The leaf temperature record of September 11, 1985, shows the effect of leaf orientation on the leaf temperature (Fig. 15). The east (westerly facing) half and the southerly facing half were irradiated on the abaxial surface in the morning until 10:00 resulting erroneously high temperature readings. Between 10:30 and 13:30 when leaves were correctly irradiated on the adaxial surfaces, the leaf temperature of the east (westerly facing) half increased, the west (easterly facing) half decreased, and the southerly facing half decreased slightly as the sun shifted. This leaf orientation effect forced the leaf temperature to be taken from selected leaves (of the southerly facing half) for a specific time period in a day (10:30-13:30) in order to reduce the variation.

2.3.1.7 Soil Temperature

The summer soil temperature, represented by the August 22, 1985 record (Fig. 16), fluctuated between 24 and 29°C in the August 19 through August 29 period in 1985. The winter soil temperature, represented by the January 19, 1986 record, fluctuated between 20 and 24°C in the January 16 through February 10 period in 1986. The misting caused a maximum of 2°C reduction in summer but the shading had no effect in winter. The misting was not used in winter, and the soil temperature under shade in summer was not recorded.

2.3.2 Development of a Leaf Temperature Model Using Clear-Sky (FULL-SUN) Data

A regression model for the leaf temperature of bird of paradise (T_{leaf} in °C) can become complex. The model can be considered not only as a multivariate model with respect to the explanatory variables, air temperature near the leaf (T_{air} in °C), air temperature 1.8 m above the ground (T_{field} in °C), and solar radiation (RAD in $MJ \cdot m^{-2} \cdot day^{-1}$), but also as a polynomial model with respect to each of the explanatory variables. Therefore, a guideline was necessary to achieve a meaningful model for T_{leaf}. The model was systematically developed by 1) determining the degree of polynomial effects for each of the explanatory variable, 2) determining the combination of explanatory variables for the multiple regression, and 3) combining the variables selected by the previous two procedures and eliminating insignificant interactions.

1) Determining explanatory variables for the degree of polynomial effect

T_{air} T_{air} had a significant straight-line effect on T_{leaf} and a quadratic effect was not significant (Table 5). Therefore, the model

was reduced to the straight-line model which still retained a relatively high coefficient of determination (R^2=0.76, Fig. 17).

T_{field} T_{field} had both straight-line and quadratic effects significant on T_{leaf} (Table 6). The plots of data were more scattered than T_{air} (R^2=0.36, Fig. 18). An imaginary straight-line boundary (I, Fig. 18) was observed where T_{leaf} approximately equaled to T_{field}, and no observation below the boundary was found. This could indicate the leaf cooling by transpiration was negligible.

RAD RAD had both straight-line and quadratic effects significant on T_{leaf} (Table 7). A negative regression coefficient for the quadratic effect (-.00000642) indicated T_{leaf} did not rise indefinitely when RAD increased (Fig. 19). Heat loss from the leaf by the longwave re-radiation could have increased as T_{leaf} increased, and the loss stabilized T_{leaf} approximately at 35°C. The coefficient of determination for RAD was the lowest (R^2=0.28) among the explanatory variables.

T_{air} vs. RAD T_{air} was plotted against RAD to examine the evenness of the distribution, because the FULL-SUN data were selected so that the air temperature response to the solar radiation was determined when all levels of RAD in a year were represented equally (Fig. 20). While the ideal observation would be the data scattered around a line from low RAD/low T_{air} to high/high with an uniform distribution, a larger

scatter was seen in low RAD region. The existence of data in high T_{air}/low RAD region indicated that the data set included some observations when the sky was cloudy in a high temperature season. The observations in the low/high and high/low regions were absent because such conditions did not occur naturally in the experimental site. Although the scatter was not perfect as no data on cloudiness was recorded, the FULL-SUN data set would represent the air temperatures in clear days in Waimanalo, Oahu.

2) Selecting the explanatory variables

Variables selected for the T_{leaf} model were T_{air} with straight-line effect and RAD with straight-line and quadratic effects. T_{field} was eliminated because T_{air} accounted for the variance in T_{leaf} more than T_{field} (R^2 of 0.76 and 0.36, respectively) and the addition of the second air temperature measurement would be redundant.

3) Combining explanatory variables and eliminating undesirable interactions

A combined model with full interactions was examined by sequentially fitting the explanatory variables on T_{leaf}: T_{air} mean, T_{air} straight-line effect, RAD straight-line effect, RAD quadratic effect, interaction between T_{air} straight-line and RAD straight-line effects, and interaction between T_{air} straight-line and RAD quadratic effect on T_{leaf} (Table 8). In this study, this variable sequence was written, according to Allen and Cady (1982), as:

T_{leaf} Mean | T_{air} | RAD | RAD·RAD | T_{air}·RAD | T_{air}·RAD·RAD

.... Variable Sequence 1

Since one of the interactions, T_{air}·RAD·RAD, was insignificant (Table 8), it was eliminated from the model. Therefore, the final model (Table 9) was determined as:

T_{leaf} Mean | T_{air} | RAD | RAD·RAD | T_{air}·RAD

.... Variable Sequence 2

and the regression equation was:

$$T_{leaf} = 2.57 + 0.829 \cdot T_{air} + 0.419 \cdot RAD - 0.0000123 \cdot RAD \cdot RAD + 0.000409 \cdot T_{air} \cdot RAD \quad \text{Eq. 1}$$

A response surface representation of the T_{leaf} estimates (Fig. 21) showed a negative quadratic effect with RAD, linear increase with T_{air}, and an interaction between linear effects of T_{air} and RAD. The increase in T_{leaf} for a unit increase in RAD was greater at the higher T_{air} than lower.

The residual plot on T_{air} for the reduced FULL-SUN model showed no apparent trend left (Fig. 22). Due to the bivariate nature of the data, the residuals appeared in a circular distribution.

2.3.2.1 Difference between Leaf and Air Temperature near the Leaf.

The difference between T_{leaf} and T_{air} ($T_{leaf-air}$) was modeled with the same variable sequence as T_{leaf} (Variable Sequence 2). The analysis of variance (Table 10) showed only the estimate of regression coefficients for T_{air} (-0.171) was different from the T_{leaf} model (0.829, Table 9). Since subtracting the explanatory variable (T_{air}) from the response variable (T_{leaf}) only affected the straight-line effect for a unity (0.829 - 1 = -0.171), no change was occurred in the regression coefficients in the variables regressed after T_{air}.

The response surface (Fig. 23) shows the difference decreases in both high and low ends of RAD, and the maximum difference 3.4-3.7°C is expected with RAD at 570-770 $J \cdot m^{-2} \cdot s^{-1}$ when T_{air} ranges 24-36°C. Under a low radiation condition (RAD < 500 $J \cdot m^{-2} \cdot s^{-1}$) the difference became less positive or more negative as T_{air} increases, while the difference becomes more positive in a high radiation condition (RAD > 500 $J \cdot m^{-2} \cdot s^{-1}$).

2.3.2.2 Difference between Leaf and Air Temperature 1.8 M above the Ground

Difference between T_{leaf} and T_{field} ($T_{leaf-field}$) was modeled with the same procedure as T_{leaf} model for FULL-SUN using T_{field} and RAD as explanatory variables. The resultant model (Table 11),

$T_{leaf-field}$ Mean | T_{field} | $T_{field} \cdot T_{field}$ | RAD | RAD·RAD |
$T_{field} \cdot$RAD | $T_{field} \cdot$RAD·RAD .... Variable Sequence 3

showed both T_{field} and RAD had significant quadratic effects. The interaction of straight-line effect of RAD and T_{field} ($T_{field} \cdot RAD$) was left in the model despite the insignificance because the quadratic interaction term following it ($T_{leaf} \cdot RAD \cdot RAD$) was significant.

The response surface (Fig. 24) shows a general decrease in the difference as T_{field} increases. The greatest difference 7-13°C is expected at the lowest T_{field} value at 24. RAD has a negative quadratic effect in the higher air temperature range ($T_{field} > 26$), while it has a positive quadratic effect in the lower air temperature range ($T_{field} < 26$).

2.3.3 Development of Leaf Temperature Model Using All-Weather (ALL-SUN) Data

The ALL-SUN data contained 3438 observations. Unlike the FULL-SUN data which was selected for clear sky, the ALL-SUN included all-weather conditions including rain. The same model building procedure as the FULL-SUN data was followed.

T_{air} T_{air} had significant straight-line and quadratic effects on T_{leaf} (T_{leaf} mean | T_{air} | $T_{air} \cdot T_{air}$, Table 12). This was different from the same variable for the FULL-SUN data which had only a straight-line effect significant. The data points were clustered tighter ($R^2=0.88$) than FULL-SUN partly due to the cloud cover reduced the variance (Fig. 25).

T_{field} T_{field} had significant straight-line and quadratic effects on T_{leaf} (T_{leaf} Mean | T_{field} | $T_{field} \cdot T_{field}$, Table 13). As with the FULL-SUN data, this variable explained less variance than T_{air} did ($R^2=0.49$, Fig. 26).

RAD RAD had significant straight-line and quadratic effects on T_{leaf} (T_{leaf} Mean | RAD | RAD·RAD, Table 14, Fig. 27).

T_{air} vs. T_{field} An additional analysis was made to examine the relationship between 2 air temperature measurements, T_{air} and T_{field}. These temperatures were highly correlated as a quadratic regression of T_{field} on T_{air} (T_{air} Mean | T_{field} | $T_{field} \cdot T_{field}$, Table 15) accounted 67% of the variation (Fig. 28). Therefore, it is unnecessary to include both variables in the model.

Although the optimal model for the ALL-SUN data would include the significant quadratic effect of T_{air}, the variable sequence for the FULL-SUN data (Variable Sequence 2) was followed for the ALL-SUN model in order to make a comparison of 2 data sets possible. The model explained 91% of the variance in the ALL-SUN data and all variables in the model were significant (Table 16).

2.3.4 Comparison of Clear-Sky and All-Weather Models

Two response surfaces (FULL-SUN and ALL-SUN) were statistically compared to determine if the differences among slopes within the surfaces were significant. Although these data sets were derived from the same source, each represented different weather conditions: the FULL-SUN for clear-sky and the ALL-SUN for all-weather conditions.

A sum of squares due to having 2 separate response surfaces was computed. 1) A new discrete variable, SET, was created which had only 2 values, FULL-SUN or ALL-SUN, to indicate the source of data. 2) A common response surface was created by combining 2 data sets and fitting a common variable sequence on T_{leaf} (T_{leaf} mean | T_{air} | RAD | RAD·RAD | T_{air}·RAD, Variable Sequence 2). 3) The main effect of SET and its interactions with the preceding variables was added in a full sequence (T_{leaf} mean | T_{air} | RAD | RAD·RAD | T_{air}·RAD | SET | SET·T_{air} | SET·RAD | SET·RAD·RAD | SET·T_{air}·RAD). 4) The full model was reduced by deleting insignificant variables.

The analysis of variance for the full model (Table 17) showed that significant differences were found in SET (having separate means, 33.4 for the FULL-SUN and 30.4 for the ALL-SUN), SET·RAD (having separate slopes with RAD, 0.0042 and 0.0019 respectively), and SET·RAD·RAD (having separate curvatures with RAD, -0.000012 and -0.0000082 respectively). However, 2 interactions in the model which involved air temperature, SET·T_{air} and SET·T_{air}·RAD, were not significant, and they were eliminated from the model. Therefore, the model for this comparison was determined as:

T_{leaf} Mean | T_{air} | RAD | RAD·RAD | T_{air}·RAD | SET | SET·RAD |
SET·RAD·RAD .... Variable Sequence 4

The analysis of variance for this reduced model showed that all variables were significant (Table 18). With a discrete variable (SET) in the model, the regression matrix became non-estimable. Therefore, the estimates of coefficients were biased. For a computational purpose, values of zero were used as a biased estimates (generalized inverse, SAS Institute, 1986).

These response surfaces were plotted together to visualize the differences (Fig. 29). T_{leaf} increases proportionally in a response to the increase in T_{air} without having an interaction with SET (having the same T_{air} slopes), but RAD interacts with SET for both linear and quadratic effects (having separate slopes and curvatures with RAD). The residual plots (Fig. 30) shows no trend left in the model.

2.3.5 Comparison of Leaf Cooling Treatments with Control

Four days with high solar integrals were identified by visually inspecting the daily plots of solar radiation for August 2 through August 19 in 1985 when the leaf temperature under misting, shading, and control were recorded simultaneously. A total of 136 data points with high radiation values were determined. A new discrete variable, TRT, was created to indicate the source of data: misting, shading, or control.

With TRT pooled, T_{air} had only a straight-line effect significant, while T_{field} and RAD had significant straight-line and quadratic effects (Table 19). T_{air} was chosen again for an explanatory temperature variable over T_{field} because of a higher coefficient of determination. The combined model was determined as T_{leaf} Mean | RAD | RAD·RAD | T_{air} leaving insignificant interactions with T_{air} in the full model (Table 20). A low coefficient of determination (R^2=0.30) indicated a large portion of the variance was still unaccounted by the model.

The final model for the leaf cooling practices was determined as a full model with TRT interactions:

T_{leaf} mean | RAD | RAD·RAD | T_{air} | TRT | TRT·RAD | TRT·RAD·RAD |
TRT·T_{air} ....Variable Sequence 5

The analysis of variance (Table 21) showed all variables were significant. Means were 28.7°C for misting, 30.1 for shading, and 33.3 for control with a standard error 0.17°C. The coefficient of determination increased from 0.30 to 0.84 by the addition of TRT to the model.

2.3.5.1 Comparison of Leaf Temperature under Misting vs. Control

The analysis of variance for the comparison of misting and control (Table 22) showed all variables in the Variable Sequence 5 were significant. The regression equation for the control was:

$$T_{leaf} = -17.9 - 0.00354 \cdot RAD - 0.00000385 \cdot RAD \cdot RAD + 1.633 \cdot T_{air} \qquad \text{Eq. 2}$$

and the regression equation for the misting was:

$$T_{leaf} = 5.14 - 0.00000416 \cdot RAD - 0.00000042 \cdot RAD \cdot RAD + 0.766 \cdot T_{air} \quad \text{.................................. Eq. 3}$$

The response surfaces representation (Fig. 31) showed that the misting was effective in reducing the leaf temperature especially at a high T_{air} condition. A small negative quadratic effect of RAD seen in the control was not recognizable in the misting treatment. The residual plot (Fig. 32) showed a high variability of the misting in the high T_{air} region.

2.3.5.2 Comparison of Leaf Temperature under Shading vs. Control

The analysis of variance for the comparison of shading and control (Table 23) showed all variables in the Variable Sequence 5 were significant. The regression equation for the shading was:

$$T_{leaf} = 15.6 + 0.000571 \cdot RAD + 0.00000161 \cdot RAD \cdot RAD + 0.426 \cdot T_{air} \quad \text{.................................. Eq. 4}$$

while the estimate equation for the control was identical to Eq. 2. The response surfaces representation (Fig. 33) showed shading was also effective in reducing the leaf temperature. However, shading was less effective at a high RAD condition as it had a positive quadratic effect with the variable. The residual plot (Fig. 34) showed no trend.

2.4 Discussion

2.4.1 Use of Leaf Temperature Estimated from Air Temperatures

Below an optimal air temperature, a high air temperature generally would result in a faster plant growth. Although the optimal air temperature for bird of paradise growth has not been determined, 30°C or higher was indicated for the daily gain in leaf dryweight of banana (Green and Kuhne, 1970). As a result, the leaf and pseudostem temperatures became better indicators for the plant growth rate than air temperature in bananas (Robinson and Alberts, 1987).

For the bird of paradise in Waimanalo, Oahu, a high air temperature generally resulted in a high leaf temperature. But, the relationship between air and leaf temperatures was not simple, as the regression analyses in this study indicated that solar radiation significantly interacted with air temperatures on the leaf temperature estimation. Therefore, leaf temperature would likely be a better estimator for the growth of bird of paradise than air temperature.

The leaf temperature of bird of paradise in Waimanalo condition was satisfactorily estimated from the air temperature and solar radiation. This made more estimates available for the leaf temperature as those environmental variables were recorded continuously for January 1984-June 1986 period. Actual leaf temperature measurements were taken only for August 1985-February 1986.

2.4.2 Comparison of Two Air Temperatures on Leaf Temperature Estimation

Two air temperature measurement taken in this experiment, 5 mm away from the abaxial surface of bird of paradise leaf and 1.8 m above the ground, showed differences quantitatively and qualitatively in estimating the leaf temperature of bird of paradise. The regression model using the former consistently estimated the leaf temperature better than the latter throughout this experiment as judged by high R^2 values (Tables 5, 6, 12, 13, and 19). When the surface characteristics for the differences between leaf temperature and those air temperature measurements were compared, the former had a tunnel shape with the temperature difference ranging -2 to 4°C (Fig. 23), while the latter had a twisted plate shape with the difference ranging -10 to 15°C (Fig. 24) which was larger than for the former.

These comparisons indicate that the air temperature 5 mm away from the leaf is a better estimator of the leaf temperature of bird of paradise than the air temperature 1.8 m above the ground.

2.4.3 Comparison of Leaf Temperature Responses to Selected and General Weather Data Sets

The cloud cover (represented by 2 data sets, clear-sky data and all-weather) prevailed in the experimental site as the frequency distribution of solar radiation (Fig. 35) for the all-weather data was dominated by low solar radiation (skewness=0.42), while that for clear-sky data were dominated by high solar radiation (skewness=-0.50). Therefore, if cloudiness interacted with the explanatory variables used for the leaf temperature estimation, the two response surfaces (in Variable Sequence 4) would show different shapes and estimates.

However, the difference in leaf temperature response between the two data sets was small. Although the response surfaces were significantly different in the quadratic effect of solar radiation (Table 18), they showed the same shapes (Fig. 29) and the estimated difference (Fig. 36) was negligible at 0.6°C maximum when solar radiation was at 550 $J \cdot m^{-2} \cdot s$.

This result allowed the use of air temperature data for estimating leaf temperature of bird of paradise without considering cloudiness. However, clouds, due to water vapor, would absorb specific wavelengths in the infrared region of the solar spectra measured on the earth surface (Gates, 1965). Therefore, if solar radiation is recorded as photosynthetic photon flux density (PPFD), the cloudiness factor will affect the model significantly.

2.4.4 Comparison of Misting and Shading on Leaf Temperature

While both leaf cooling practices, misting and shading, reduced the leaf temperature of bird of paradise in summer at Waimanalo, Oahu, misting treatment was more effective than shading. A converging line of the response surfaces for misting and control (Fig. 31) ranged 26-27°C of air temperature near the leaf (T_{air}). Therefore, misting became effective in reducing leaf temperature above 26-27°C air temperature.

On the other hand, a converging line of the response surfaces for shading and control (Fig. 33) ranged 27.5-30.5°C of air temperature near the leaf (T_{air}). This temperature range was higher than for the misting. Therefore, although shading reduced leaf temperature at a high

T_{air} (27.5°C or higher), the reduction was not as effective as misting since misting became effective at a lower T_{air} than shading.

Shading was also less effective at a high T_{air} as the positive quadratic effect of solar radiation increasingly reduced the leaf temperature reduction as solar radiation neared the maximum (Fig. 33).

2.5 Summary

1. The leaf cooling practices, misting and shading, were both effective in significantly reducing the leaf temperature of bird of paradise in summer in Waimanalo, Oahu.
2. While the mean leaf temperature of model in the full sunlight was 33.3°C during an average summer day, misting reduced the leaf temperature more (4.6°C) than shading (3.2°C). While the shading became less effective in reducing the leaf temperate in a high solar radiation and high temperature condition, misting was still effective.
3. The leaf temperature of bird of paradise was successfully modeled using air temperature 5 mm away from the leaf and solar radiation and accounted for 79 percent of the variation in the leaf temperature.
4. The effectiveness of misting and shading was also modeled as the mixed model (variable sequence 5) and accounted for 84 percent of the variation in the leaf temperature.
5. The estimation of temperature differences between the leaf and the air temperatures, 5 mm away from the leaf and 1.8 m above the

ground, showed different characteristics, and the former was a better estimator for the leaf temperature than the latter.

6. Cloud cover did not significantly alter the regression equation for the leaf temperature, and it was unnecessary to select data for clear skys only. The use of air temperature for all-weather conditions was justified by neglecting possible photomorphogenetic effects which might be present due to an altered spectral composition.

Table 1. The use of evaporative cooling for reducing temperatures of various organs of horticultural crops.

Plant Part	Crop	Application Method	Temperature Reduction	Literature
Leaf	Prune	Sprinkling	8°C	Even-Chen, et al., 1981
Leaf	Grape	Sprinkling	15-25°C	Gilbert, et al., 1971
Leaf	Grape	Misting	8.4°C	Matthias and Coates, 1986
Leaf	Apple	Sprinkling	9.2°C	Unrath, 1972
Leaf	Pear	Sprinkling	5.5-7.0°C	Lombard, et al., 1966
Leaf	Potato	Sprinkling	6.1°C	Peterson and Weigle, 1970
Leaf	Pea	Misting	3.2°C	Howell, et al., 1971
Flower bud	Apple	Sprinkling	10°C	Anderson, et al., 1975
Flower bud	Peach	Sprinkling	6°C	Bauer, et al., 1976
Fruit	Plum	Misting	6°C	Gay, et al., 1971
Stem	Tomato	Misting	17°C	Bible, et al., 1968

Table 2. Weekly sum of water delivered to a bird of paradise plant by misting treatment in 1985. All experimental plants, including those under misting treatment, received 102 liters water weekly (34 liters a day, 3 days a week) with spot-spray irrigation.

1985		
Week Ending On (1985)	Total On-Time (sec)	Total Delivery ($l \cdot plant^{-1} \cdot wk^{-1}$)
June 19	624	35.6
June 26	484	27.6
July 3	759	43.3
July 10	1892	107.8
July 17	1712	97.6
July 24	1760	100.3
July 31	1808	103.1
August 7	1536	87.6
August 14	1437	81.9
August 21	1431	81.6
August 28	1557	88.7
September 4	1655	94.3
September 11	1092	62.2
September 18	1304	74.3
September 25	1116	63.6
October 2	912	52.0

Table 3. Analysis of variance for the calibration of a thermistor assembly and the regression coefficients of all the assemblies. The calibrated variable (TEMP) is expressed in actual temperature in degree Celsius and the sensor readings (T1-T4) are electrical potential in mV.

Analysis variance for the calibration of a thermistor assembly

Dependent variable: TEMP

Source	DF	Sum of Squares	F Value	Pr > F
Model	2	1882.39	1165.55	0.0001
Error	23	18.57		
Corrected Total	25	1900.96		

R-Square	CV	TEMP Mean
0.99	3.61	24.9

Source	DF	Type I SS	F Value	Pr > F
T1	1	1873.55	2320.15	0.0001
T1xT1	1	8.84	10.94	0.0031

Regression coefficients

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	92.2	17.31	0.0001	5.3
T1	-35.9	-7.81	0.0001	4.6
T1xT1	3.22	3.31	0.0031	0.97
INTERCEPT	96.2	26.27	0.0001	3.7
T2	-38.7	-12.34	0.0001	3.1
T2xT2	3.72	5.66	0.0001	0.66
INTERCEPT	85.5	27.40	0.0001	3.1
T3	-30.5	-11.32	0.0001	2.7
T3xT3	2.20	3.85	0.0008	0.57
INTERCEPT	82.9	25.56	0.0001	3.2
T4	-28.9	-10.28	0.0001	2.8
T4xT4	1.96	3.29	0.0032	0.60

Table 4. Mean solar radiation for the 15 days selected for representing clear-sky weather in Waimanalo, Oahu.

Date (1985)	Period	Mean Solar Radiation ($J \cdot m^{-2} \cdot s^{-1}$)
August 18	11:00-15:00	917
August 24	13:00-16:00	770
August 27	11:00-15:00	787
September 6	11:00-15:00	785
September 12	11:00-14:00	939
September 24	11:00-15:00	706
October 2	11:00-13:00	797
October 4	10:00-16:00	614
October 14	10:00-15:00	723
October 28	10:00-14:00	647
November 14	10:00-14:00	649
November 19	10:00-14:00	601
November 26	10:00-14:00	530
December 20	10:00-14:00	550
December 30	11:00-14:00	476

Table 5. Analyses of variance and regression coefficients for regressing bird of paradise leaf temperature (T_{leaf} in °C) under clear sky on air temperature near the leaf (T_{air} in °C). A quadratic model was reduced to a straight-line model due to insignificance to the quadratic effect.

A quadratic model

Dependent Variable: T_{leaf}

Source	DF	Sum of Squares	F Value	Pr > F
Model	2	2672.82	575.02	0.0001
Error	360	836.68		
Corrected Total	362	3509.49		

R-Square	CV	T_{leaf} Mean
0.76	4.56	33.4

Source	DF	Type I SS	F Value	Pr > F
T_{air}	1	2671.90	1149.65	0.0001
$T_{air} x T_{air}$	1	0.91	0.39	0.5310

A straight-line model

Dependent Variable: T_{leaf}

Source	DF	Sum of Squares	F Value	Pr > F
Model	1	2671.90	1151.59	0.0001
Error	361	837.59		
Corrected Total	362	3509.49		

R-Square	CV	T_{leaf} Mean
0.76	4.56	33.4

Source	DF	Type I SS	F Value	Pr > F
T_{air}	1	2671.90	1151.59	0.0001

Regression coefficients for the straight-line model

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	-0.547	-0.54	0.5864	1.005
T_{air}	1.10	33.94	0.0001	0.03

Table 6. Analysis of variance and regression coefficients for regressing bird of paradise leaf temperature (T_{leaf} in °C) under clear sky on air temperature 1.8 m above the ground (T_{field} in °C).

Analysis of variance

Dependent Variable: T_{leaf}

Source	DF	Sum of Squares	F Value	Pr > F
Model	2	1278.42	103.14	0.0001
Error	360	2231.07		
Corrected Total	362	3509.49		

R-Square	CV	T_{leaf} Mean
0.36	7.45	33.4

Source	DF	Type I SS	F Value	Pr > F
T_{field}	1	1255.10	202.52	0.0001
$T_{field}xT_{field}$	1	23.32	3.76	0.0532

Regression coefficients

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	-14.9	-1.12	0.2633	13.3
T_{field}	2.56	2.79	0.0055	0.92
$T_{field}xT_{field}$	-0.0307	-1.94	0.0532	0.0158

Table 7. Analysis of variance and regression coefficients for regressing leaf temperature (T_{leaf} in °C) of bird of paradise under clear sky on solar radiation (RAD in $J \cdot m^{-2} \cdot s^{-1}$).

Analysis of variance

Dependent Variable: T_{leaf}

Source	DF	Sum of Squares	F Value	Pr > F
Model	2	990.70	70.80	0.0001
Error	360	2518.80		
Corrected Total	362	3509.49		

R-Square	CV	T_{leaf} Mean
0.28	7.91	33.4

Source	DF	Type I SS	F Value	Pr > F
RAD	1	954.19	136.38	0.0001
RADxRAD	1	36.50	5.22	0.0229

Regression coefficients

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	25.5	22.08	0.0001	1.2
RAD	0.0163	4.44	0.0001	0.0037
RADxRAD	-0.00000642	-2.28	0.0229	0.00000281

Table 8. Analysis of variance and regression coefficients for regressing leaf temperature of bird of paradise (T_{leaf} in °C) under clear sky. A full sequence of the explanatory variables, air temperature near the leaf (T_{leaf} in °C) and solar radiation (RAD in $J \cdot m^{-2} \cdot s^{-1}$), was applied to the model.

Analysis of variance

Dependent Variable: T_{leaf}

Source	DF	Sum of Squares	F Value	Pr > F
Model	5	2783.53	273.77	0.0001
Error	357	725.96		
Corrected Total	362	3509.49		

R-Square	CV	T_{leaf} Mean
0.79	4.26	33.4

Source	DF	Type I SS	F Value	Pr > F
T_{air}	1	2671.90	1313.93	0.0001
RAD	1	14.01	6.89	0.0090
RADxRAD	1	88.12	43.33	0.0001
T_{air}xRAD	1	8.43	4.14	0.0425
T_{air}xRADxRAD	1	1.07	0.52	0.4697

Regression coefficients

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	-1.76	-0.26	0.7987	6.89
T_{air}	0.973	4.15	0.0001	0.234
RAD	0.0208	0.88	0.3772	0.0236
RADxRAD	-0.0000268	-1.33	0.1837	0.0000201
T_{air}xRAD	-0.000136	-0.17	0.8613	0.000779
T_{air}xRADxRAD	0.000000470	0.72	0.4697	0.000000650

Table 9. Analysis of variance and regression coefficients for the clear-sky model (FULL-SUN). Leaf temperature of bird of paradise (T_{leaf} in °C) was regressed on the reduced variable sequence of air temperature near the leaf (T_{air} in °C) and solar radiation (RAD in $J \cdot m^{-2} \cdot s^{-1}$).

Analysis of variance

Dependent Variable: T_{leaf}

Source	DF	Sum of Squares	F Value	Pr > F
Model	4	2782.46	342.53	0.0001
Error	358	727.03		
Corrected Total	362	3509.49		

R-Square	CV	T_{leaf} Mean
0.79	4.26	33.4

Source	DF	Type I SS	F Value	Pr > F
T_{air}	1	2671.90	1315.68	0.0001
RAD	1	14.01	6.90	0.0090
RADxRAD	1	88.12	43.39	0.0001
T_{air}xRAD	1	8.43	4.15	0.0424

Regression coefficients

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	2.57	0.75	0.4538	3.42
T_{air}	0.829	6.67	0.0001	0.124
RAD	0.00419	0.81	0.4165	0.00516
RADxRAD	-0.0000123	-6.49	0.0001	0.0000019
T_{air}xRAD	0.000409	2.04	0.0424	0.000201

Table 10. Analysis of variance and regression coefficients for regressing temperature difference between bird of paradise leaf and air near the leaf (T_{leaf}-T_{air}) under clear sky on air temperature near the leaf (T_{air} in °C) and solar radiation (RAD in $J \cdot m^{-2} \cdot s^{-1}$).

Analysis of variance

Dependent Variable: T_{leaf}-T_{air}

Source	DF	Sum of Squares	F Value	Pr > F
Model	4	133.95	16.49	0.0001
Error	358	727.03		
Corrected Total	362	860.98		

R-Square	CV	T_{leaf}-T_{air} Mean
0.16	54.12	2.6

Source	DF	Type I SS	F Value	Pr > F
T_{air}	1	23.39	11.52	0.0008
RAD	1	14.01	6.90	0.0090
RADxRAD	1	88.12	43.39	0.0001
T_{air}xRAD	1	8.43	4.15	0.0424

Regression coefficients

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	2.57	0.75	0.4538	3.42
T_{air}	-0.171	-1.37	0.1702	0.124
RAD	0.00419	0.81	0.4165	0.00516
RADxRAD	-0.0000123	-6.49	0.0001	0.0000019
T_{air}xRAD	0.000409	2.04	0.0424	0.000201

Table 11. Analysis of variance and regression coefficients for regressing temperature difference between bird of paradise leaf and air 1.8 m above the ground under clear sky (T_{leaf}-T_{field} in °C) on solar radiation (RAD in $J \cdot m^{-2} \cdot s^{-1}$) and air temperature 1.8 m above the ground (T_{field} in °C).

Analysis of variance

Dependent Variable: T_{leaf}-T_{field}

Source	DF	Sum of Squares	F Value	Pr > F
Model	6	414.44	12.73	0.0001
Error	356	1932.34		
Corrected Total	362	2346.78		

R-Square	CV	T_{leaf}-T_{field} Mean
0.18	51.26	4.5

Source	DF	Type I SS	F Value	Pr > F
T_{field}	1	92.39	17.02	0.0001
T_{field}xT_{field}	1	23.32	4.30	0.0389
RAD	1	222.02	40.90	0.0001
RADxRAD	1	47.37	8.73	0.0033
T_{field}xRAD	1	0.61	0.11	0.7385
T_{field}xRADxRAD	1	28.75	5.30	0.0220

Regression coefficients

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	32.9	1.87	0.0620	17.6
T_{field}	-0.922	-0.92	0.3599	1.006
T_{field}xT_{field}	-0.0105	-0.59	0.5550	0.0177
RAD	-0.0925	-2.01	0.0455	0.0461
RADxRAD	0.0000779	2.07	0.0387	0.0000376
T_{field}xRAD	0.00378	2.30	0.0219	0.00164
T_{field}xRADxRAD	-0.00000299	-2.30	0.0220	0.00000130

Table 12. Analysis of variance and regression coefficients for regressing leaf temperature of bird of paradise (T_{leaf} in °C) under all-weather conditions on air temperature near the leaf (T_{air} in °C).

Analysis of variance

Dependent Variable: T_{leaf}

Source	DF	Sum of Squares	F Value	Pr > F
Model	2	49695.21	12882.73	0.0001
Error	3435	6625.26		
Corrected Total	3437	56320.47		

R-Square	CV	T_{leaf} Mean
0.88	4.57	30.4

Source	DF	Type I SS	F Value	Pr > F
T_{air}	1	49615.62	25724.21	0.0001
T_{air}xT_{air}	1	79.58	41.26	0.0001

Regression coefficients

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	4.04	2.81	0.0050	1.44
T_{air}	0.580	5.73	0.0001	0.101
T_{air}xT_{air}	0.0114	6.42	0.0001	0.0018

Table 13. Analysis of variance and regression coefficients for regressing leaf temperature of bird of paradise (T_{leaf} in °C) under all-weather conditions on air temperature 1.8 m above the ground (T_{field} in °C).

Analysis of variance

Dependent Variable: T_{leaf}

Source	DF	Sum of Squares	F Value	Pr > F
Model	2	27482.40	1636.76	0.0001
Error	3435	28838.06		
Corrected Total	3437	56320.47		

R-Square	CV	T_{leaf} Mean
0.49	9.54	30.4

Source	DF	Type I SS	F Value	Pr > F
T_{field}	1	27101.25	3228.12	0.0001
$T_{field} x T_{field}$	1	381.15	45.40	0.0001

Regression coefficients

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	-23.3	-6.59	0.0001	3.5
T_{field}	2.79	10.98	0.0001	0.25
$T_{field} x T_{field}$	-0.0307	-6.74	0.0001	0.0046

Table 14. Analysis of variance and regression coefficients for regressing leaf temperature of bird of paradise (T_{leaf} in °C) under all-weather conditions on solar radiation (RAD in $J \cdot m^{-2} \cdot s^{-1}$).

Analysis of variance

Dependent Variable: T_{leaf}

Source	DF	Sum of Squares	F Value	Pr > F
Model	2	34949.89	2808.83	0.0001
Error	3435	21370.58		
Corrected Total	3437	56320.47		

R-Square	CV	T_{leaf} Mean
0.62	8.21	30.4

Source	DF	Type I SS	F Value	Pr > F
RAD	1	32380.28	5204.64	0.0001
RADxRAD	1	2569.60	413.02	0.0001

Regression coefficients

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	22.1	138.46	0.0001	0.2
RAD	0.0254	36.36	0.0001	0.0007
RADxRAD	-0.0000130	-20.32	0.0001	0.0000006

Table 15. A quadratic relationship between two air temperature measurements under all-weather conditions: near the leaf of bird of paradise (T_{air} in °C) and 1.8 m above the ground (T_{field} in °C).

Analysis of variance

Dependent Variable: T_{air}

Source	DF	Sum of Squares	F Value	Pr > F
Model	2	21983.43	3454.51	0.0001
Error	3435	10929.65		
Corrected Total	3437	32913.08		

R-Square	CV	T_{air} Mean
0.67	6.17	28.9

Source	DF	Type I SS	F Value	Pr > F
T_{field}	1	21309.42	6697.18	0.0001
$T_{field} x T_{field}$	1	674.01	211.83	0.0001

Regression

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	-29.1	-13.38	0.0001	2.2
T_{field}	3.23	20.65	0.0001	0.16
$T_{field} x T_{field}$	-0.0409	-14.55	0.0001	0.0028

Table 16. Analysis of variance and regression coefficients for the all-weather model (ALL-SUN). Leaf temperature of bird of paradise (T_{leaf} in °C) was regressed on the same variable sequence of clear-sky model (T_{leaf} Mean|T_{air}|RADxRAD|T_{air}xRAD).

Analysis of variance

Dependent Variable: T_{leaf}

Source	DF	Sum of Squares	F Value	Pr > F
Model	4	51193.11	8569.02	0.0001
Error	3433	5127.36		
Corrected Total	3437	56320.47		

R-Square	CV	T_{leaf} Mean
0.91	4.02	30.4

Source	DF	Type I SS	F Value	Pr > F
T_{air}	1	49615.62	33219.89	0.0001
RAD	1	1022.38	684.53	0.0001
RADxRAD	1	445.89	298.54	0.0001
T_{air}xRAD	1	109.21	73.12	0.0001

Regression coefficients

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	2.00	4.09	0.0001	0.49
T_{air}	0.868	43.94	0.0001	0.020
RAD	0.00189	2.04	0.0418	0.00093
RADxRAD	-0.00000821	-18.39	0.0001	0.00000045
T_{air}xRAD	0.000339	8.55	0.0001	0.000040

Table 17. Analysis of variance for regressing bird of paradise leaf temperature (T_{leaf} in °C) on air temperature near the leaf (T_{air} in °C) and solar radiation (RAD in $J \cdot m^{-2} \cdot s^{-1}$) with a full variable sequence as shown by the variable listing under source. The SET, a discrete variable with 2 levels, represented 2 types of solar measurements in Waimanalo, Oahu: clear-sky and all-weather conditions (363 and 3438 observations respectively).

Analysis of variance

Dependent Variable: T_{leaf}

Source	DF	Sum of Squares	F Value	Pr > F
Model	9	57068.94	4106.10	0.0001
Error	3791	5854.39		
Corrected Total	3800	62923.34		

R-Square	CV	T_{leaf} Mean
0.91	4.05	30.7

Source	DF	Type I SS	F Value	Pr > F
T_{air}	1	55180.81	35732.22	0.0001
RAD	1	1135.22	735.11	0.0001
RADxRAD	1	565.59	366.25	0.0001
T_{air}xRAD	1	126.56	81.96	0.0001
SET	1	41.98	27.19	0.0001
SETxT_{air}	1	2.37	1.53	0.2156
SETxRAD	1	4.84	3.13	0.0768
SETxRADxRAD	1	11.34	7.34	0.0068
SETxT_{air}xRAD	1	0.24	0.15	0.6961

Table 18. Analysis of variance and regression coefficients for regressing bird of paradise leaf temperature (T_{leaf} in °C) on air temperature near the leaf (T_{air} in °C) and solar radiation (RAD in $J \cdot m^{-2} \cdot s^{-1}$) with a reduced variable sequence. The SET, a discrete variable with 2 levels, represented 2 types of solar measurements in Waimanalo, Oahu: clear-sky (FULL-SUN, 363 observations) and all-weather conditions (ALL-SUN, 3438 observations).

Analysis of variance

Dependent Variable: T_{leaf}

Source	DF	Sum of Squares	F Value	Pr > F
Model	7	57068.70	5281.81	0.0001
Error	3793	5854.64		
Corrected Total	3800	62923.34		

R-Square	CV	T_{leaf} Mean
0.91	4.05	30.7

Source	DF	Type I SS	F Value	Pr > F
T_{air}	1	55180.81	35749.58	0.0001
RAD	1	1135.22	735.47	0.0001
RADxRAD	1	565.59	366.42	0.0001
T_{air}xRAD	1	126.56	82.00	0.0001
SET	1	41.98	27.20	0.0001
SETxRAD	1	7.19	4.66	0.0310
SETxRADxRAD	1	11.35	7.35	0.0067

Regression coefficients

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		1.57	2.07	0.0387	0.76
T_{air}		0.866	43.99	0.0001	0.020
RAD		0.00577	2.94	0.0033	0.00196
RADxRAD		-0.0000119	-8.90	0.0001	0.0000013
T_{air}xRAD		0.000343	8.89	0.0001	0.000039
SET	ALL-SUN	0.464	0.84	0.3991	0.550
	FULL-SUN	0.0 (Biased)	.	.	.
SETxRAD	ALL-SUN	-0.00397	-2.24	0.0250	0.00177
	FULL-SUN	0.0 (Biased)	.	.	.
SETxRADxRAD	ALL-SUN	0.00000370	2.71	0.0067	0.00000136
	FULL-SUN	0.0 (Biased)	.	.	.

Table 19. Analyses of variance for regressing bird of paradise leaf temperature (T_{leaf} in °C) on the environmental variables: air temperature near the leaf (T_{air} in °C), air temperature 1.8 m above the ground (T_{field} in °C), and solar radiation (RAD in $J \cdot m^{-2} \cdot s^{-1}$). Leaf cooling treatments, misting, shading, and control, were pooled.

Analysis of variance

Source	DF	Sum of Squares	T_{leaf} Mean
Corrected Total	407	3027.46	30.7

Dependent Variable: T_{leaf}

R-Square	CV
0.30	7.47

Source	DF	Type I SS	F Value	Pr > F
T_{air}	1	894.21	169.99	0.0001
$T_{air} x T_{air}$	1	2.73	0.52	0.4718

Dependent Variable: T_{leaf}

R-Square	CV
0.15	8.19

Source	DF	Type I SS	F Value	Pr > F
T_{field}	1	436.67	69.03	0.0001
$T_{field} x T_{field}$	1	28.87	4.56	0.0333

Dependent Variable: T_{leaf}

R-Square	CV
0.16	8.14

Source	DF	Type I SS	F Value	Pr > F
RAD	1	434.81	69.64	0.0001
RADxRAD	1	64.02	10.25	0.0015

Table 20. Analysis of variance for regressing bird of paradise leaf temperature (T_{leaf} in °C) on solar radiation (RAD in $J \cdot m^{-2} \cdot s^{-1}$) and air temperature near the leaf (T_{air} in °C). Leaf cooling treatments, misting, shading, and control, were pooled.

Analysis of variance for full model

Dependent Variable: T_{leaf}

Source	DF	Sum of Squares	F Value	Pr > F
Model	5	897.84	33.90	0.0001
Error	402	2129.62		
Corrected Total	407	3027.46		

R-Square	CV	T_{leaf} Mean
0.30	7.50	30.7

Source	DF	Type I SS	F Value	Pr > F
RAD	1	434.81	82.08	0.0001
RADxRAD	1	64.02	12.09	0.0006
T_{air}	1	397.71	75.07	0.0001
T_{air}xRAD	1	1.30	0.25	0.6208
T_{air}xRADxRAD	1	0.00	0.00	0.9992

Analysis of variance for reduced model

Dependent Variable: T_{leaf}

Source	DF	Sum of Squares	F Value	Pr > F
Model	3	896.54	56.66	0.0001
Error	404	2130.92		
Corrected Total	407	3027.46		

R-Square	CV	T_{leaf} Mean
0.30	7.48	30.7

Source	DF	Type I SS	F Value	Pr > F
RAD	1	434.81	82.43	0.0001
RADxRAD	1	64.02	12.14	0.0005
T_{air}	1	397.71	75.40	0.0001

Table 21. Analysis of variance for regressing bird of paradise leaf temperature (T_{leaf} in °C) on solar radiation (RAD in $J \cdot m^{-2} \cdot s^{-1}$), air temperature near the leaf (T_{air} in °C), and leaf cooling treatments (TRT; misting, shading, and control). To test the sum of squares for having different treatments, a common variable sequence (T_{leaf} Mean|RAD|RADxRAD|T_{air}) was fitted before the treatments and the interactions were added to the model.

Analysis of variance

Dependent Variable: T_{leaf}

Source	DF	Sum of Squares	F Value	Pr > F
Model	11	2557.06	195.69	0.0001
Error	396	470.41		
Corrected Total	407	3027.46		

R-Square	CV	T_{leaf} Mean
0.84	3.55	30.7

Source	DF	Type I SS	F Value	Pr > F
RAD	1	434.81	366.03	0.0001
RADxRAD	1	64.02	53.90	0.0001
T_{air}	1	397.71	334.81	0.0001
TRT	2	1461.70	615.25	0.0001
TRTxRAD	2	35.14	14.79	0.0001
TRTxRADxRAD	2	47.91	20.17	0.0001
TRTxT_{air}	2	115.76	48.73	0.0001

Table 22. Analysis of variance and regression coefficients for the comparison of bird of paradise leaf temperature (T_{leaf} in °C) between misting treatment and control (TRT). Treatment variables and the interactions were added after the common variable sequence.

Analysis of variance

Dependent Variable: T_{leaf}

Source	DF	Sum of Squares	F Value	Pr > F
Model	7	2290.50	217.16	0.0001
Error	264	397.80		
Corrected Total	271	2688.30		

R-Square	CV	T_{leaf} Mean
0.85	3.96	31.0

Source	DF	Type I SS	F Value	Pr > F
RAD	1	263.18	174.66	0.0001
RADxRAD	1	90.85	60.29	0.0001
T_{air}	1	430.24	285.53	0.0001
TRT	1	1395.96	926.44	0.0001
TRTxRAD	1	33.21	22.04	0.0001
TRTxRADxRAD	1	20.95	13.90	0.0002
TRTxT_{air}	1	56.11	37.24	0.0001

Regression coefficients

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		5.14	1.85	0.0648	2.77
RAD		-0.00000416	-0.00	0.9984	0.00204620
RADxRAD		-0.00000042	-0.27	0.7841	0.00000152
T_{air}		0.766	7.63	0.0001	0.100
TRT	Control	-23.0	-5.86	0.0001	3.9
	Misting	0.0 (Biased)	.	.	.
TRTxRAD	Control	0.00354	1.22	0.2223	0.00290
	Misting	0.0 (Biased)	.	.	.
TRTxRADxRAD	Control	-0.00000343	-1.59	0.1128	0.00000215
	Misting	0.0 (Biased)	.	.	.
TRTxT_{air}	Control	0.867	6.10	0.0001	0.142
	Misting	0.0 (Biased)	.	.	.

Table 23. Analysis of variance and regression coefficients for the comparison of bird of paradise leaf temperature (T_{leaf} in °C) between shading treatment and control (TRT). Treatment variables and the interactions were added after the common variable sequence.

Analysis of variance

Dependent Variable: T_{leaf}

Source	DF	Sum of Squares	F Value	Pr > F
Model	7	1601.21	332.24	0.0001
Error	264	181.76		
Corrected Total	271	1782.97		

R-Square	CV	T_{leaf} Mean
0.90	2.62	31.7

Source	DF	Type I SS	F Value	Pr > F
RAD	1	412.42	599.03	0.0001
RADxRAD	1	53.62	77.88	0.0001
T_{air}	1	316.81	460.15	0.0001
TRT	1	660.63	959.53	0.0001
TRTxRAD	1	2.81	4.09	0.0442
TRTxRADxRAD	1	46.04	66.88	0.0001
TRTxT_{air}	1	108.87	158.13	0.0001

Regression coefficients

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		15.6	8.34	0.0001	1.9
RAD		0.000571	0.41	0.6800	0.001383
RADxRAD		0.00000161	1.57	0.1187	0.00000103
T_{air}		0.426	6.28	0.0001	0.068
TRT	Control	-33.4	-12.62	0.0001	2.6
	Shading	0.0 (Biased)	.	.	.
TRTxRAD	Control	0.00296	1.52	0.1308	0.00196
	Shading	0.0 (Biased)	.	.	.
TRTxRADxRAD	Control	-0.00000545	-3.75	0.0002	0.00000146
	Shading	0.0 (Biased)	.	.	.
TRTxT_{air}	Control	1.21	12.57	0.0001	0.10
	Shading	0.0 (Biased)	.	.	.

Figure 4. A plastic nozzle, circular mist with a delivery of 0.057 liter per second, used for evaporative cooling of bird of paradise leaves.

Figure 5. The equipment used for controlling misting and recording environmental variables. **A**, the SolaSpray for controlling misting in the field; **B**, the Datapod for recording solar radiation and air temperature; **C**, the Easylogger for recording air, leaf, and soil temperature.

Figure 6. The shadecloth used to reduce leaf temperature of bird of paradise. The material was black polypropylene and rated for 30 percent shading.

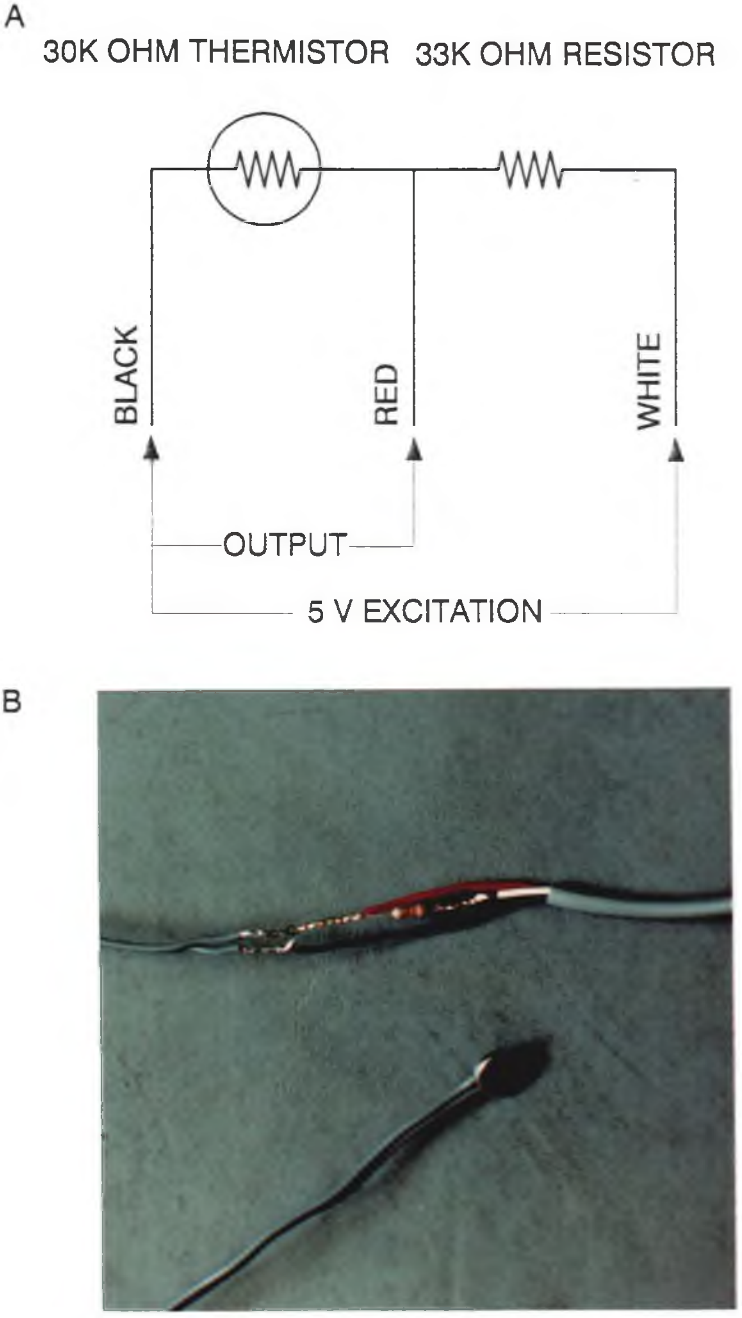

Figure 7. A thermistor assembly used for sensing leaf temperature of bird of paradise. **A**, a bridge circuit which converted the electrical potential to the Celsius unit; **B**, the construction of the thermistor assembly.

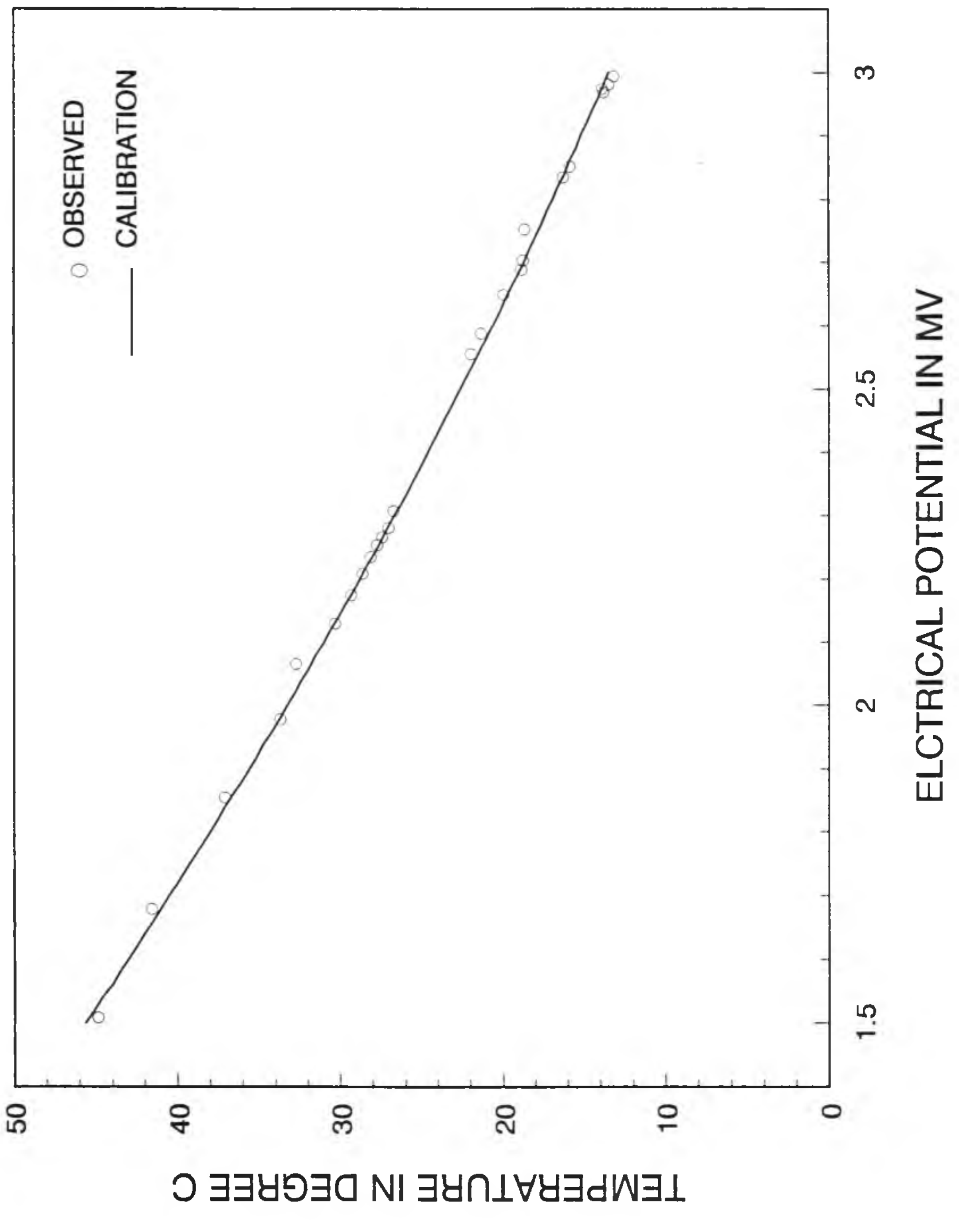

Figure 8. A calibration line for the thermistor assembly (Table 3). The electrical potential created by the assembly was converted into Celsius units before recording by the Easylogger.

Figure 9. The placement of the thermistors for the leaf temperature recording of bird of paradise and the air temperature near the leaf.

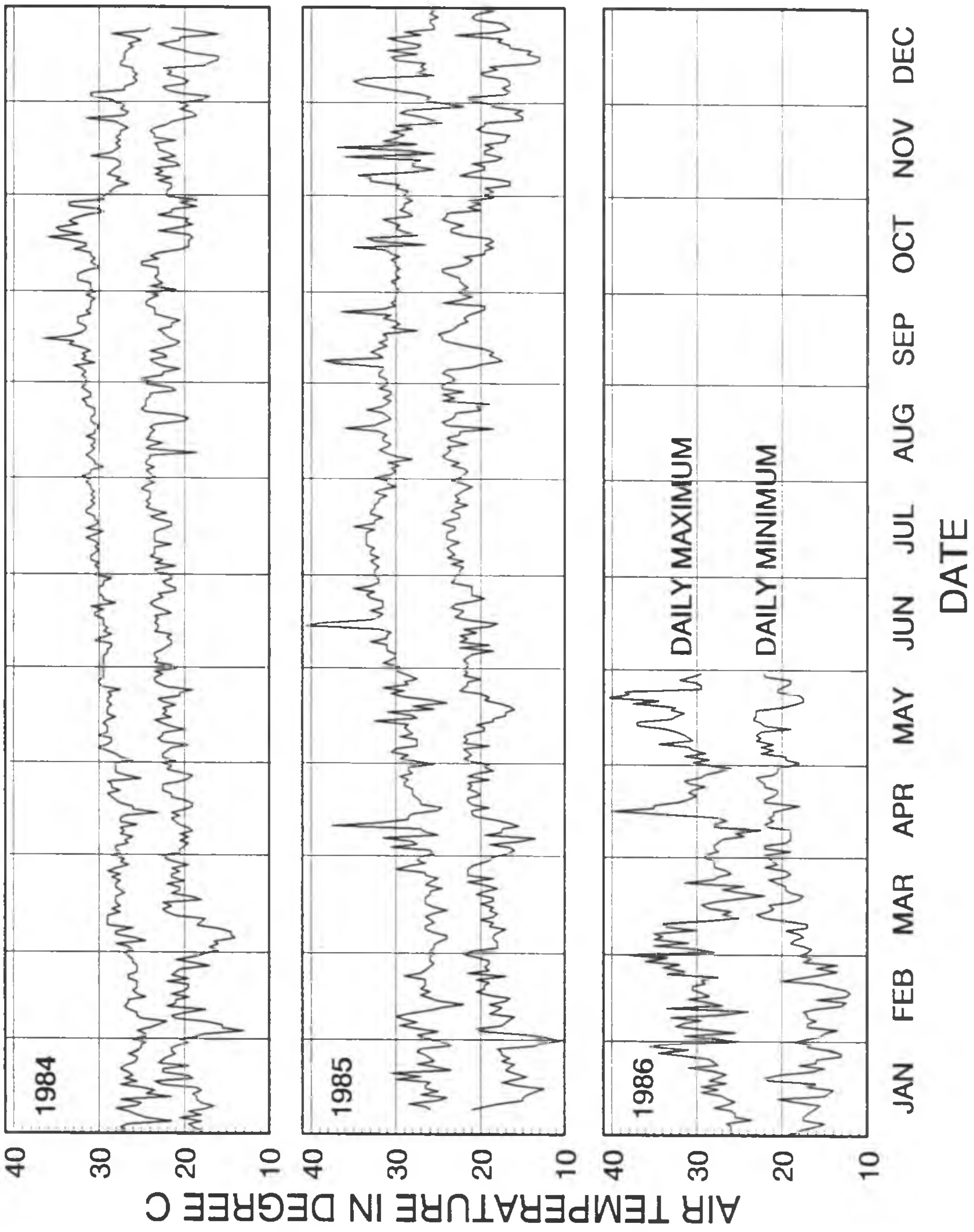

Figure 10. The daily maximum and minimum air temperatures 1.8 m above the ground from January 1984 to May 1986 at the bird of paradise field in Waimanalo, Oahu.

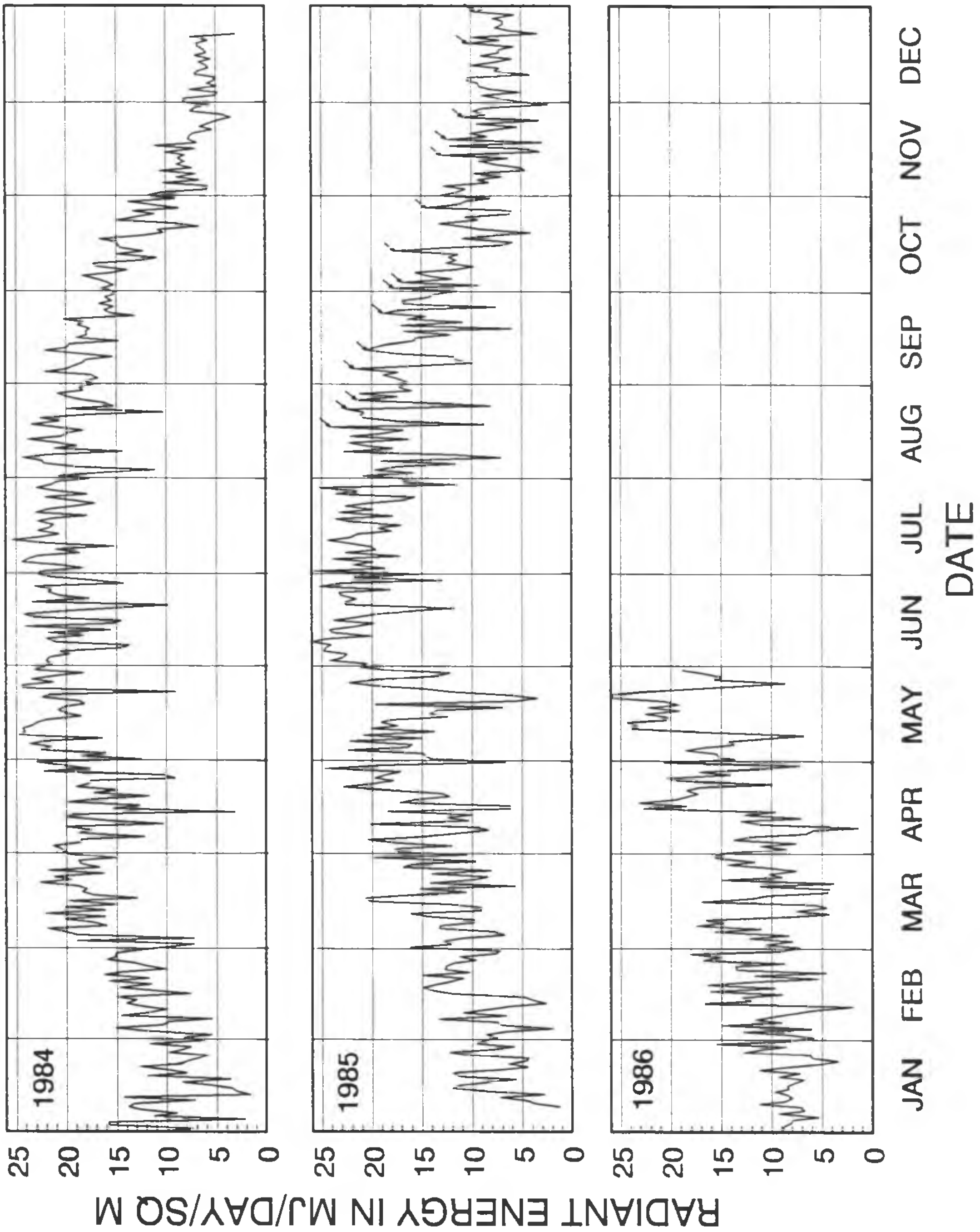

Figure 11. The daily sum of solar radiation received from January 1984 to May 1986 at the bird of paradise field in Waimanalo, Oahu. The arrows indicate the days selected for representing clear-sky conditions in the site.

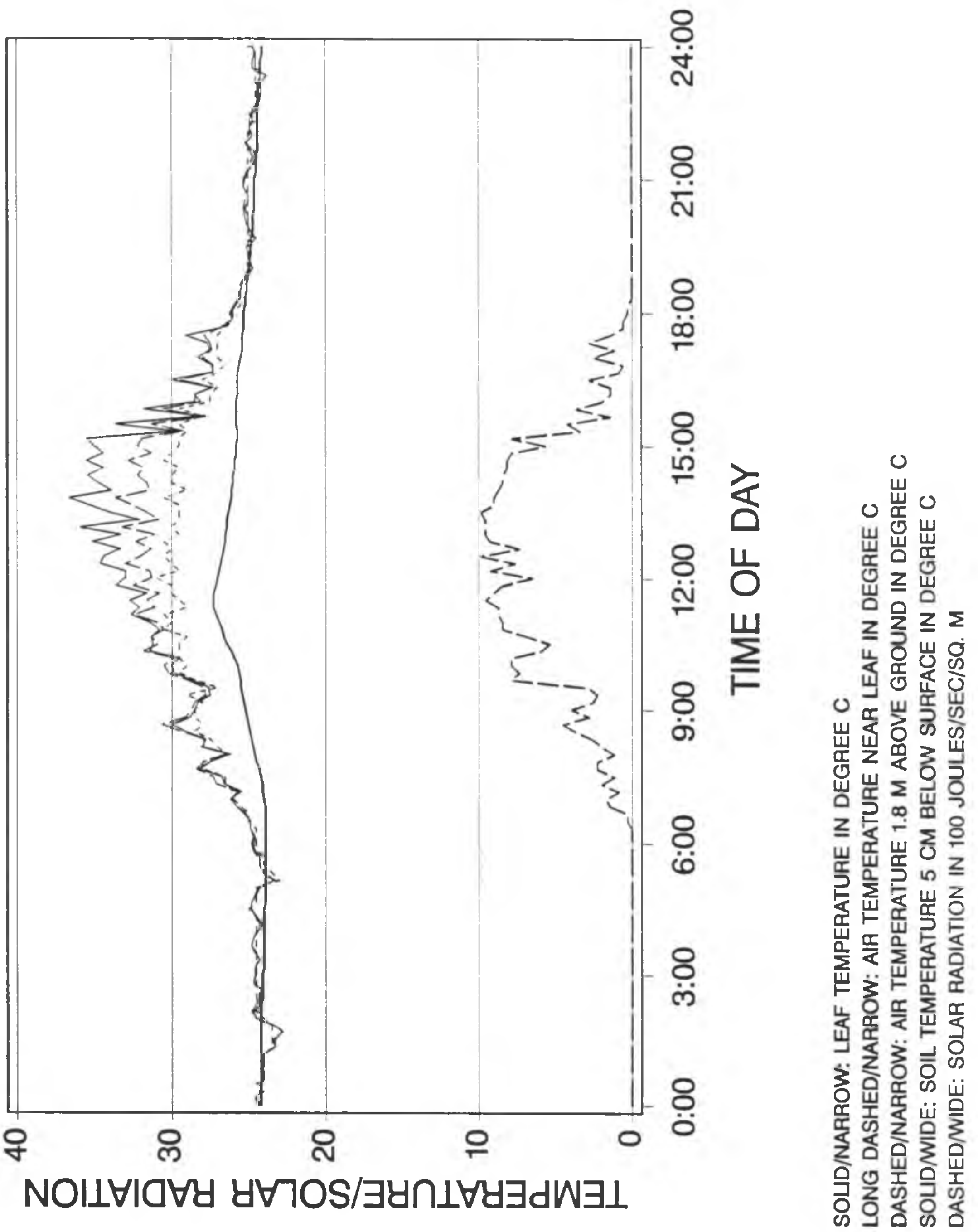

Figure 12. The relationships among the variables recorded in the bird of paradise field in Waimanalo, Oahu in 10-minute intervals on August 22, 1985. The variables recorded were leaf temperature of bird of paradise, air temperature near the leaf, air temperature 1.8 m above the ground, soil temperature 5 cm below the surface, and solar radiation.

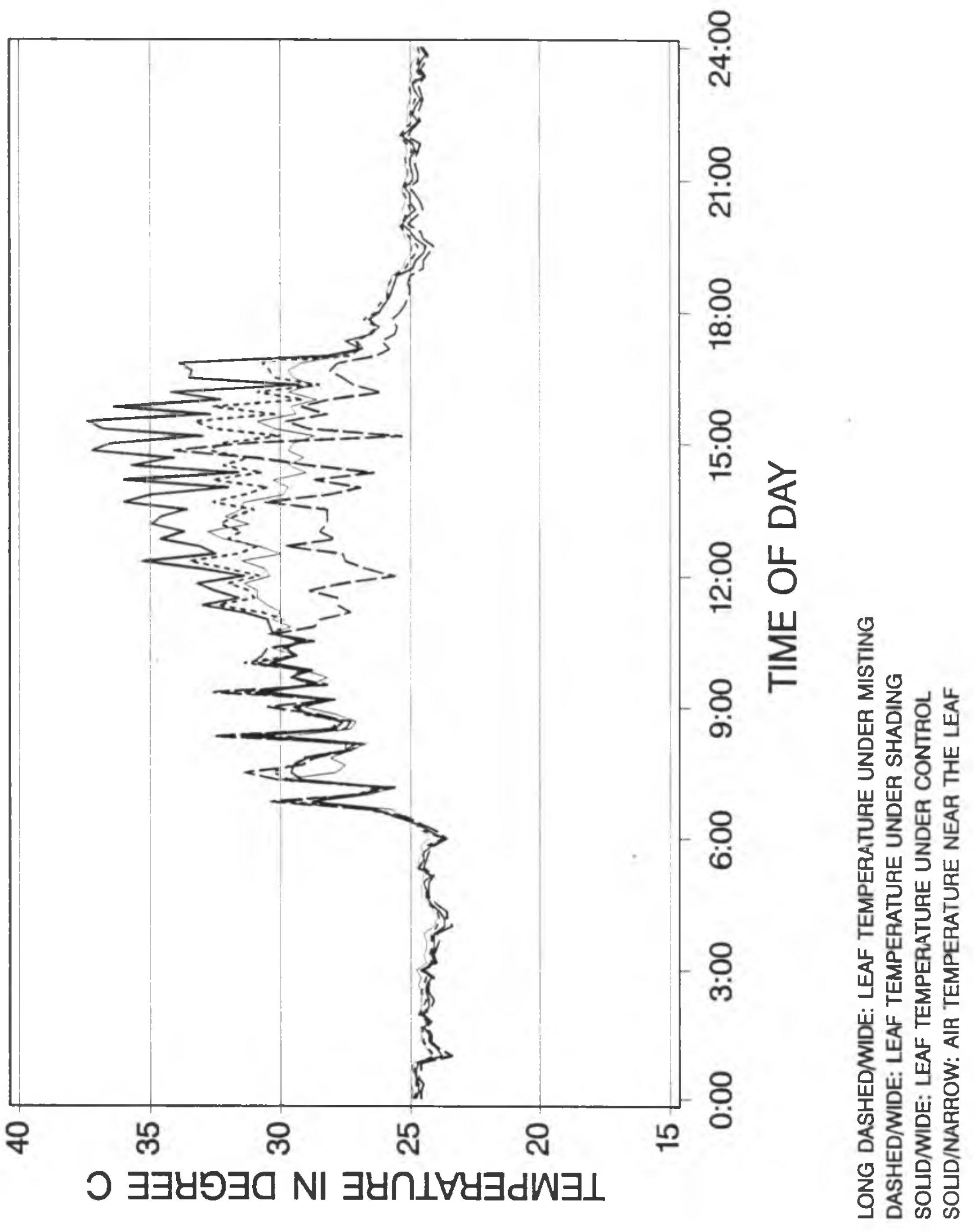

Figure 13. The comparison of leaf cooling practices on the bird of paradise in Waimanalo, Oahu. Misting and shading treatment both reduced the leaf temperature. The data presented were recorded instantaneously at 10-minute intervals on August 15, 1985.

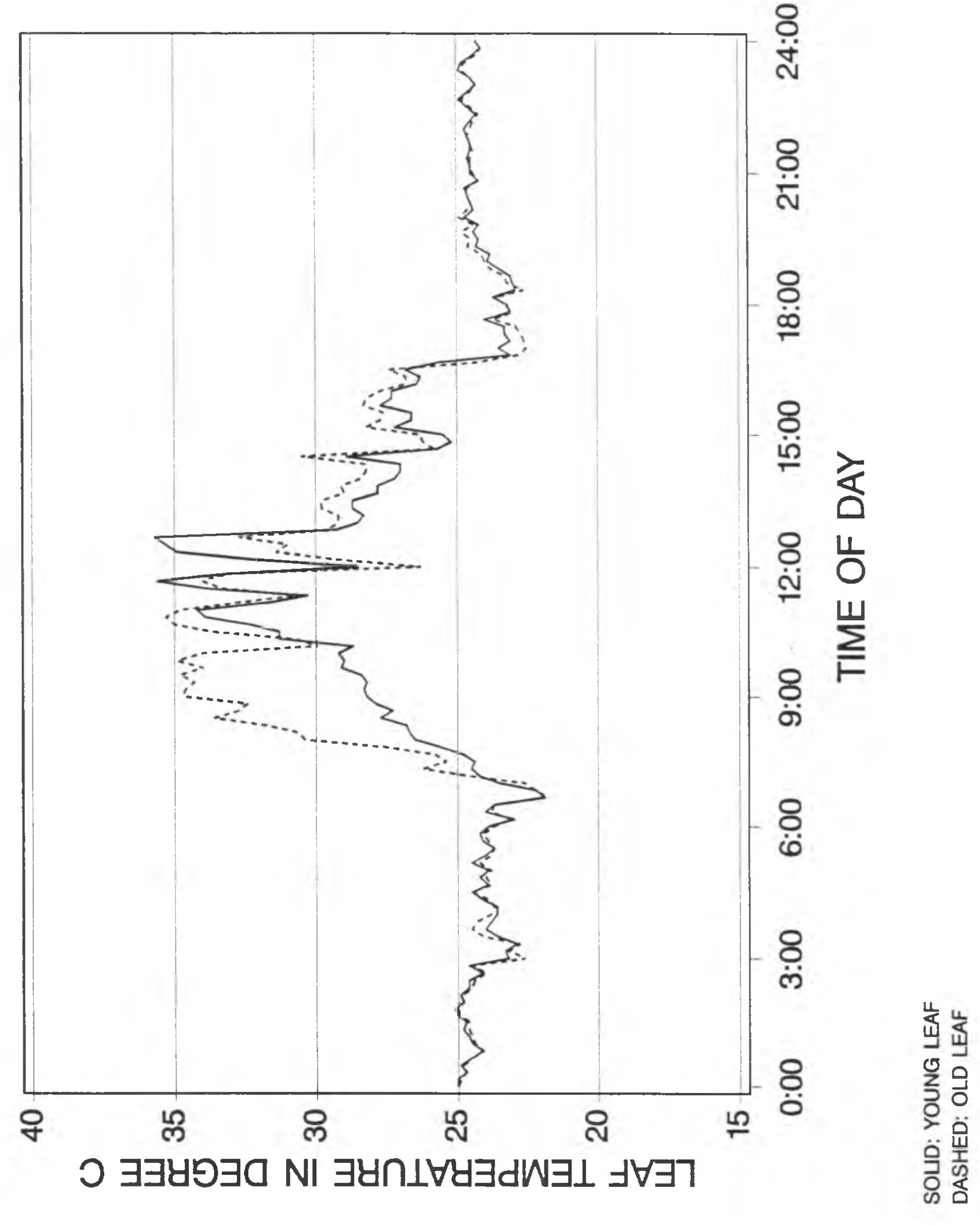

Figure 14. The comparison of leaf temperatures of young and old leaves in Waimanalo, Oahu. The temperature of the old leaf increased at a faster rate than the young leaf. The data presented were in 10-minute intervals on September 29, 1985.

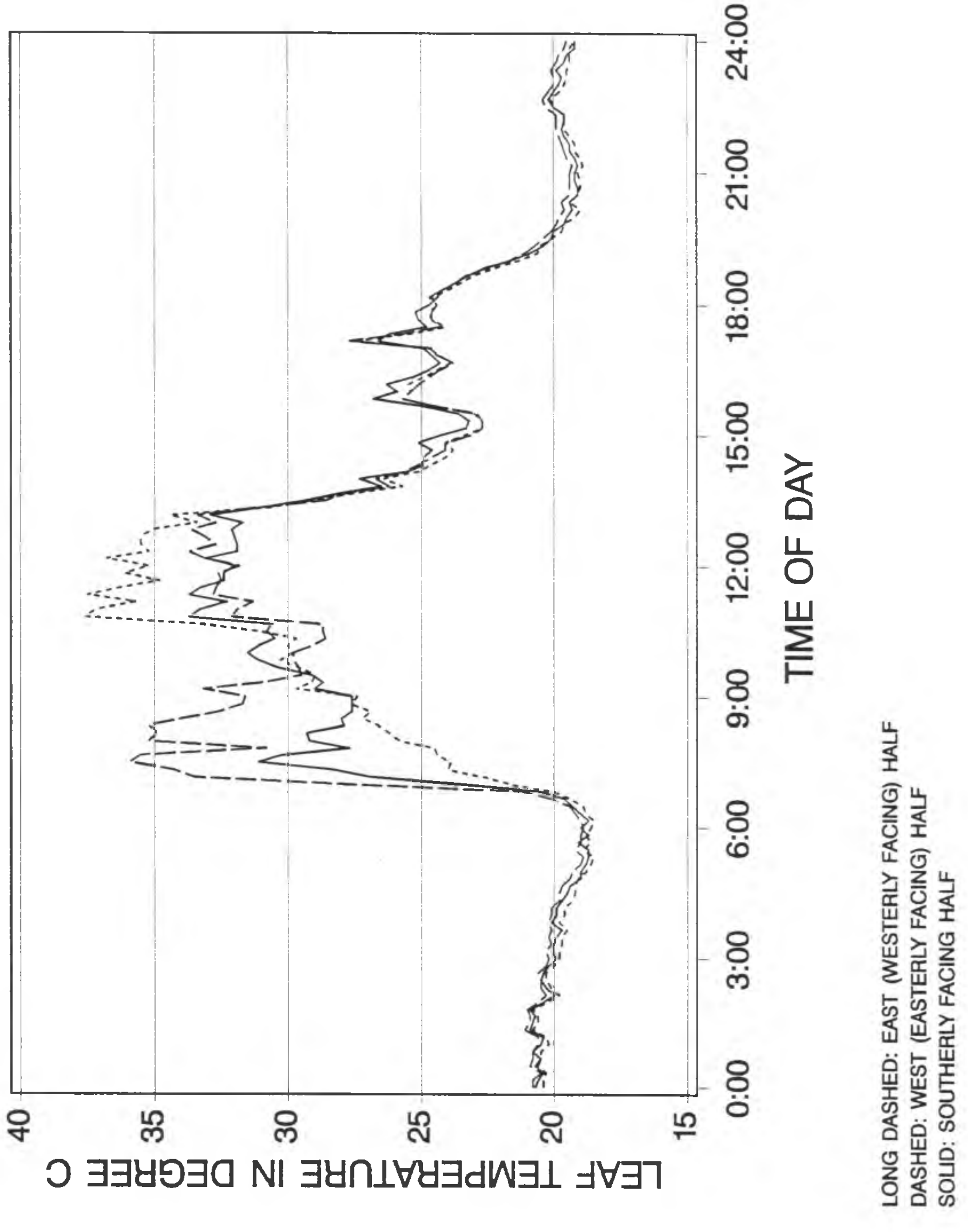

Figure 15. The comparison of leaf temperature of bird of paradise with different orientation in Waimanalo, Oahu. The easterly and westerly facing half of the leaf showed the opposite trend in 10:30-13:00 period while the southerly facing half was relatively constant. The data presented were in 10-minute intervals on September 11, 1985.

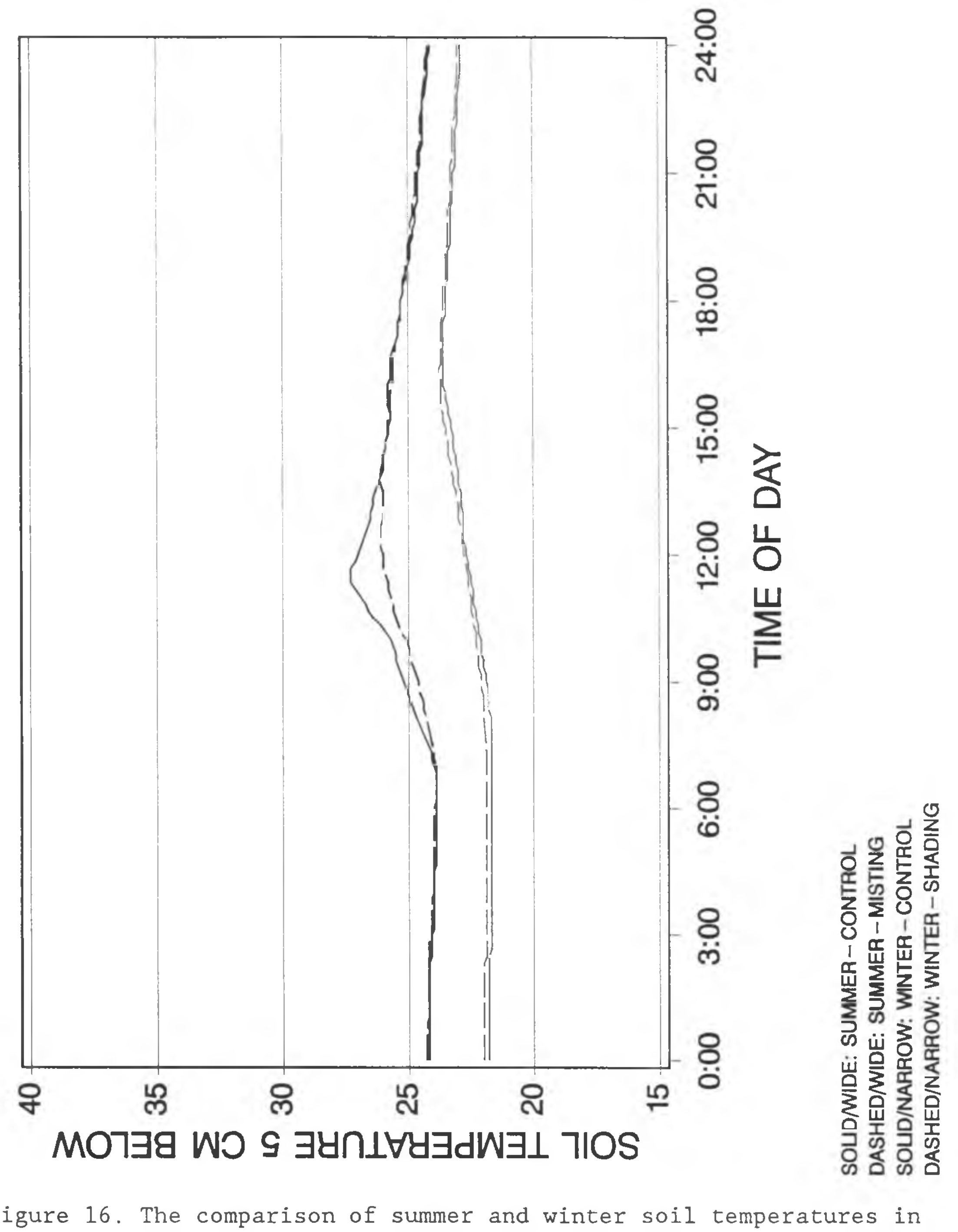

Figure 16. The comparison of summer and winter soil temperatures in Waimanalo, Oahu. The soil temperature fluctuated between 20 and 29°C and was 4-5°C higher in summer. Misting in summer reduced the soil temperature in the day while shading had no effect in winter. The data presented were recorded in 10-minute intervals on August 22, 1985 and January 19, 1986.

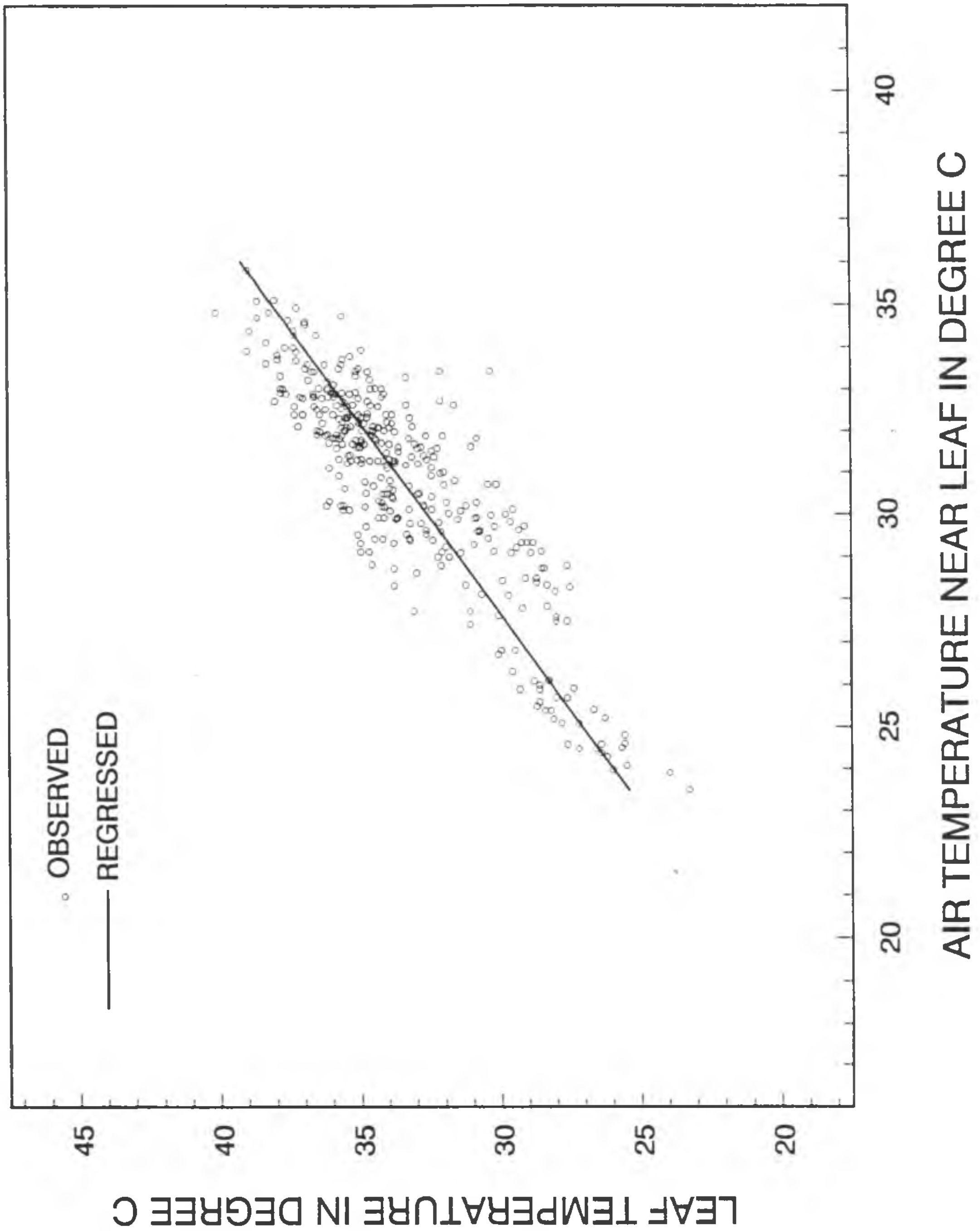

Figure 17. A straight-line regression of leaf temperature of bird of paradise on air temperature near the leaf (Table 5). The data were selected to represent clear-sky conditions in Waimanalo, Oahu.

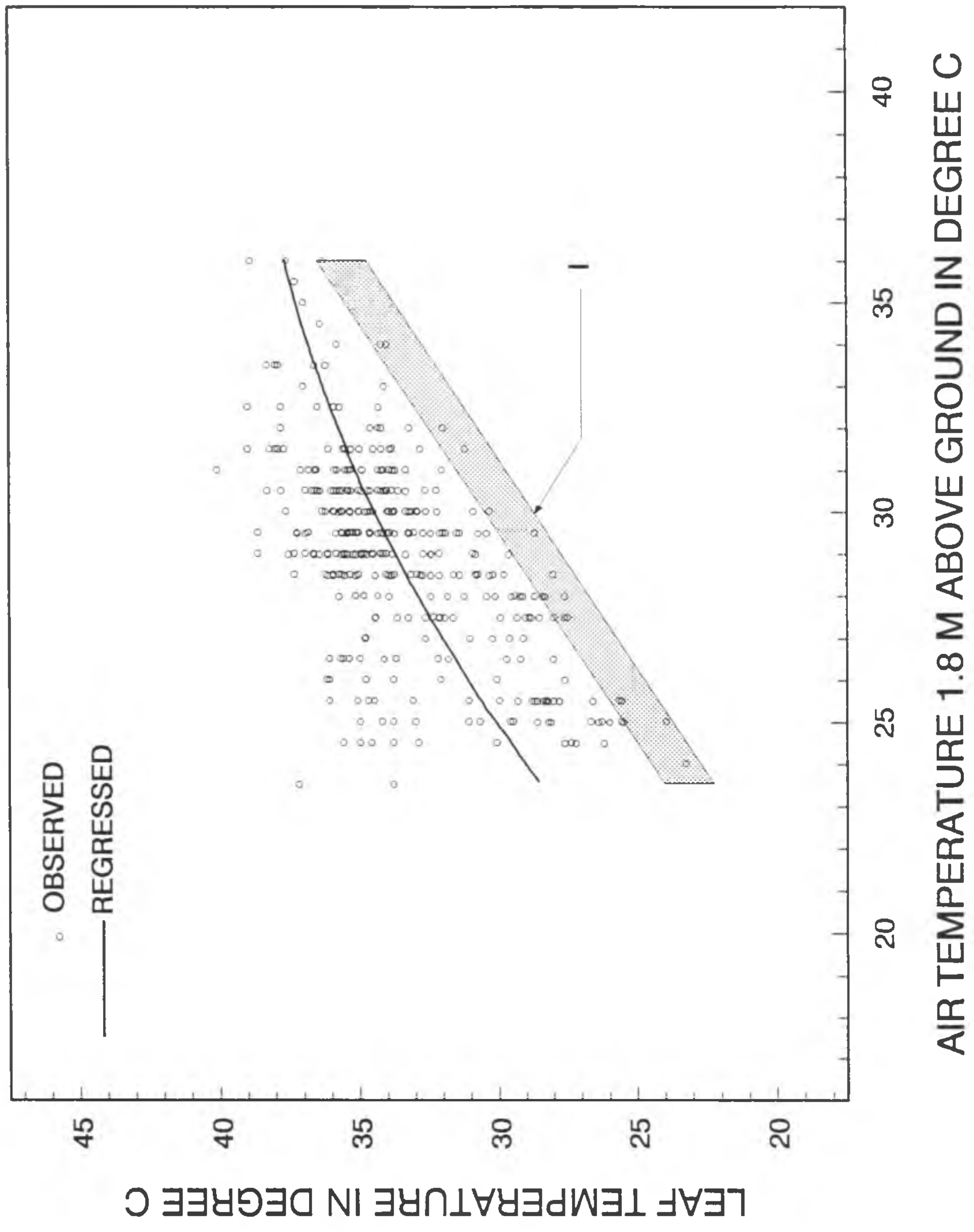

Figure 18. A quadratic regression of leaf temperature of bird of paradise on air temperature 1.8 m above the ground (Table 6). The existence of an imaginary boundary (I) where the air temperature equaled the leaf temperature showed the leaf temperature did not become lower the air temperature. The data were selected to represent clear-sky conditions in Waimanalo, Oahu.

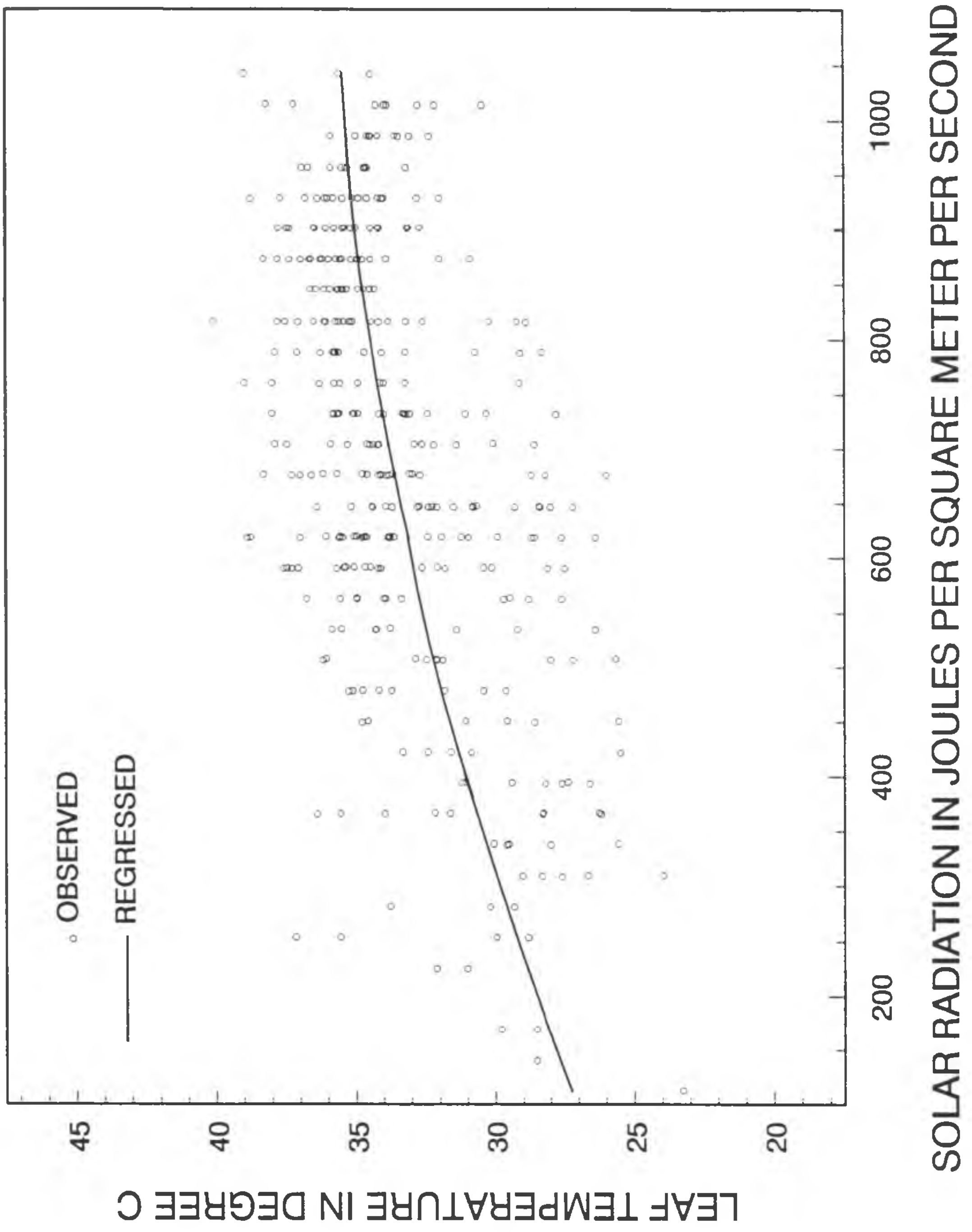

Figure 19. A quadratic regression of leaf temperature of bird of paradise on solar radiation (Table 7). The data were selected to represent clear-sky conditions in Waimanalo, Oahu.

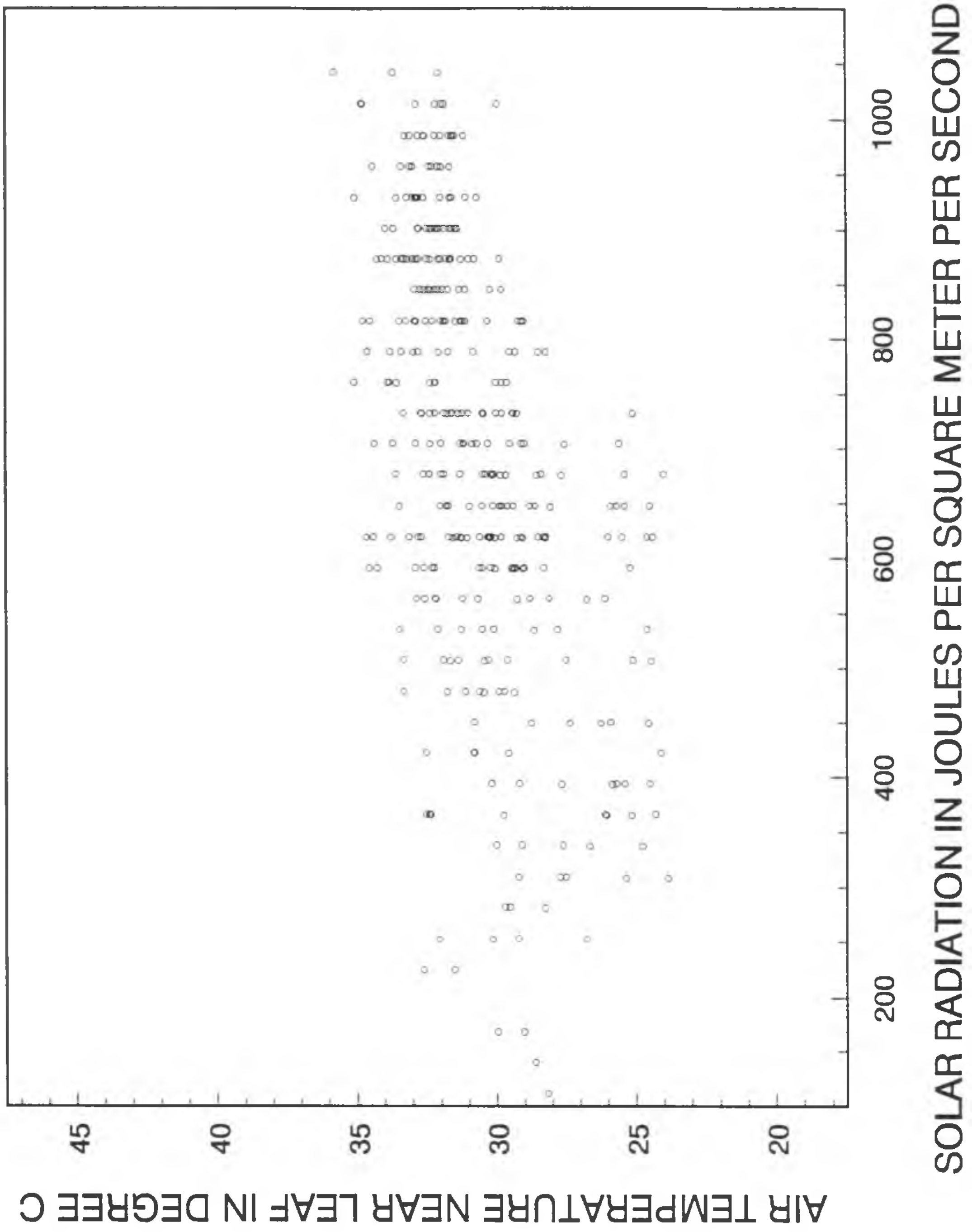

Figure 20. The distribution of the explanatory variables in the data selected to represent clear-sky conditions in Waimanalo, Oahu. The presence of data points in the area at high temperature and low solar radiation indicated the possible inclusion of cloudy-sky observations.

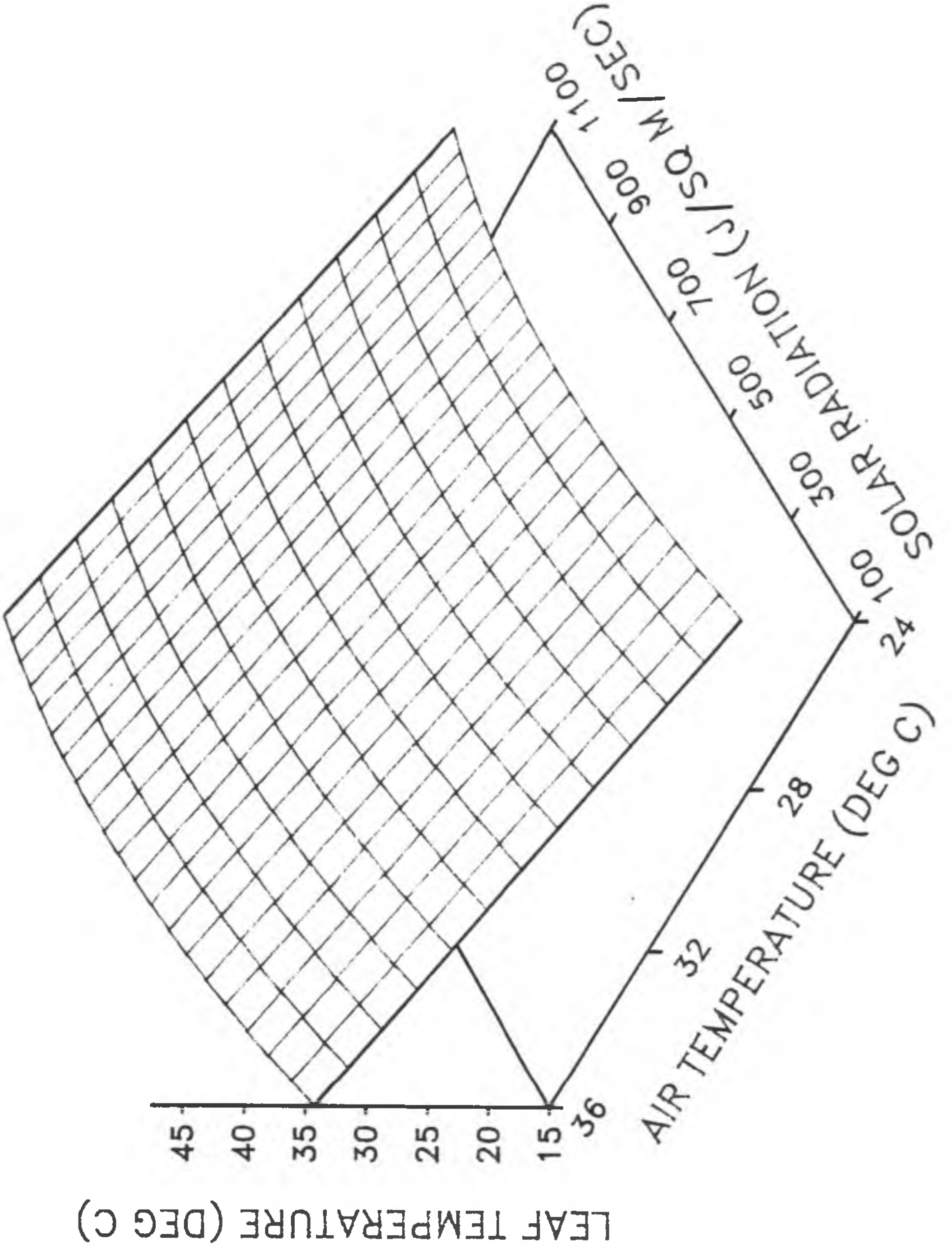

Figure 21. The leaf temperature response of bird of paradise for the clear-sky conditions (FULL-SUN data) in Waimanalo, Oahu. The explanatory variables were added to the model with the Variable Sequence 2 (Table 9).

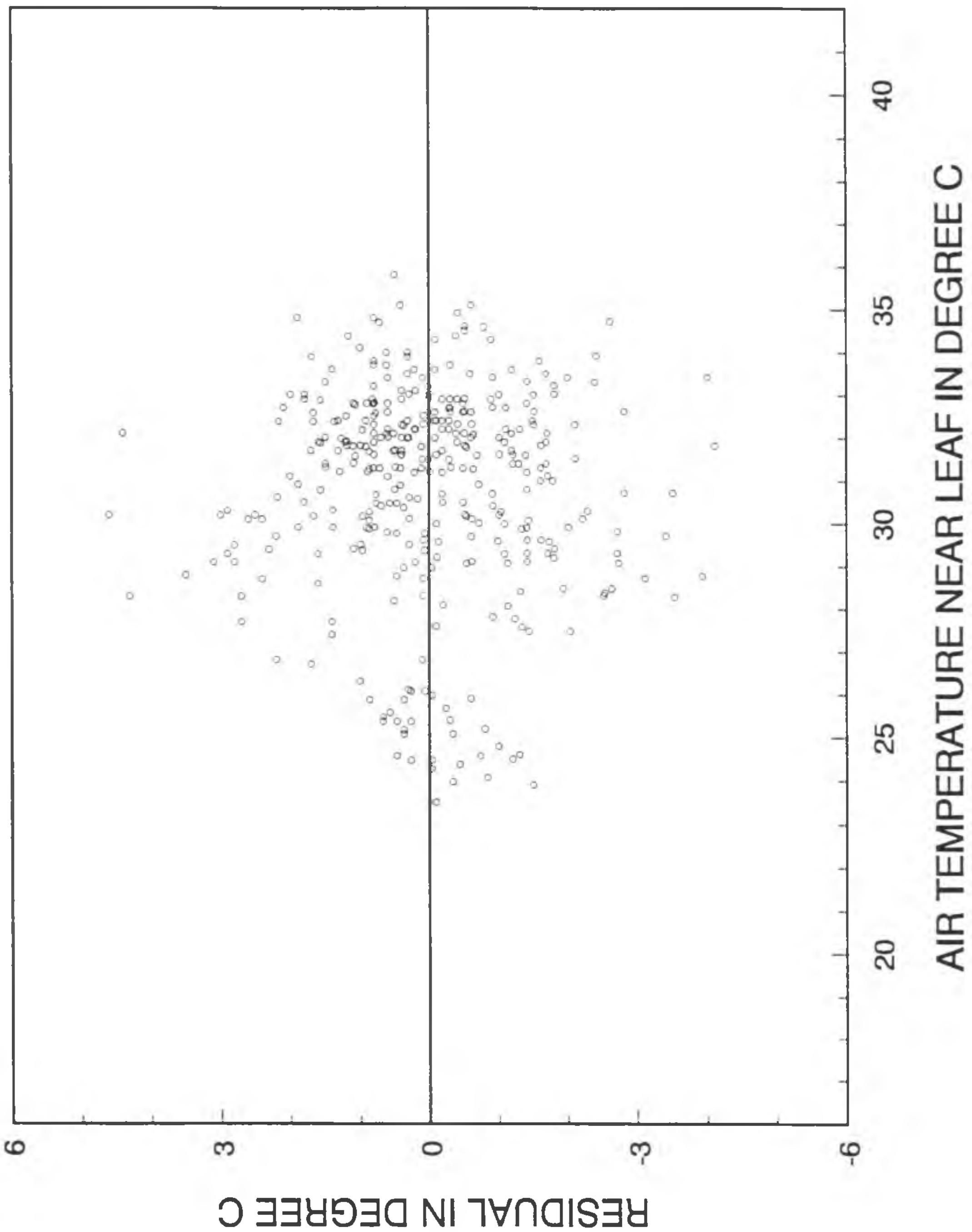

Figure 22. The residual plots for the FULL-SUN model. There was no visible trend left in the residuals.

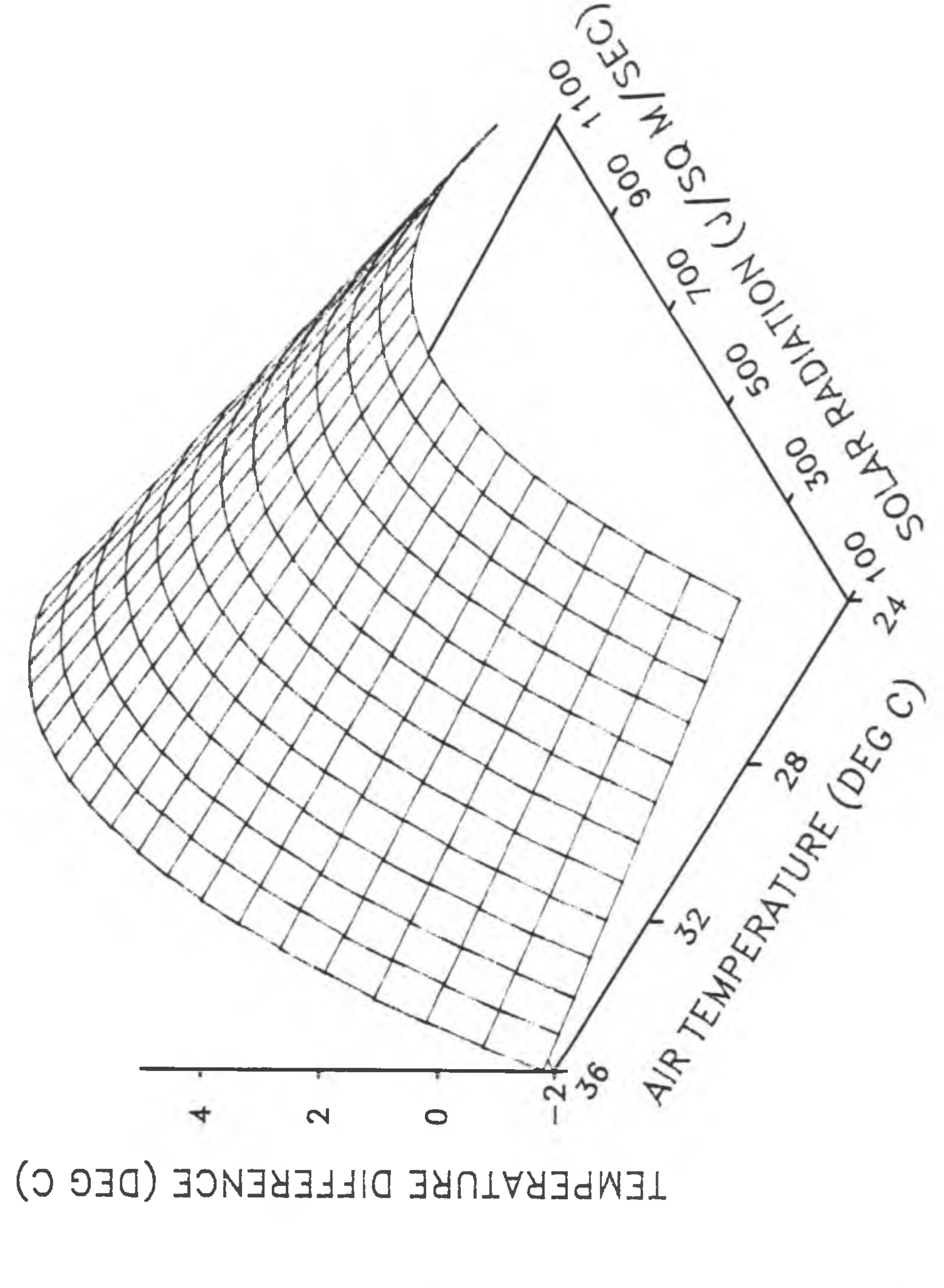

Figure 23. The response surface for the temperature difference between the leaf of bird of paradise and the air near the leaf for the clear-sky conditions in Waimanalo, Oahu. The explanatory variables were added to the model with the Variable Sequence 2 (Table 10).

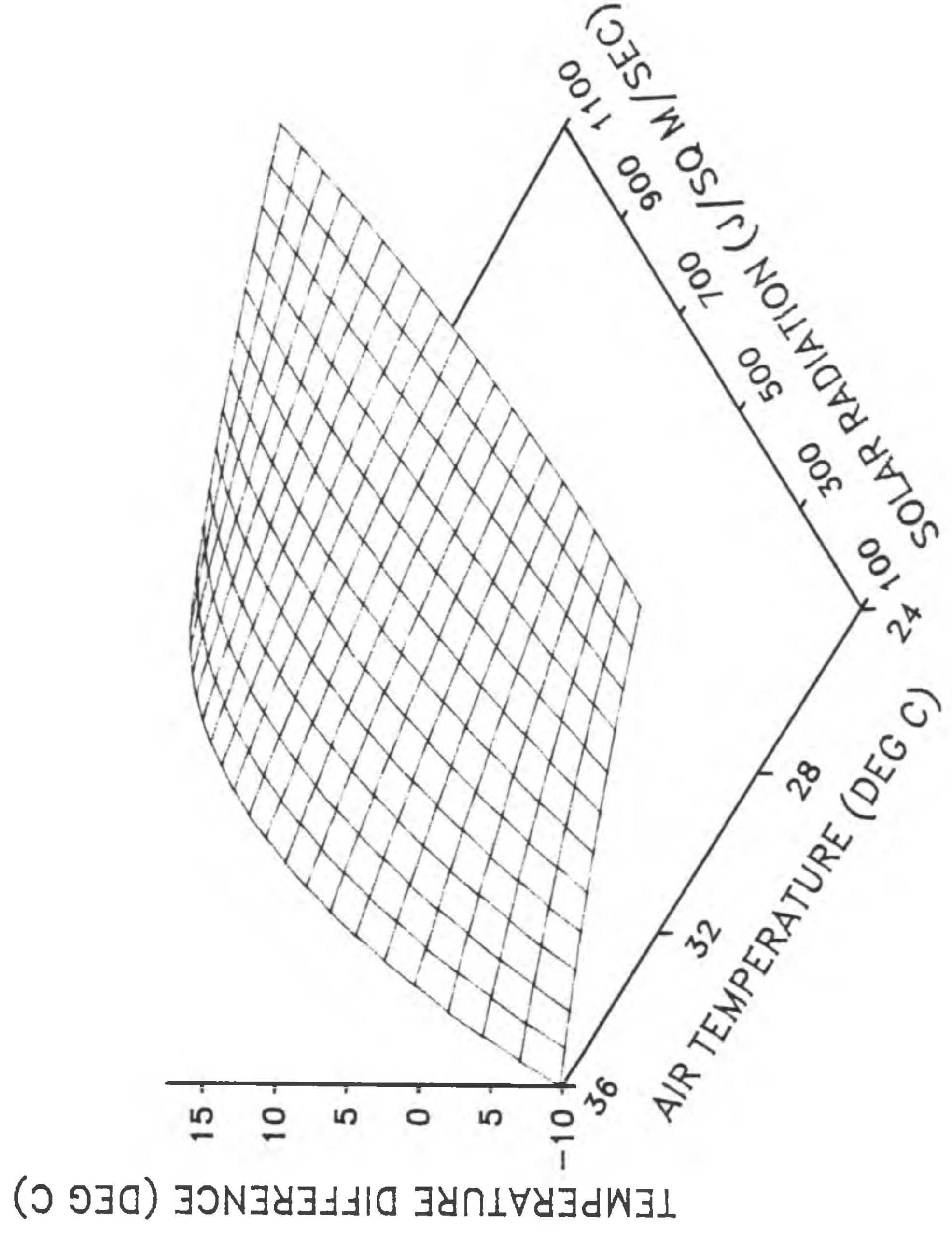

Figure 24. The response surface for the temperature difference between the leaf of bird of paradise and the air 1.8 m above the ground for the clear-sky conditions in Waimanalo, Oahu. The explanatory variables were added to the model with the Variable Sequence 3 (Table 11).

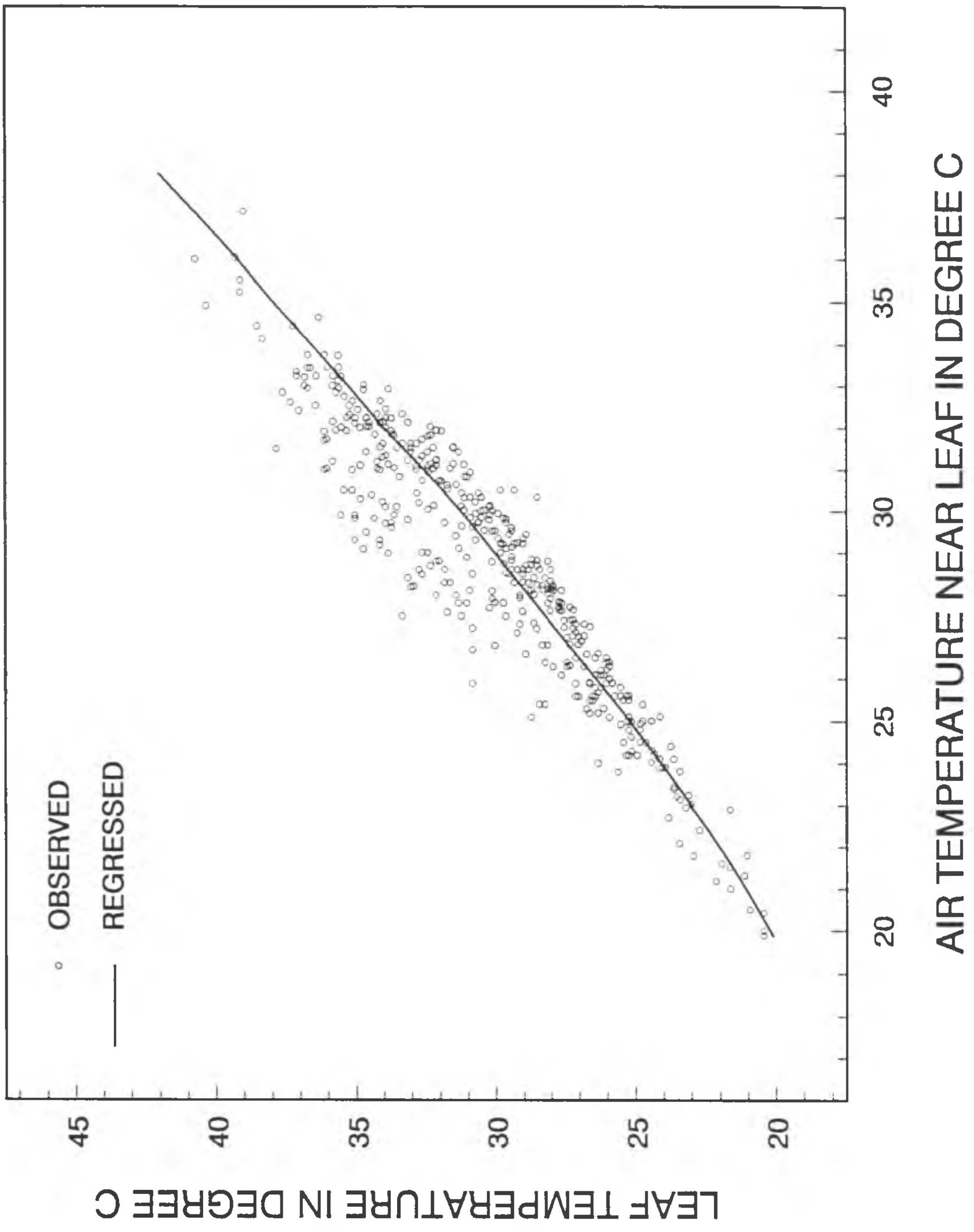

Figure 25. A quadratic regression of leaf temperature of bird of paradise on air temperature near the leaf (Table 12). The data were selected for representing all-weather conditions in Waimanalo, Oahu. Every 8th observation was plotted.

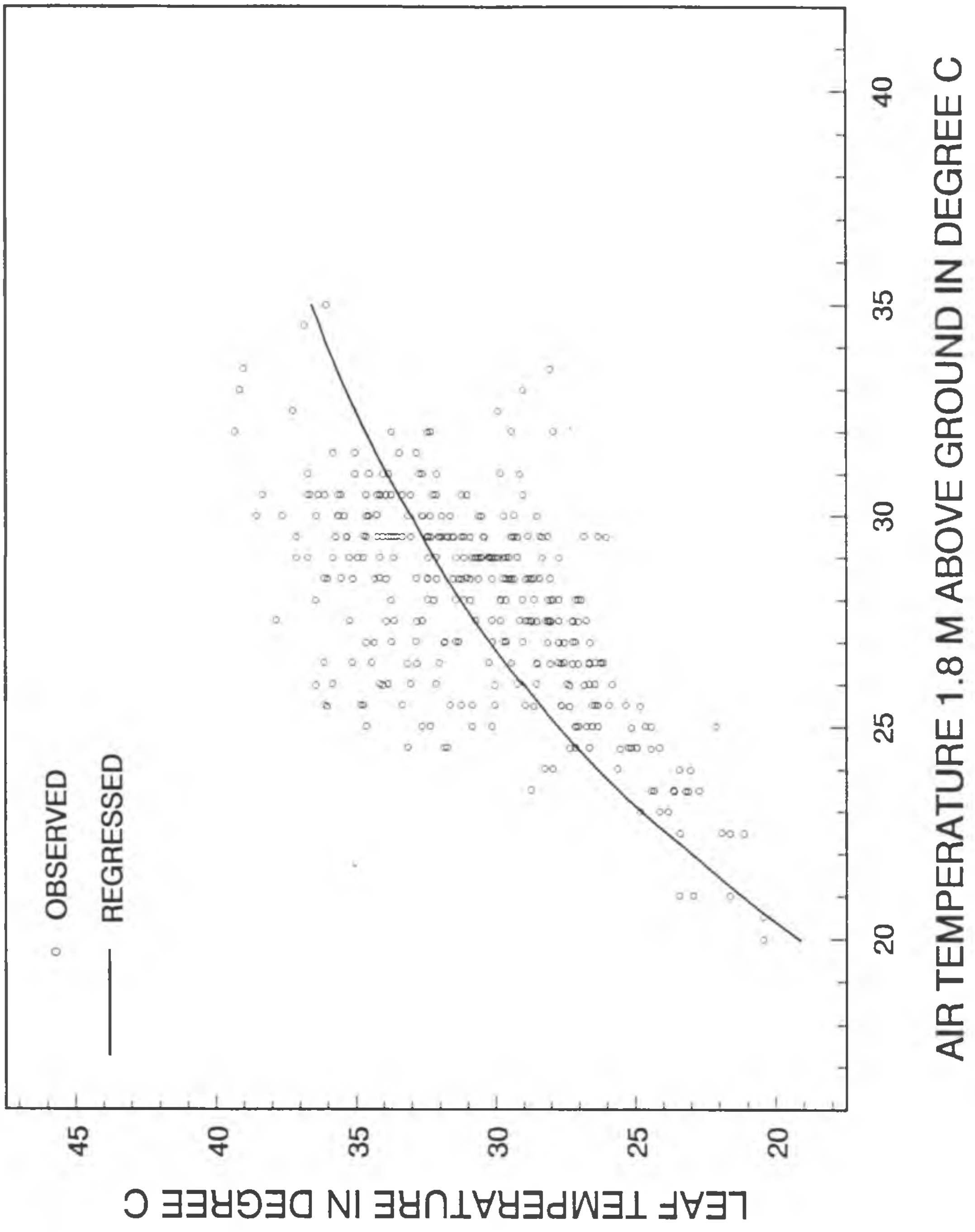

Figure 26. A quadratic regression of leaf temperature of bird of paradise on air temperature 1.8 m above the ground (Table 13). The data were selected to represent all-weather conditions in Waimanalo, Oahu. Every 8th observation was plotted.

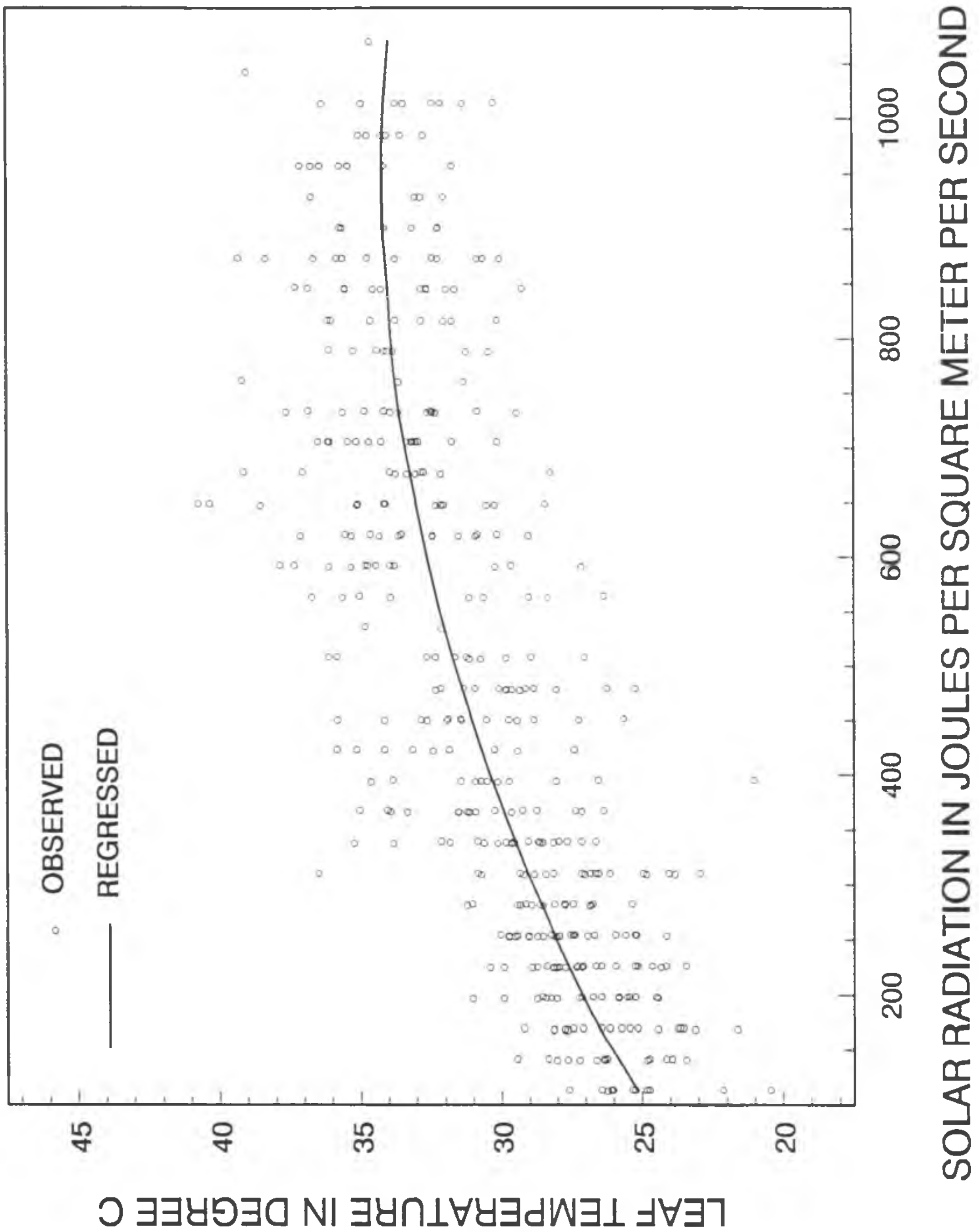

Figure 27. A quadratic regression of leaf temperature of bird of paradise on solar radiation (Table 14). The data were selected for representing all-weather conditions in Waimanalo, Oahu. Every 8th observation was plotted.

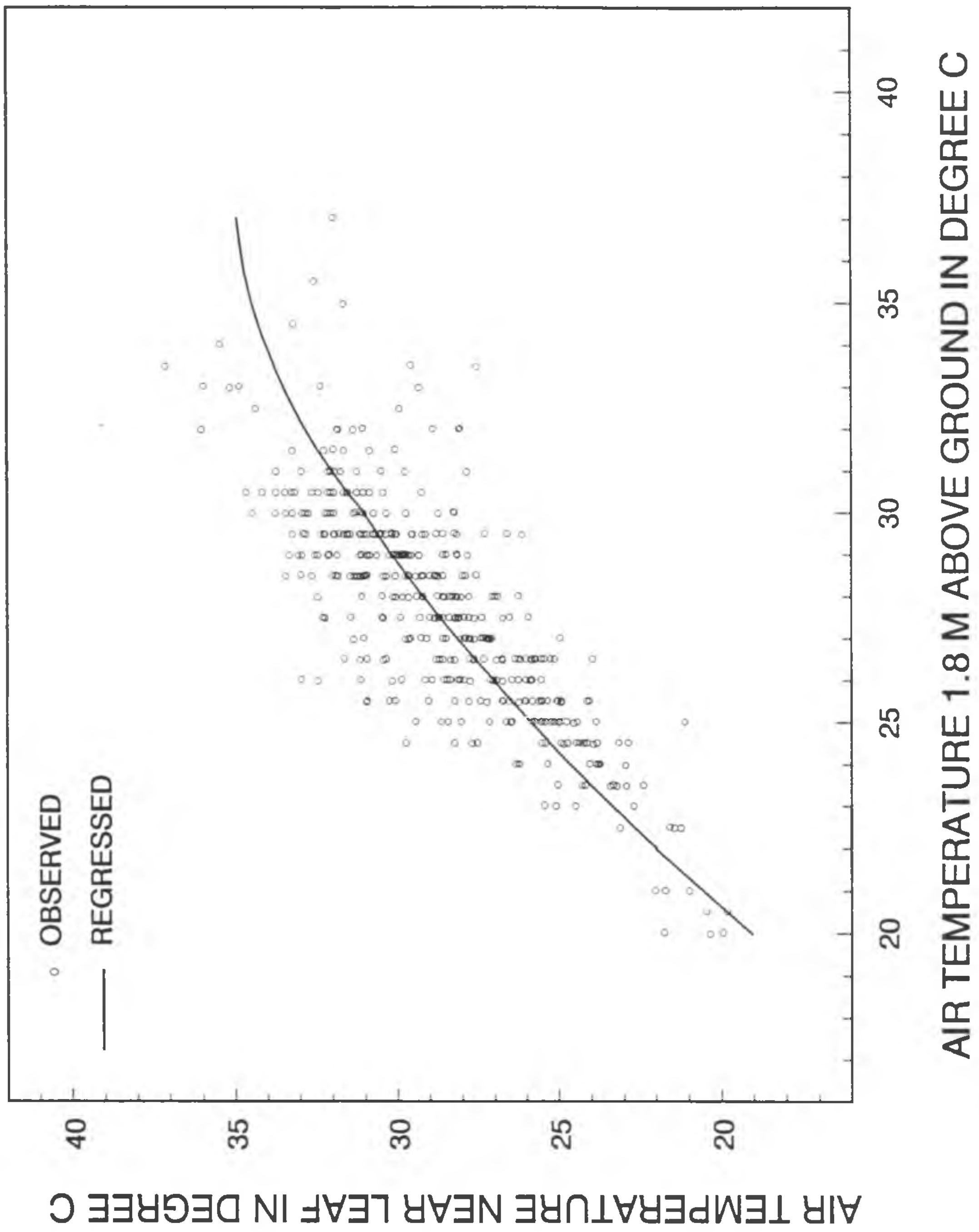

Figure 28. The relationship of the two air temperature measurements (Table 15). A quadratic regression of the air temperature near the bird of paradise leaf on the air temperature 1.8 m above the ground accounted for 67 percent of the variation.

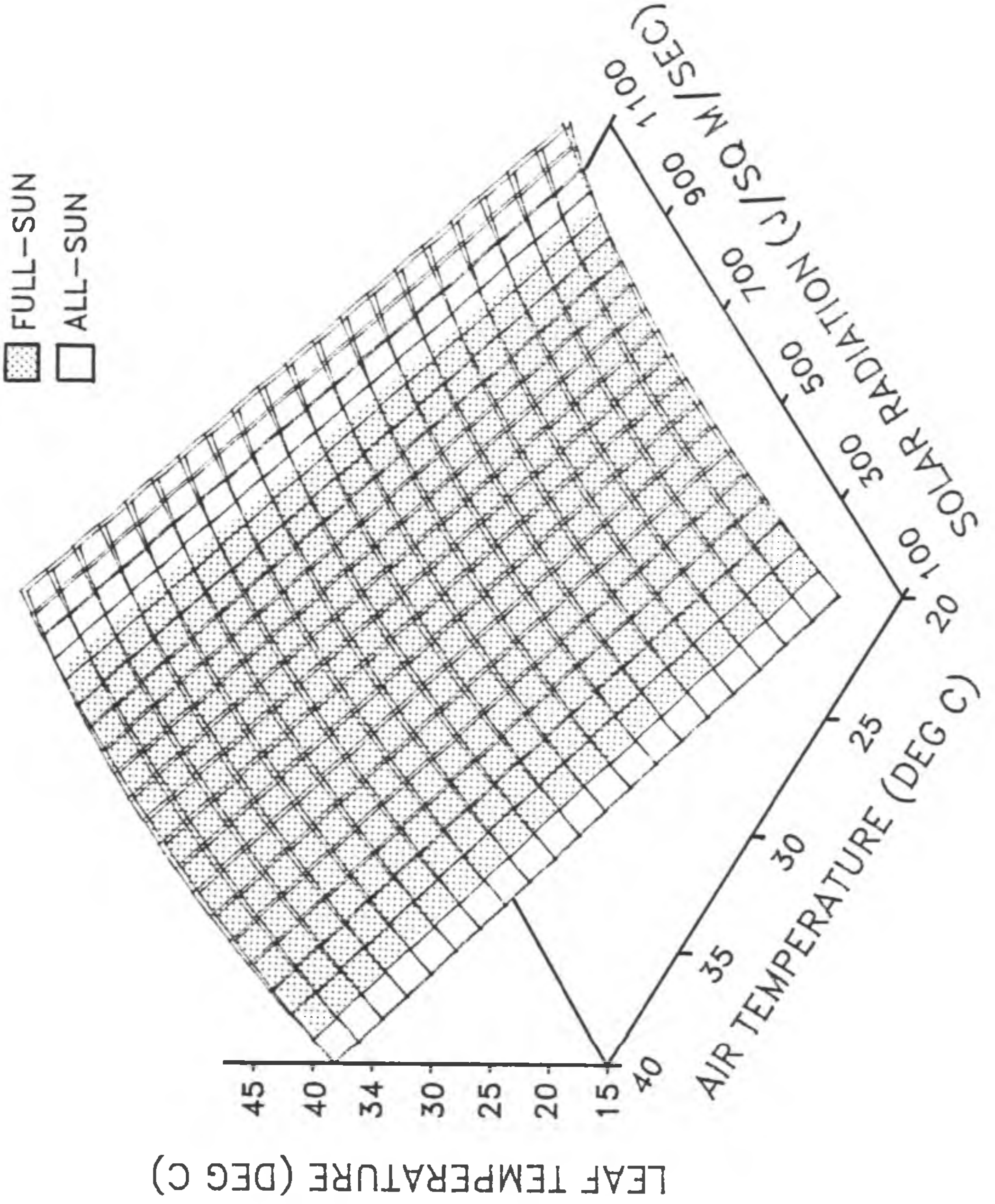

Figure 29. The comparison of leaf temperature responses of bird of paradise under clear-sky conditions (FULL-SUN data) and all-weather conditions (ALL-SUN data) in Waimanalo, Oahu. The explanatory variables were added to the model with the Variable Sequence 4 (Table 18). Statistical differences between the data sets were found for the interactions with the straight-line and quadratic effects of solar radiation. The ALL-SUN data were represented by every 10th observation.

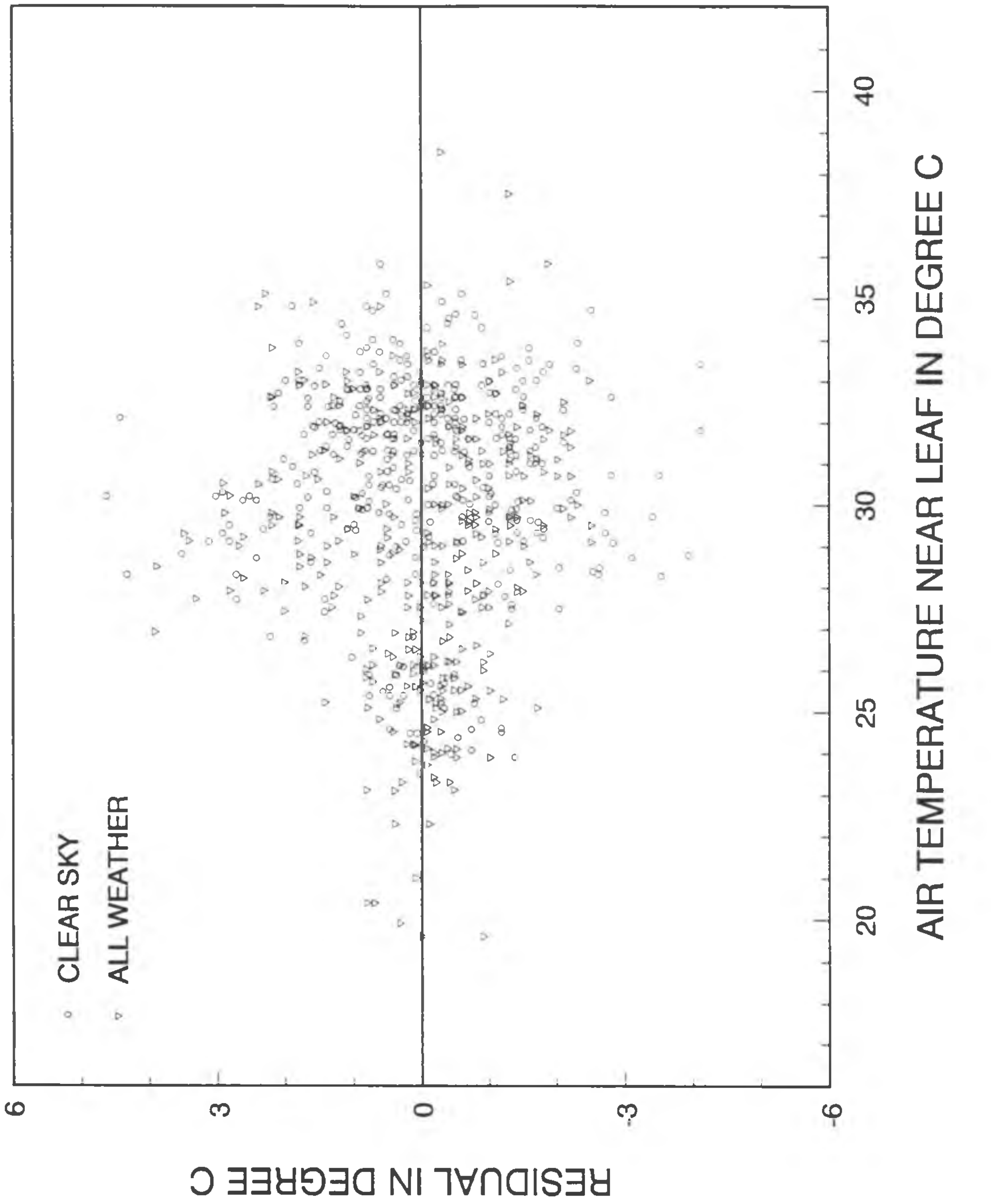

Figure 30. The residual plots for the comparison of the two response surfaces representing leaf temperatures in clear-sky and all-weather conditions. There was no visual trend left in the residuals. The ALL-SUN data were represented by every 10th observation.

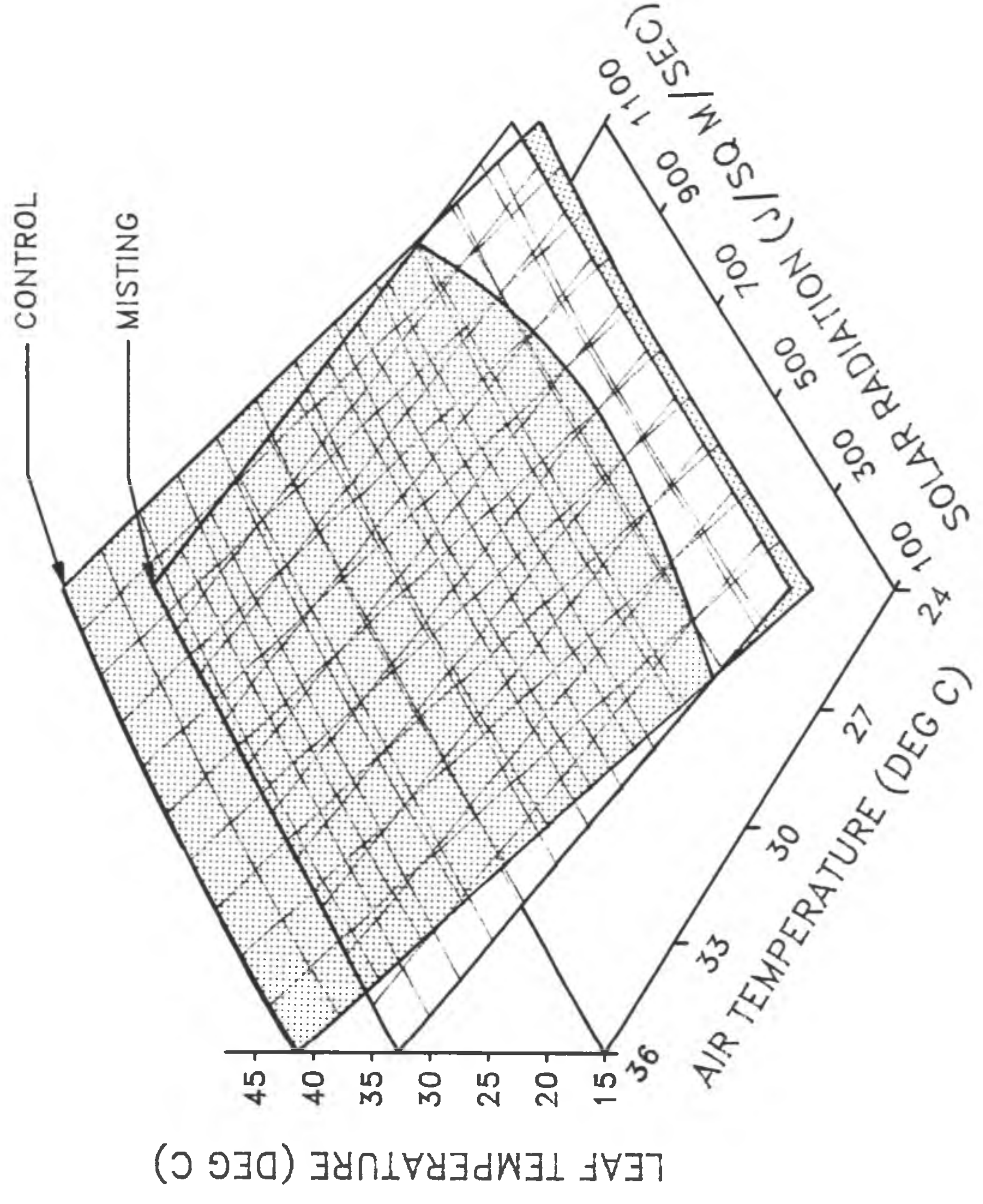

Figure 31. The comparison of leaf temperature responses of bird of paradise under mist and control in Waimanalo, Oahu (Table 22). The explanatory variables were added to the model with the Variable Sequence 5. The statistical differences between the treatments were found for the interactions with the straight-line and quadratic effects of solar radiation and the straight-line effect of air temperature near the leaf.

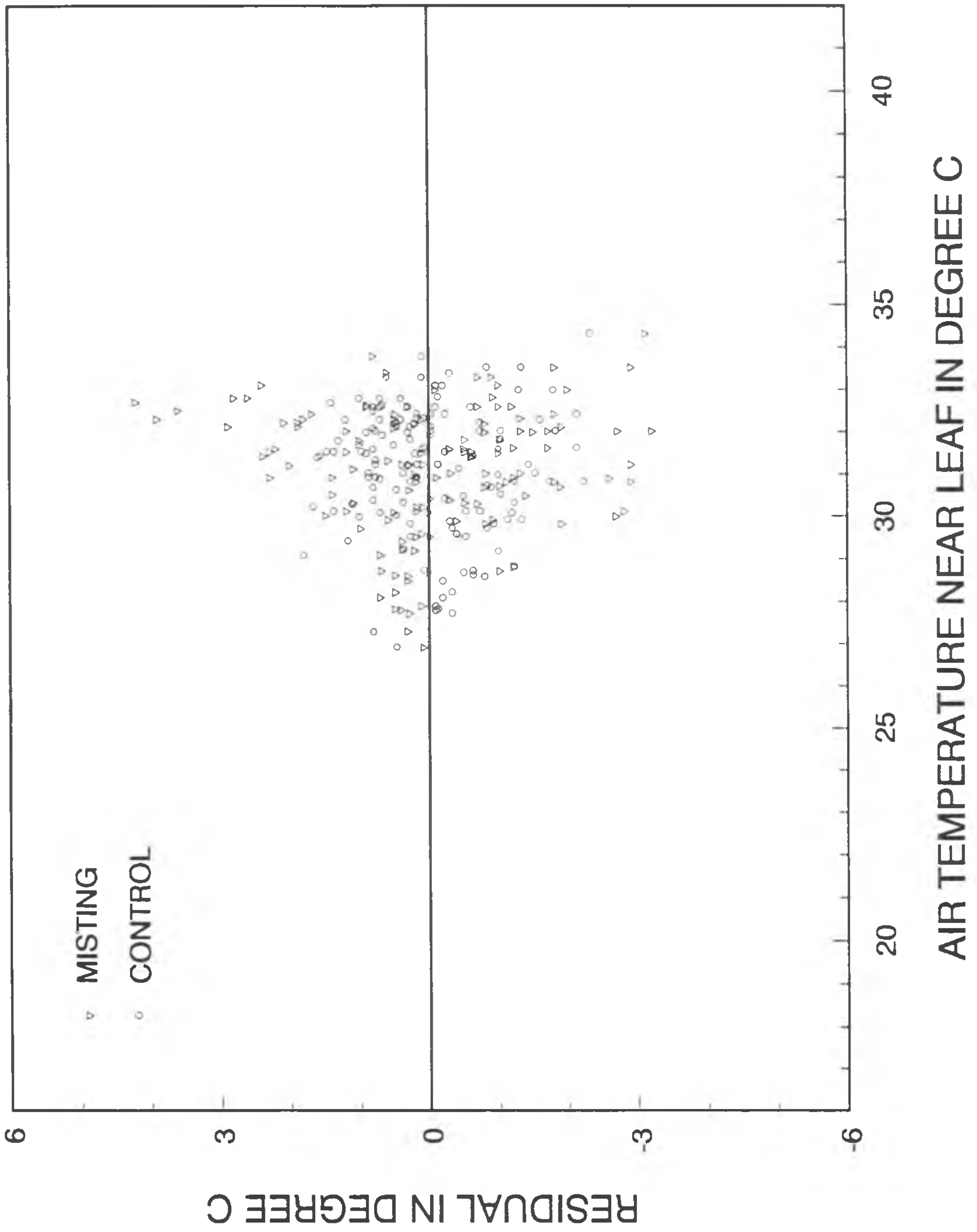

Figure 32. The residual plots for the comparison of leaf temperature responses of bird of paradise under misting and control in Waimanalo, Oahu. The misting treatment had a larger variance than the control at a high air temperature near the leaf.

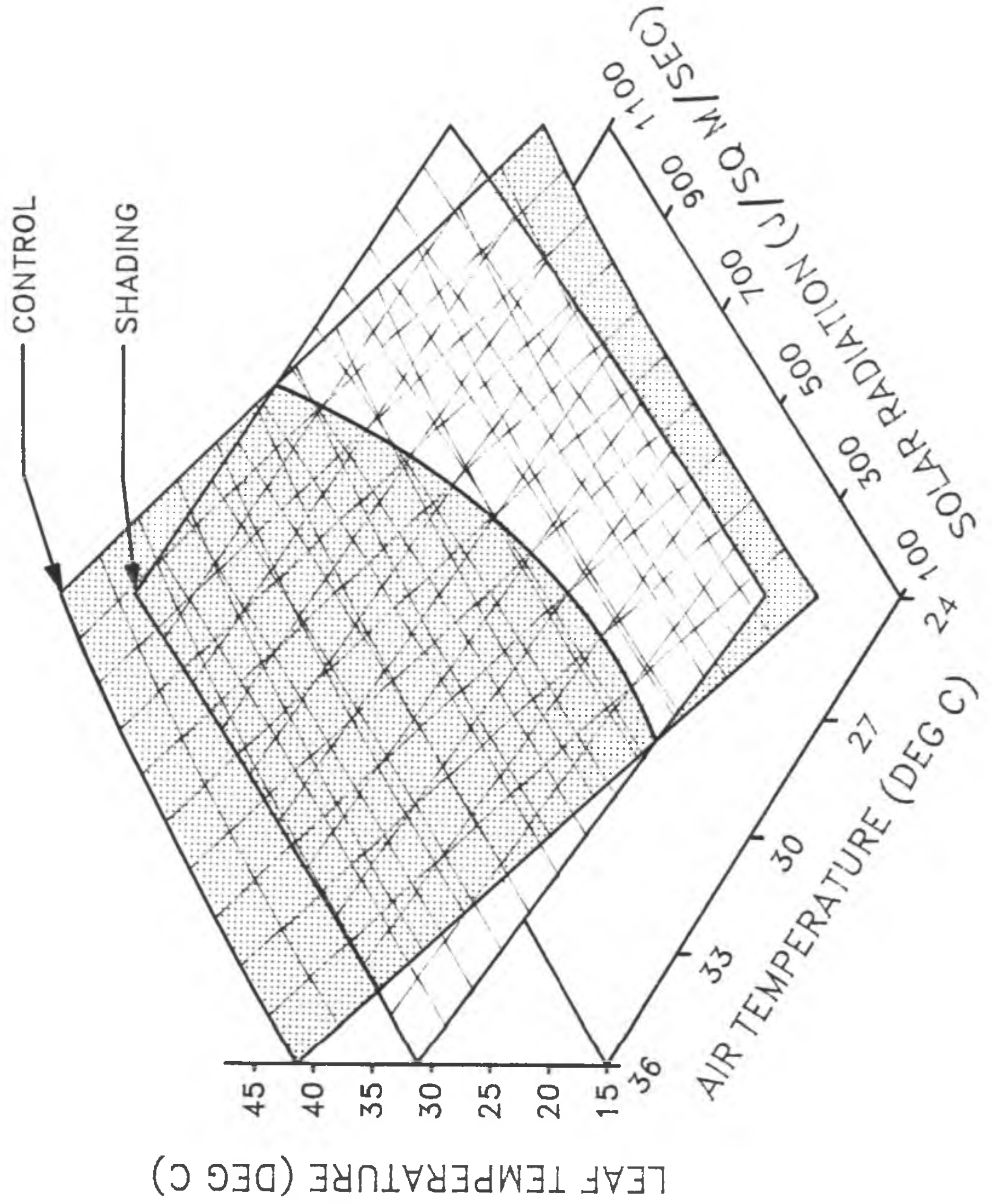

Figure 33. The comparison of leaf temperature responses of bird of paradise under shade and control in Waimanalo, Oahu. The explanatory variables were added to the model with the Variable Sequence 5 (Table 23). Statistical differences between the treatments were found for the interactions with the straight-line and quadratic effects of solar radiation and the straight-line effect of air temperature near the leaf.

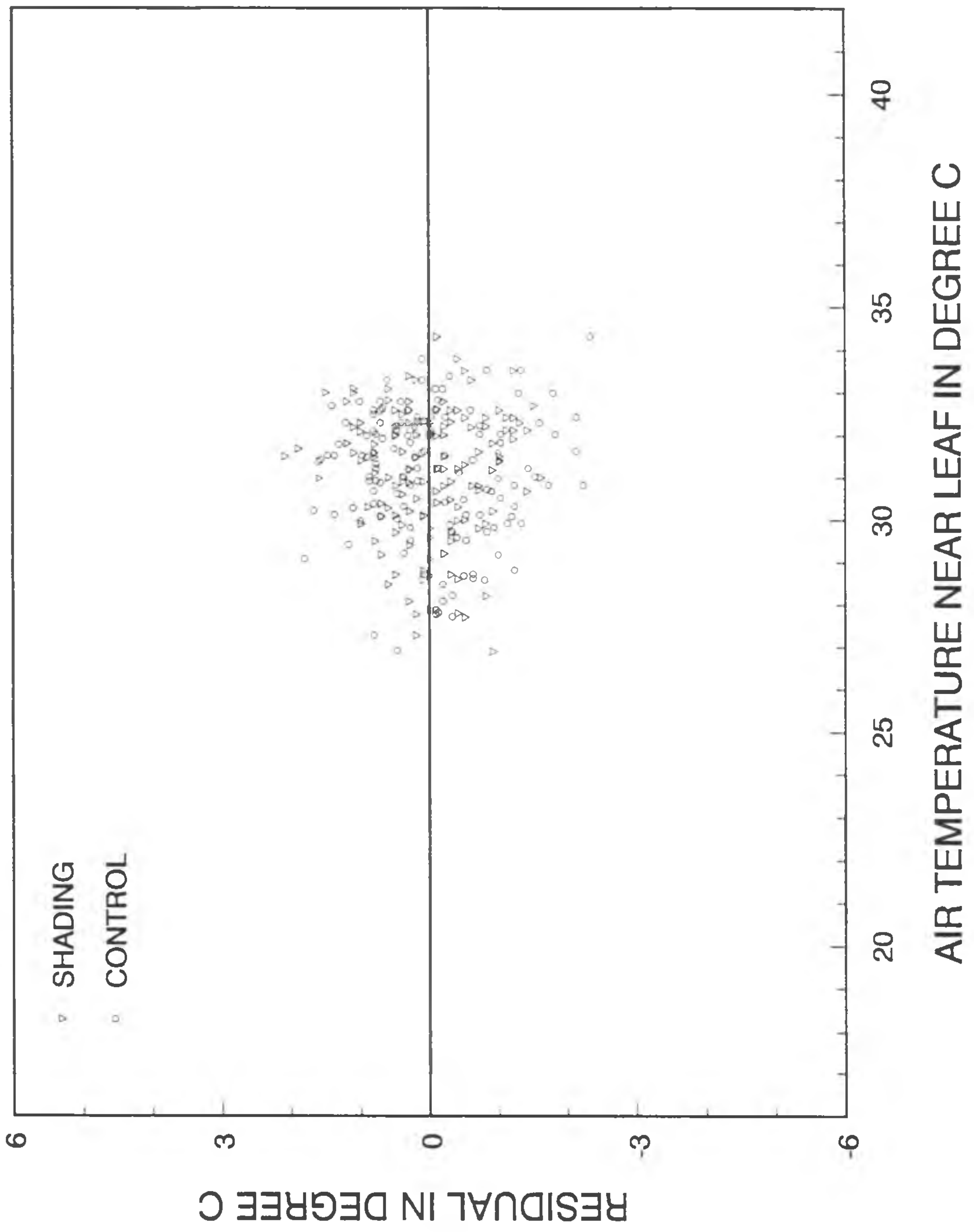

Figure 34. The residual plots for the comparison of leaf temperature responses of bird of paradise under misting and control in Waimanalo, Oahu. There was no visual trend left in the residuals.

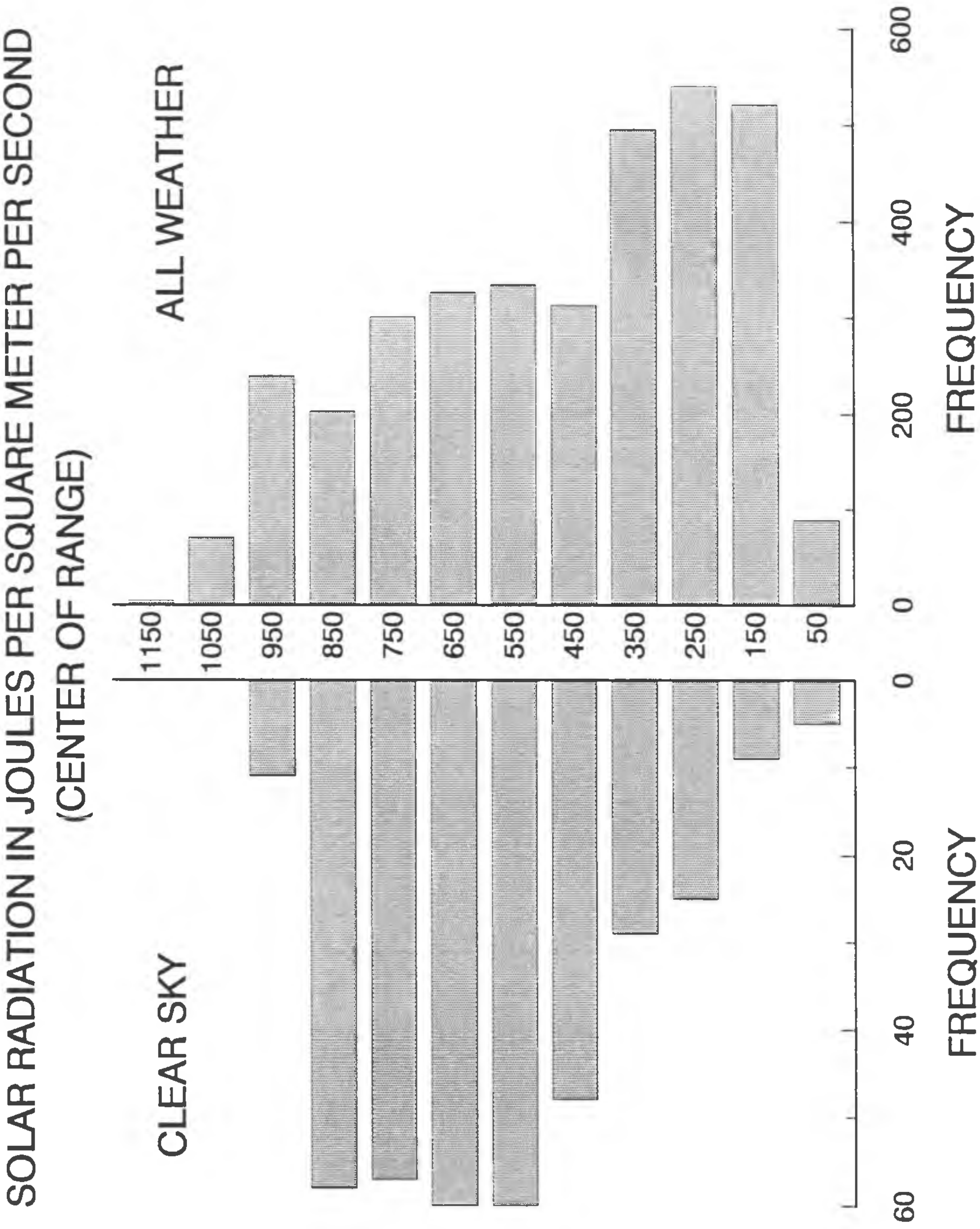

Figure 35. Frequency distributions of solar radiation in Waimanalo, Oahu. The all weather represented the readings between 11:00-14:00 from August 2, 1985, to February 10, 1986; the clear-sky data were visually selected for high solar radiation. The skewness showed the difference in the characteristics between the data sets.

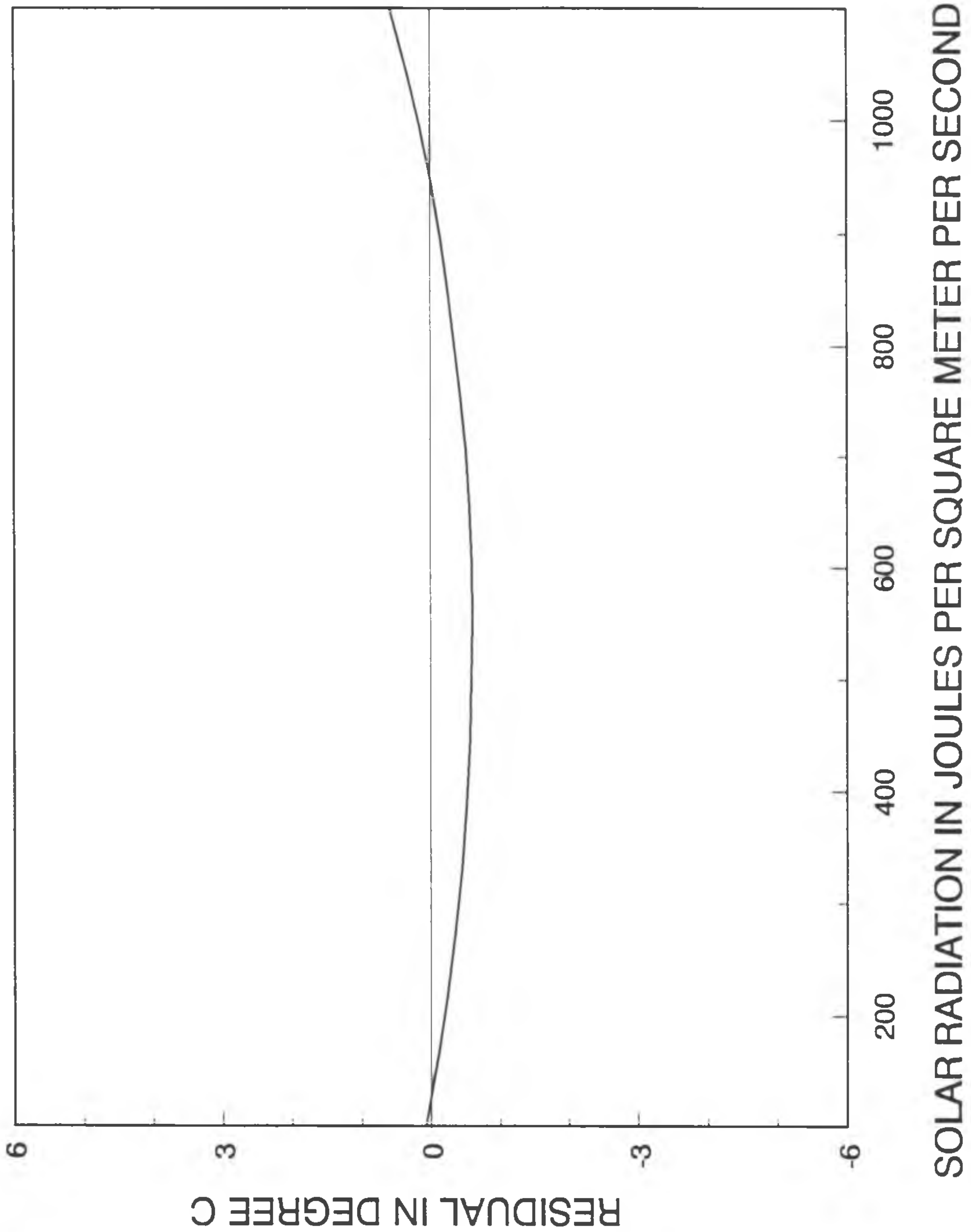

Figure 36. Estimated differences between two response surfaces representing all-weather and clear-sky conditions in Waimanalo, Oahu. Although the difference was statistically significant, the magnitude of the difference was small enough to be negligible.

CHAPTER 3

FLOWER PRODUCTION OF BIRD OF PARADISE AS AFFECTED BY LEAF COOLING PRACTICES

Bird of paradise has been known to have an unpredictable seasonal flowering characteristic which varies with the environment of the production site (Halevy, et al., 1987). Peak flowering periods were found in a August-October in Hawaii (Criley and Kawabata, 1984), October-December and February-May in California (Besemer, et al., 1982b), March-April and September in Israel (Halevy, et al., 1976), and fall-winter-spring in South Africa (van de Venter, et al., 1980).

Reasons for this variation were attributed to the seasonal changes in the rate of flower development and the occurrence of flower abortion (Kawabata, et al., 1984). It would be important for growers to be able to predict the seasonality in flower production for site selection, and to be able to modify flower production peaks if the plants are already established in a site for the best marketability of the flower.

Since intermittent misting and shading were determined to be effective in reducing leaf temperature in experiments reported in Chapter 2, altering the flower production pattern of bird of paradise by leaf cooling practices became a possibility and a study was initiated.

3.1 Literature Review

Flower development. Bird of paradise is a self-inductive plant (Criley and Halevy, 1985) in which flowers are initiated in any environmental condition favorable for vegetative growth. Since the leaf subtends 1 flower stalk at the base of each leaf axil (Fisher, 1976), the total number of leaves produced determines the potential flower production.

In greenhouse experiments, more leaves were produced under 20-25°C air temperature than under 15°C (Fransen, 1977), 27-32°C than 17-22°C (Halevy and Khayat, unpublished data), 25°C than 22°C (van der Krogt, 1981), and 25°C than 15-20°C (Vonk Noordegraaf, 1975). Therefore, a warm air temperature would have a potential for a higher flower production than a cold one.

Since the early stage of flower development in bird of paradise cannot be observed without destroying the plant, it was more convenient to examine development as based on visually observable events (Kawabata, et al., 1984). The flower development of bird of paradise was identified by 4 successive events: flower bud initiation (FI, the precise time has not been determined), leaf emergence (LE, the first indication of the development of flowers), flower emergence (FE, the first evidence of the existence of flowers), and flower cut (FC, anthesis). The total development period can be divided into 3 stages: flower initiation to leaf emergence (FILE), leaf emergence to flower emergence (LEFE), and flower emergence to flower cut (FEFC) (Halevy, et al., 1987). A total development time, FI to FC, was suggested to be approximately 28 months (Criley and Halevy, 1985) which may be prolonged by a cold air temperature and shortened by a warm air temperature (Kawabata, et al., 1984).

Flower bud abortion. Bird of paradise produces leaves sequentially in an opposite and spiral (distichous) arrangement. Since the flower stalks subtended by these leaves also emerged sequentially, a lack of some flower emergences indicated flower abortion. Flowering percentage in this study is defined as the number of flowers harvested as a percentage of the number of leaves produced.

The occurrence of abortion seemed to be seasonal: leaves which emerged in June-August period had low flowering percentages in the Netherlands (Fransen, 1977), in summer-fall period in South Africa (van de Venter, et al., 1980), in May-July in France (Berninger, 1981), and in April-July in Hawaii (Criley and Kawabata, 1984). Abortion occurred when flower buds were approximately 2-cm long when they were at the flower differentiation stage (FD) between LE and FE (Criley and Kawabata, 1984).

Although sampling and tagging of emerging leaves allowed the estimation of monthly percentages of flower abortion in Hawaii (Criley and Kawabata, 1984), the actual number of occurrence could not be determined because monthly totals of leaf emergence were not recorded. Therefore, the time of LE for every leaf would be needed in order to determine the total number of occurrences of flower abortion assuming leaves which did not show flowers at their leaf axils had aborted flowers.

Factors possibly affecting flower abortion. High air temperatures were associated with flower abortion in greenhouse experiments, since lower flowering percentages were recorded at 25°C air temperature than 20°C in the Netherlands (Fransen, 1977; van der Krogt, 1981), 27-32°C than 17-22°C in Israel (Halevy and Khayat, unpublished data), and 28°C than 21°C in California (Halevy, et al., 1976). A high temperature threshold of 27°C was proposed for abortion using temperature records in Hawaii (Kawabata, et al., 1984).

Limited water availability increased the chance for the abortion as reducing water application to the soil reduced flowering percentages (van der Krogt, 1985).

These results indicated a possibility that high leaf temperatures induced by water stress caused the abortion in the previous experiments. However, a growth chamber experiment conducted under minimum water stress still showed the occurrences of flower abortion in 17 and 22°C air temperature chambers (flowering percentages of 22 and 48%, respectively), while none flowered in 27 and 32°C chambers (Halevy and Khayat, unpublished data). Therefore, a direct effect of high air temperature as the cause for the flower abortion was suggested (Criley and Halevy, 1985), although the flower abortion could occur in the cooler temperature range also (12-17°C).

Daylength control (16-hr dark for short-day, and 22:00-3:00 night interruption for long-day) did not change the total flower production

(Halevy, et al., 1976), although a reduced solar radiation sum could reduce flower production (Halevy, et al., 1976) or cause blasting (van de Venter, et al., 1980).

Therefore, possible environmental factors for flower abortion in bird of paradise were 1) a high air temperature (Kawabata, et al., 1984); 2) water stress (van der Krogt, 1985); and 3) an undetermined factor which could cause abortion in low temperature and no water stress condition, since none of the environmental conditions provided in the previous experiments avoided the occurrence of flower abortion.

In Chapter 2, leaf temperature of bird of paradise was estimated from environmental factors, solar radiation and air temperature; and the reduction of leaf temperature by the application of misting or shading was also estimated. Therefore, if a high air temperature in summer was causing the flower abortion in bird of paradise through raising the leaf temperature, the application of leaf cooling practices would reduce the number of incidents of abortion. Application of adequate irrigation should minimize the occurrence of flower abortion caused by water stress and isolate the effect of high air temperature. If the flower abortion were observed all year round, it would suggest the existence of the third and unknown cause for the abortion.

The objective in this experiment was to determine:

1. The magnitude of flower abortion in flowering percentage which would affect the bird of paradise flower production.
2. The effectiveness of leaf cooling practices in raising flowering percentages by reducing the number of flower abortion in bird of paradise.

3.2 Materials and Methods

Preparation of plant material. Seed pods from selected bird of paradise plants in the Waimanalo Experiment Farm collection were chosen for high yield and for bright red color on the boat-shaped bract and peduncle below the bract since the flower characteristics of bird of paradise seedlings were generally true to the parent (Besemer, et al., 1982a). The seeds were sown in flats of vermiculite in a greenhouse for germination. Young seedlings were transplanted in 15-cm pots of soil-cinder-peat moss medium and placed on outdoor benches in June 1982.

The seedlings were planted in Waimanalo Experiment Farm in November 1982 when they had an average of 10.5 (a range of 7-13) leaves emerged of which an average of 3.0 oldest leaves were desiccated. They were planted in 4 rows, and each row consisted of 20 seedlings from the same seed pod. The spacings were 3.0 m between rows and 2.4 m between plants within a row (Fig. 37).

The plants received 14N-6P-12K controlled release fertilizer semi-annually at a rate of 175 Kg $N \cdot ha^{-1} \cdot yr^{-1}$. Water was applied by overhead sprinklers (25 mm weekly) until July 19, 1984 when irrigation lines were installed. With the irrigation each plant received 34 liters water 3 days a week from a nozzle which formed 90° fan shape spray. Field was mowed periodically. Herbicides and pesticides were applied as they were needed.

Treatments. Misting and shading were applied as leaf cooling treatments along with control (no treatment). A plastic nozzle was used for misting which emitted 0.057 liter·sec^{-1} water in a 360° circular pattern with 2 m diameter. Mist was applied to each of 6 plants on the west end of each row for the periods of August 20-November 2 in 1984 and June 14-October 2 in 1985. The on-time of mist was set to 4 sec in every 10-15 min during daylight hours controlled by a mist controller (SolaSpray, Appendix A).

Shading was applied by 30%, black polypropylene shadecloth installed 2.4-3.0 m above the ground over 6 plants in each row on the east end in June 1984. This treatment was maintained continuously until the data collections were terminated in June 1986.

Six plants in the center of each row were used as control plants leaving 2 columns of plants between the treatments (8 in total) for border plants. Each treatment had 24 plants at the planting (Fig. 37). In this layout, variation among plants was minimized within each row, thus, the error due to plants which were derived from different seed pods was minimized.

Data collection. The numbers of leaves emerged before June 1983 when the seedlings were planted in the field were recorded, and LE, FE, and FC for all the leaves on each plant since June 1983 were recorded weekly through June 1986. A skipped flower emergence in the LE order in a fan was recorded as a flower abortion. Other attributes for the fan development, flower growth and abnormal characteristics were also recorded (Table 24).

Instead of sampling leaves, all of the emerged leaves were observed since total number of LE was needed to determine the potential flower production (or total number of LEs). The difficulties in collecting data in such a fashion were 1) to identify the large numbers of individual leaves, 2) to repeat the observations weekly for 3 years, 3) to update information as plants grew, and 4) to manage the field activity simply and quickly.

A data collection form (Append. C) made this observation possible. When new fans were identified (emergence of 2 or more leaves as a result of dichotomous branching, split of a fan) each new leaf was given an identification number and a data collection form at a beginning of a new fan. While each plant was identified by the row and column numbers of the field, the location of each fan on the plant was identified by mapping the relative position to its sister fans on the data collection form. Since the leaves sequentially emerged in a distichous arrangement, individual leaf in a fan could be identified by a serial leaf number starting at 0 for the split leaf. By following fans starting from the first generation fan in a plant, each leaf on a plant was identified quickly and correctly in the field without marking on them.

Data analysis. Complete observations were made on 49 plants: 17, 16, and 16 for control, misting, and shading, respectively. The 31 plants eliminated from the analysis were due to the following reasons: 16 plants did not survive transplanting; 7 were used as border plants; and 8 were unsuitable due to prolonged juvenility, slow growing habit, abnormally fast splits, herbicide damage, or hard scale infection (Table 25).

The data on collection forms were transferred to a disk file, and a master data set (a SAS data set) was created from the original by a SAS program ("MASTER.SAS", Program 2) running on an IBM PC/AT. The following attributes were recorded for each leaf: plant identification number; fan identification number; treatment; dates of LE, FE, and FC; intervals of LE, FE, and FC from the previous ones; periods of LEFE, FEFC, and LEFC, status of flower abortion (flowered, aborted, blasted, or missing data); flower stem length in cm; and characteristics of leaves and flowers (split leaf, deformed leaf, bent flower stem, double flowers on a stalk, multiple flower stalks, flower emerged early from the loose leaf sheath, flower emerged early from the side of fan, and other miscellaneous notes). This data set also served as the master data set in the subsequent Chapters in this study.

Flowering percentages (100 x number of flowers harvested / number of leaves produced) were computed for all treatments. The differences among treatments, which could be attributed to the leaf cooling, were tested by chi-square tests with hypotheses that there were no differences among the flowering percentages. The total flowering percentages were further partitioned into monthly flowering percentages to examine the seasonal pattern of flower abortion.

Flowering percentages were also computed according to the leaf number and the number of leaves leading to a split. These would display the effect, if existed, of rank order of leaf emergence in a fan on the flower abortion.

The differences among total flower yields for the treatments were tested by orthogonal contrasts using individual plants as experimental units. A completely randomized design was used although treatments were not randomized in order to reduce the influences of a treatment to adjacent plants (shading adjacent plant and drift of mist).

Monthly totals of flower yield were computed according to the months of LE and FC to examine the effects of shading and misting on the flower production pattern.

3.3 Results

In an attempt to identify the influence of flower abortion on the flower production, the flower production was investigated from two aspects: flowering percentage and total flower yield.

3.3.1 Flowering Percentage

3.3.1.1 Comparison of Flowering Percentages as Affected by Leaf Cooling Treatments

Among a total of 3879 leaves which emerged on 49 plants in August 1984-June 1986 and had complete FE and FC data, 2250 leaves subtended successful flowers, 12 had blasted flowers, and 1617 showed flower abortions. Flowering percentages were 63% for control, 53% for misting, and 58% for shading (Fig. 38). Chi-square tests (Table 26) indicated the flowering percentage for misting was significantly lower than that for control, while the flowering percentage for shading, although lower, was not significantly different from the control.

A chart of monthly flowering percentages for the leaves which emerged in August 1984-December 1985 (Fig. 39) showed low percentage periods existed in March-July for control, June-September for misting, and April-July for shading. Misting had higher flowering percentages than control only in March-April 1985 and December 1986. Shading also had higher flowering percentages in July-October 1985, but it was not consistent with the same months in 1984. Low flowering percentages in September 1984 probably resulted from insufficient available moisture for differentiation and development before an irrigation system was installed. The effect of drought on the plant development of bird of paradise will be discussed in Ch. 4.

3.3.1.2 Relation of Leaf Number to Flowering Percentage

Flowering percentage increased as more leaves were present in a fan (Fig. 40): from 45% for leaf 0 in a fan (the first leaf which resulted from the split) to 71% for leaf 13 (14th emerged leaf). The increase trend continued beyond leaf 13, although the number of sample fans became small and the flowering percent became less reliable. While leaf numbers up to 19 were recorded, the desiccation of early leaves were observed for many-leaved fans before next splits were observed.

On the other hand, flowering percentages on the number of leaves leading to splits showed no apparent trend (Fig. 41) which fluctuated between 45% for 3 leaves to split and 66% for 7 leaves.

3.3.2 Total Flower Yield

3.3.2.1 Comparison of Total Flower Yield as Affected by Leaf Cooling Treatments

The means for total flower cut per plant for which LE occurred between August 1984 and December 1985 were 53% for control, 46% for misting, and 38% for shading (Fig. 42). The orthogonal contrasts among treatments (Table 27) indicated shading resulted in significantly fewer flower cuts per plant (for 11.1) than full sunlight treatments (control and misting combined), while the mean for misting was not significantly lower than the mean for control.

Monthly flower harvest as a percent of the total (Fig. 43) showed peak flowering periods in June-October in 1985 for control (A), September-November in 1985 for misting (B), and September and again in March-April in 1986 for shading (C).

The magnitude of seasonal fluctuation was the largest for shading (4% for December 1985 and 11% for April 1986), while control and misting remained relatively constant.

3.3.2.2 Comparison of Flower Yield Pattern by Month of Leaf Emergence

A high flower yield period was found in flowers for which leaf emergence occurred in July-October 1985 followed by a sharp drop in November for all 3 treatments (Fig. 44). Low flower yield periods were found in February-April, and control showed its lowest in March-April in 1985. The magnitude of seasonal difference was the largest for shading (3-11%) while control and misting remained relatively constant.

3.3.3 Occurrence of Abnormal Flowers

Among 3255-3319 flower stalks observed, the following abnormal flowering characteristics were recorded: 173 double flowers on a stalk

(5.3%), 137 early flower emergences from the side of fan (4.2%), 132 early flower emergences from the loose leaf sheath (4.1%), 124 bent flower stalks (3.7%), and 29 multiple flower stalks (0.9%). Although the numbers of occurrences of these abnormal flowers were small, they were removed from the analyses in order to reduce errors. The average flower stalk was 83.6 ± 0.32(SE) cm long.

3.4 Discussion

Leaf cooling practices in this experiment, intermittent misting in summer and 30%, continuous shading, were not effective in reducing flower abortion determined by the chi-square tests (significant reduction in flowering percentage for misting and no difference for shading, Table 26), or increasing flower production determined by *t* tests (Table 27).

Misted plants had a lower flowering percentage than control plants (Table 26), while misting did not reduce the flower yield per plant (Table 27). This would indicate that the misted plants had a larger leaf number per plant than the control plants (86.6 and 83.8, respectively in August 1984-June 1986 period). However, the increased leaf production per plant by misting was not unquestionable as misting in this experiment was applied only 7 months in 2 summers. Although no detrimental effect was seen on the treated plants, misted plants were shorter (visual observation) and stunting of some leaves was observed.

On the other hand, shaded plants had a lower flower yield per plant than control plants (Table 27) while no difference was found in the flowering percentage (Table 26). This would indicate that, due to the reduced leaf temperature or light intensity, shading reduced the rate of leaf production (or the rate of plant growth) resulting in the lower flower production.

Flower abortion caused by high air temperatures. A reduction in the number of occurrences of flower abortion by lowering leaf temperature in summer was sought in this experiment. The mean leaf temperature of control was 33.3°C in summer afternoon, while means for misted and shaded leaves were significantly lower than the control by 4.6 and 3.2°C, respectively (Ch. 2). Although the reduction of leaf temperature was effective by leaf cooling treatments, no increase in flowering percentage was observed (Fig. 38).

Flowering percentage for mist treatment (53%, Fig. 38) could have been different if the treatment were applied continuously through the experiment. However, misting in summer, which would have been most effective in reducing high leaf temperatures, actually reduced the overall flowering percentage (from 63% for control, Fig. 38). Therefore, the continuous mist treatment probably would not increase flowering percentage, and such a treatment could induce side effects such as stunting of plants.

Therefore, these results would reject a hypothesis that a high leaf temperature directly caused flower abortion if:

1. The side effects of treatments such as reduced gas exchange due to wetting leaves or reduced photosynthesis by shading induced the flower abortion.

2. The reduction of leaf temperatures was not sufficient to reduce the flower abortion, that is, leaf temperature remained high enough (25-30°C, page 30) to contribute to flower abortion.
3. Duration of the treatment was not long enough to reduce flower abortion in the misting treatment.

Previous studies proposed relationships between flower abortion and a high air temperature: a sharp drop in flower production in fall occurred 23 weeks after weekly maximum temperature of air exceeded 27°C in spring (Kawabata, et al., 1984); and leaves which emerged in spring had a low flowering percentage (as low as 20% for June leaves) believed to be due to a high temperature in summer, when the flower buds subtended were in an abortion sensitive stage (Criley and Kawabata, 1984).

However, it is unlikely that the 27°C threshold exists as the sharp drop in flower production in fall was not repeated in this study. Since the weekly maximum temperature exceeded the proposed 27°C threshold in the end of March 1985 (Fig. 10), a sharp reduction in the flower production was expected in early September 1985 but it was not observed (Fig. 43). The sharp drop was also missing in a separate observation of the collection plants in Waimanalo when weekly totals from 14 selected plants were recorded in 1982-1984 (Fig. 45).

The flowering percentage in this experiment (with a low of 45% for the leaves emerged in July 1985, Fig. 39) was not affected as much as previously indicated (20% for June, Criley and Kawabata, 1984) while the high abortion period (March-July 1985) coincided with the previous report. Although the plants used in this experiment were younger than those in the previous experiment, these results would indicate that the data collected for the flower abortion in this experiment were comparable to the previous experiment except for the high minimum flowering percentage in this experiment.

These findings indicated that a high air temperature would not be the primary factor for the flower abortion of field grown bird of paradise in Hawaii, and alternative causes were sought.

Flower abortion caused by water stress. A severe drought condition occurred in Waimanalo in 1984 when a prolonged period of low rainfall started in 1983 and extended through November 1984. No irrigation water was available in spring-summer-fall period in 1984 (Figs. 46 and 47). Since limited available water reduces flower production in bird of paradise (van der Krogt, 1985), the general reduction in monthly flower yields in entire 1984 period for the collection plots in Waimanalo (Fig. 45) could have been caused by the flower abortion induced by the drought.

The rainfall and irrigation records also showed that the experimental site was rarely watered for the scheduled 25-mm a week overhead sprinkler irrigation. Instead, the site was watered as supplement to precipitation which resulted in monthly totals of water for approximately 100 mm (Figs. 46 and 47). As air temperature increases during the warm season, plant water requirement would increase due to more vigorous growth than in cool season, and water loss from the soil also would increase. If 100 mm water received by the field monthly was not adequate for the bird of paradise summer growth in Hawaii, an increase in flower abortion could occur due to water deficit since the prolonged occurrences of blasting and a general reduction in flower production in the collection plots were observed in the drought in 1984.

Therefore, sharp drops in flower production observed in the previous research (Criley and Kawabata, 1984) could be an indication that the watering level (100 mm per month) was not adequate, since the drops in flower yield occurred every year while mild droughts were seen in 1977 and 1979. Therefore, it is possible that the sharp drop in flower production in Hawaii was due to flower abortion induced by water deficit in summer and the drought condition enhanced the reduction.

Other indirect evidence for water deficit as a cause of flower abortion was displayed in the number of splits. The record for the number of splits from the establishment of plants in the field in 1982 to June 1986 (Fig. 48) showed that first splits were observed in July 1983 followed by a general increase over time as plants grew larger except for the depression in July 1984 and a subsequent rise in August-October. These fluctuations in July-October in 1984 occurred after an installation of irrigation line in the field on July 17, 1984, while the drought was in effect. The depressed number of splits might represent a temporary arrest of leaf growth due to the water deficit, and the subsequent rise could be a sign of the resumption of plant growth which resulted in a large number of split emergence. This delay of leaf growth was seen as increasing leaf emergence intervals for May-August period in 1984 (48 to 55 days, Fig. 49) in which leaf emergence period should be decreasing (59 to 50 days, Criley and Kawabata, 1984).

Despite of the irrigation installed for this field experiment, flower abortion in bird of paradise occurred all year regardless of the leaf cooling practices (an average flowering percentage of 63%, Fig. 39) while more abortions were recorded in warm season than cool season (a maximum difference of 35%). The flower abortions also occurred at all air temperature regimes (17-32°C) in a greenhouse experiment in which the water stress was minimized (Halevy and Khayat, unpublished data).

Therefore, these results could indicate that although water deficit in bird of paradise could cause the flower abortion, it would not be the primary cause of the flower abortion in Hawaii.

Flower abortion caused by nutritional competition among flower buds.

Another possible cause of flower abortion was the availability of carbohydrate for the flower bud growth and the competition for the carbohydrate among flowers.

The relationship of the flowering percentage and the number of leaves in a fan was displayed (Fig. 40) as number of leaves already emerged in a fan increased, the flowering percentage also increased.

The size of carbohydrate source of a fan could increase as the number of emerged and matured leaves in a fan increased (1-20 leaves per fan). On the other hand, the number of developing flower buds was relatively constant, approximately 6-8 (7-9 leaf primordia, Criley and Kawabata, 1984, minus 1 as the first flower primordia were found in the axils of the second youngest leaf primordia, Fisher, 1976). Therefore, if carbohydrate produced in a leaf was shared by flower buds subtended by other leaves in the fan, the amount of carbohydrate available for each developing flower bud would increase with the increasing number of emerged leaves in a fan. If the carbohydrate availability were not enough to support all developing flower buds, the increasing flowering percentage with increasing number of leaves in a fan (Fig. 40) would be an indication of the lack of carbohydrate.

The sign of nutritional competition among flower buds was also sought assuming that the flower abortion was solely induced by the lack of carbohydrate at the abortion sensitive FD stage (flower parts differentiation stage). The possible competitions were between abortion sensitive flower buds (approximately 2-cm long, Criley and Kawabata, 1984) and between an abortion sensitive bud and a neighboring larger developing flower stalk.

Leaf emergences occurred most frequently in October as LE intervals were the shortest in 1986 (Fig. 49), and the flower buds subtended by the leaves which emerged in this period would have reached the FD stage more frequently than any other time in the year. Therefore, if the competition was between flower buds in FD stage, the lowest flowering percentage would have occurred to the flower buds whose subtending leaves emerged in October 1986 or immediately after. However, the flowering percentage occurred to October leaves or the immediately following leaves did not have low flowering percentages until March leaves would appear or a 5-month delay (Fig. 39). Therefore, it would be unlikely that the flower abortion would occur due to the competition between 2 or more flower buds in FD stage.

On the other hand, the 5-month delay could be explained by the competition between a flower bud in FD stage and an older developing flower stalk: lack of nutrition for a flower bud in FD stage was the severest when the flower stalk subtended by the preceding leaf had the fastest growth 5 months after passing its FD stage. The delay would agree with the flower stalk development model (Fig. 6, Kawabata, et al., 1984) where LE and the fastest growing stage in a cool season growth were hypothesized 25 and 5 weeks before FC, respectively or an approximately 5 months between the 2 stages. This is interpreted as follows. When flower buds of March leaves become the FD stage, flower stalks of October leaves (or 2-ranks earlier flowers in the fan development) would be growing at the fastest rate, and the flower buds of March leaves would have the strongest competition with flower stalks of October leaves. Since LEs occurred most frequently in October, a low flowering percentage period would start appearing in March.

While these experiments supports nutritional competition among flowers as an explanation for flower abortion, and if it is true, the competition would be between large growing flower stalks and flower buds in the FD stage rather than between flower buds in the FD stage.

Flower yield patterns Although only 1 year of a complete flower production cycle was recorded and analyzed, the following observations of the seasonal pattern of flower production summarize the important results.

1. The numbers of flowers cut, totaled by the month of FC (expressed as percentages of the total, Fig. 43), showed shifts in high production peaks among the treatments. The misting treatment delayed the beginning of peak flowering period in summer 1985 for 2 months and the end for 1 month (**A** and **B**, Fig. 43), and a delay in the increase of flower yield in spring in April-July 1985 (D, Fig. 43), while the shading treatment showed a delay in the peak flowering period in September 1985 for 2 month. However, when FCs were totaled by the month of LE (Fig. 44), the shifts in monthly production patterns became very small or unrecognizable compared with the monthly totals by FC. Therefore, the shifts in peaks in yield as expressed by months of LE and FC must be due to differences in time period spent (LEFE) in flower development.
2. While full sun treatments (control and misting) showed single-peak production patterns (Fig. 43), shading treatments showed a 2-peak pattern. Although another experiment would be necessary for a confirmation, a 30% reduction in solar radiation caused a change in the number of peaks in flower production patterns possibly by slowing down the rate of flower development. The 2-peak pattern was also observed in California and Israel (Besemer, et al., 1982b; Halevy, et al., 1976) where weaker solar radiation is expected as the latitudes are approximately 10° farther to the north than Hawaii.

Since no major difference in the trend of monthly flowering percentage was found among treatments (Fig. 39), the shifts of peaks observed could be attributed to the difference in the length of LEFC (leaf emergence to flower cut) period among the plants given leaf cooling treatments.

Therefore, these findings indicated that the primary cause for the occurrence of seasonal fluctuation pattern in bird of paradise flower production would be the seasonal change in the rate of flower development instead of the seasonal change in the occurrence of flower abortion.

Although the delay in the peak flowering period would be a disadvantage for Hawaii growers as the delay represents a stronger competition with California growers (Besemer, et al., 1982b), a possibility of modifying the natural flowering pattern of bird of paradise was demonstrated.

3.5 Summary

1. Flower abortion occurred in 37% of the leaves emerged (or a flowering percent of 63%), and the leaf cooling treatments, misting and shading, did not reduce the occurrence of the flower abortion when the total harvest was examined for flowers for which leaf emergences occurred in August 1984 or later and in which anthesis occurred by June 1986.
2. Misting reduced the overall flowering percentage of emerged leaves to 53% (from 63% for control) although no significant reduction in

flower production per plant was found due to a large number of leaf emergences than control.

3. Shading did not affect flowering percentage, although it reduced the number of flowers produced per plant (38 for shaded plants and 53 for control plants for the above period) due to a low number of leaves produced than control.
4. The leaf cooling treatments did not show the evidence that a high air temperature itself was the primary cause of the flower abortion in Waimanalo.
5. A single-peak pattern appeared on the flower production for control with a high production period in July-October, however, the magnitude of the seasonal fluctuation was smaller than previously presented for this environment possibly due to the young plants used (5-year-old) in this experiment.
6. Misted plants showed a single peak flower production pattern, while shaded plants showed a 2-peak pattern. A shift in peaks was found as misting delayed the onset of the peak flowering period for 2 months and the end of the peak for 1 month.

Table 24. Variable names, variable types, and the descriptions in the data set for the bird of paradise growth collected in Waimanalo, Oahu.

Variable	Type	Description
		Identifications
FAN	Numeric	Fan identification which includes plant and branch identifications
PLANT	Numeric	Plant identification which includes row and column number in the field
BR0	Numeric	Original fan, always had a value 1
BR1-BR7	Numeric	Branch number for the nth generation split
ROW	Numeric	Row number in the field
COL	Numeric	Column number in the field
TRT	Character	Treatments: control, mist, shade, or border
LEAF	Numeric	Leaf number starting 0 for split leaf
		Dates and intervals
LE	Numeric	Date for leaf emergence
FE	Numeric	Date for flower emergence
FC	Numeric	Date for flower cut
LEFE	Numeric	Interval between LE and FE in days
FEFC	Numeric	Interval between FE and FC in days
LEFC	Numeric	Interval between LE and FC in days
LEINT	Numeric	Interval between successive LEs, in days missing for the split leaf
FEINT	Numeric	Interval between successive FEs in days, missing if FE for the previous leaf is missing
FCINT	Numeric	Interval between successive FCs in days, missing if FC for the previous leaf is missing
LEPREV	Numeric	LE date for the previous leaf
FEPREV	Numeric	FE date for the previous leaf
FCPREV	Numeric	FC date for the previous leaf
		Attributes of flowers and leaves
STEMLEN	Numeric	Flower stalk length in cm
BENT	Numeric	Bent flower stalk: 1, bent; 0, normal
DOUBLE	Numeric	Double flower on a stalk: 1, double; 0, normal
MULTFL	Numeric	Multiple flower stalk: 1, multiple; 0, normal
EARLYSHW	Numeric	Early LE due to abnormally open leaf sheath: 1, early; 0, normal
SIDEMERG	Numeric	FE from the side of a fan: 1, side; 0, normal
LEAFDEF	Numeric	Leaf deformation: 1, deformed; 0, normal
NOTE	Numeric	Other notes taken: 1, yes; 0, no
X	Character	Temporary variable
SPLIT	Numeric	Emergence of split leaves: 1, yes; 0, no
INCOMP	Numeric	Completion of a fan at the termination of data collection: 1, incomplete; 0, complete

Table 25. List of plants deleted from the data analysis for the bird of paradise flower abortion experiment. Border plants were also deleted without considering the plant performances.

Plant ID Row	Column	Reason for the deletion
1	05	Long juvenility. No flower was produced.
1	08	Hard scale infection. Stunted.
1	18	Hard to record growth due to abnormal splits.
2	02	Damaged by herbicide spray.
2	04	Very few splits. Small plant
2	10	Plant did not survive transplanting.
2	13	Small plant. Very few flowers were produced.
2	18	Hard to record growth due to too often split.
2	19	Small plant. Very few flowers were produced.
3	01	Hard to record growth due to abnormal splits.
3	02	Plant did not survive transplanting.
3	04	Damaged by a tractor.
3	08	Plant did not survive transplanting.
3	11	Plant did not survive transplanting.
4	04	Small plant.
4	06	Plant did not survive transplanting.
4	09	Hard to record growth due to too many splits.
4	16	Very weak flower stalks and they often bent.
4	17	Plant did not survive transplanting.
4	18	Plant did not survive transplanting.
4	19	Hard to record growth due to abnormal splits.
4	20	Abnormal splits and weak flower stalks.

Table 26. Chi-square tests for comparing leaf cooling treatments with control on flowering percentage of all leaves produce in August 1984-June 1986 period. Using a null hypothesis that no difference existed among the flowering percentages, a significantly lower flowering percentage was shown for misting, while no difference was shown for shading.

Comparison between control and misting

Treatment	Leaves Emerged	Flowers Produced	Flowering Percentage	Expected Flowering
Control	1425	895	62.8%	828
Misting	1389	740	53.3%	807
Combined	2814	1635	58.1%	1635

Chi-square	DF	Probability
10.9	1	0.001 > Pr

comparison between control and shading

Treatment	Leaves Emerged	Flowers Produced	Flowering Percentage	Expected Flowering
Control	1425	895	62.8%	864
Shading	1065	615	57.7%	646
Combined	2490	1510	60.1%	1510

Chi-square	DF	Probability
2.60	1	0.25 > Pr > 0.10

Table 27. An orthogonal contrast of leaf cooling treatments on flower yield per plant for the initial 5 years of bird of paradise growth. While shading (S, mean=38.4) had a significantly lower mean than no-shading treatments: control (C) and misting (M); misting (46.3) was not significantly lower than control (52.7).

Means of flower number per plant

Treatment	N	Minimum	Maximum	Median	Mean	SE
Control	17	32	99	50	52.7	17.3
Misting	16	20	82	32	46.3	22.6
Shading	16	16	64	40	38.4	16.1

Analysis of variance

Source	DF	Sum of Squares	F Value	Pr > F
Model	2	1666.85	2.34	0.108
Error	46	16366.82		
Corrected Total	48	18033.67		

Orthogonal contrast

Contrast	DF	Contrast SS	F Value	Pr > F
S vs C+M	1	1329.63	3.74	0.059
C vs M	1	337.30	0.95	0.335

Estimate of difference

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
S - (C+M)	-11.1	-1.93	0.059	5.75
C - M	6.4	0.97	0.335	6.57

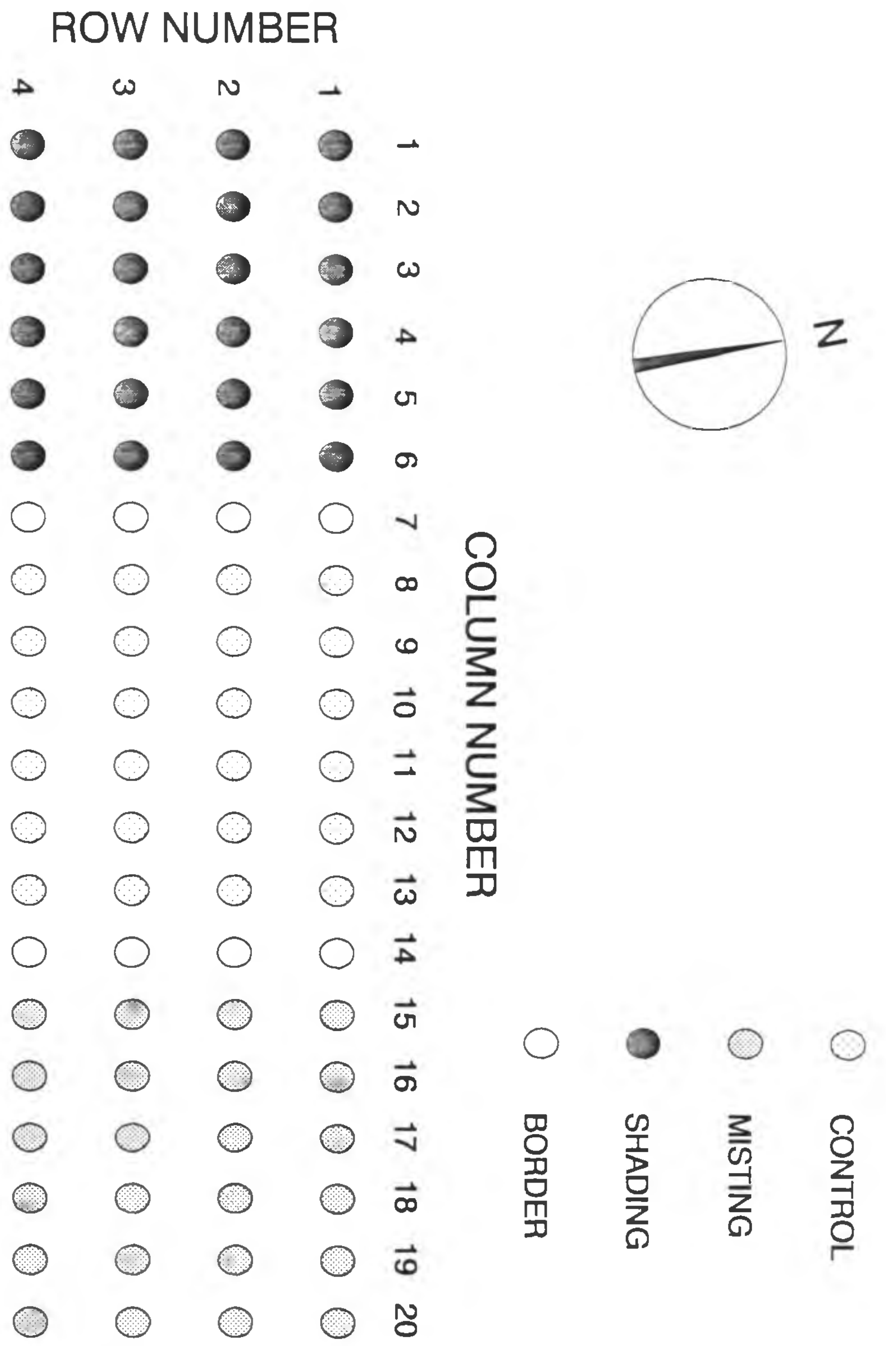

Figure 37. The layout of bird of paradise seedlings planted in November 1982 for the leaf cooling experiment in Waimanalo, Oahu. Each of the 3 treatments, misting, shading, and control, started with 24 plants and they were planted in the field in 3 sections. Placing the misting treatment on the west side of field minimized the drift of mist since the wind was predominantly from the northeast. Seedlings were spaced 3.0 m between rows and 2.4 m between plants in a row. Each row was derived from siblings of the same seed pod.

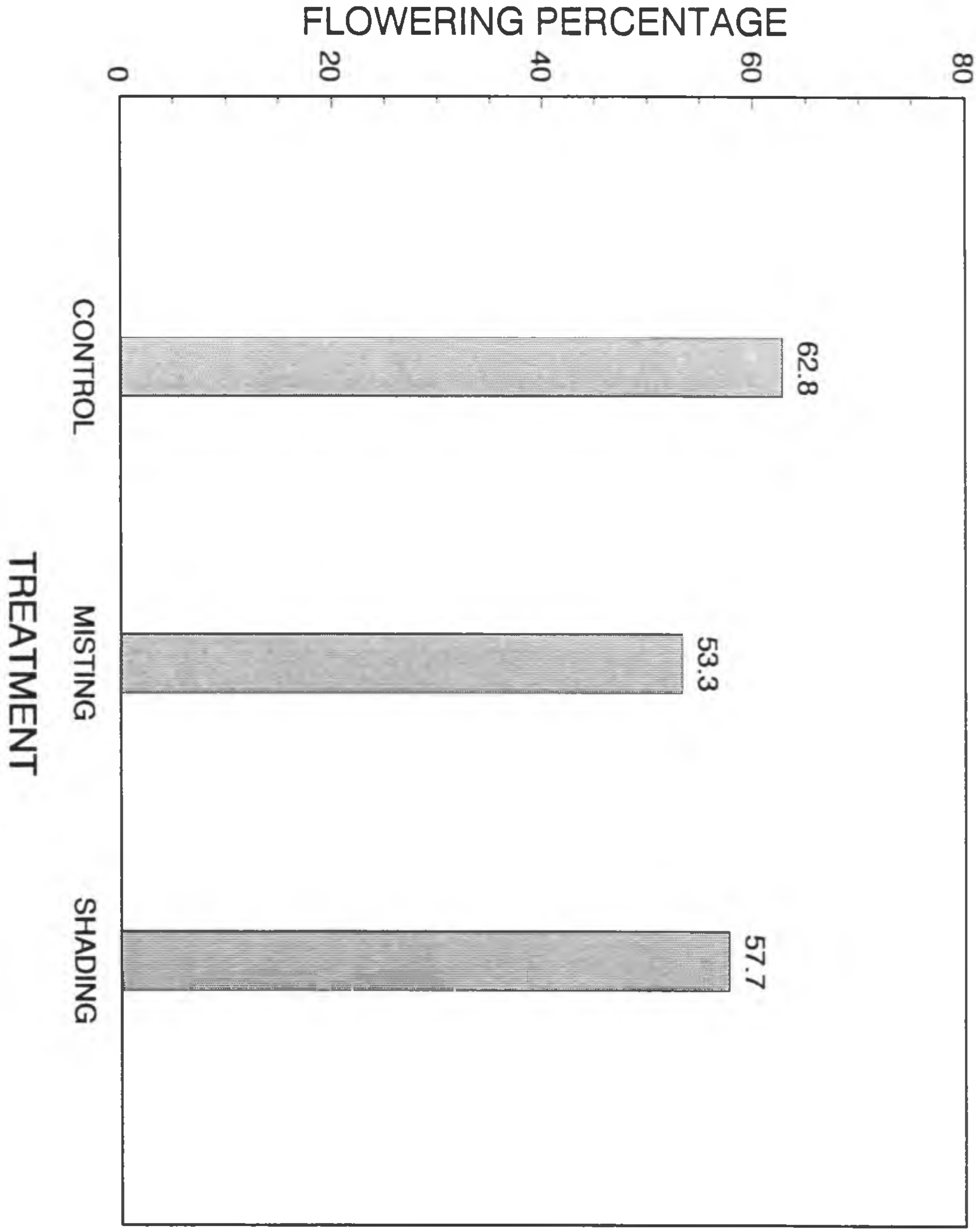

Figure 38. Comparison of leaf cooling treatments on the flowering percentages of bird of paradise leaves in Waimanalo, Oahu for August 1984-December 1985 period. Misting was applied as intermittent mist for 3-4 months in warm season, while shading was applied all year. While flowering percentage for shading was not significantly different from control, misting was significantly lower than control by the chi-square tests in Table 26.

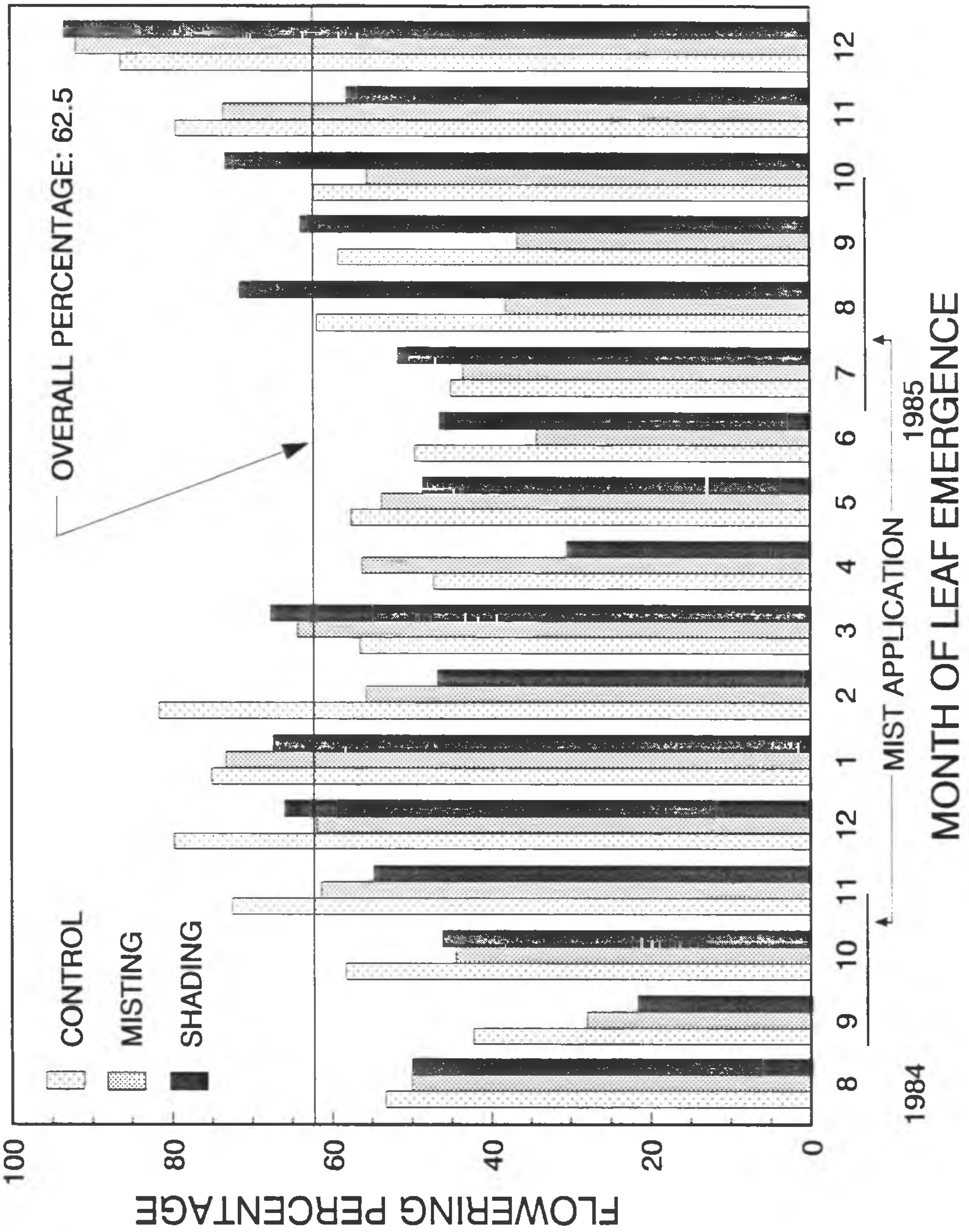

Figure 39. Flowering percentages of bird of paradise in Waimanalo, Oahu partitioned by the month of leaf emergence in August 1984-December 1985. Low flowering percentage period was found April-July in 1985. Low values for leaves which emerged in September 1984 were probably caused by a drought before an irrigation system was installed in July 1984.

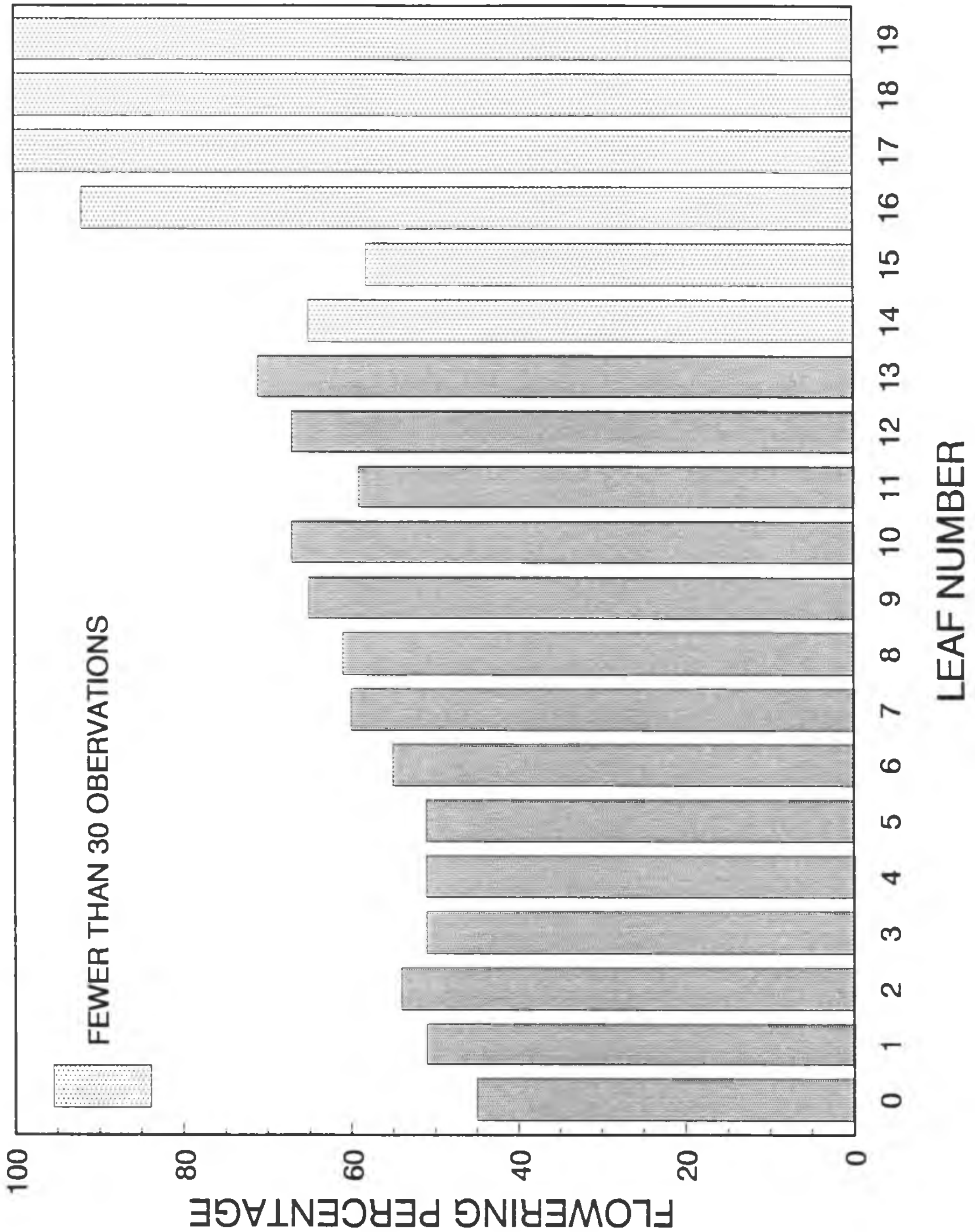

Figure 40. Flowering percentage of bird of paradise as indicated by the leaf number. Flowering percentage increased as more leaves existed in the fan. While a total of 5087 leaves were recorded, fewer than 30 fans had leaves numbered higher than 14.

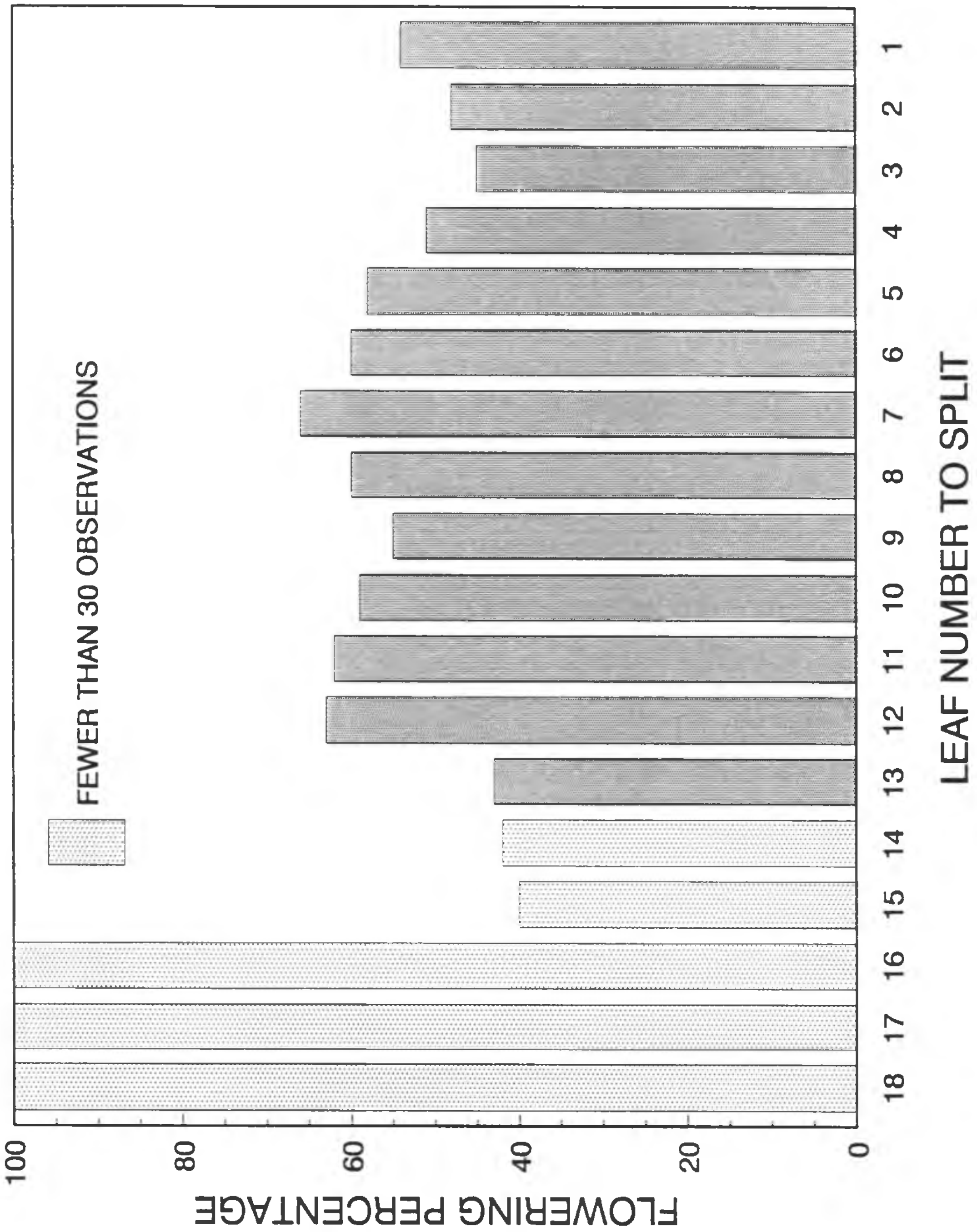

Figure 41. Flowering percentage of bird of paradise as indicated by the number of leaves before a split of fan was observed. No apparent trend was found.

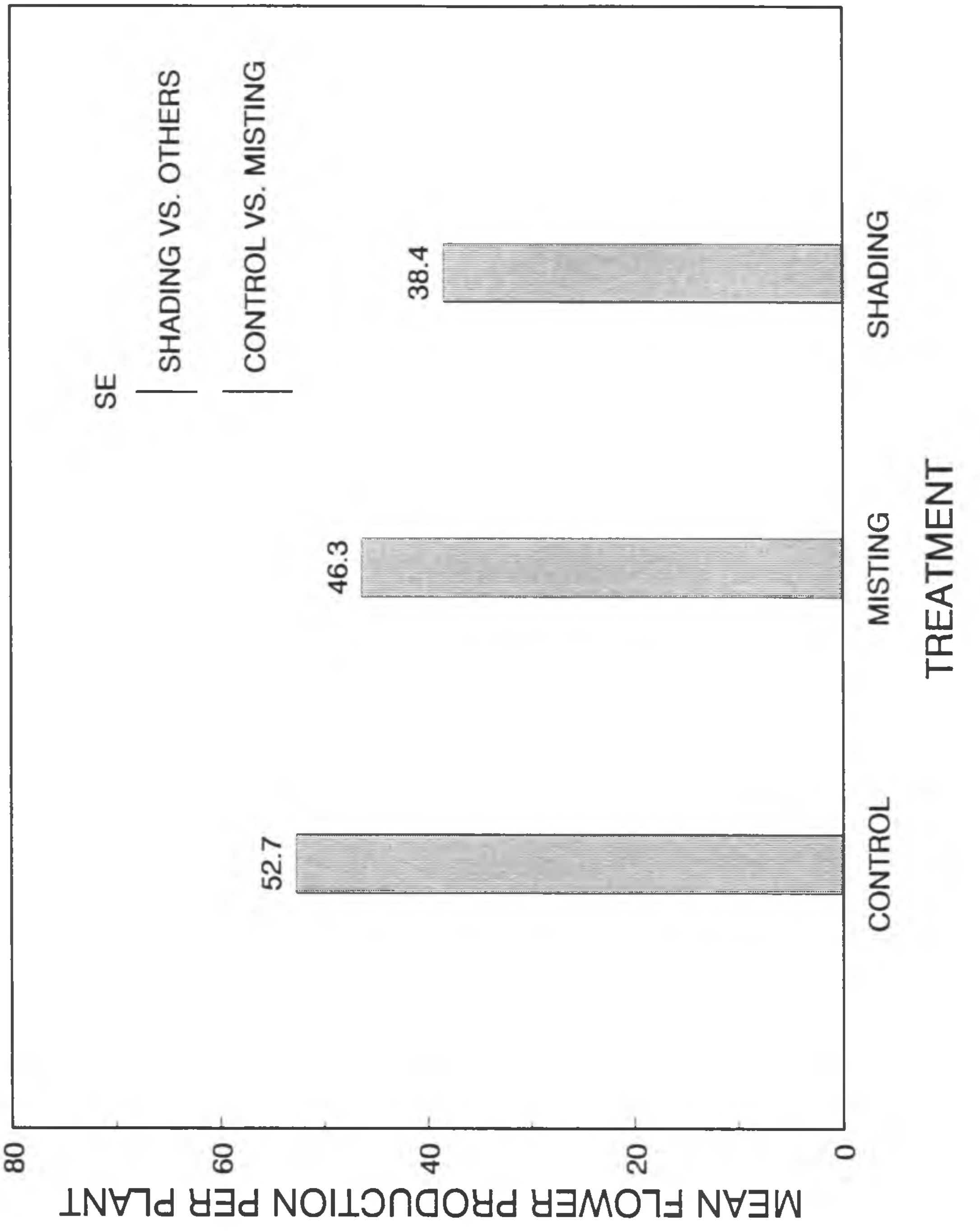

Figure 42. Comparison of leaf cooling treatments on the mean of bird of paradise flowers produced per plant in Waimanalo, Oahu for August 1984-December 1985. There were 17 plants for control and 16 each for misting and shading. While shading had a significantly lower mean than others, there was no difference between control and misting (Table 27).

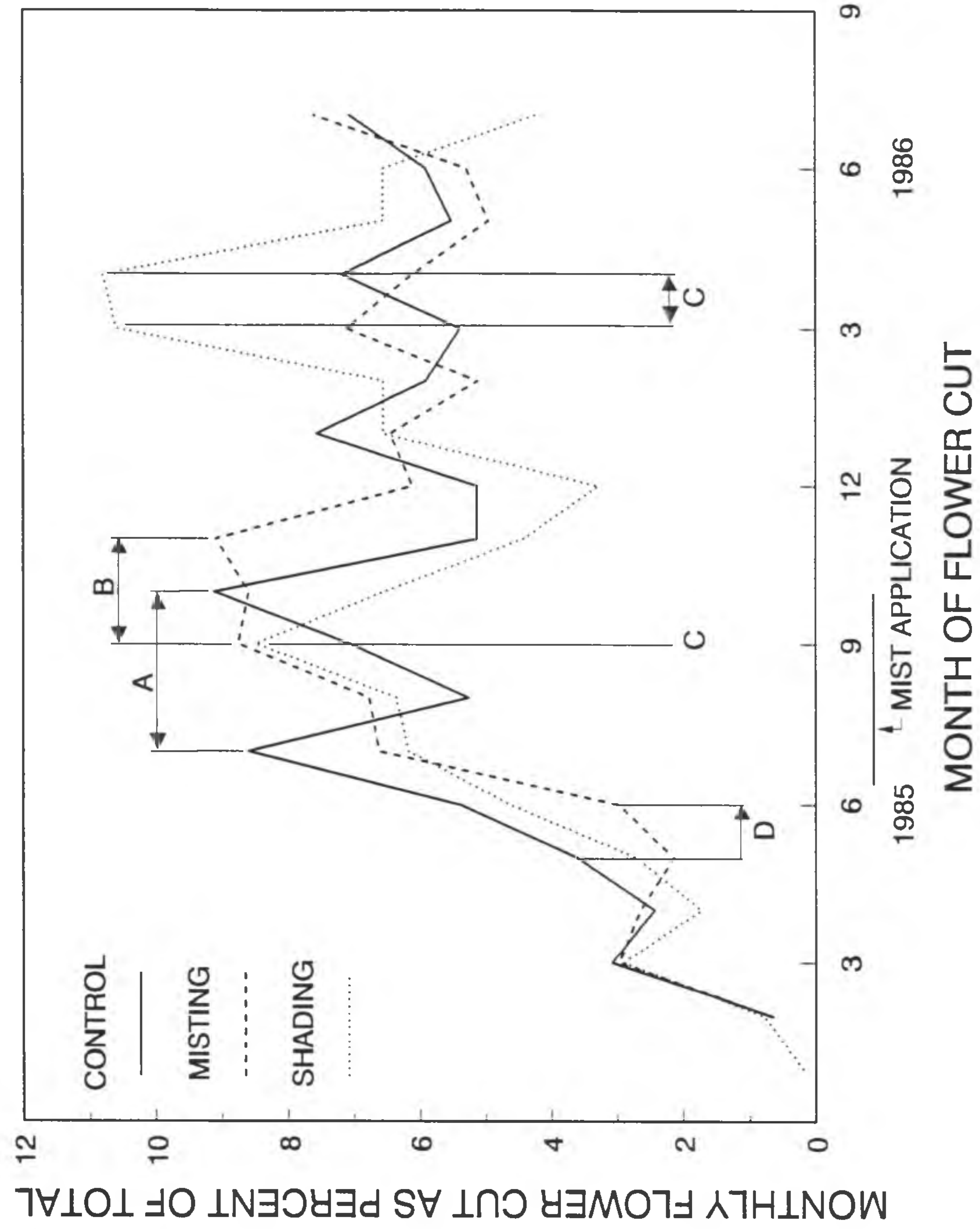

Figure 43. Comparison of leaf cooling treatments on bird of paradise, misting and shading, on monthly totals of the flower cut in Waimanalo, Oahu. The production was expressed as a percentage of total for the respective treatment. While control showed its production peak in July-October 1985 (A), misting delayed the peak to September-November 1985 (B), and shading showed two peaks production pattern, in September 1985 and again in March-April 1986 (C). A delay in the rise of flower production in spring was found for misting treatment (D).

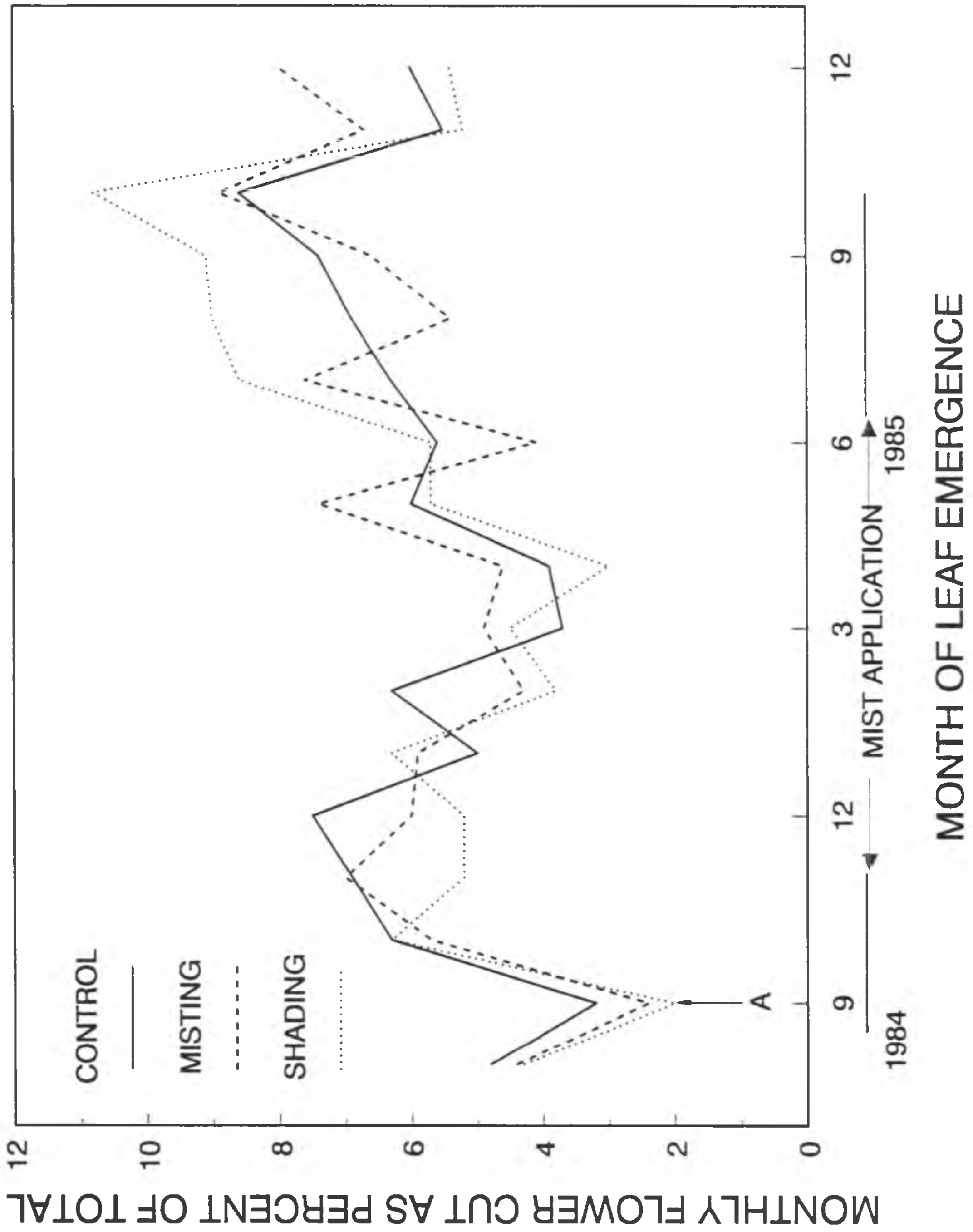

Figure 44. Comparison of leaf cooling treatments on bird of paradise, misting and shading, on the flower production as referenced by the month of leaf emergence in Waimanalo, Oahu. The production was expressed as a percentage of total over 17 months for the respective treatment. A general reduction was observed in September 1984 possibly due to a drought (A).

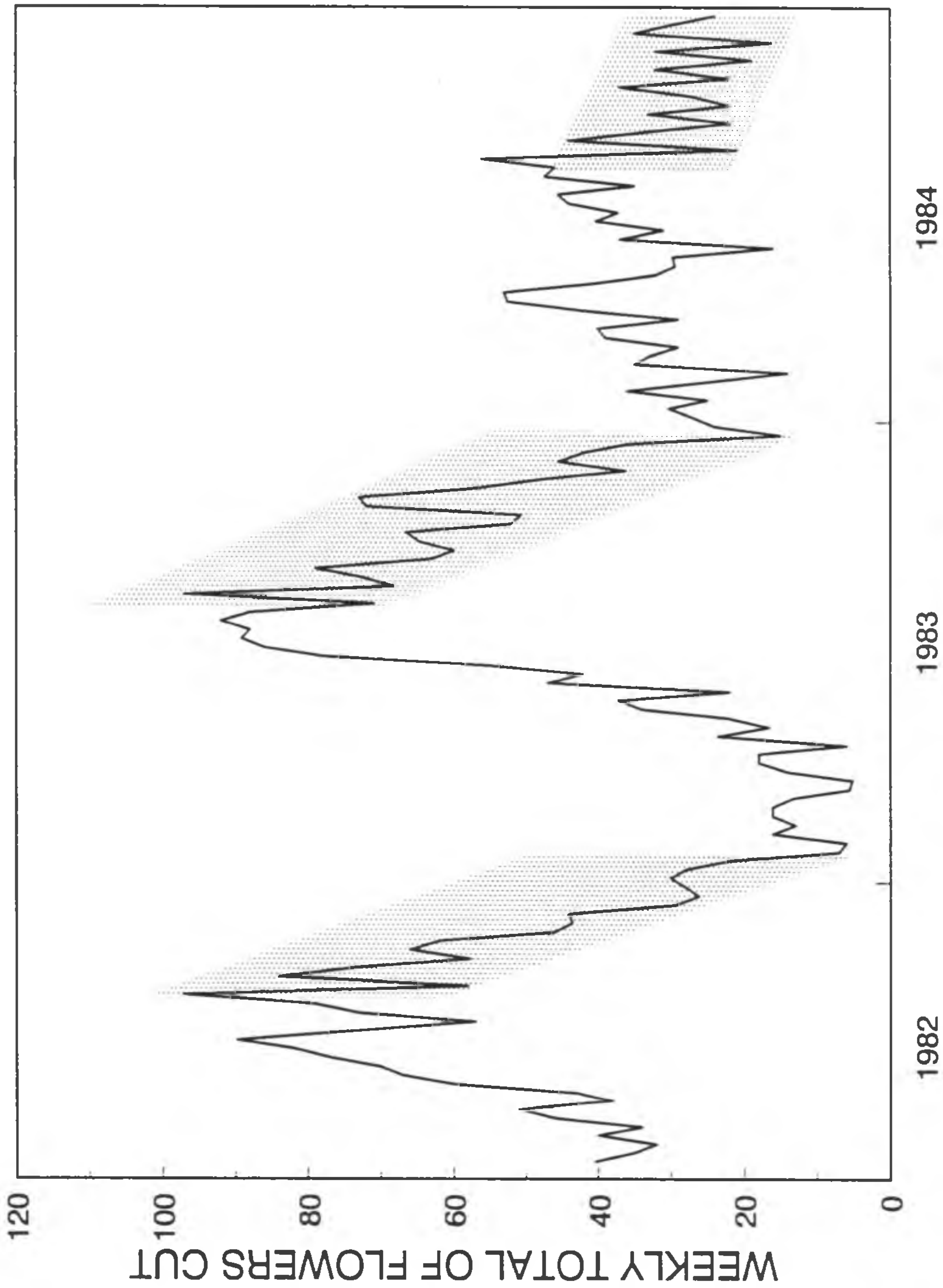

Figure 45. Weekly totals of bird of paradise flowers from 40 selected plants in 14 plots of the collections in Waimanalo, Oahu. A sharp drop expected in fall was not observed in each of the 3 years as weekly flower production gradually declined (shaded area) in decreasing phase of the production. The general reduction in 1984 was probably caused by a drought in 1984.

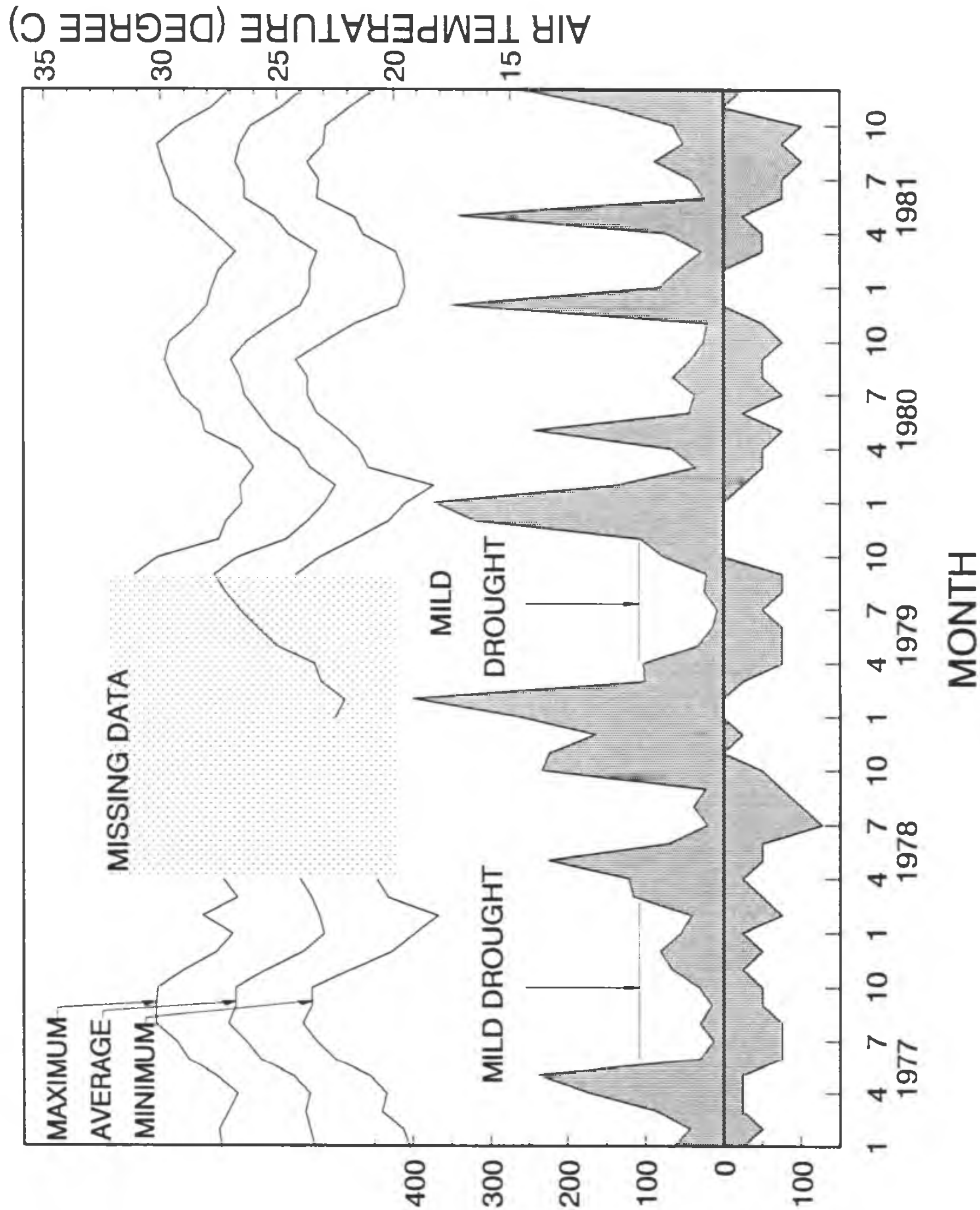

Figure 46. Plots of environmental variables in Waimanalo, Oahu for 1977-1981: monthly averages of daily maximum, minimum, and average and monthly total of precipitation and irrigation. The reduced precipitation due to the mild droughts in 1977 and 1978 was compensated by irrigation which made up to approximately 100 mm of total water per month.

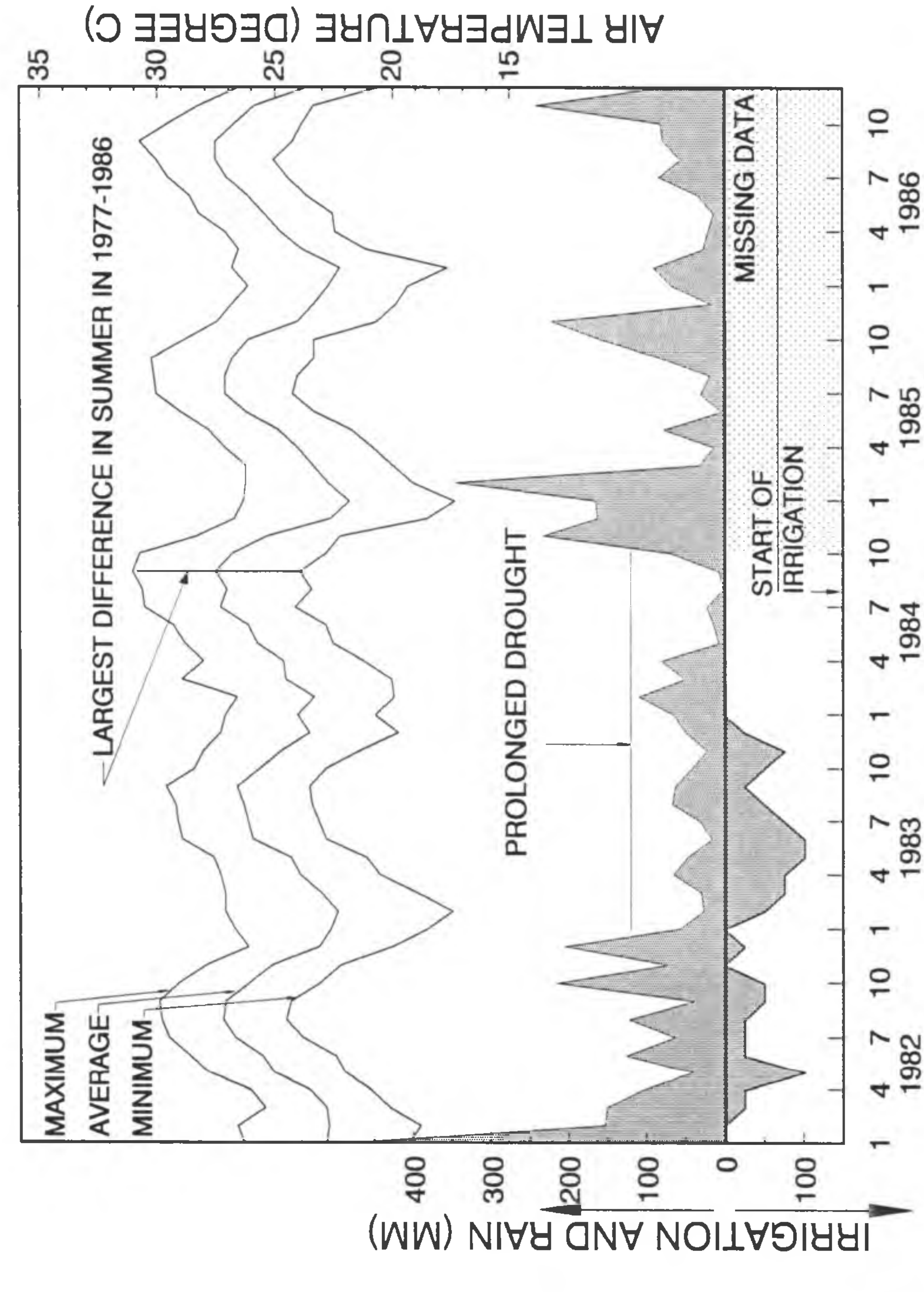

Figure 47. Plots of environmental variables in Waimanalo, Oahu for 1982-1986: monthly averages of daily maximum, minimum, and average and monthly total of precipitation and irrigation. A prolonged drought period was identified in 1983-1984 in which the severest period occurred in May-September 1984. While the low precipitation in 1983 was compensated by irrigation, no irrigation for the test plot was available until 19 July 1984 when city water was made available for irrigation.

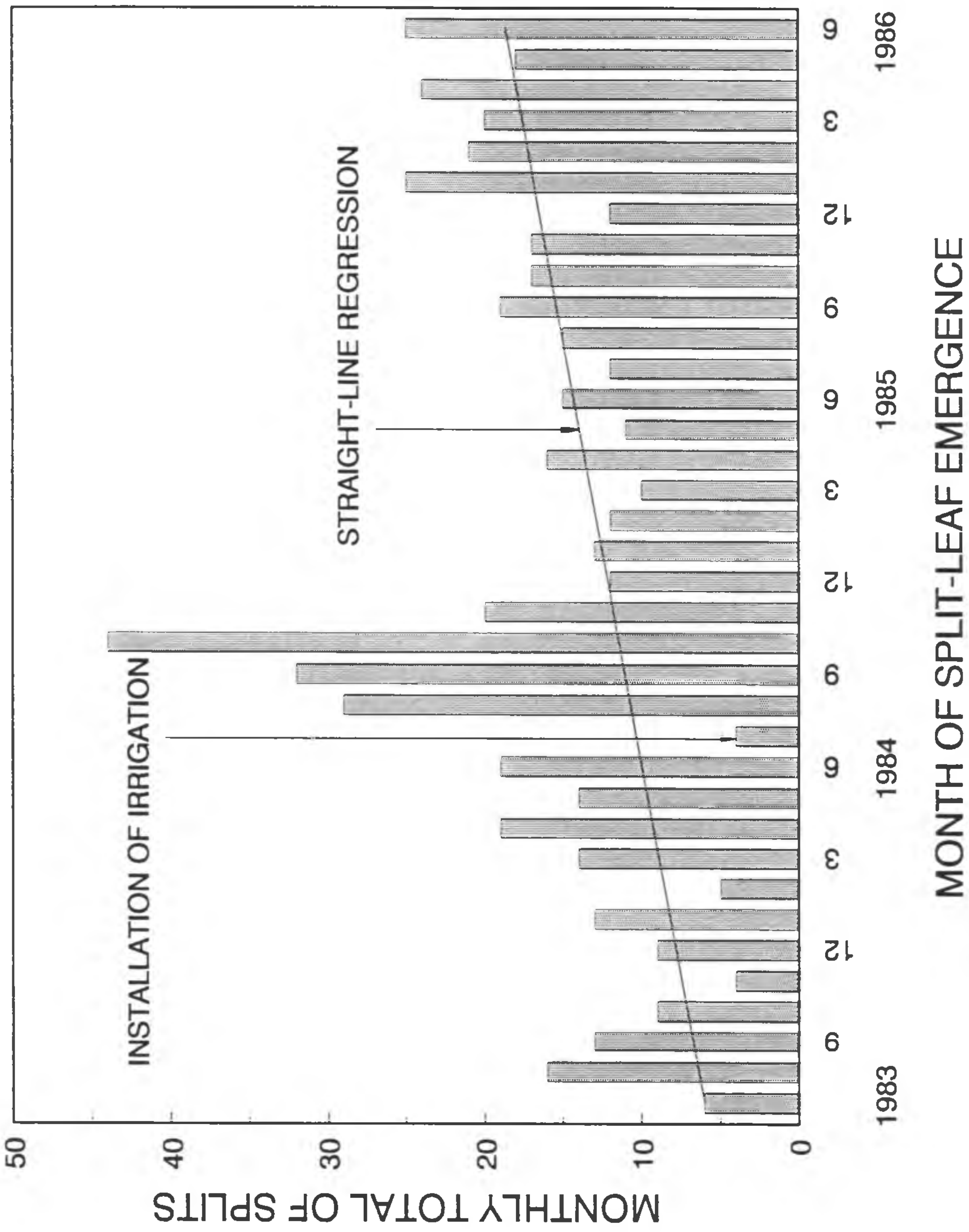

Figure 48. Monthly totals of splits from 80 bird of paradise plants established in Waimanalo, Oahu. They were propagated in 1981 and planted in the field in 1982. A reduction in the appearances of splits in July 1984 was followed by an increase in August-October. This abnormal appearance coincided with the installation of irrigation system in the field in July 1984 while a general drought was in effect.

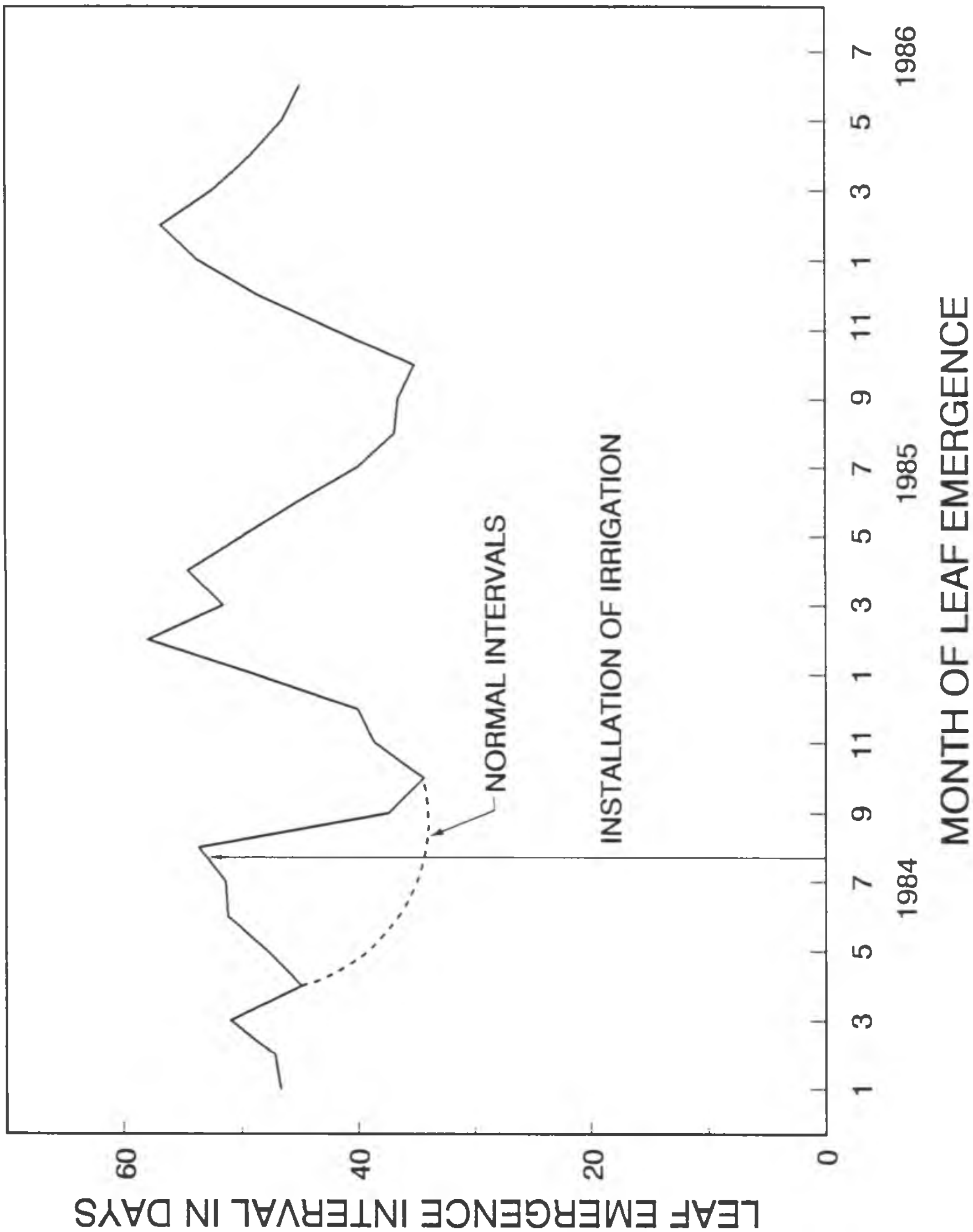

Figure 49. Monthly averages of Leaf emergence interval of bird of paradise in Waimanalo, Oahu. The interval was generally shorter in warm period (July-December) and longer in cool period (January-June). An abnormally long leaf emergence interval was observed in May-August in 1984 when a general drought was in effect. The plants resumed the seasonal fluctuation pattern after an irrigation system was installed in the field on July 19, 1984.

CHAPTER 4

CHARACTERISTICS OF BRANCH AND FAN DEVELOPMENT OF BIRD OF PARADISE AND EFFECT OF LEAF COOLING PRACTICES

The fluctuation of flower yield in bird of paradise at Waimanalo, Oahu was attributed to two trends: a long-term gradual increase due to the plant growth and a short-term annual fluctuation (Ch. 1).

Since the potential flower production could be determined by the number of leaves produced, and in turn, the number of leaves could be determined by dichotomous branching, it is important to be able to parameterize the characteristics of branching to model the long term increase.

It also would be necessary to identify the effect of leaf cooling treatments on the plant growth, since the modification of flower production pattern by the leaf cooling treatments (Ch. 3) could have been due to modifying the branch development (long-term effect) as well as the leaf and flower growth (short-term effect).

4.1 Literature Review

The branch development characteristics in bird of paradise are a) the number of splits per plant or per unit time, b) the split interval, c) the number of daughter fans per split, d) the number of leaves per fan, and e) the leaf emergence interval (LE interval). Among these, three characteristics, the split interval, the number of daughter fans per split, and the number of leaves per fan, are the most important factors for the flower production since they determine the potential number of leaves produced by a plant and subsequently the number of flowers. However, no comprehensive study has been made which enables the modeling of bird of paradise growth.

Vonk Noordegraaf and van der Krogt (1976) reported 0.5 to 1.5 division of fans occurred a year in their container grown plants with a higher day air temperature (25°C) resulting more splits than a low (15°C). These numbers can be converted to split intervals of 0.7-2 years.

Dyer (1972) reported that the increase in the number of fans was due to dichotomous branching (2 daughter fans per split).

Fisher (1976) reported the mean number of leaves produced by a fan 15.4 with a range of 7-25 for the field grown bird of paradise in Florida. He also reported 37% of the splits showed fasciated split leaves (joining of blades or petioles).

Halevy, et al. (1987) reported the number of leaves per fan per year deviated in 4.0-7.7 among production sites in Australia, in South Africa, in California, and in Hawaii.

The LE intervals was the most frequently studied factor among others: 1.5-7 months in France (Berninger, 1981), 6-34 weeks in the Netherlands (van de Venter, et al., 1980), 41.3-79.1 days in the growth chambers of 32/27 and 17/12°C (day/night air temperatures, Halevy, et al., 1987), and 43-65 days with an annual sine-curve fluctuation in Hawaii (Kawabata, et al., 1982).

Besemer, et al. (unpublished data) made an attempt to model the branch development with a hypothesis that all fans uniformly produced 6 leaves annually for 2 years and each fan produced a new fan at the end of each year. Although the model successfully fit the percentage of the flower-yielding leaves to the total leaf production for each year (stabilized to 42%), it would not be a credible model since the dichotomous branching and flower abortion (Ch. 3) were not considered in the model.

Previous knowledge of bird of paradise growth was not enough to build a branch development model that would enable to estimate the long-term flower production increase (Ch. 1). The objectives in this experiment were:

1. To parameterize the characteristics of branch and fan development in bird of paradise: number of splits, split interval, number of daughter fans per split, number of leaves per fan, and leaf emergence interval.
2. To determine the effect of leaf cooling treatments on the parameters of the plant growth characteristics in bird of paradise.

4.2 Materials and Methods

The bird of paradise plants used for the flower production experiment (Ch. 2) served for this experiment. Along with a control treatment (full-sun), these plants were subjected to the leaf cooling treatments; intermittent misting in August 22-November 14 in 1984 and again in June 14-October 2 in 1985; and 30% shadecloth (black polypropylene) for August 1, 1984, to June 30, 1986. The following variables were recorded for appropriate analyses.

Number of splits. The split of a fan was identified by 2 or more back-to-back leaf emergences in the MASTER data set (Ch. 3). The monthly totals were computed and regressed on month number starting with 1 for July 1983 to study the change in frequency of split over time.

The treatment effect on the mean split number was analyzed by one-way ANOVA using individual plants within treatments, 17 for control and 16 each for misting and shading, as the source of variation. The treatment means were also contrasted. Since the treatments were first applied in August 1984 and the effect of treatments would not be observed immediately, a portion of data in which leaf emergence (LE) occurred after January 1985 was also subjected to the analysis.

Split interval. A program BRANCH.SAS (Program 3) written in SAS (SAS Institute, 1985) was executed to create a data set BRANCH (Append. D) from the MASTER data set (Ch. 3) by extracting the characteristics of branch development in bird of paradise. The variables included in the data set were: the number of days between successive splits (SPLITINT, a time interval between the first leaves of a fan and of the next fan), the number of daughter fans produced by a fan (NSPLIT), the number of leaves produced in a fan (LEAF), and the generation number of a fan (GEN, 1 for the initial fan, 2 for the daughter of the initial, etc.).

The treatment effect on the split interval was subjected to one-way ANOVA using individual fans within treatment as the source of variation. Since the treatments were first applied in August 1984, a portion of the BRANCH data set in which first LE occurred after August 1984 was also subjected to the analysis.

The split intervals were also regressed on the generation number and the month number starting 1 with January 1983 to investigate the effect of plant growth on the split intervals.

Number of daughter fans per split. The number of split occurrences was tabulated by the leaf cooling treatments and by the number of daughter fans resulting from a split. The deviations among treatments in the proportion of frequencies for the number of daughter fans created by a fan were tested by a chi-square test for heterogeneity (Little and Hills, 1978:279-282) with a null-hypothesis that there was no difference in proportion among the treatments.

The number of daughter fans per split was also regressed on the generation of mother fan and the month number to study if the number of daughter fan per split was affected seasonally or by the generation of fan.

Number of leaves per fan. The mean for the number of leaves produced by a fan was computed for each treatment, and the effect of treatments was tested by one-way ANOVA using individual fan in a treatment as the source of variation.

The number of leaves per fan was also regressed on the generation number and on the date of fan completion (LE date of the last leaf in a fan) to study the change due to the plant development.

LE interval. LE intervals for control leaves were fit with a time-dependent, sine-curve regression model (Kawabata, et al., 1982). Since this experiment was done on younger plants (0- to 5-year-old) than for the previous research (7- to 10-year-old), the regression equation was compared with the previous one to check for a discrepancy which would show the effect of plant maturity.

Combined regression analyses with control were done for each treatment to estimate the mean differences in LE interval and their significances: LE intervals were first fitted with a common mean and a common sine-curve, then the residuals were fitted with a separate mean for each treatment for heterogeneity of means (Allen and Cady, 1982).

4.3 Results

4.3.1 *Number of splits.* The first split was observed in 1983 in one of the experimental plants, and they showed 2-18 splits per plant from the seeding in 1981 to June 1986. The treatment means varied from 8.2 for the shading to 11.6 for the misting with an overall mean of 9.8 ± 0.62(SE) (Table 28). The contrasts among treatments showed the misting resulted in a significantly larger mean than the shading at

2.4% level (MISTING vs. SHADING, Table 28). However, when the leaf cooling treatments were combined together they did not significantly differ from the control (CONTROL vs. OTHERS, Table 28).

Although a significant difference was observed among treatments for the initial 5-year growth period, no difference was detected when the splits earlier than January 1985 were deleted, leaving the data only for the treatment period (MISTING vs. SHADING, Table 29).

Monthly totals of splits showed a straight-line increase trend (regression prediction, Fig. 50), but no apparent seasonal trend was observed except for a suspiciously large total for October 1984. This occurrence is discussed later in this chapter.

4.3.2 *Split interval.* The split intervals for the initial 5-year growth period ranged from 28-713 days (4-102 wks) with a mean of 293 ± 7.8(SE), and no significant difference due to the treatments were found (Table 30). Despite a smaller mean for the misting (293 days) than others (349, control; 341, shading) the split intervals since August 1984 also showed no significant difference among treatments (Table 31).

The split interval increased with the generation of fans (branches) as a straight-line regression on generation number was significant with a positive slope (Table 32). Although a small positive quadratic trend was seen (Fig. 51), it was not statistically significant (Table 32).

A straight-line regression of monthly means of split interval on the month of LE for the first leaf (Table 33) also showed a significant positive increase (Fig. 52). While the increase was gradual and no apparent seasonal trend was seen, a suspiciously long mean interval appeared for the fans which emerged in July 1984 (**A**, Fig. 52). This large deviation in mean from the regression line was judged significant at 3.4% level (Table 33).

4.3.3 *Number of daughter fans per split.* A total of 425 splits were observed in the initial 5-year growth of 49 plants. Among these splits, 394 fans produced 2 daughter fans, 29 split to 3 daughter fans, and 1 each split to 4 and 5 daughter fans (Table 34). Although dichotomous branching (Dyer, 1972) was predominant (93% at Waimanalo, Oahu), splits to 3 daughter fans were not uncommon (7%). Unusually many daughter fans for a split (4 and 5) were also observed which could have resulted from successive splits without a production of normal leaves. However, the true origin of many daughter fans (4 and 5) was not determined as dissections were necessary which would destroy the plants.

By selecting fans which had the first LE (emergence of the first leaf) after July 1985 for a stronger effect of leaf cooling treatments, 132 splits were observed (Table 35). Among those splits, 124 splits (94%) had 2 daughter fans, 8 splits (6%) had 3 daughter fans, and no split had more than 3 daughter fans. A chi-square test for heterogeneity (Little and Hills, 1978:279-282) showed that there was no significant difference between treatments in the occurrence of multiple daughter fans per split.

A plot of means of daughter fans per split by generation (Fig. 53) showed a reduction from 2.3 daughter fans per split for the first generation to 2.0 for the 5th generation. A significant regression of fan number after natural-log transformation on the generation number (3.4%, Table 36) displayed this trend: high values for early generations (1-2) leveled approximately to 2 for the later generations (3-5). Some 6th generation fans existed, however, they did not show splits at the end of data collection period in June 1986.

When monthly means of the number of fans per split was plotted against the month of LE of the daughter fans (Fig. 54), there was a period between September 1984 and September 1985 in which all 184 fans split into 2 new fans. An examination of fans which split in October 1985-March 1986 indicated that the increase in the number of daughter fans per split was due to the splits of slow growing 4th generation fans. Therefore, the number of daughter fans per split had a tendency to become 2 (dichotomous branching) by the 5th generation in the initial 3- to 4-year growth.

4.3.4 *Number of leaves per fan.* The number of leaves per fan for the initial 5-year growth ranged from 1 (emergence of successive back-to-back split leaves without normal leaf production between them) to 20 with a mean of 6.6 ± 0.17(SE) (Table 37). Since the distribution appeared skewed to low value range (**ACTUAL**, Fig. 55), a natural-log transformation of the number of leaves per fan was done as an attempt to improve the normality judged by W-statistics (**LOG TRANSFORMED**, Fig.

55). However, the transformation did not improve the normality of distribution. Therefore, even though the distribution of leaf number per fan violated the assumption for a normality, an analysis of variance was performed on non-transformed numbers, and no difference between treatments was found (6.9 for control, 6.4 for misting, and 6.6 for shading, Table 37).

When the emergence of first leaf was restricted to January 1985 or later to eliminate the data before the treatment effect would appear, the mean of all treatments was 6.2 ± 0.50(SE) and no significant difference was detected between the treatments (Table 37). Although the mean for control (5.0) was small compared to the misting (6.5) and shading (6.9), these means were not as reliable as the prior result using all data as the number of observations was severely reduced to a total of 24 for this test from 425 for the former test. The majority of new fans had not shown splits at the end of data collection in June 1986, and the fans which had a small number of leaves were represented with a greater chance than the fans with a large number of leaves. Therefore, 6.2, mean leaf number per fan in the treatment period, was artificially smaller than a true mean, and 6.6 for all fans would be a better mean for the number of leaves per fan.

The regression of the number of leaves per fan on the generation number (Table 38) showed a mild straight-line effect, significant at 7.8%, and no quadratic effect. The slope was positive increasing from an expected value of 6.1 for the second generation to 7.3 for the 5th generation (Fig. 56). The first generation fans had a high value of

17.5 ± 0.36(SE); however, the data were not included in the regression, since they were not produced by splits of fans, they might have represented a juvenility, and transplanting seedlings into the field in the midst of fan development would have affected the shoot development.

The number of leaves per fan, regressed on the date of leaf emergence of the last leaf in a fan, showed a positive quadratic effect (Table 39) with the expected values increasing from 4 in the late 1983 to 12 in the early 1986 (Fig. 57). No apparent seasonality was observed.

These results indicated that the number of leaves per fan gradually increased with the plant growth up to 5th generation.

4.3.5 *LE interval.* In a wide range search of the best lag (phase shift) for the sine curve regression of LE interval in the treatment period, -100 to 60 days by increments of 20, good fits resulted from -40 to 0 days lag using R^2 as an indicator for fitness (Fig. 58). In a subsequent narrow search, -40 to 0 day by increments of 5, the best fit was determined to be -25 days lag (Fig. 59). The sine curve component was significant (Table 40), and it resulted in a regression equation,

$$\text{LE interval} = 45.5 + 9.1 \cdot \sin(2 \cdot \text{PI} \cdot \text{TIME} + 25) / 365.25 \text{ .... Eq. 5}$$

where TIME is Julian date and PI is 3.1416 (Fig. 60). The equation indicated the estimate of the longest LE interval was 55 (or 45.5 plus 9.1 in Eq. 5) days occurred in the beginning of March and the shortest was 36 days in the beginning of September. This result was similar to the previous study (Kawabata, et al., 1982) in which the best lag was estimated as -10 days and maximum and minimum as 60 and 48 days respectively for a 10-year-old.

Since a sine-curve response of LE interval on the time in a year was significant, analyses of variances for a mixed mode (regression of a dependent variable on numeric and discrete variables in a same variable sequence, Allen and Cady, 1982) were performed on time and treatments. While the mean LE intervals for control were estimated 45.3 or 45.4 days (50.5 - 5.2 or 50.3 - 4.9), the misting and the shading increased LE intervals by 5.2 ± 0.5(SE) and 4.9 ± 0.5(SE) days, respectively (Table 41).

Both leaf cooling treatments extended approximately 11% of the normal LE intervals (100 x 5.2 / 45.3 =10.7 for misting and 100 x 4.9 / 45.4 = 11.4 for shading). However, while the extension by shading affected LE interval all year, the extension by misting was averaged over entire annual cycle because misting was applied only in summer. Therfore, the treatment effect for misting would be larger than the estimated difference (5.2 days) in a short period.

4.4 Discussion

Characteristics of branch development. The parameters and characteristics of branch development in bird of paradise at Waimanalo, Oahu, are summarized on Table 42. These results indicated the typical plant growth at Waimanalo: an average bird of paradise seedling produced 17.5 leaves (not shown on the table) before the first split-leaves emerged which developed into 2-5 daughter fans (branches) with a 2.3 mean. Then, the daughter fans subsequently produced 1-20 leaves with a 6.6 mean. The split intervals ranged 28-713 days with a 293 mean. While the split interval and number of leaves per fan showed straight-line increase as plant grew larger and time, the number of daughter fans per split diminished reduced predominantly to 2 before the 5th generation branches.

No significant difference due to the leaf cooling treatments was detected among the characteristics for the branch development (split interval, number of splits per fan, and number of leaves per fan) except for the LE interval which showed treatment effects in extending LE interval by 4.9-5.2 days. The LE interval also showed a strong seasonality which was modeled with a sine-curve.

These findings indicated that leaf cooling treatments did not alter the development of bird of paradise branches which would affect the long-term increasing trend in flower production (Ch. 1). Therefore, if the flower production pattern was modified by the leaf cooling treatments, it was due to altering the flower growth rate which would appear in the short-term (annual) fluctuation and not due to altering the branch development characteristics (long-term increase).

Suspiciously frequent occurrence of split. Since monthly sum of split occurrences showed a large value for October 1984 (Fig. 50) in which all treatments were combined, another large value was sought in each treatment for the universal occurrences. While the magnitude of differences from the respective regression estimates varied, all treatments showed the largest discrepancies in summer 1984 (Fig. 61). An analysis for a suspiciously large value (Snedecor and Cochran, 1967:157-158) was performed to verify the observation that the large values did not occur by chance as follows:

1. To compute the expected values, straight-line regressions were performed for each treatment and also for all treatments combined (Table 43). Then the residuals (difference between the actual number of occurrences and the expected) were observed to identify the months of largest deviations. While October 1984 showed the largest deviations, up to 3 months in summer 1984 could be identified as abnormal: August-October for control; October-November for misting; and October for shading (Fig. 61).
2. These month with large values were subsequently deleted from the original data sets, and straight-line regressions were performed again (Table 43) to test if the deleted data deviated significantly from rest of the data. The significant deviations (0.1-4.7% probabilities) indicated that, in accordance with the visual observation, the largest deviations in October 1984 occurred for each of the treatments (Table 43).
3. The modified t-tests (Table 44) showed that the large values for October 1984, when the treatments were combined, significantly deviated from the regression estimates at 3.6% level. The large October 1984 values for individual treatments were also significant at 3.5-9.2% level.

Therefore, the abnormally frequent splits were determined that they did not occur by chance, thus the cause of the frequent occurrences in October 1984 was sought.

The cause of frequent split occurrence. Kawabata, et al. (1984) reported that changes in environmental factors at Waimanalo, Oahu (maximum and minimum air temperatures, solar radiation integral, and daylength) were interrelated, and no one factor alone could be related to the seasonal fluctuation in flower production of bird of paradise in Hawaii. The plots of air temperatures for 1977-1986 period (Figs. 46 and 47) showed the annual fluctuation pattern at the site (National Climatic Center, 1977-1986), however, no irregularity was observed before October 1984. The solar radiation (not presented in Figs. 46 and 47) also did not have irregular occurrence as it was related to air temperatures.

Since no irregularity was found on air temperatures and solar radiation, an irregular occurrence was sought in the availability of water. It could be the only other environmental factor which would be highly variable over time and would have a dominant effect on plant growth. This variable, available water, was not included in the search of the environmental factor in the previous study (Kawabata, et al., 1984) because overhead irrigation was operated by the farm which should supply 25 mm water weekly to the field.

Monthly totals of irrigation and rainfall records for 1977-1986 were plotted in Figs. 46 and 47 for an inspection. The occurrence of rainfall was irregular and the amount was also variable, however, a period could be seen in which rainfall was low in December 1982-September 1984 period. On the other hand, overhead irrigation appeared to be applied as a supplement to rainfall rather than as periodic applications and independent of rainfall. Between precipitation and the irrigation, an approximate total water of 100 mm was maintained monthly except in 1984.

When 2 low-rainfall years, 1983 and 1984, were compared (Fig. 47), total available water was much less in 1984 than in 1983: while the low rainfall in 1983 was compensated for by irrigation, the low rainfall in 1984 was not compensated. The reason for the unavailability of irrigation water was due to the depletion of reservoir water until October 1984 when it was replenished by a heavy rain period. It was likely that the plants experienced a severe water deficit in the first 7 month in 1984 especially in May-July period as the available water was the lowest until July 17 when a spot-spraying irrigation system using city water (Ch. 2) was installed.

Although the amount of application by the spot-spraying irrigation was small (40 $\mathrm{mm \cdot month^{-1}}$), the irrigation was effective as water was applied to a small area at the base of plant while rainfall and overhead sprinkler irrigation loses water to the ground between plants.

The effect of drought in summer 1984 was also demonstrated by the temperature difference between monthly averages of maximum and minimum. When a soil becomes dry, its heat capacity is reduced, and daily fluctuation of soil temperature becomes large. Since air temperatures in this experiment were measured near the soil surface, the air temperature fluctuation also could be larger than over a moist soil surface. The record of the monthly air temperature difference (National Climatic Center, 1977-1986) showed that the largest deviations occurred in September-October 1984 among summers of 1977-1986 (Fig. 47).

These findings suggested that bird of paradise plants in Waimanalo temporarily reduced growth rates due to an inadequate water supply in the first half of 1984, and as a result, leaf emergences were delayed. When rapid plant growth resumed as adequate water became available in July 1984 by the spot-spraying irrigation, leaves which should have emerged earlier appeared in a short period. Then, split leaves also appeared more frequently than normal which resulted in abnormally large number of split appearances in August-November in 1984 (Fig. 61)

The effects of drought. A direct evidence for the relationship between the plant growth characteristics in bird of paradise and available water could not be presented since this experiment was not set up to test for the effect of water availability. However, there were observations which would support the inference that the drought condition in Waimanalo, Oahu, in 1984 interfered the plant growth:

1. Frequent occurrences of split emergences for October 1984 (Fig. 50).
2. Significantly long split interval for the fans which first leaves emerged in July 1984 (Fig. 52).

3. The number of daughter fans produced by a split was always 2 for the fans emerged in a year period starting September 1984 (Fig. 54).
4. Long leaf emergence interval in April-September 1984 (Fig 49, or Fig. 62 presented in the following section).

These observations could be an indication that an adequate water supply was essential for the bird of paradise growth, and the lack of it could alter the flower production pattern.

In addition to vegetative aspect of plant growth, a drought condition also could affect the flower production:

1. A general reduction of flower yield from selected plants in the collection plots in 1984 (Ch. 3).
2. Mild drought periods could be identified in 1977 and 1979 (Fig. 46), and they coincided with the occurrence of sharp drops in flower production from the collection plots in the falls of 1977 and 1979 (Kawabata and Criley, 1984). If 100 mm of total rain and overhead irrigation were not enough, the sharp drop in 1978 in the study also could be justified.

LE interval. Despite the significant sine-curve regression model (Fig. 60), monthly means of LE interval were plotted to study the details of each treatment (Fig. 62). Since the misting treatment was applied only in summer while the shading was applied all year round, some differences among treatments could be expected on LE intervals.

For each treatment, the LE interval gradually increased from approximately 25 days for July 1983 to 50 days for summer 1984, then it started showing the sine-curve fluctuation. A simple multiplication of the LE interval mean (45.5 days, Table 42) with the average number of leaves per fan (6.6, Table 42) would give an estimate of 300 days of split interval for an average fan. The actual mean split interval recorded was 293 ± 7.7(SE) (Table 42) which would validate the correct relationship among these variables. Therefore, it would be possible to estimate the total leaf production over time and the subsequent potential flower production.

The longest LE intervals were found every year in January-March period with clear peaks in 1985-1986 (Fig. 62). However, a period was also found when the intervals were suspiciously high in April-September 1984 (**S**, Fig. 62). It was probable that these long intervals were caused by limited water availability since the high LE period coincided with the drought in 1984 (Fig. 47). Large standard error bands appearing in 1984 (Fig. 62) until after the start of irrigation in July 1984 also could be an indication of the drought. By September 1984 the LE intervals became synchronized with the sine-curves which would indicate the end of drought effect.

If insufficient water availability temporarily reduced the rate of flower stalk elongation within the plant at Waimanalo, the long LE intervals starting April 1984 could be justified. Then, an early recovery from the drought in September 1984, 1-2 months after the installation of irrigation in July 1984, would indicate that flower stalks had been stored within the plant and that they emerged shortly after plants were relieved from the water stress. Thus, if a sufficient water was available, LE intervals in 1984 also could have shown a sine-curve fluctuation as in 1985-1986.

The differences between the control and the leaf cooling treatments were investigated by overlaying plots together (Fig. 63). The misting treatment showed the largest effect of extending LE interval in March-April in the subsequent years, while no or less effect appeared immediately after the treatment in December 1984-February 1985 and November-December 1985. On the other hand, the shading treatment showed a more even difference against control (Fig. 64) than misting.

The different response patterns of LE interval to the treatments was probably because the shading treatment was in effect continuously throughout the experiment while the misting was applied only in summer. Since both leaf cooling treatments extended LE interval similarly for 4.9-5.2 days in average (Table 41), intermittent misting (when it was applied in summer) had a greater effect on extending LE interval than the 30% shading, and the main leaf cooling effect appeared on the LE interval 6 months later for 1984 misting and 8 months for 1985 misting.

4.5 Summary

1. The parameters for the branch characteristics in bird of paradise were determined (Table 42) for the split interval, number of splits, the number of daughter fans (branches) per split, and the number of leaves per fan. These parameters would enable the estimation of the potential flower production for a bird of paradise plant in Waimanalo, Oahu.

2. The leaf cooling treatments, intermittent misting and 30% shading, did not significantly alter the characteristics of the branch development, and the first effect on the plant growth was observed in extending the leaf emergence interval.
3. The leaf cooling treatments showed their effect on extending leaf emergence interval 6-8 months after the treatments were given. While both treatments extended the leaf emergence interval, 5.2 days for misting and 4.9 days for shading (or approximately 11% of 45 days mean leaf emergence interval), the intermittent misting effect was greater than the 30% shading considering the duration of the treatments.
4. Abnormally large numbers appeared in the split interval, the numbers of split, and the leaf emergence interval. The occurrences were associated with the limited water availability in 1984 due to a drought and relieved by a subsequent installation of irrigation system in July 1984.

Table 28. An analysis of variance for the number of splits per plant (SPLIT) for the initial 5 years of bird of paradise growth in Waimanalo, Oahu. Along with full-sun treatment (CONTROL); intermittent misting (MISTING), August 22-November 14 in 1984 and June 14-October 2 in 1985; and 30% black plastic shade (SHADING), August 1, 1984-June 1986, were applied as leaf cooling treatments. A significant difference was found for the contrast for MISTING vs. SHADING.

Dependent Variable: SPLIT

Descriptive statistics

Treatment	Number of Plants	SPLIT Minimum	SPLIT Maximum	SPLIT Mean	SPLIT SE
CONTROL	17	5	17	9.7	0.96
MISTING	16	4	18	11.6	1.03
SHADING	16	2	18	8.2	1.10

Analysis of variance

Source	DF	Sum of Squares	F Value	Pr > F
Model	2	94.98	2.74	0.075
Error	46	797.72		
Corrected Total	48	892.69		

R-Square	CV	SPLIT Mean
0.11	42.3	9.8

Source	DF	Type I SS	F Value	Pr > F
Treatments	2	94.98	2.74	0.075

Contrasts

Contrast	DF	Contrast SS	F Value	Pr > F
CONTROL vs. OTHERS	1	0.45	0.03	0.873
MISTING vs. SHADING	1	94.53	5.45	0.024

Table 29. An analysis of variance for the number of splits per plant (SPLIT) of 5-year-old bird of paradise plants at the end of the experimental period, January 1985-June 1986, in Waimanalo, Oahu. Along with full-sun treatment (CONTROL); intermittent misting (MISTING), August 22-November 14 in 1984 and June 14-October 2 in 1985; and 30% black plastic shade (SHADING), August 1, 1984-June 1986, were applied as leaf cooling treatments. No significant difference in number of splits was found between treatments.

Dependent Variable: SPLIT

Descriptive statistics

Treatment	Number of Plants	SPLIT Minimum	SPLIT Maximum	SPLIT Mean	SPLIT SE
CONTROL	17	2	9	4.8	1.16
MISTING	16	2	12	6.3	1.56
SHADING	14	1	12	4.7	0.78

Analysis of variance

Source	DF	Sum of Squares	F Value	Pr > F
Model	2	24.02	1.74	0.187
Error	44	302.92		
Corrected Total	46	326.94		

R-Square	CV	SPLIT Mean
0.07	49.9	5.3

Source	DF	Type I SS	F Value	Pr > F
Treatments	2	24.02	1.74	0.187

Contrasts

Contrast	DF	Contrast SS	F Value	Pr > F
CONTROL vs. OTHERS	1	5.58	0.81	0.373
MISTING vs. SHADING	1	17.61	2.56	0.117

Table 30. An analysis of variance for the split interval (SPLITINT in days) for the initial 5 years of bird of paradise growth in Waimanalo, Oahu. Along with full-sun treatment (CONTROL); intermittent misting (MISTING), August 22-November 14 in 1984 and June 14-October 2 in 1985; and 30% black plastic shade (SHADING), August 1, 1984-June 1986, were applied as leaf cooling treatments. No significant difference in the split intervals was found between treatments.

Dependent Variable: SPLITINT

Descriptive statistics

Treatments	Number of fans	-------SPLITINT------ Mean	SE
CONTROL	114	300	14.4
MISTING	140	281	11.4
SHADING	99	302	15.0

Analysis of variance

Source	DF	Sum of Squares	F Value	Pr > F
Model	2	33060.55	0.78	0.458
Error	350	7391917.10		
Corrected Total	352	7424977.65		

R-Square	CV	SPLITINT Mean
0.004	49.5	293

Source	DF	Type I SS	F Value	Pr > F
Treatments	2	33060.55	0.78	0.458

Table 31. An analysis of variance for the split interval (SPLITINT in days) of 5-year-old bird of paradise plants at the end of the observation period, August 1984-June 1986, in Waimanalo, Oahu. Along with full-sun treatment (CONTROL); intermittent misting (MISTING), August 22-November 14 in 1984 and June 14-October 2 in 1985; and 30% black plastic shade (SHADING), August 1, 1984-June 1986, were applied as leaf cooling treatments. No difference in the split intervals was found between treatments.

Dependent Variable: SPLITINT

Descriptive statistics

Treatments	Number of fans	SPLITINT Mean	SPLITINT SE
CONTROL	40	349	26.1
MISTING	53	293	15.9
SHADING	35	341	23.8

Analysis of variance

Source	DF	Sum of Squares	F Value	Pr > F
Model	2	85405.10	2.19	0.116
Error	125	2432811.26		
Corrected Total	127	2518216.37		

R-Square	CV	SPLITINT Mean
0.034	43.1	324

Source	DF	Type I SS	F Value	Pr > F
Treatments	2	85405.10	2.19	0.116

Table 32. Analyses of variance for regressing the split interval (SPLITINT) of bird of paradise on the number of branch generation (GEN). The plants were grown in Waimanalo, Oahu, and branch generation numbers were sequentially assigned at the emergence of split leaves starting with 1 for the initial seedling fan growth. The split interval showed a straight-line increase on the branch generations 2-4. Fifth generation branches were excluded from these analyses since most of them did not produce split leaves at the end of 5-year growth.

Dependent Variable: SPLITINT

Analysis of variance for a quadratic regression

Source	DF	Sum of Squares	F Value	Pr > F
Model	2	374238.04	9.23	0.001
Error	344	6970168.98		
Corrected Total	346	7344407.02		

R-Square	CV	SPLITINT Mean
0.05	48.5	293

Source	DF	Type I SS	F Value	Pr > F
GEN	1	367444.58	18.13	0.001
GEN x GEN	1	6793.46	0.34	0.563

Analysis of variance for a straight-line regression

Source	DF	Type I SS	F Value	Pr > F
GEN	1	367444.58	18.17	0.001

Prediction equation for the straight-line regression

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	164	5.16	0.001	31.6
GEN	44	4.26	0.001	10.2

Table 33. A test for the suspiciously large mean split interval (MSPL) for July 1984 (Fig. 52). A straight-line regression of MSPL on the number of months starting January 1983 (MONTH) was significant with a positive slope. The large mean (417 days) for July 1984 deviated significantly at 3.4% level from the predicted value (316 days) computed from by regressing all other data points (Snedecor and Cochran, 1967:157-158).

Dependent Variable: MSPL

ANOVA for regression and prediction equation including July 1984 value

Source	DF	Sum of Squares	F Value	Pr > F
MONTH	1	29694.90	25.57	0.0001
Error	16	18583.87		
Corrected Total	17	48278.77		

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	175.2	6.92	0.0001	25.31
MONTH	7.8	5.06	0.0001	1.55

ANOVA for regression and prediction equation excluding July 1984 value

Source	DF	Sum of Squares	F Value	Pr > F
MONTH	1	23772.70	38.59	0.0001
Error	15	9240.18		
Corrected Total	16	33012.88		

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	180.8	9.78	0.0001	18.49
MONTH	7.1	6.21	0.0001	1.14

Test for a suspiciously large value for July 1984

-----------DF----------				SS	Variance	N	1/N	x^2/SSx	Mult
Tot	Mean	Slope	Error	Error	Error				Factor
17	1	1	15	9240.18	616.01	17	0.059	0.029	1.088

Variance	SE	----MSPL-July 1984----			T	Pr > |T|	Pr > |T|
Pred	Pred	Actual	Pred	Diff	DF=15	Random	Suspected
670.23	25.89	416.6	315.7	100.8	3.895	0.0019	0.0343

Table 34. The number of new branches (daughter fans) produced by a split for the initial 5 years of bird of paradise growth in Waimanalo, Oahu after germination. Along with full-sun treatment (CONTROL); intermittent misting (MISTING), August 22-November 14, 1984 and June 14-October 2, 1985; and 30% black plastic shade (SHADING), August 1 1984-June 1986, were applied as leaf cooling treatments. Although splits to 2 daughter fans were predominant, splits to 3-5 fans were not uncommon.

New Branches	Number of Occurrences				Percent of Total
	Control	Misting	Shading	Sum	
2	130	152	112	394	92.7
3	14	9	6	29	6.8
4	0	1	0	1	0.2
5	1	0	0	1	0.2
Total	144	162	118	425	100.0

Table 35. The number of new branches (daughter fans) produced by a split of 5-year-old bird of paradise plants at the end of the experimental period, January 1985-June 1986, in Waimanalo, Oahu. Along with full-sun treatment (CONTROL); intermittent misting (MISTING), August 22-November 14 in 1984 and June 14-October 2 in 1985; and 30% black plastic shade (SHADING), August 1, 1984-June 1986, were applied as leaf cooling treatments. A chi-square test for heterogeneity showed the ratio of occurrences of 2 to 3 new branches (94 : 6) was not significantly different between the treatments.

Number of occurrence of splits

New Branches	Number of Occurrences				Percent of Total
	Control	Misting	Shading	Sum	
2	38	51	35	124	93.9
3	5	2	1	8	6.1
Total	43	53	36	132	100.0

Chi-square test for heterogeneity

Source	DF	Chi-square (93.9:6.1)	Pr
Control	1	2.341	
Misting	1	0.487	
Shading	1	0.682	
Total	3	3.509	
Pooled	1	0.000	
Heterogeneity	2	3.509	0.173

Table 36. An analysis of variance for regressing the number of new branches (NSPLIT) produced by a split on the generation of branches. Branches up to 5 generation completed in the initial 5 years of bird of paradise growth in Waimanalo, Oahu. A gradual shift in the means from 2.3 to 2.0 in Fig. 3 was modeled by a significant straight-line regression on the natural-log of the generation number (LNGEN).

```
========================================================================
Dependent Variable: NSPLIT

Source                    DF    Sum of Squares      F Value       Pr > F
===============          ===    ==============      =======       ======
Model                      1       2.15              24.47        0.0001
Error                    423      37.13
Corrected Total          424      39.28

                    R-Square                 CV              NSPLIT Mean
                    ========               ====              ===========
                       0.055               14.2                      2.1


Source                    DF         Type I SS      F Value       Pr > F
======                    ==         =========      =======       ======
LNGEN                      1              2.15        24.47       0.0001


                                 T for H0:     Pr > |T|     Std Error of
Parameter              Estimate  Parameter=0                   Estimate
=========              ========  ===========   ========     ============
INTERCEPT                  2.24        63.78     0.0001            0.035
LNGEN                    -0.167        -4.95     0.0001            0.034

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```

Table 37. An analysis of variances for the number of leaves per fan (LEAF) affected by leaf cooling treatments (TREATMENT) in bird of paradise in 2 periods: the first 4-year growth period, and January 1985-June 1986 in which the treatment effect would show. The treatments consisted of intermittent misting (MISTING) applied August 22-November 14 in 1984 and July 14-October 2 in 1985 and 30% black plastic shade (SHADING) installed on August 1, 1984 along with the full-sun treatment (CONTROL). No significant difference was observed in either of the periods.

Dependent Variable: LEAF

Analysis of variance using all data

Source	DF	Type I SS	F Value	Pr > F
TREATMENT	2	17.19	0.70	0.498
Error	422	5189.29		
Corrected Total	424	5206.48		

Level of TREATMENT	LEAF N	Minimum	Maximum	Mean	SE
CONTROL	145	1	19	6.9	0.32
MISTING	162	1	20	6.4	0.25
SHADING	118	1	20	6.6	0.32
All	425	1	20	6.6	0.17

Analysis of variance using fans emerged after January 1985

Source	DF	Type I SS	F Value	Pr > F
TREATMENT	2	12.37	1.02	0.378
Error	21	127.58		
Corrected Total	23	139.96		

Level of TRT	LEAF N	Mean	SE
CONTROL	6	5.0	1.31
MISTING	11	6.5	0.69
SHADING	7	6.9	0.74
All	24	6.2	0.50

Table 38. An analysis of variances for regressing the number of leaves per fan (LEAF) on branch generation (GEN) in bird of paradise in Waimanalo, Oahu. A straight-line effect was significant at 7.8% level, but a quadratic effect was not significant.

Dependent Variable: LEAF

Analysis of variance for quadratic model

Source	DF	Sum of Squares	F Value	Pr > F
(Model)	(2)	(42.05)	(1.60)	(0.204)
GEN	1	41.00	3.12	0.078
GEN x GEN	1	1.06	0.08	0.777
Error	373	4904.42		
Corrected Total	375	4946.47		

R-Square	CV	LEAF Mean
0.009	55.2	6.6

Analysis of variance for straight-line model

Source	DF	Type I SS	F Value	Pr > F
GEN	1	41.00	3.13	0.078
Error	374	4905.47		
Corrected Total	375	4946.47		

R-Square	CV	LEAF Mean
0.009	55.2	6.6

Regression estimates

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	5.3	7.13	0.0001	0.74
GEN	0.4	1.77	0.0779	0.24

Table 39. Analysis of variances for regressing the number of leaves per fan (LEAF) on the number days of the last-leaf emergence from December 31, 1982 (DAYS) in bird of paradise in Waimanalo, Oahu. Both straight-line and quadratic effects was significant at 0.1%.

Dependent Variable: LEAF

Analysis of variance for a straight-line regression

Source	DF	Sum of Squares	F Value	Pr > F
DAYS	1	1934.19	240.55	0.0001
Error	369	2967.07		
Corrected Total	370	4901.26		

R-Square	CV	LEAF Mean
0.39	43.2	6.6

Analysis of variance for a quadratic regression

Source	DF	Sum of Squares	F Value	Pr > F
(Model)	(2)	(2059.62)	(133.36)	(0.0001)
DAYS	1	1934.19	250.48	0.0001
DAYS x DAYS	1	125.42	16.24	0.0001
Error	368	2841.65		
Corrected Total	370	4901.26		

R-Square	CV	LEAF Mean
0.42	42.3	6.6

Regression estimates

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	5.7	3.27	0.001	1.74
DAYS	-0.0088	-1.90	0.058	0.00460
DAYS x DAYS	0.000011	4.03	0.001	0.0000029

Table 40. A sine curve regression of the leaf emergence interval (LEINT) in bird of paradise in Waimanalo, Oahu on the number of days from January 1, 1985 (TIME). The best lag was obtained by searching between -100 and 60 days (Figs. 58 and 59) which resulted in -25 days lag for the sine function (FM25, sin(2 x 3.14 x (TIME + 25) / 365.25)).

Dependent Variable: LEINT

Analysis of variance

Source	DF	Sum of Squares	F Value	Pr > F
FM25	1	63003.51	388.76	0.0001
Error	1532	248277.99		
Corrected Total	1533	311281.50		

R-Square	CV	LEINT Mean
0.20	27.5	46.3

Regression estimates

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	45.5	138.59	0.0001	0.33
FM25	9.1	19.72	0.0001	0.46

Table 41. Comparisons of leaf emergence intervals (LEINT) between control (full-sun, CONTROL) and leaf cooling treatments: intermittent misting (MISTING), August 22-November 14 in 1984 and June 14-October 2 in 1985; and 30% black plastic shade (SHADING), August 1, 1984-June 1986. While a sine curve function (FM25, sin(2 x 3.14 x ((Number of days from January 1, 1985 + 25) / 365.25)) was significant, both treatments significantly extended the leaf emergence intervals by 5.2 days for misting and 4.9 days for shading.

Dependent Variable: LEINT

Comparison of control and misting

Source	DF	Sum of Squares	F Value	Pr > F
(Model)	(2)	(196940.62)	(526.90)	(0.0001)
FM25	1	175613.50	939.69	0.0001
CONTROL vs MISTING	1	21327.12	114.12	0.0001
Error	3120	583079.46		
Corrected Total	3122	780020.08		

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	50.5 Biased	147.04	0.0001	0.34
FM25	10.8	30.89	0.0001	0.35
CONTROL	-5.2 Biased	-10.68	0.0001	0.49
MISTING	0.0 Biased	.	.	.

Comparison of control and shading

Source	DF	Sum of Squares	F Value	Pr > F
(Model)	(2)	(138521.05)	(407.62)	(0.0001)
FM25	1	122622.86	721.67	0.0001
CONTROL vs SHADING	1	15898.19	93.57	0.0001
Error	2716	461490.78		
Corrected Total	2718	600011.83		

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	50.3 Biased	132.48	0.0001	0.38
FM25	9.7	27.00	0.0001	0.36
CONTROL	-4.9 Biased	-9.67	0.0001	0.50
SHADING	0.0 Biased	.	.	.

Table 42. Summary of characteristics in bird of paradise branch development for the initial 5-year growth in Waimanalo, Oahu. The leaf cooling treatments, misting and shading, were initiated in the fourth year, resulted in extending the leaf emergence intervals. However, no significant difference was observed among characteristics which would determine the total leaf production (split interval, number of daughter fans produced by a split, and number of leaves per fan).

Characteristics of Branch Development in Bird of Paradise	Estimates (Mean)	Influencing Factors		
		Leaf Cooling (ANOVA)	Generation (Curve Type)	Time and Plant Growth (Curve Type)
Number of splits for the initial 5 year growth	9.8 ± 0.62 (total per plant, Table 28)	Not Significant	-	Straight-line increase
Split interval	293 ± 7.8 days (Table 30)	Not significant	Straight-line increase	Straight-line increase
Number of daughter fans per split	2 (93% of the time, Table 34)	Not significant	2.3 to 2	Not clear
Number of leaves per fan	6.6 ± 0.17 (Table 37)	Not significant	Straight-line increase	Quadratic-curve increase
Leaf emergence interval	45.5 ± 9.1 days (Table 40)	5.2 (Misting) 4.9 (Shading)	-	Sine-curve fluctuation

Table 43. Regressions for the monthly totals of splits in bird of paradise to identify observations which had the largest deviations from the expected values. Regressions were performed again after the large observations were excluded.

ITEM	ALL	CONTROL	MISTING	SHADING
ANOVA for regression using all observations				
SS for slope (DF)	196.85 (1)	17.40 (1)	40.98 (1)	11.95 (1)
SS for error (DF)	1311.90(34)	301.49(34)	194.91(34)	208.80(34)
SS for total (DF)	1508.75(35)	318.89(35)	235.89(35)	220.75(35)
F	5.10	1.96	7.15	1.95
Pr > F	0.030	0.170	0.011	0.172
Regression estimates				
Intercept	8.92	3.206	3.156	2.557
Month	0.225	0.067	0.103	0.055
Month of largest dev	Oct. 1984	Oct. 1984	Oct. 1984	Oct. 1984
Month number	16	16	16	16
ANOVA for regression excluding the largest observation				
SS for slope (DF)	225.88 (1)	27.56 (1)	46.99 (1)	14.82 (1)
SS for error (DF)	694.52(33)	173.16(31)	100.45(32)	114.73(33)
SS for total (DF)	920.40(34)	200.73(32)	147.44(33)	129.54(34)
F	10.73	4.93	14.97	4.26
Pr > F	0.003	0.034	0.001	0.047
Regression estimates				
Intercept	7.92	2.315	2.626	2.166
Month	0.241	0.085	0.110	0.062
Month for prediction	16	16	16	16
Predicted	11.78	3.67	4.39	3.16
Actual	37	12	12	13
SS for month	3878.57	3842.91	3876.03	3878.57

Table 44. T-tests for the suspiciously frequent split occurrences in bird of paradise in Waimanalo, Oahu for each leaf cooling treatments: control (CONTROL), misting (MISTING), shading (SHADING), and all treatments combined (ALL). The deviations of large numbers observed for October 1984 from the expected values (Table 43) were significant by t-tests at least at 3.4% level except for CONTROL which was significant at 9.2% (Snedecor and Cochran, 1967:157-158).

Item	ID	Formula or Source	Treatment			
			ALL	CONTROL	MISTING	SHADING
Degree of freedom						
Total	A	Table 43	35	33	34	35
Mean	B	1	1	1	1	1
Slope	C	1	1	1	1	1
Error	D	A - B - C	33	31	32	33
Standard error for an observation						
SS for error	E	Table 43	694.52	173.16	100.45	114.73
Var for error	F	E / F	21.05	5.59	3.14	3.48
Correction for mean	G	1 / A	0.029	0.030	0.029	0.029
Month of largest dev	H	Table 43	16	16	16	16
Mean of month	I	Table 43	18.57	18.82	18.62	18.57
Deviation	J	H - I	-2.57	-2.82	-2.62	-2.57
SS for month	K	Table 43	3878.57	3842.91	3876.03	3878.57
Correction for slope	L	J^2 / K	0.002	0.002	0.002	0.002
Mult factor	M	1 + G + L	1.03	1.03	1.03	1.03
Var for prediction	N	F x M	21.68	5.77	3.24	3.58
SE for prediction	O	$N^{0.5}$	4.66	2.40	1.79	1.89
Estimating the largest difference						
Actual	P	Table 43	37	12	12	13
Estimated	Q	Table 43	11.78	3.67	4.39	3.16
Difference	R	P - Q	25.22	8.33	7.61	9.84
T-test						
T value	S	R / O	5.42	3.47	4.23	5.20
Pr > |T| (Random)	T	at DF=D	>0.001	0.0027	>0.001	>0.001
Pr > |T| (Suspected)	U	T x (A + 1)	>0.036	0.092	>0.035	>0.036

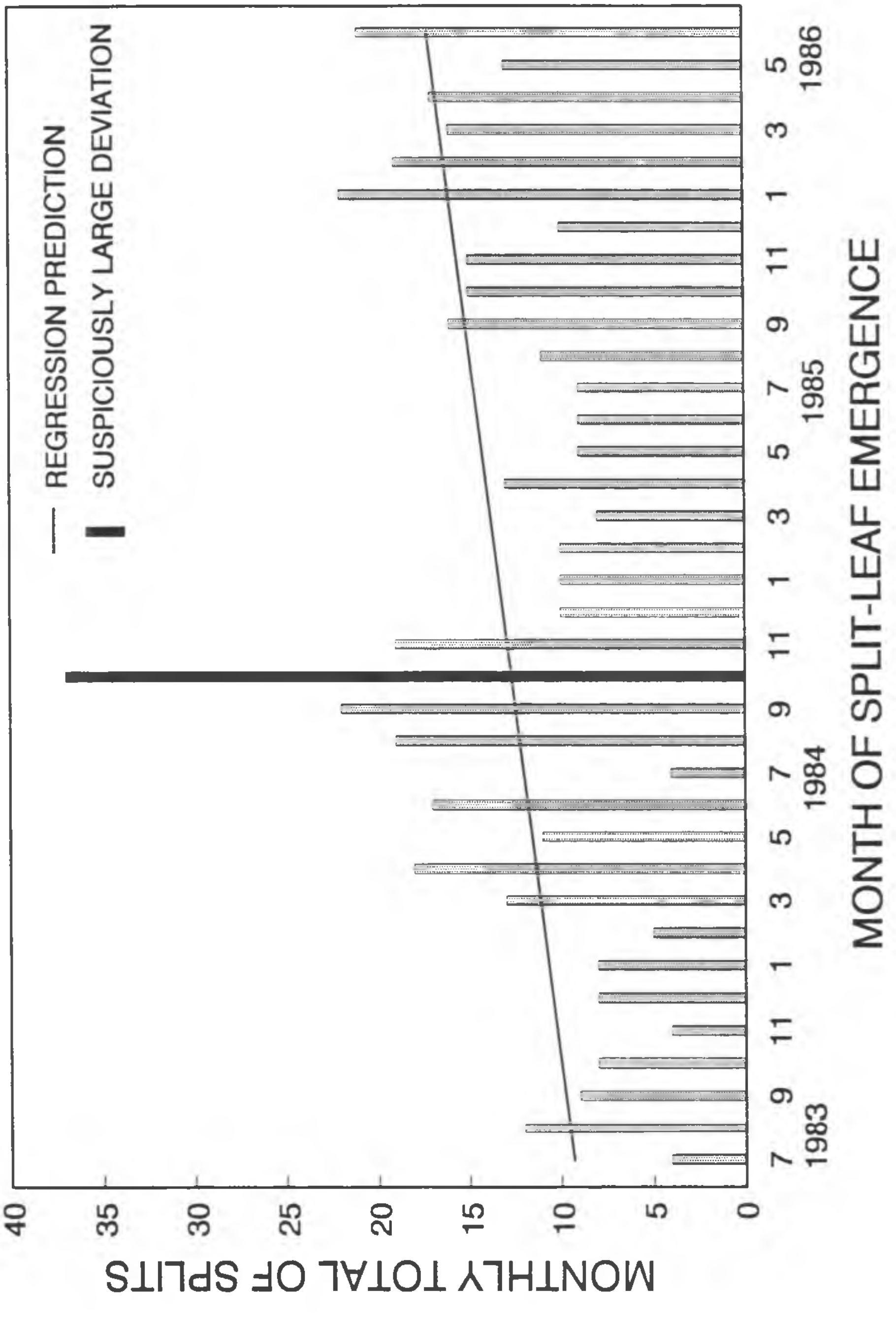


Figure 50. Monthly total of splits from 49 bird of paradise plants (16, misting; 16, shading; 17, control) in Waimanalo, Oahu showed a straight-line increase (Table 43) for the initial 5-year growth. All treatments were combined. Although no seasonal trend was apparent, a suspiciously large total appeared for October 1984.

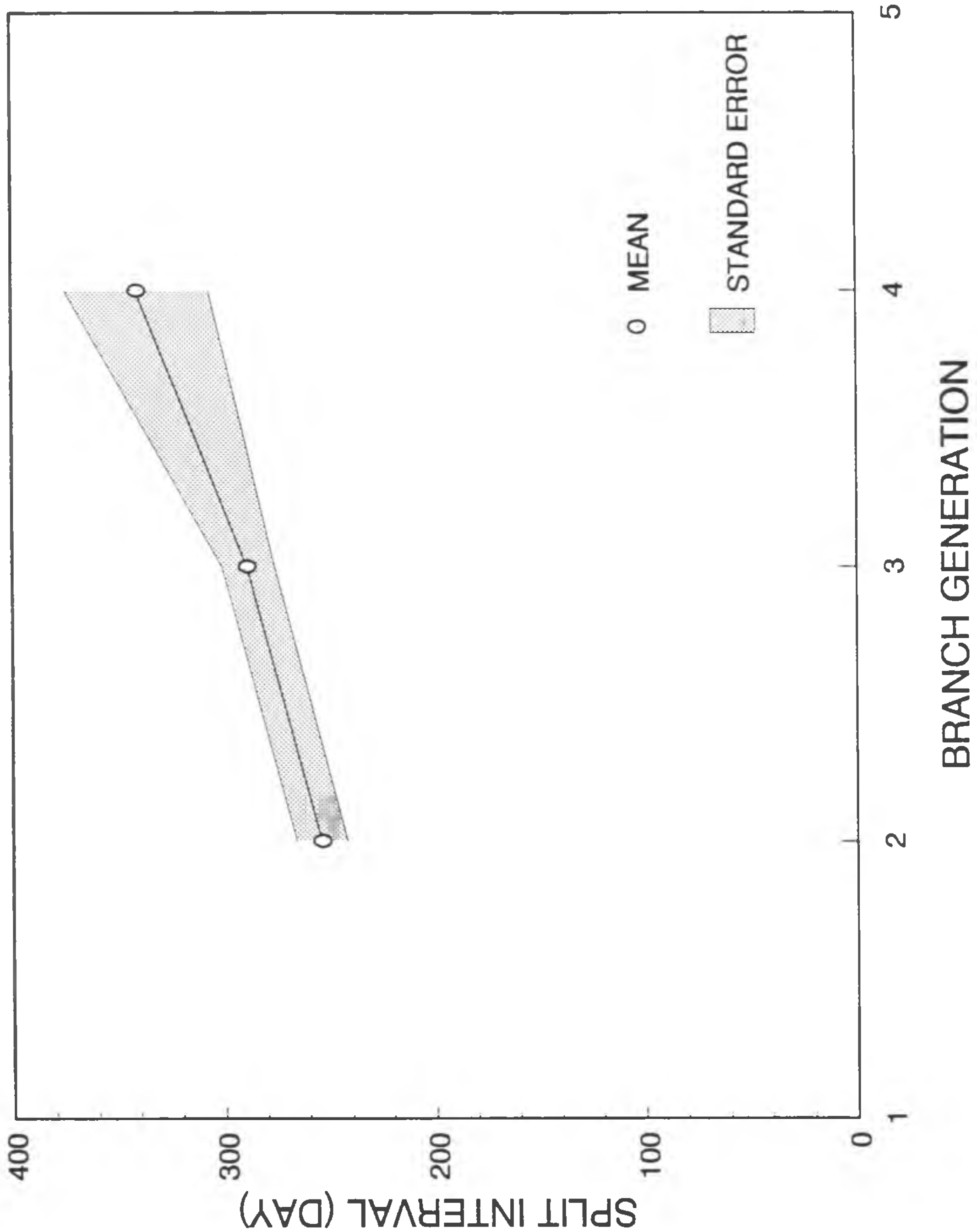


Figure 51. The split intervals of bird of paradise in Waimanalo, Oahu showed a significant positive straight-line trend while the quadratic trend was not significant (Table 32). Although 5th generation fans were observed, they were excluded from this analysis since the number of observations was small (6) and they could represent only fans which had short split intervals.

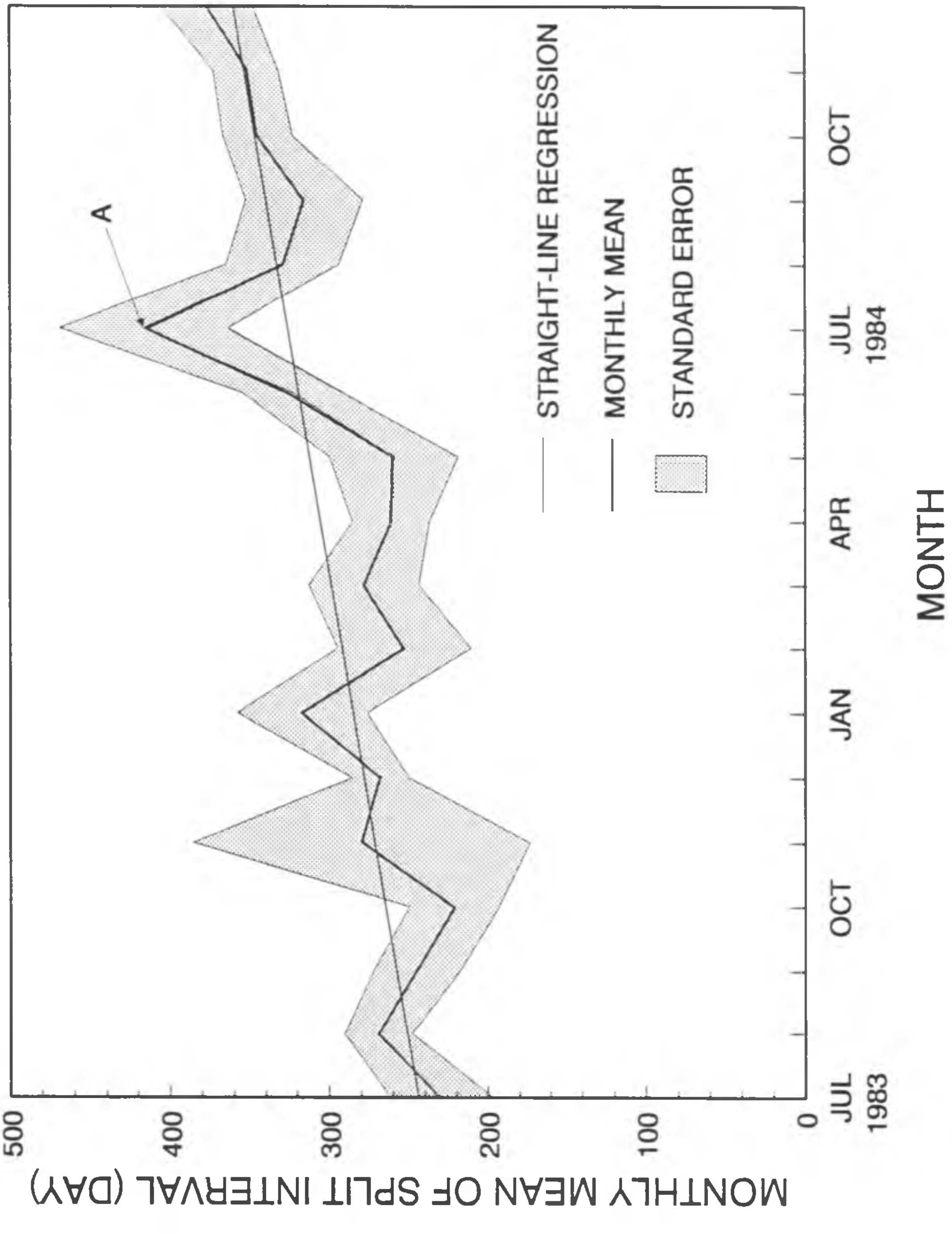


Figure 52. The split intervals of bird of paradise in Waimanalo, Oahu plotted against the month of leaf emergence for the first leaf in a fan showed a positive straight-line increase. January 1983 was set for the month 1. A large value for July 1984 (A) deviated significantly from the regression estimate (Table 33).

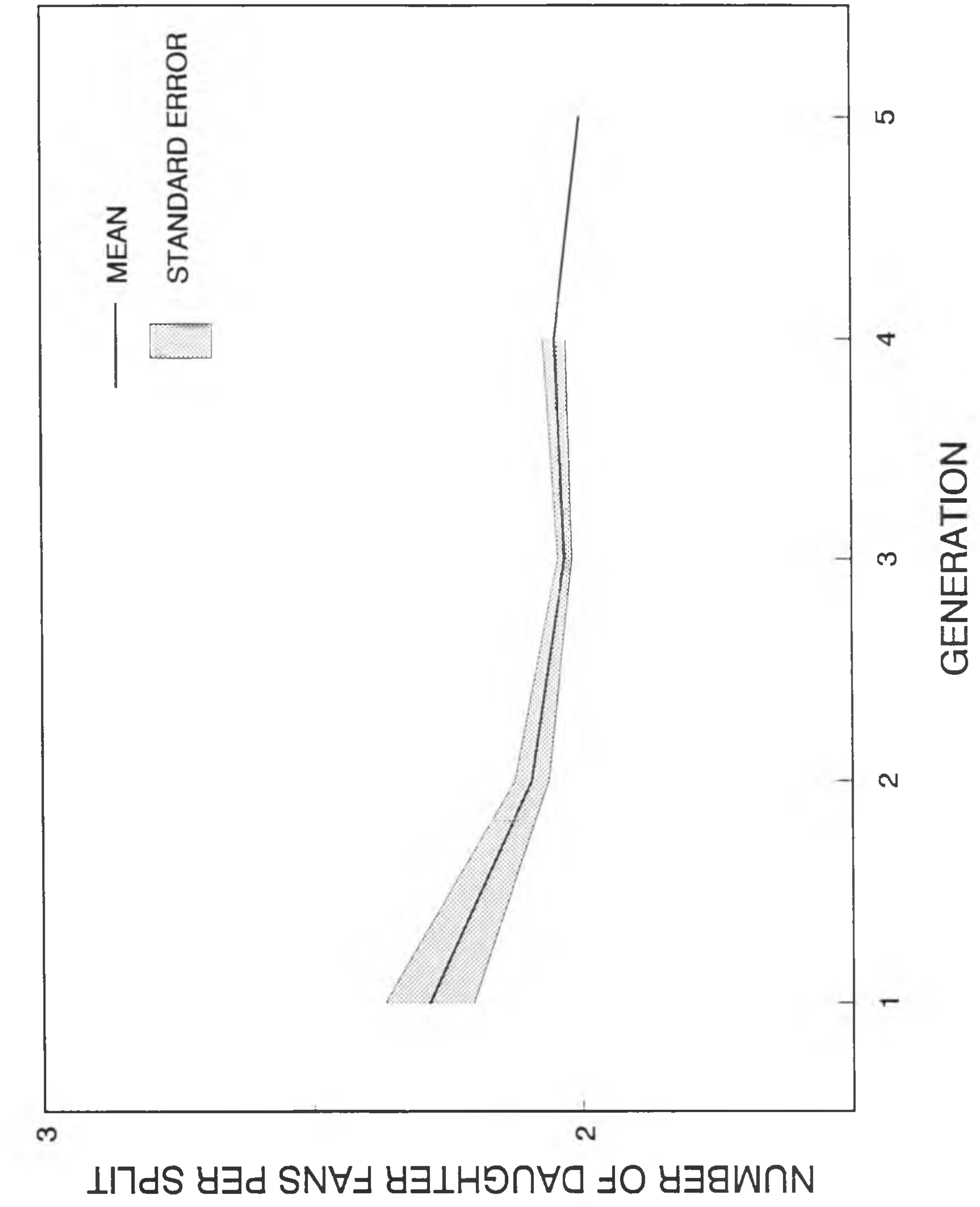


Figure 53. The number of daughter fans per split became stabilized at near 2 in the 4-5th generation fans from 2.3 for the first generation fans in bird of paradise in Waimanalo, Oahu. There was no standard error for the fifth generation fans since all the 5th generation fans split into 2 daughter fans.

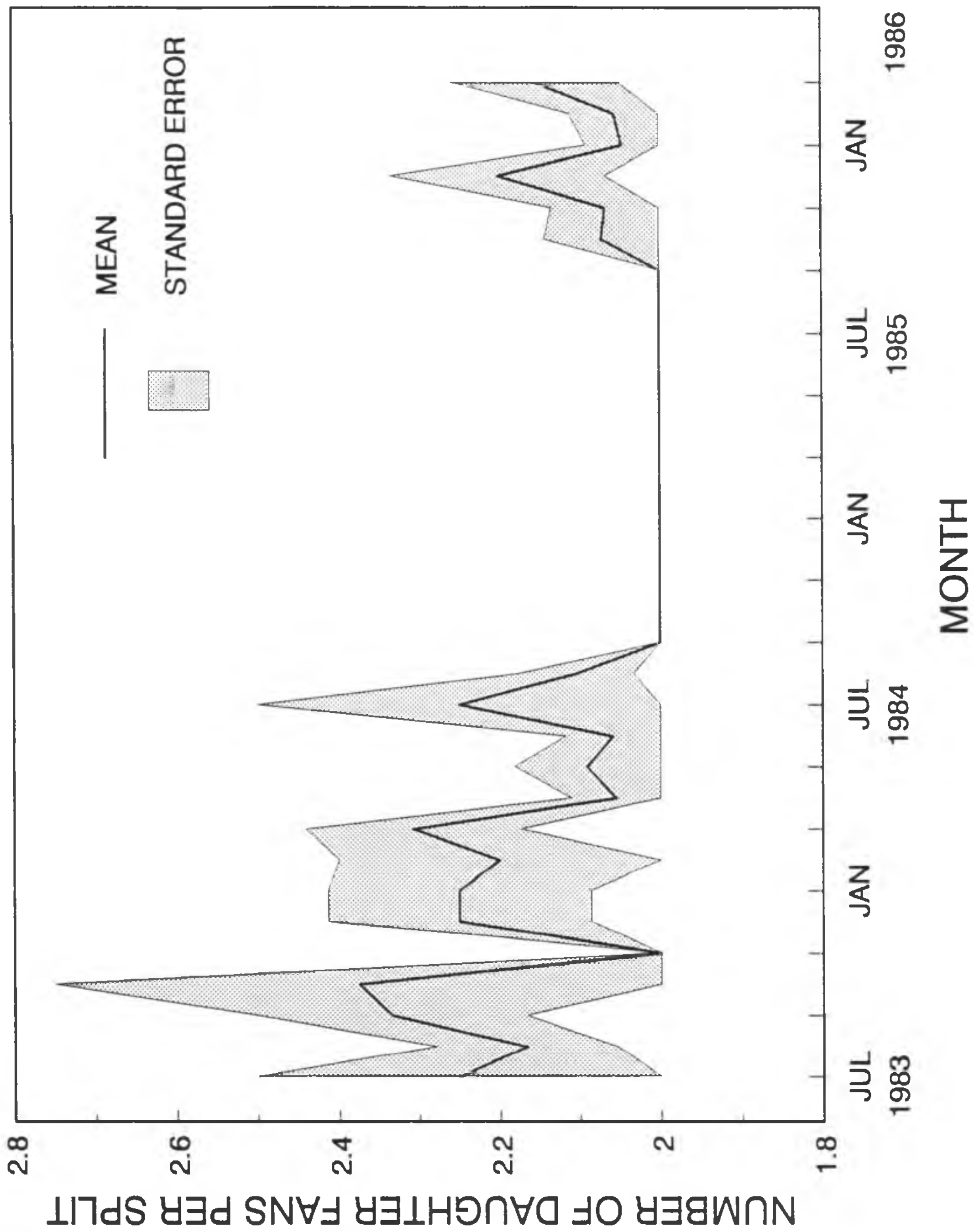


Figure 54. The number of daughter fans per split showed no variation in September 1984-September 1985 period in which all 184 fans split into 2 daughter fans (dichotomous branching).

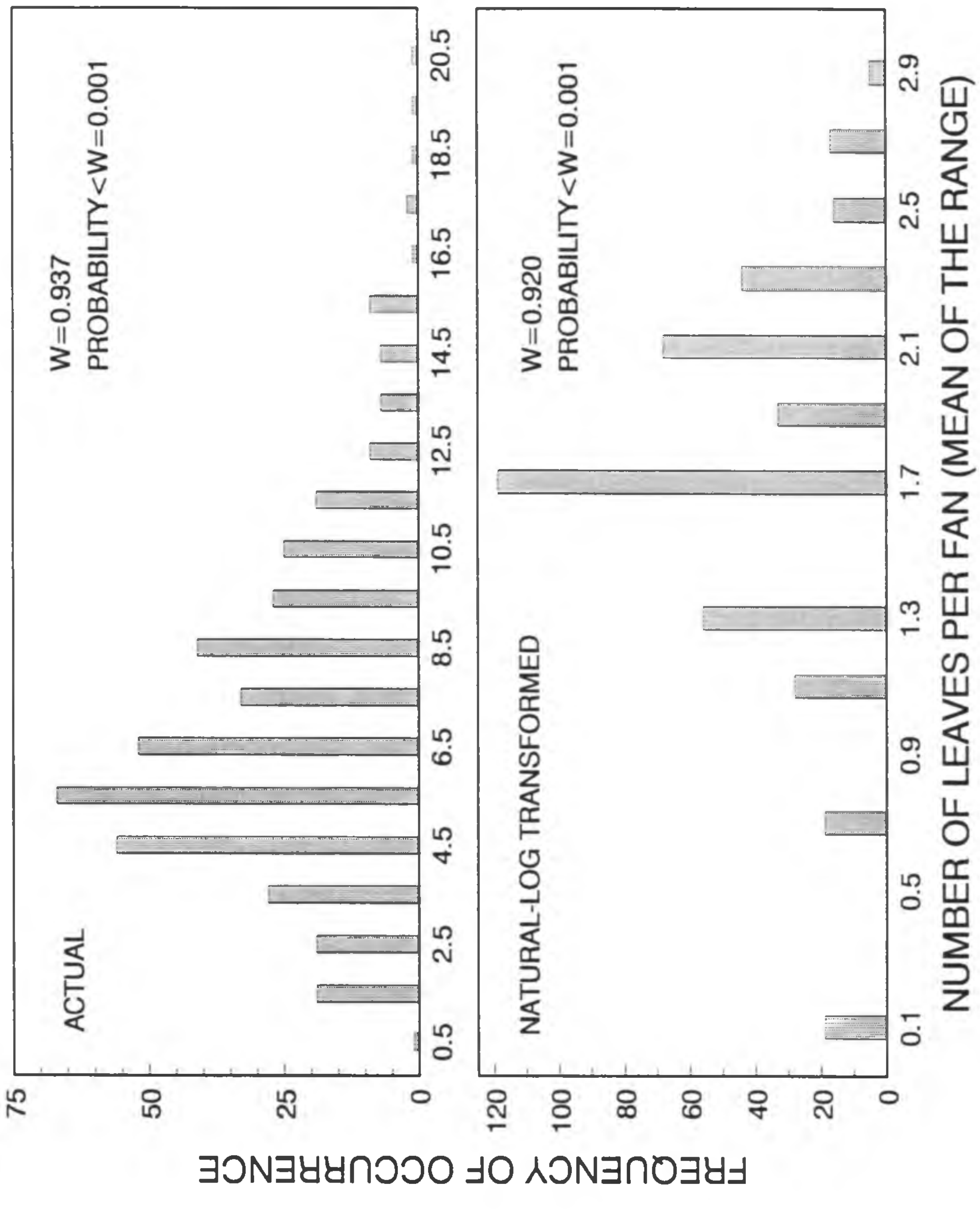


Figure 55. The frequency distribution of the number of leaves produced by a fan in bird of paradise in Waimanalo, Oahu. Although the distribution showed a characteristic of log-normal (**ACTUAL**), a log transformation did not significantly increase the normality.

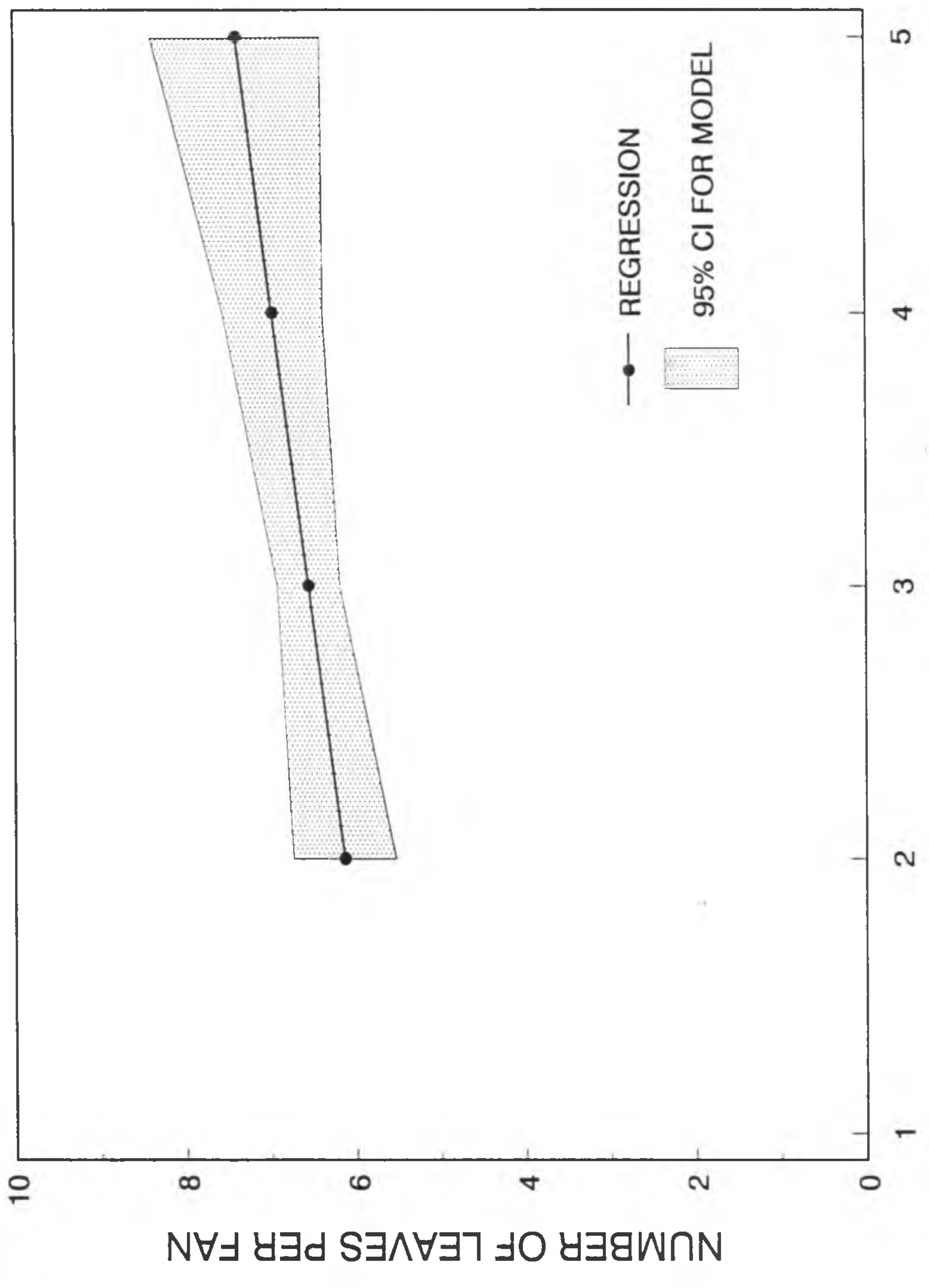


Figure 56. The number of leaves per fan in bird of paradise in Waimanalo, Oahu regressed on the 2-5th generation. A positive straight-line effect was significant at 7.8% level (Table 38).

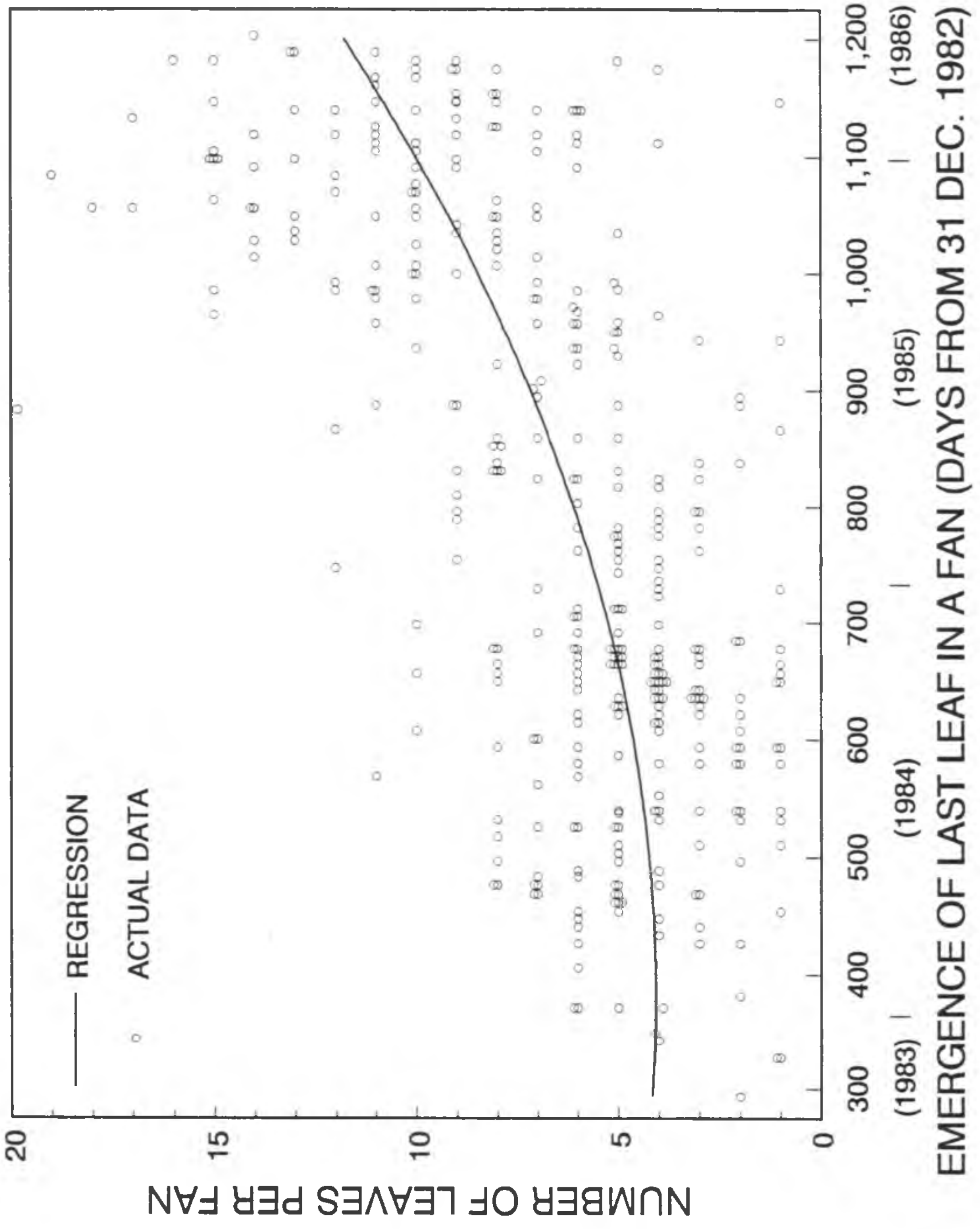


Figure 57. The number of leaves per fan in bird of paradise in Waimanalo, Oahu regressed on the number of days between December 31, 1982, and the emergence date for the last leaf in a fan. Both straight-line and quadratic effects were significant at 0.1% level (Table 39).

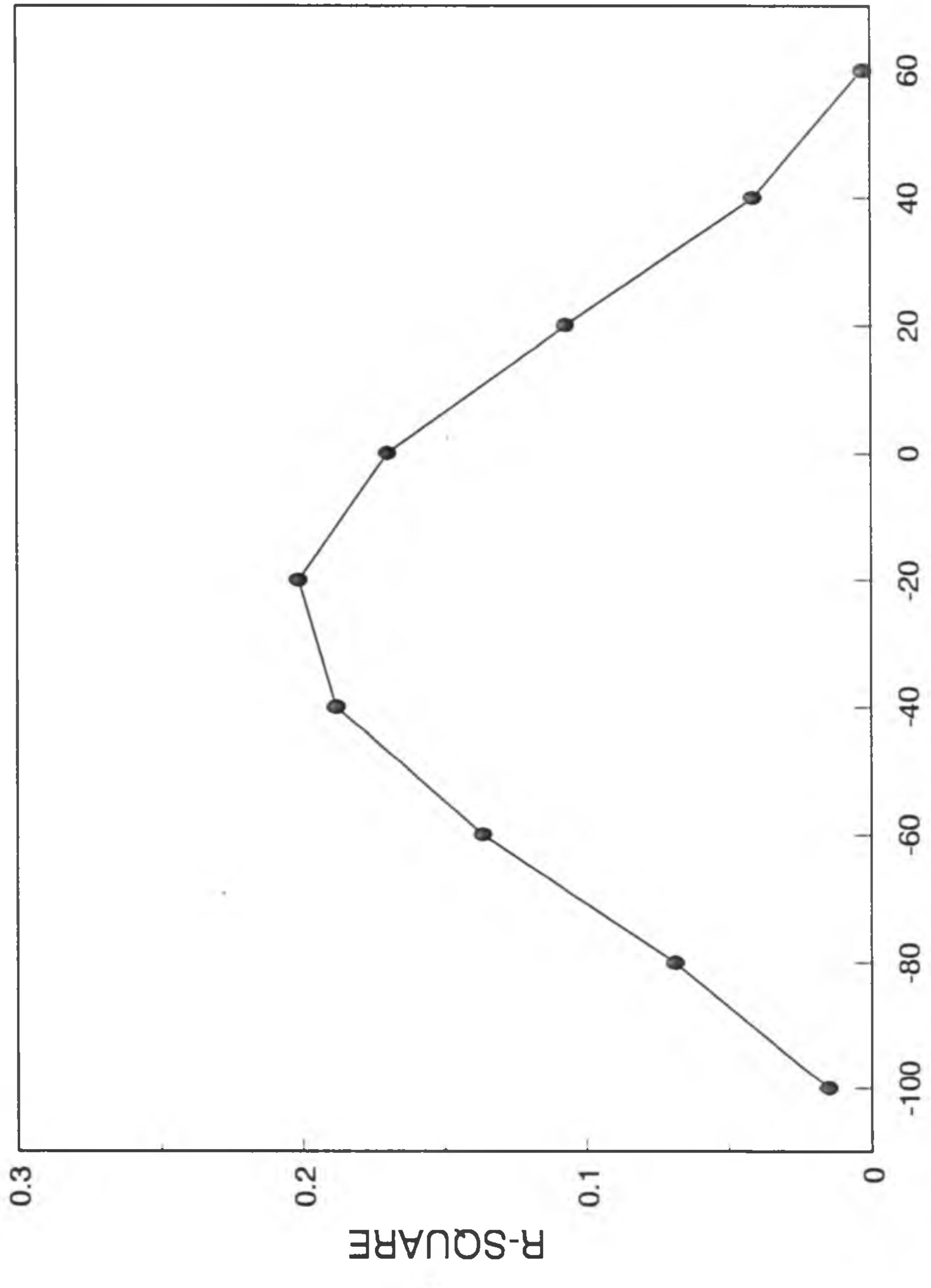


Figure 58. The response of R^2 values for regressing the leaf emergence intervals in bird of paradise in Waimanalo, Oahu on lags for a sine curve function. High R^2 values were found in lags between -40 to 0 days.

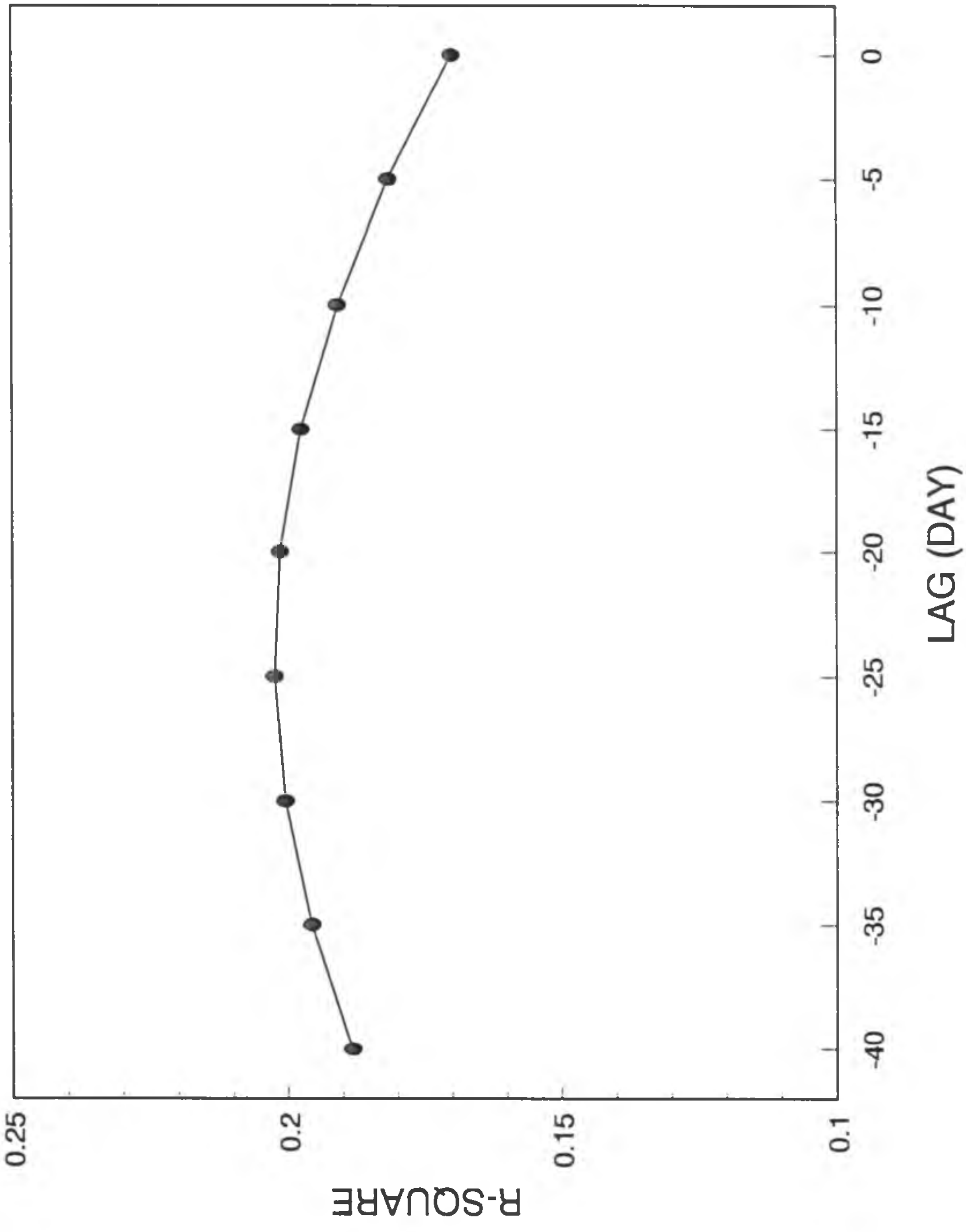


Figure 59. The response of R^2 values for regressing the leaf emergence intervals in bird of paradise in Waimanalo, Oahu on lags for a sine curve function. The best lag was determined as -25 days, and the sine curve effect was significant (Table 40).

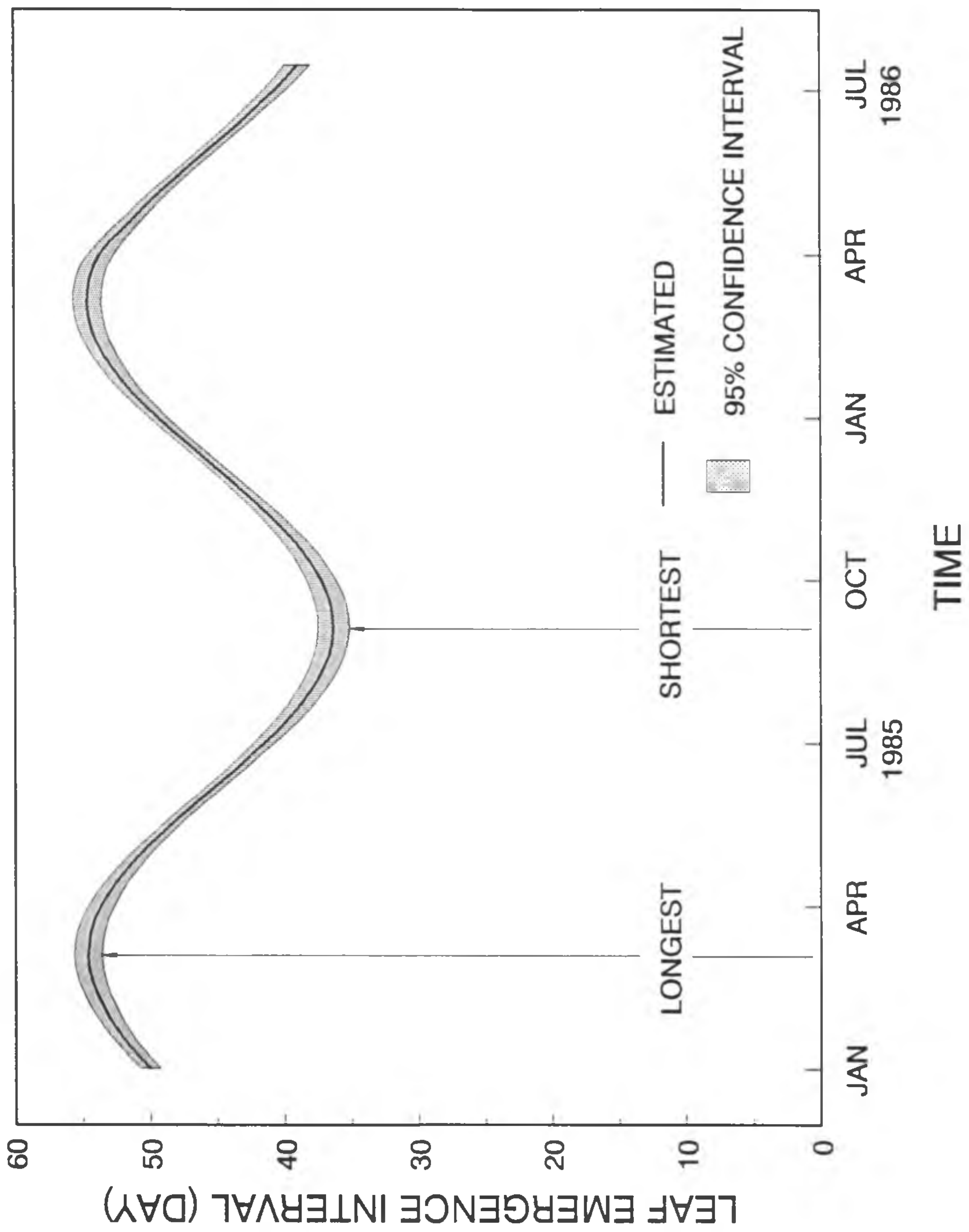


Figure 60. A sine curve regression model (Eq. 5, Table 40) of the leaf emergence interval in bird of paradise in Waimanalo, Oahu. The sine curve function accounted for the largest variance with -25 days lag.

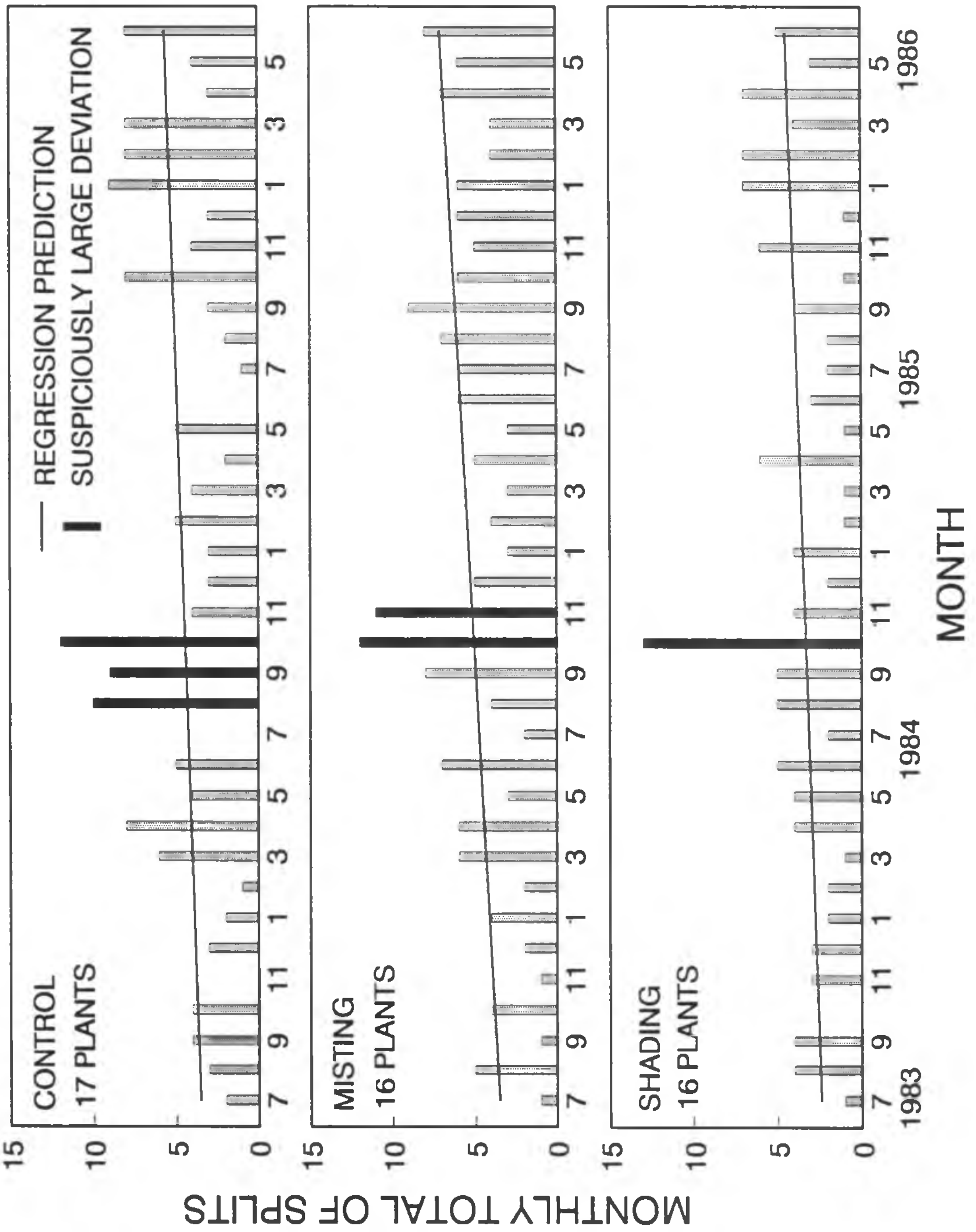


Figure 61. Abnormally large number of splits were observed in summer 1984 in each of the treatment: the full-sun control (**CONTROL**), the intermittent misting in summer (**MISTING**), and the 30% black shade cloth (**SHADING**). While the magnitude of the difference varied, the largest values, occurred for October 1984 in each treatment (Table 43), significantly deviated from the rest of the observations.

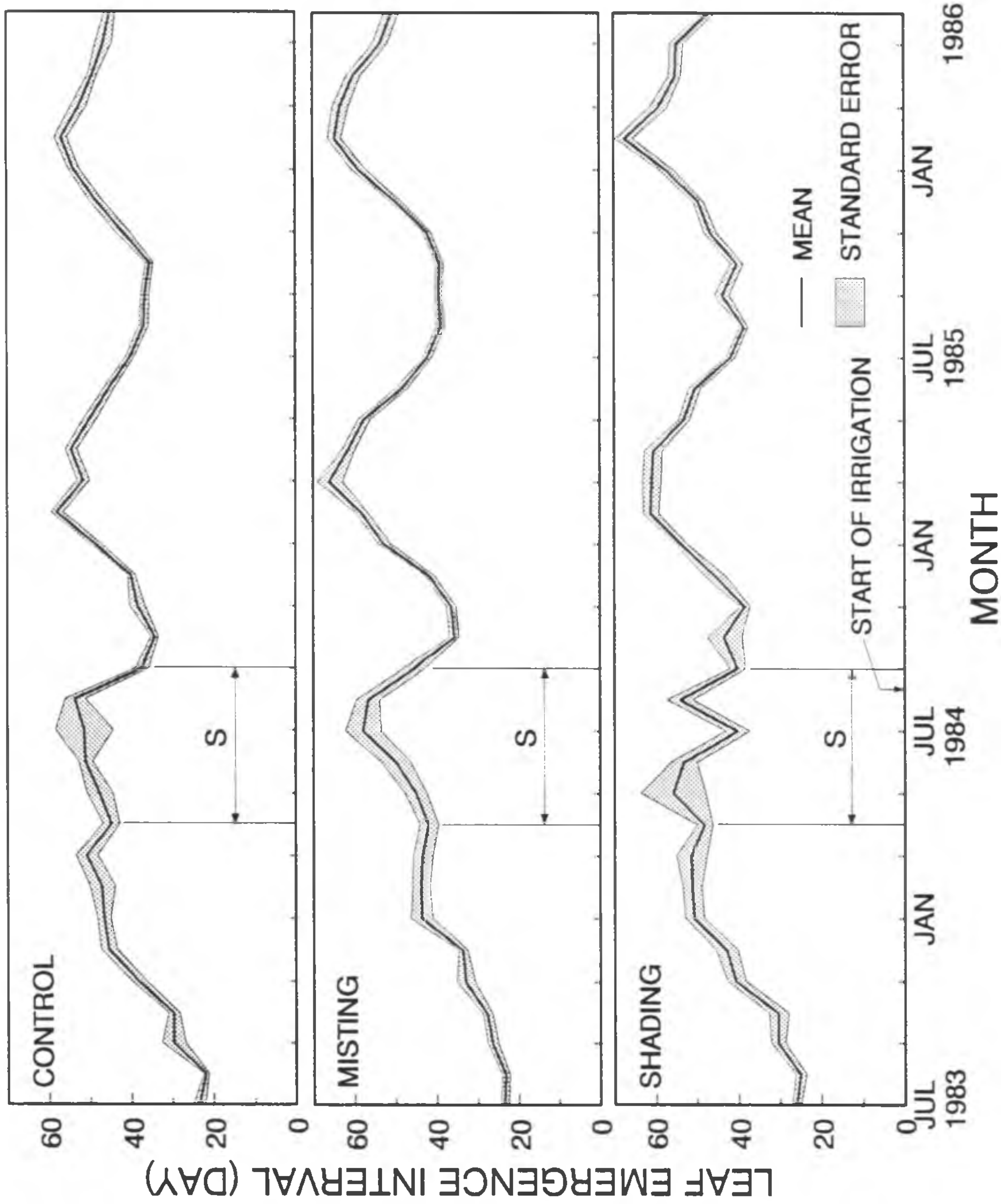


Figure 62. Monthly mean of leaf emergence interval in Waimanalo, Oahu for each of the leaf cooling treatments: the full-sun control (**CONTROL**), the intermittent misting in summer (**MISTING**), and the 30% black shade cloth (**SHADING**). While sine curve showed seasonal trends, suspiciously long leaf emergence intervals appeared (**S**)in each treatment. They were attributed to the limited water availability in 1984, and normal growth resumed with the installation of irrigation system using city water.

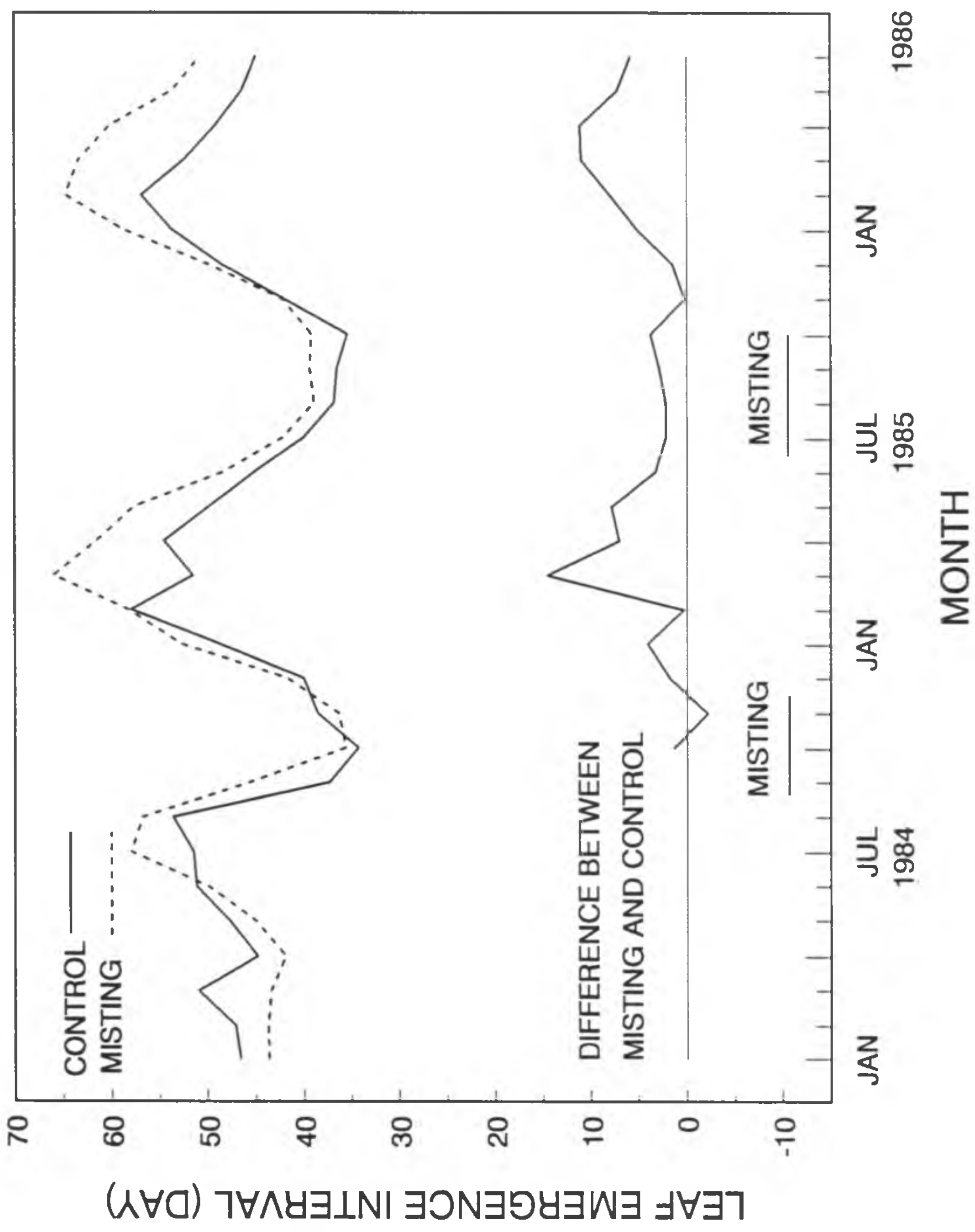


Figure 63. The comparison of the misting treatment (**MISTING**) with the control (**CONTROL**) on the monthly mean of leaf emergence interval in bird of paradise in Waimanalo, Oahu. The difference of 2 treatments (**DIFFERENCE**) indicated that the largest leaf cooling effect was observed 6-8 months later by the extension of the leaf emergence intervals for more than 10 days with an annual mean of 5.2 days.

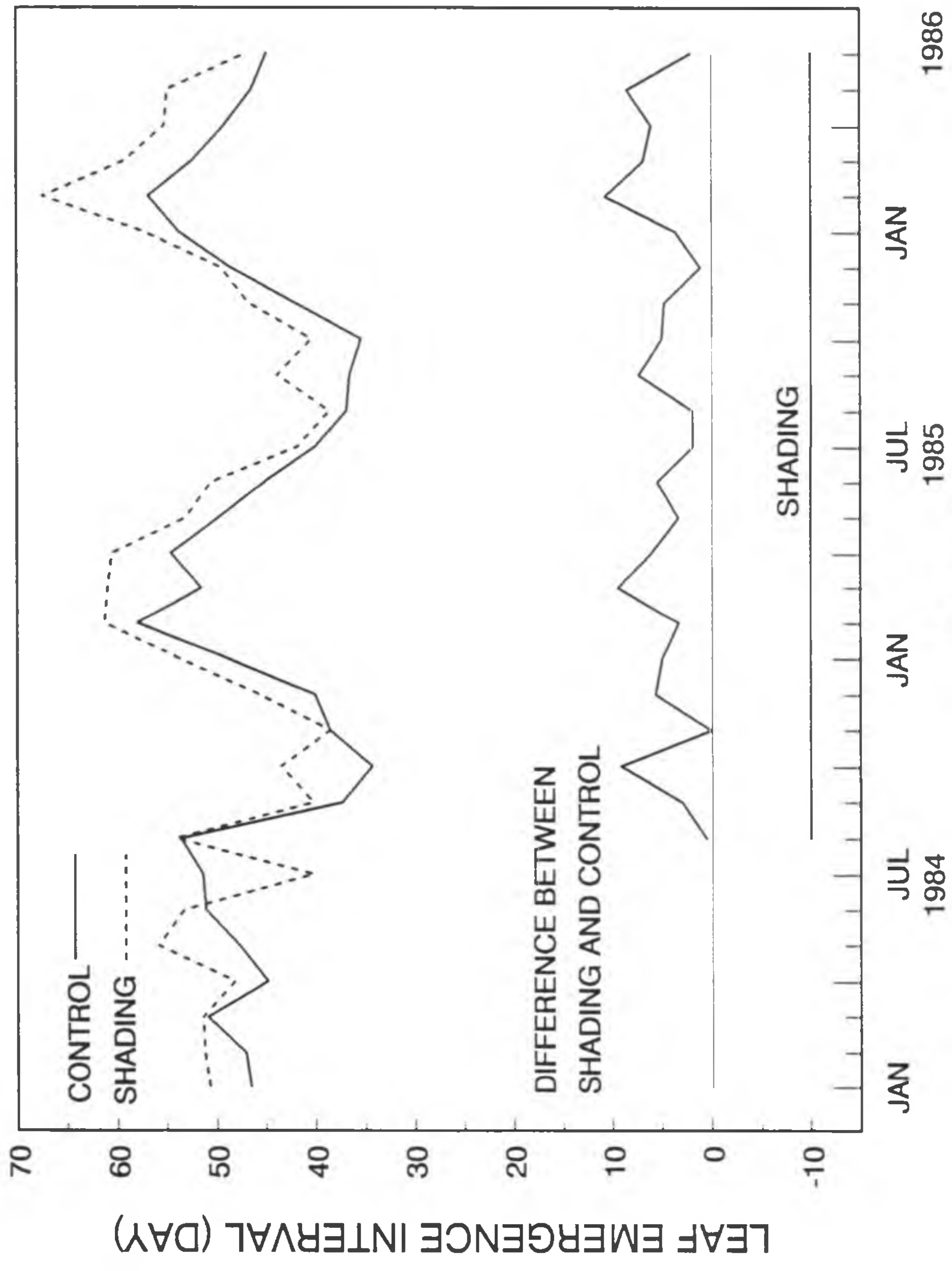


Figure 64. The comparison of the shading treatment (**SHADING**) with the control (**CONTROL**) on the monthly mean of leaf emergence interval in bird of paradise in Waimanalo, Oahu. The difference of 2 treatments (**DIFFERENCE**) showed the leaf cooling evenly extended the leaf emergence intervals for an annual mean of 4.9 days.

CHAPTER 5

GROWTH OF BIRD OF PARADISE INFLORESCENCE BUD BEFORE FLOWER EMERGENCE

Seasonal fluctuations of bird of paradise flower production in Hawaii were attributed to two seasonal characteristics: changes in the rate of flower development and the occurrence of flower bud abortion (Kawabata, et al., 1984). In this chapter, the early development of inflorescence bud before flower emergence was studied to determine the stage in which seasonal change in the rate of flower development begin.

5.1 Literature Review

The knowledge on growth and development of bird of paradise inflorescence buds before flower emergence (FE) is limited. The development of flower initials start in an early stage of the subtending leaf growth as flower initials were identified at the leaf axil as early as on the 2nd youngest leaf primordium (Fisher, 1976). In Hawaii, 7-9 leaf primordia and young leaves were found on a compressed stem between the shoot apex and the youngest emerged leaf. Inflorescence buds were 3-5 mm long at the time of leaf emergence (LE) and 16-20 mm long in the axils of the 2nd and 3rd youngest emerged leaf at which size flower abortion was observed (Criley and Kawabata, 1984). The time period elapsed for the development of an inflorescence bud between LE and FD (flower differentiation) was estimated as 8-18 weeks with a slow straight-line growth at Waimanalo (Kawabata, et al., 1984). No arrested development stage or dormancy was observed in the inflorescence buds (Criley and Kawabata, 1984).

A possible mode of the seasonal fluctuation in bird of paradise flower production in Hawaii was proposed (Kawabata, et al., 1984) using a seasonal shift in the rate of inflorescence development. Due to a long development time between LE and anthesis (represented by the time of flower cut, FC), flowers which reached FC in low flower production period (winter-spring, cool season) had early FD in the warm season. However, the inflorescences were subjected to cool season growth conditions after FD, resulting in a slow growth until FC. On the other hand, flowers which reached FC in a high production period (summer-fall, cool season) had late FD in cool season, then, they were subjected to a warm season growth until FC.

Seasonal flower development patterns could account for the relatively uniform development time for LEFC (time period between LE and FC) when LE was grouped monthly despite a strong occurrence of seasonal flower production (Criley and Kawabata, 1984). However, inflorescence development before FD was not investigated for warm and cool seasons.

Although each leaf subtended an inflorescence bud (Fisher, 1976) and the loss of flowers was due to flower abortions or blasting (Halevy, et al., 1976), some leaves did not have flower buds in their leaf axils (Criley and Kawabata, 1984). Since the absent inflorescence buds would affect the potential flower production, it would be desirable to determine what percentage of the flower production was affected by the absence of the inflorescence of flower buds.

Therefore, the objectives in this chapter were:

1. To determine the differences in time and status of inflorescence bud development before flower emergence between warm and cool season growths.
2. To determine the percentage of leaves which would not subtend flowers at Waimanalo.

5.2 Materials and Methods

Plants used. The bird of paradise collection at the Waimanalo Experimental Farm was used for sampling inflorescence buds. These 15- to 16-year-old plants were irrigated weekly with 25 mm water by overhead sprinklers, and fertilized semiannually with a control release 14N-6P-12K fertilizer at the rate of 175 kg $N \cdot ha^{-1} \cdot yr^{-1}$.

Three plants in the collection were chosen based on 1982-1984 flower production records for their seasonal fluctuation patterns: Plant 8 (the identification in the field as Plot 8, Plant 1) for the greatest seasonal fluctuation (Fig. 65), Plant 20 (Plot 20, Plant 2) for the least (Fig. 65), and Plant 24 (Plot 24, Plant 2) for the intermediate characteristics (investigator's observation). These plants represented a possible variation of the collection plants.

A variance due to seasonal change in the growth rate of inflorescence bud was represented by taking samples twice from each plant: in June-July 1985 for the warm season growth and in October

1985-January 1986 for the cool season growth. Approximately a quarter (6-16 fans) of the shoot mass was dug out at each sampling (Table 45). Although the influence of the loss of fans on the growth of other fans was not measured, the effect on the bud growth was probably be small as even rootless divisions still supported flower growth from flower emergence to anthesis and the development of subsequent flower growth. The root system for the fans left in the field was not disturbed.

Data collection. At the sampling in the field, fans were dug out of the ground and separated, roots were removed, and fans were cleaned for dissections. For each fan, the youngest emerged leaf was numbered as 0, then the younger leaves were numbered in a negative order (-1, -2, and so forth), and older leaves were numbered in a positive order (1, 2, and so forth). Each inflorescence bud in a fan was referenced by the leaf number of the subtending leaf since 1 leaf subtended only 1 inflorescence bud.

Data recorded were leaf number, flower bud length (mm), and the status of flower bud: flowered, aborted (identified by browning of the inflorescence bud, Criley and Kawabata, 1984), growing, too small to measure, or absent, along with plant identification and sampling date. The lengths of inflorescence buds were measured for regression analyses in which the individual bud in a fan served as the experimental unit.

Aborted inflorescence buds of various sizes were saved to count the number of leafy sheaths produced at the time of abortion. Live buds of Plant 20 were also saved for investigating the degree of morphological development before FD. They were killed and fixed by FAA (formaldehyde-acetic acid-alcohol), dehydrated by a TBA series (tertiary butyl alcohol-ethanol-water), infiltrated with paraffin, sliced into 15 micrometer-thick sections, mounted on slides with Haupt's adhesive, stained with toluidine blue O (Sakai, 1973), and embedded in a synthetic resin before they were subjected to microscopic inspection.

The growth of inflorescence bud before FD. The length and number of leafy sheaths produced on the live inflorescence buds of Plant 20 were determined from the slides prepared for microscopy. The inflorescence bud length was regressed for polynomial effects on the number of leafy sheaths. The maximum number of leafy sheaths was 7, and the minimum was 3, below which the inflorescence buds were too small to be subjected to the slide making process.

Seasonal difference in the size of aborted inflorescence bud. The length of aborted inflorescence buds subtended by leaves 1-3 were selected from all buds collected to investigate the existence of differences in the aborting size due to seasonal and plant variations. Leaf numbers 1-3 were chosen since inflorescence buds subtended by leaves 0 or younger were small and they were not abortion-sensitive (Criley and Kawabata, 1984), and choosing buds subtended by leaves 4 or older would include the buds aborted in an opposite season. The bud length data were subjected to analysis of variance with a factorial treatment design for 2 seasons and 3 plants.

The occurrence of absent inflorescence buds. The numbers of leaves which did not subtend inflorescence buds (absent inflorescence buds) were summed along with the buds present for each plant and season. The variations due to seasons and plants on the occurrence of absent inflorescence buds were subjected to chi-square tests for heterogeneity (Little and Hills, 1978) for determining the effect of non-producing leaves on the flower production.

5.3 Results

The growth of inflorescence bud before FD. The size increase in bird of paradise flower buds of Plant 20 before FD showed an exponential growth (Fig. 66). The least square estimates of flower length was performed (Table 46) on the number of leafy sheaths produced after taking natural log of the bud length. The analysis of variance for the regression indicated that a satisfactory fit was achieved which yielded the following regression equations:

$$\mathrm{Ln(FLLEN)} = -1.21 + 0.59 \times \mathrm{SHEATH} \quad \ldots\ldots \text{Eq. 6}$$

or, when above equation was expressed in an exponential form,

$$\mathrm{FLLEN} = 0.298 \times e^{(0.59 \times \mathrm{SHEATH})} \quad \ldots\ldots \text{Eq. 7}$$

where FLLEN is flower bud length in mm, and SHEATH is sheath number.

The residual plot (Fig. 67) showed a weak occurrence of quadratic trend. However, since the quadratic trend would not significantly improve the regression model (Table 46), the simple exponential curve was determined as satisfactory for the inflorescence growth before FD.

Seasonal difference on the size of aborted inflorescence bud. Dissection of 74 sampled fans revealed 356 aborted inflorescence buds in 845 leaf axils or 58% flowering. The aborting size was 15.6 ± 0.71(SE) mm, mean and standard error, respectively, which was similar to the previous study (15.8 mm computed from Table 1, Criley and Kawabata, 1984). However, the range of aborting size was wider in this experiment, 5-55 mm, excluding 3 buds which were aborted at longer than 65 mm (Fig. 68) than 10-28 mm for the previous study.

Among inflorescence buds subtended by leaves 1-3, a total of 87 aborted buds were identified in the dissected fans among 3 plants over 2 seasons (Fig. 69). The overall mean length of these aborted buds was 12.5 ± 0.55(SE) mm. An analysis of variance (Table 47) indicated that at least 1 plant was significantly different from others at 0.05% level with a significant interaction between seasons and plants at 4.7%. However, the difference among growing seasons was not significant (significance level at 19.9%).

The contrast among least square means (Table 47) indicated the aborting size of Plant 24 was larger than those of Plants 8 and 20 (significant at 0.01%) with an estimated difference of 6.7 mm, while no significant difference was detected between plants 8 and 20.

The mild interaction between seasons and plants in the analysis of variance (significant at 4.7%, Table 47) was due to the seasonal difference within Plant 24 where aborted buds in summer were larger than those in winter with an estimated difference of 6.6 mm (significant at 0.9%).

The occurrence of absent inflorescence buds. A total of 29 out of 845 sampled leaves (or 3.4% of total) did not subtend inflorescence buds. A chi-square test for the heterogeneity among 6 groups (all combinations, Table 48) indicated at least one of the groups, ranging 0.6-7.7%, deviated significantly from the overall, 3.4%. The detailed tests (*Seasons* and *Plants*, Table 48) showed the significant difference was attributed to the variation among plants (1.0% for Plant 8 to 5.1% for Plant 24), but not to the seasons. Since chi-squares were not additive (Little and Hills, 1978), homogeneity for the interaction between seasons and plants was not tested.

5.4 Discussion

Seasonal difference in the stage of inflorescence bud development. A flower development stage in which the difference in flower size became significant was sought. The sequence of inflorescence bud development in bird of paradise followed FI, LE, FD, FE, and FC (flower initiation, leaf emergence, flower differentiation, flower emergence, and anthesis or flower cut, respectively), and the effect of season in the rate of inflorescence bud development was suggested to occur before FE (Kawabata, et al., 1984).

Inflorescence bud lengths of leaf 0 were compared between seasons as those buds would represent the inflorescence bud size at the time of LE or within 1 LE interval. The inflorescence buds averaged 5.2 mm long and the difference between seasons was not significant (Table 49). Therefore, these results narrowed the possible beginning of the seasonal difference in inflorescence development to LE-FD-FE period.

If a seasonal difference in flower development were observed at FD, it would indicate that the difference was started in LEFD period, and if not, the difference was started in FDFE period. Therefore, an attempt was made to determine whether the initiation of seasonal difference in flower development could be detected at FD.

Although inflorescence buds aborted at a predetermined stage in the flower development (after the formation of 7th leafy sheath on the inflorescence bud), a single inflorescence length could not be used as an indicator of flower abortion, since a significant difference in aborting size existed among plants (Table 47). However, since the number of leafy sheaths produced on a inflorescence would satisfactorily predict the length of not-aborted infloresence buds within a plant (Figure 66, Table 46), a range of inflorescence size in which inflorescences were abortion-sensitive could be determined for each plant, and then the stage of development, expressed as leaf number, also could be determined.

For each plant, the following procedure was developed to determine the leaf number at which inflorescence buds became abortion-sensitive in each season:

1. Inflorescence bud length was regressed for each season with an exponential curve using leaf number as an independent variable (Table 50).
2. The leaf number at which abortion occurred to the subtending inflorescence most recently was determined using 50% or more of the total as a critical value (Table 51).
3. Mean length and standard error of aborted inflorescence buds were computed for the leaf numbers determined in step 2 (Table 52).
4. The results of step 1, inflorescence bud growth models, and step 3, mean aborting size, were plotted together (Figs. 70-72). Two vertical reference lines, drawn to the horizontal axis (leaf number) from the intersections of growth model (solid exponential line) and the minimum and maximum of aborting size (mean ± standard error, shaded area), represented a range in leaf number when inflorescence buds were abortion-sensitive.

Although actual LE dates were not known in these data, the leaf number of inflorescence buds could also represent time axes (Figs. 70-72). Since LE would vary only 12 days annually for these plants (48-60 days, Criley and Kawabata, 1984) and if 6 leaves emerged in a fan annually (or 3 leaves in a half year cycle), the mean difference among successive leaf emergences would be approximately 4 days (12 divided by 3, if the change in LE interval were straight-line). The mean difference was small compared with LE intervals (less than 10%), thus the use of leaf number as a time indicator was justified.

Aborting size varied from 11.2 ± 3.5(SE) mm, the smallest, for warm season inflorescence buds of Plant 8 to 26.3 ± 7.5(SE) mm, the largest, for warm season buds of Plant 24 (Table 52). Abortion-sensitive stage for the inflorescence buds in Plants 8 and 20 both occurred earlier in cool season when the majority of subtending leaves were numbered 1 (or the 2nd youngest emerged leaf) than in warm season when the majority of subtending leaves were numbered 2 (or the 3rd youngest emerged leaf). No seasonal difference was found for Plant 24 as the inflorescence buds reached abortion-sensitive stage at leaf number 2 in both seasons.

Although Plant 24 did not show a seasonal difference in the inflorescence bud development, it could have shown the difference since the sampling date for cool season growth (October 19, 1985, Table 45) was too early when the plant was still in the warm season growth.

Therefore, since seasonal difference on the inflorescence bud development was detected at FD and no difference was found among seasons at LE (Table 49), the initiation of seasonal difference in flower development was determined to occurr in LEFD period.

The size of aborted inflorescence bud. While the size of aborted inflorescence buds had the largest population in 10-15 mm range (Fig. 68), the inspection of longitudinal sections of inflorescence buds showed that the majority of aborted buds had at least 6 distinguishable leafy sheaths produced even in the inflorescence sizes as small as 6 mm long (**A**, Fig. 73). This would agree with the regression model for the inflorescence growth where 6 mm long inflorescence would fall between 5 and 6 leafy sheath production (Fig. 66).

The existence of small aborted inflorescence bud less than 5 mm long (Fig. 68) also indicated that inflorescence abortion could have occurred to buds which had not reached the usual abortion-sensitive FD stage (B, Fig. 73). However, the occurrence of this abortion type was not frequent as it was observed among 1.7% of the total abortions, and it could have been resulted by the severe water deficit in the previous year (Ch. 3 and 4).

5.5 Summary

1. The seasonal difference in the rate of inflorescence development was initiated between LE and FD. The time difference in reaching FD was observed as much as 1 LE interval (48-60 days, Criley and Kawabata, 1984) as inflorescence buds sampled in warm season had FD in the axils of the 3rd youngest emerged leaves (leaf number 2) while the cool season buds had FD in the axils of 2nd youngest leaves (leaf number 1).
2. A total of 3.4 percent of the leaves did not subtend inflorescence buds and no seasonal difference was detected on the absence of inflorescence buds.
3. Mean aborting sizes of inflorescence buds were variable among 3 plants ranging from 9.9 to 17.4 mm with a overall mean of 11.5 ± 0.55(SE) mm. Inflorescence buds less than 5 mm long before reaching FD stage could also abort.
4. Inflorescence buds showed an exponential growth to FD, and no arresting of the inflorescence buds was observed.

Table 45. Bird of paradise fans sampled in Waimanalo Experimental Farm on Oahu, Hawaii. These plants were used for determining the seasonal difference in the inflorescence bud development before flower differentiation.

Plant Identification	Flowering Characteristics	Date of Sampling	Season Representing	Number of Fans Collected
8	Relatively seasonal	June 13, 1985	Warm	10
		Dec. 3, 1985	Cool	16
20	Relatively uniform	July 20, 1985	Warm	10
		Jan. 2, 1986	Cool	16
24	Intermediate	June 5, 1985	Warm	6
		Oct. 19, 1985	Cool	16

Table 46. Analyses of variance for regressing inflorescence bud length (FLLEN) on the number of leafy sheath produced (SHEATH) for Plant 20. A straight-line regression was satisfactory as SHEATH was significant at 0.01% level after transforming inflorescence bud length with natural log (LNFLLEN). Although a residual plot showed a quadratic trend (Fig. 67), the effect was not significant (significant at 12% level).

Dependent Variable: LNFLLEN

Analysis of variance for a straight-line regression

Source	DF	Sum of Squares	F Value	Pr > F
Model	1	8.70	288.20	0.0001
Error	16	0.48		
Corrected Total	17	9.19		

R-Square	CV	LNFLLEN Mean
0.95	9.30	1.9

Source	DF	Type I SS	F Value	Pr > F
SHEATH	1	8.70	288.20	0.0001

Estimates for the straight-line regression

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT	-1.21	-6.50	0.0001	0.186
SHEATH	0.59	16.98	0.0001	0.035

Analysis of variance for a quadratic regression

Source	DF	Sum of Squares	F Value	Pr > F
Model	2	8.78	160.71	0.0001
Error	15	0.41		
Corrected Total	17	9.19		

R-Square	CV	LNFLLEN Mean
0.96	8.85	1.89

Source	DF	Type I SS	F Value	Pr > F
SHEATH	1	8.70	318.72	0.0001
SHEATHxSHEATH	1	0.07	2.69	0.1215

Table 47. An Analysis of variance for the aborting size of inflorescence buds of bird of paradise in Waimanalo, Oahu to determine the existence of seasonal difference and the variation among plants. SEASON represented 2 sampling periods; summer 1985 (W) and fall-winter 1986 (C): and PLANT represented 3 plant individuals; Plants 8, 20, and 24. The contrasts indicated significant differences existed between Plant 24 and the others, and 2 seasons within Plant 24.

Dependent Variable: FLLEN

Analysis of variance

Source	DF	Sum of Squares	F Value	Pr > F
Model	5	523.20	4.92	0.0006
Error	81	1722.52		
Corrected Total	86	2245.72		

R-Square	CV	FLLEN Mean	SE
0.23	36.94	12.5	0.55

Source	DF	Type I SS	F Value	Pr > F
SEASON	1	35.74	1.68	0.1985
PLANT	2	352.55	8.29	0.0005
SEASONxPLANT	2	134.90	3.17	0.0472

Least squares means

SEASON	FLLEN LSMEAN	PLANT	FLLEN LSMEAN	SEASON	PLANT	FLLEN LSMEAN
S	13.9	20	11.6	S	20	12.7
W	12.0	24	17.4	S	24	20.8
		8	9.9	S	8	8.3
				W	20	10.4
				W	24	14.1
				W	8	11.4

Estimates and contrasts

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	SE of Estimate	Contrast SS
SEASON	-1.9	-1.40	0.1648	1.385	41.78
PLANT 24 vs. 20+8	6.7	4.49	0.0001	1.491	429.67
PLANT 20 vs. 8	-1.7	-1.02	0.3107	1.671	22.13
SEASON in PLANT 20	-2.2	-1.49	0.1389	1.519	47.50
SEASON in PLANT 24	-6.6	-2.69	0.0087	2.471	153.55
SEASON in PLANT 8	3.0	1.04	0.3034	2.977	22.82

Table 48. Chi-square tables for testing the absence of inflorescence buds of bird of paradise in Waimanalo, Oahu. Expected numbers, absent and present, were computed from the total leaf numbers and percentage of absent buds, then Chi-squares were computed for the heterogeneity among all combinations (interactions), seasons, and plants. A total of 3.4 percent of leaves did not subtend inflorescence buds. The significant heterogeneity among all combinations was attributed to the difference in plants.

Season	Plant	Number of Absent	Number of Present	Total	Percent	DF	Chi-square	Pr
				All combinations				
Warm	8	2	130	132	1.5	1	1.46	
Warm	20	8	96	104	7.7	1	5.81	
Warm	24	2	56	58	3.5	1	<0.01	
Cool	8	1	177	178	0.6	1	4.42	
Cool	20	6	191	197	3.1	1	0.09	
Cool	24	10	166	176	5.7	1	2.69	
Total		29	816	845	3.4	6	14.47	
Pooled						1	0.00	
Heterogeneity						5	14.47	.05>Pr>.01
				Seasons				
Warm	All	12	282	294	4.1	1	0.37	
Cool	All	17	534	551	3.1	1	0.20	
Total		29	816	845	3.4	2	0.57	
Pooled						1	0.00	
Heterogeneity						1	0.57	.50>Pr>.10
				Plants				
All	8	3	307	310	1.0	1	5.68	
All	20	14	287	301	4.7	1	1.35	
All	24	12	222	234	5.1	1	2.03	
Total		29	816	845	3.4	3	9.06	
Pooled						1	0.00	
Heterogeneity						2	9.06	.05>Pr>.01

Table 49. Analysis of variance for the inflorescence bud length (FLLEN) of bird of paradise subtended by the youngest emerged leaf (leaf number 0 or at leaf emergence, LE). Although there were significant variations among Plants 8,20, and 24 (PLANT) no difference was detected between warm and cool seasons (SEASON).

Dependent Variable: FLLEN

Source	DF	Sum of Squares	F Value	Pr > F
Model	5	76.46	3.36	0.0112
Error	47	213.65		
Corrected Total	52	290.11		

R-Square	CV	FLLEN Mean
0.26	41.1	5.2

Source	DF	Type I SS	F Value	Pr > F
SEASON	1	7.25	1.59	0.21
PLANT	2	28.36	3.12	0.05
SEASONxPLANT	2	40.85	4.49	0.02

Table 50. Regressions of inflorescence bud length (LNFLLEN, natural log of flower length in mm) on leaf number (LEAF) of the subtending leaf performed for each of 2 seasons and 3 plants. Live inflorescence buds were transformed with natural log for the analyses which was equivalent to regressions using exponential curves (Figs. 70-72). All regressions were satisfactory as the analyses of variance indicated the significance levels less than 0.01%.

Season	Warm Season			Cool Season		
Plant ID	8	20	24	8	20	24
Analysis of variance for regression						
Source	LEAF	LEAF	LEAF	LEAF	LEAF	LEAF
SS for Source	17.38	6.63	9.03	27.27	29.66	19.06
DF for Source	1	1	1	1	1	1
Error SS	8.32	1.86	0.93	6.38	10.27	5.55
DF for Error	27	15	11	42	46	31
Corrected total	25.70	8.49	9.97	33.65	39.93	24.62
F Value	56.36	53.54	106.54	179.49	132.92	106.45
Pr > F	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
R-Square	0.68	0.78	0.91	0.81	0.74	0.77
CV	33.1	21.6	15.2	22.3	31.0	36.8
LNFLLEN Mean	1.6791	1.6260	1.9193	1.7510	1.5229	1.1742
Regression estimates						
INTERCEPT						
Estimate	1.3731	1.3820	1.8026	1.5283	1.6951	1.1273
T	12.38	15.08	22.10	25.03	24.28	15.27
Pr > |T|	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
SE	0.11088	0.09166	0.08155	0.06107	0.06980	0.07381
LEAF						
Estimate	0.6339	0.6913	0.7587	0.6533	0.7518	0.7783
T	7.51	7.32	10.32	13.40	11.53	10.32
Pr > |T|	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
SE	0.08444	0.09448	0.07351	0.04877	0.06521	0.07495

Table 51. Percentage of the number of aborted inflorescence buds to the total buds observed (Percentage = 100 x A / (A + G + F) where A, aborted; F, flowered; G, growing) for each leaf number. For each plant and season, leaf number at which percent flower abortion first exceeded 50% was determined critical, and the estimates of mean and SE of abortion size for the leaf number was computed in Table 52.

Plant	Season	Type of Sum	-------Number of Buds Observed------- Leaf Number -3	-2	-1	0	1	2	3	4	Leaf Number Selected
8	Warm	A	0	0	0	0	0	1	2	5	
		G + F	8	9	9	8	9	7	6	2	
		Percent	0	0	0	0	0	13	25	71	4
8	Cool	A	0	0	0	0	0	1	11	12	
		G + F	11	14	15	15	13	11	1	1	
		Percent	0	0	0	0	0	8	92	92	3
20	Warm	A	0	0	0	0	1	5	8	10	
		G + F	6	7	10	7	8	3	0	0	
		Percent	0	0	0	0	11	63	100	100	2
20	Cool	A	0	0	0	0	0	12	15	15	
		G + F	16	16	16	16	13	2	0	1	
		Percent	0	0	0	0	0	86	100	94	2
24	Warm	A	0	0	0	0	0	4	3	4	
		G + F	3	5	5	4	6	1	2	1	
		Percent	0	0	0	0	0	80	60	80	2
24	Cool	A	1	2	2	0	2	13	12	10	
		G + F	11	13	12	12	12	2	1	2	
		Percent	8	13	17	0	17	87	92	83	2

Table 52. Estimation of leaves which subtended inflorescence buds sensitive to flower abortion. For each plant and season, leaves which had 50% or more aborted flower buds were identified (Table 51). Mean length and standard error of the aborted inflorescence buds of the leaf number were computed and overlaid on the plot of the flower bud growth (Figs. 70-72). Then a horizontal axis range of 2 intersects of growth curve and mean ± standard error was estimated which would indicate the inflorescence buds in the range were sensitive to flower abortion.

Plant	Season	Total number of buds aborted	Youngest leaves which had more than 50% flower abortion	Mean length (mm)	SE	Leaf number at which Inflorescence bud became abortion sensitive
8	Warm	8	4	11.2	3.5	2
	Cool	24	3	11.6	3.5	1
20	Warm	24	2	18.2	7.8	2
	Cool	42	2	11.8	4.4	1
24	Warm	11	2	26.3	7.5	2
	Cool	42	2	12.2	3.3	2

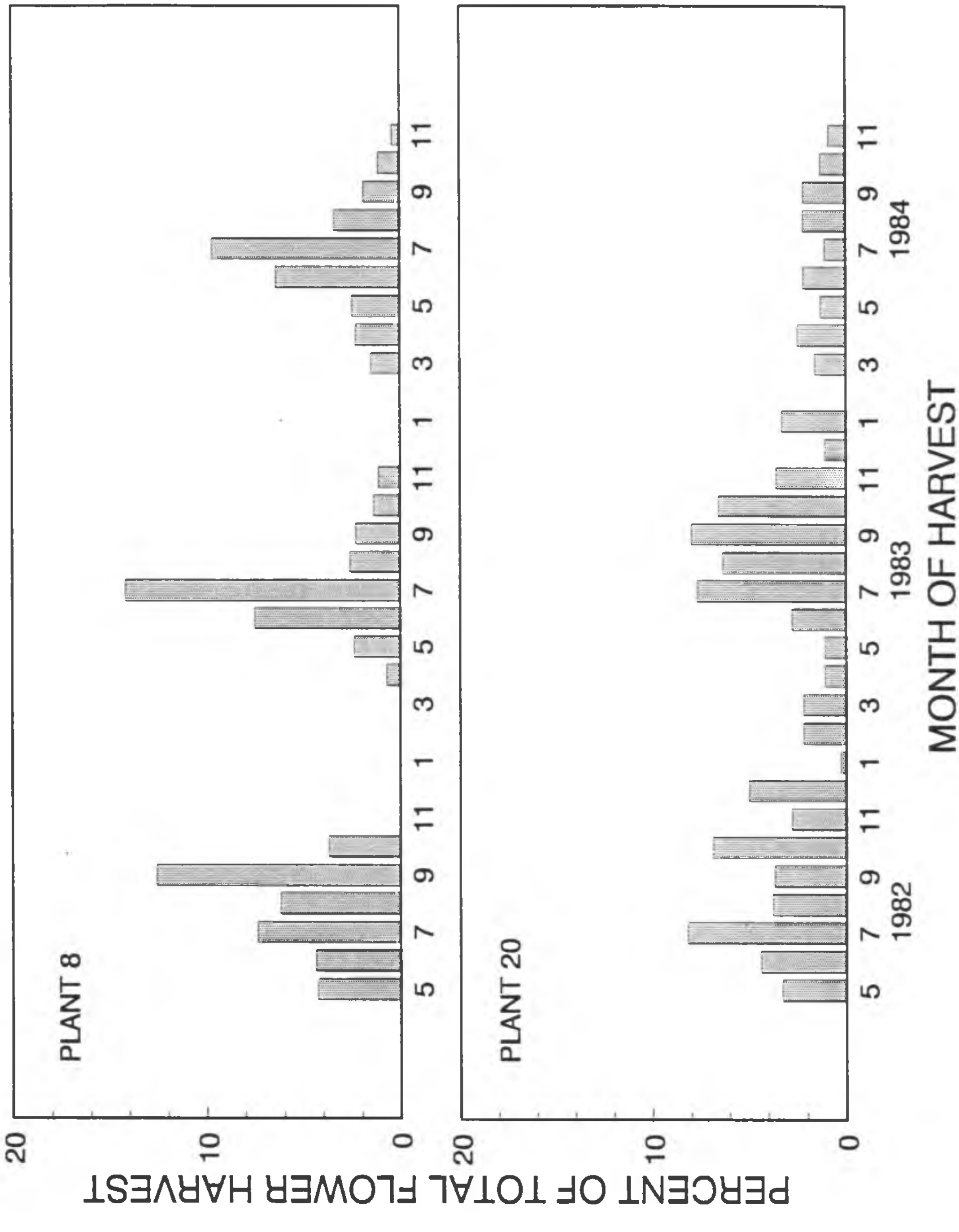


Figure 65. Monthly totals of bird of paradise flower cut expressed as percentage of the total during May 1982-November 1984 in Waimanalo, Oahu. Plant 8 had a high seasonal flowering characteristic while Plant 20 was relatively constant.

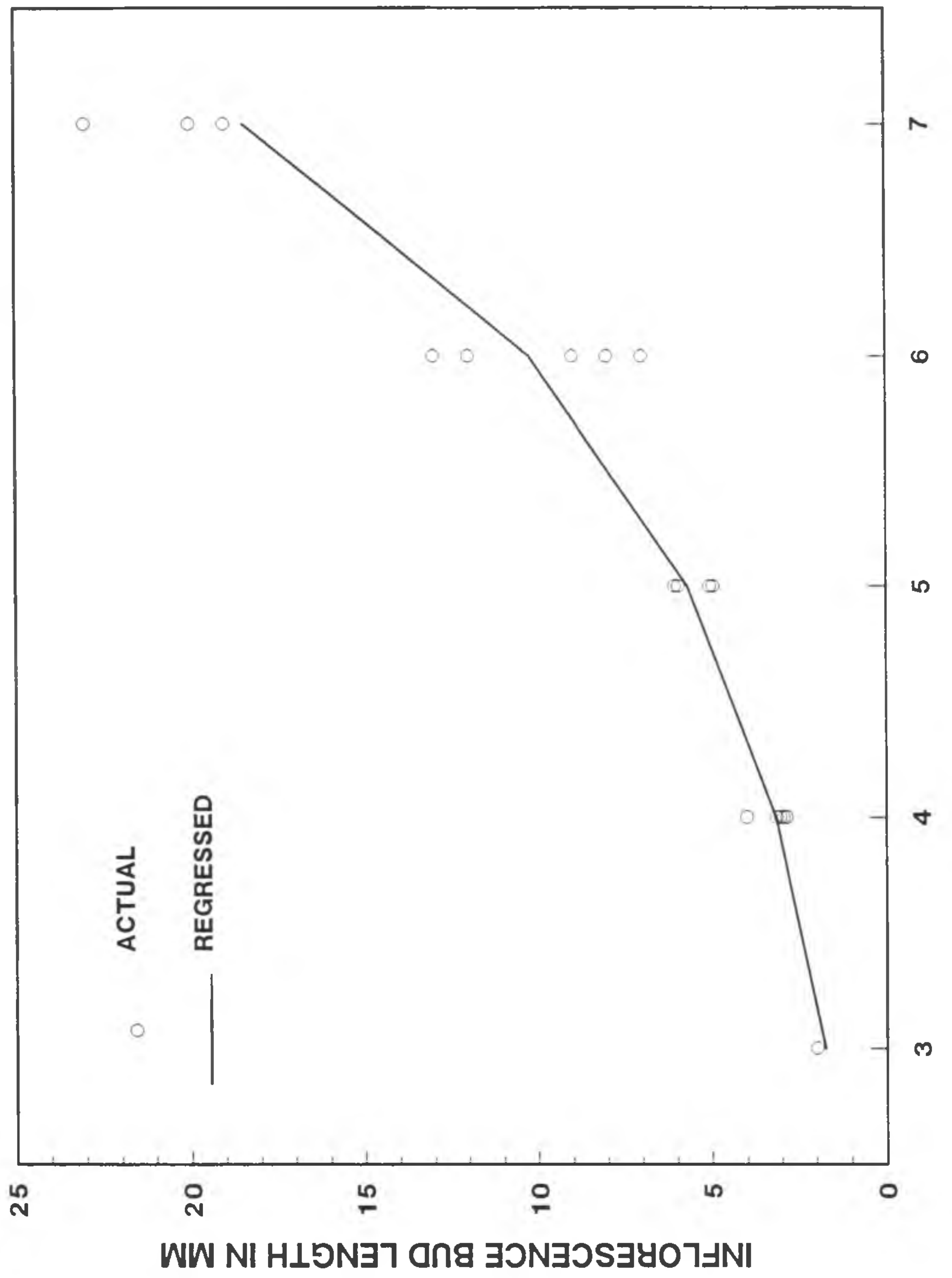


Figure 66. Growth of inflorescence bud of bird of paradise in Hawaii. The actual data (∘) were regressed with an exponential line on the number of leafy sheaths produced (Table 46). Most inflorescence bud became susceptible to flower abortion at the sheath number 7.

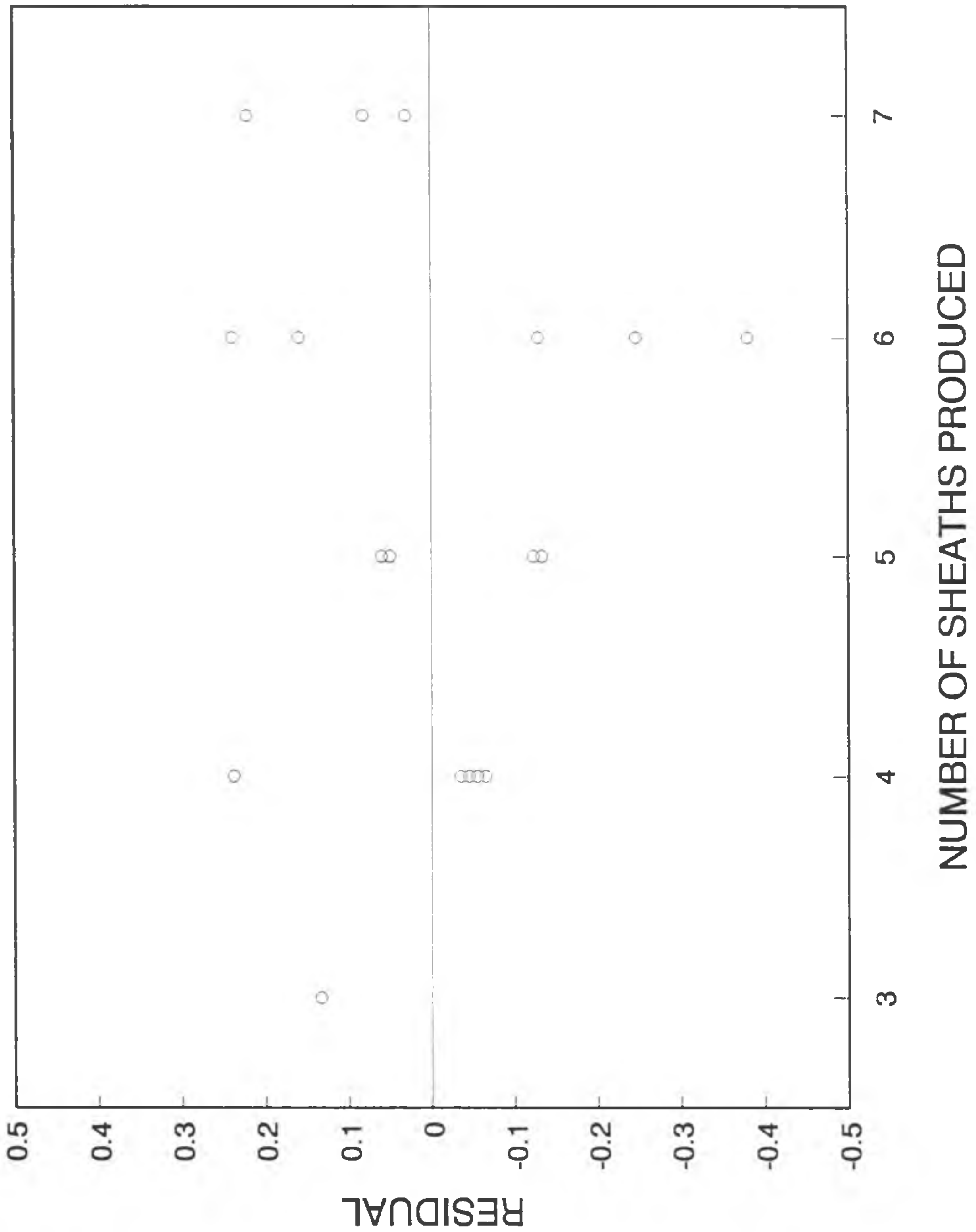


Figure 67. Residual plots for the regression of inflorescence bud growth (Fig. 66). A weak occurrence of quadratic trend was not significant (Table 46).

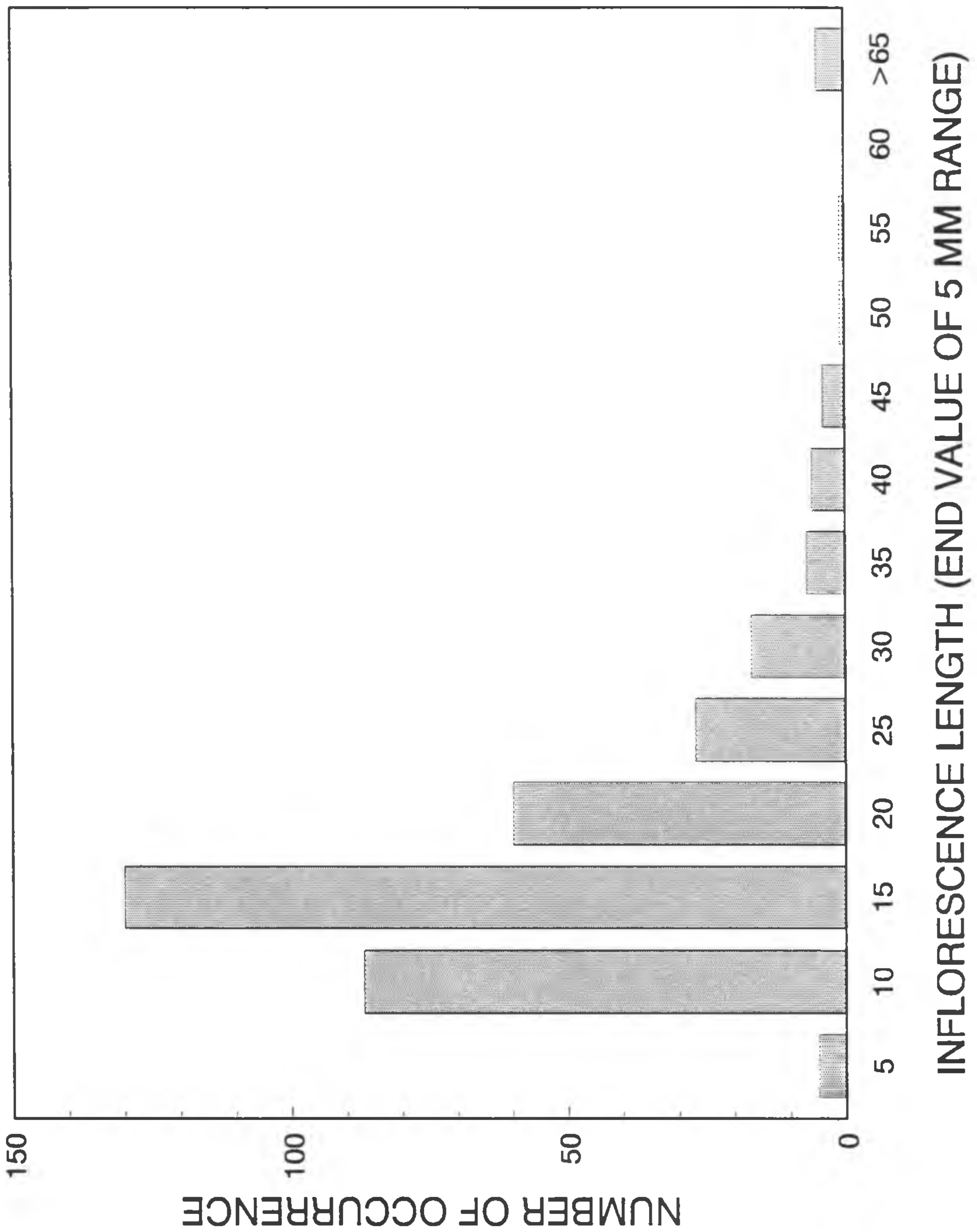


Figure 68. A frequency distribution of the length of aborted inflorescence buds of bird of paradise in Waimanalo, Oahu. The mean was 15.6 ± 0.71 mm and 79% of the total were in 5-20 mm range.

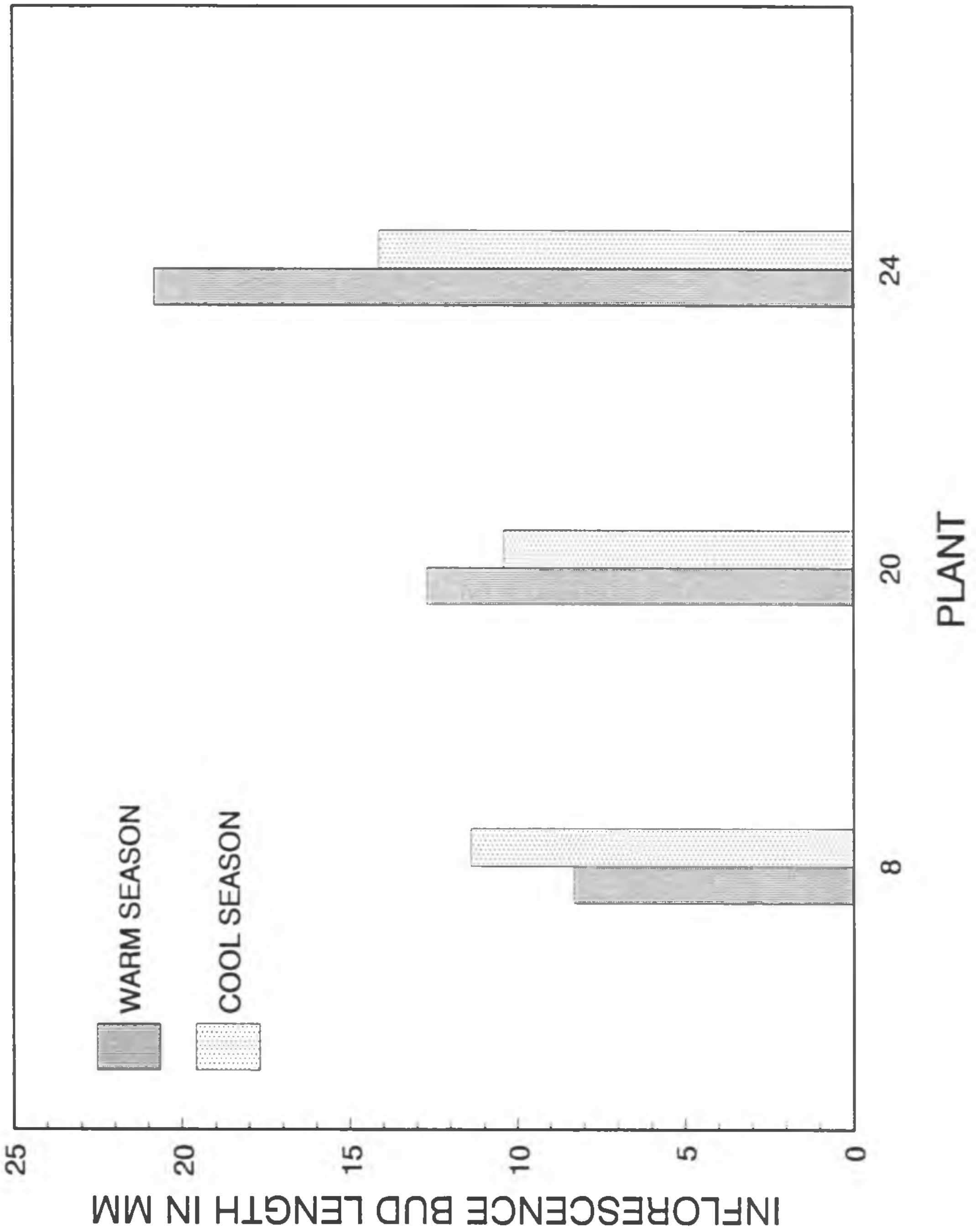


Figure 69. Mean aborting size of bird of paradise inflorescence buds sampled from 3 plants in 2 seasons. Plant 8 represented a highly seasonal flower productivity, Plant 20 represented relatively constant, and Plant 24 represented intermediate. There was a significant difference among plants (24 vs. 8 and 20), but the difference between seasons was not significant (Table 47).

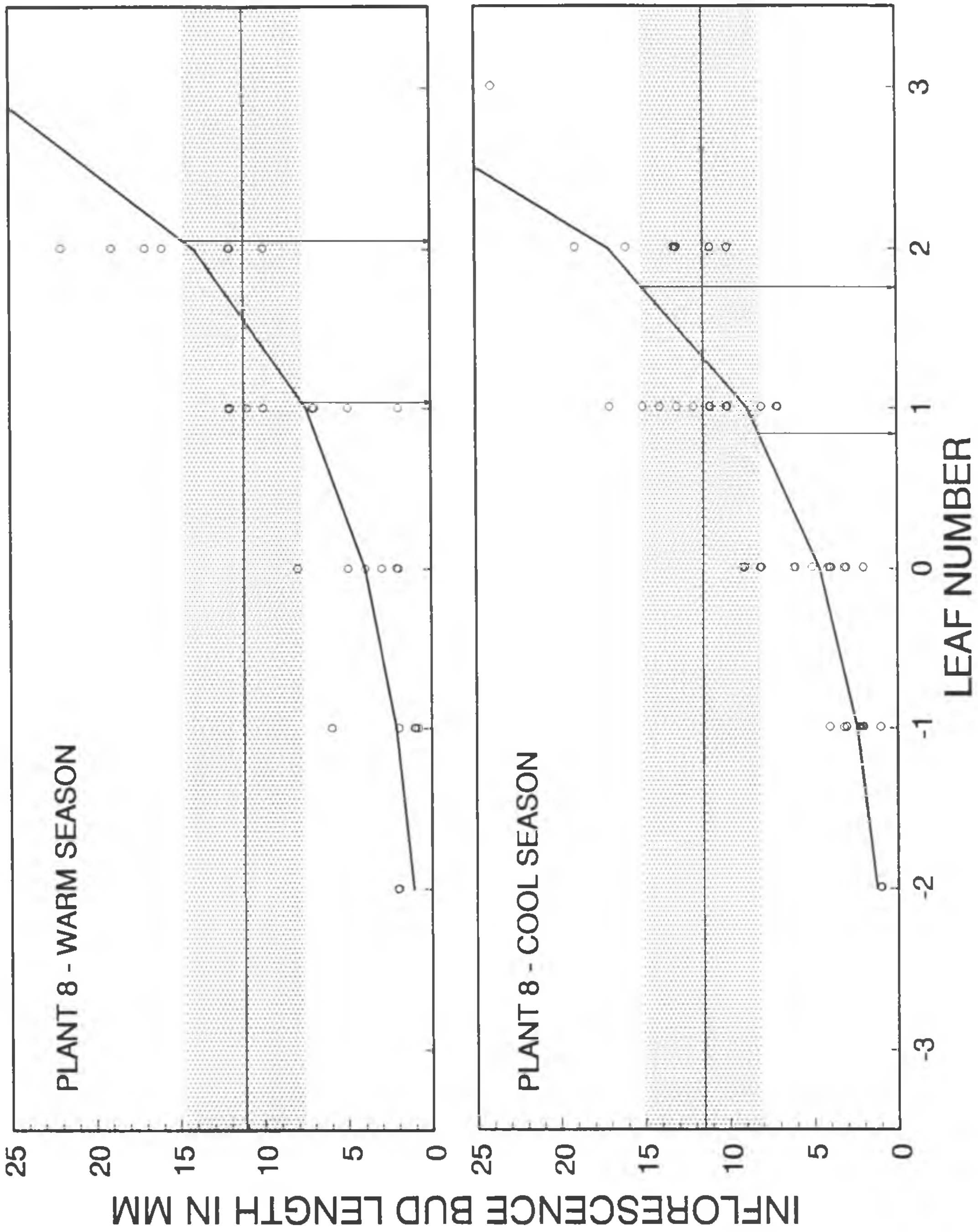


Figure 70. Comparison of the time at which inflorescence buds of Plant 8 became abortion-sensitive in 2 seasons. The exponential curve represented the inflorescence growth (Table 50) and the shaded area represented a range of aborting-sensitive size (mean ± SE, Table 51). The inflorescence buds reached abortion sensitive stage in the axils of the 2nd youngest emerged leaf in cool season (leaf number 1) while they reached abortion sensitive stage in the axil of the 3rd youngest leaf (leaf number 2) in warm season.

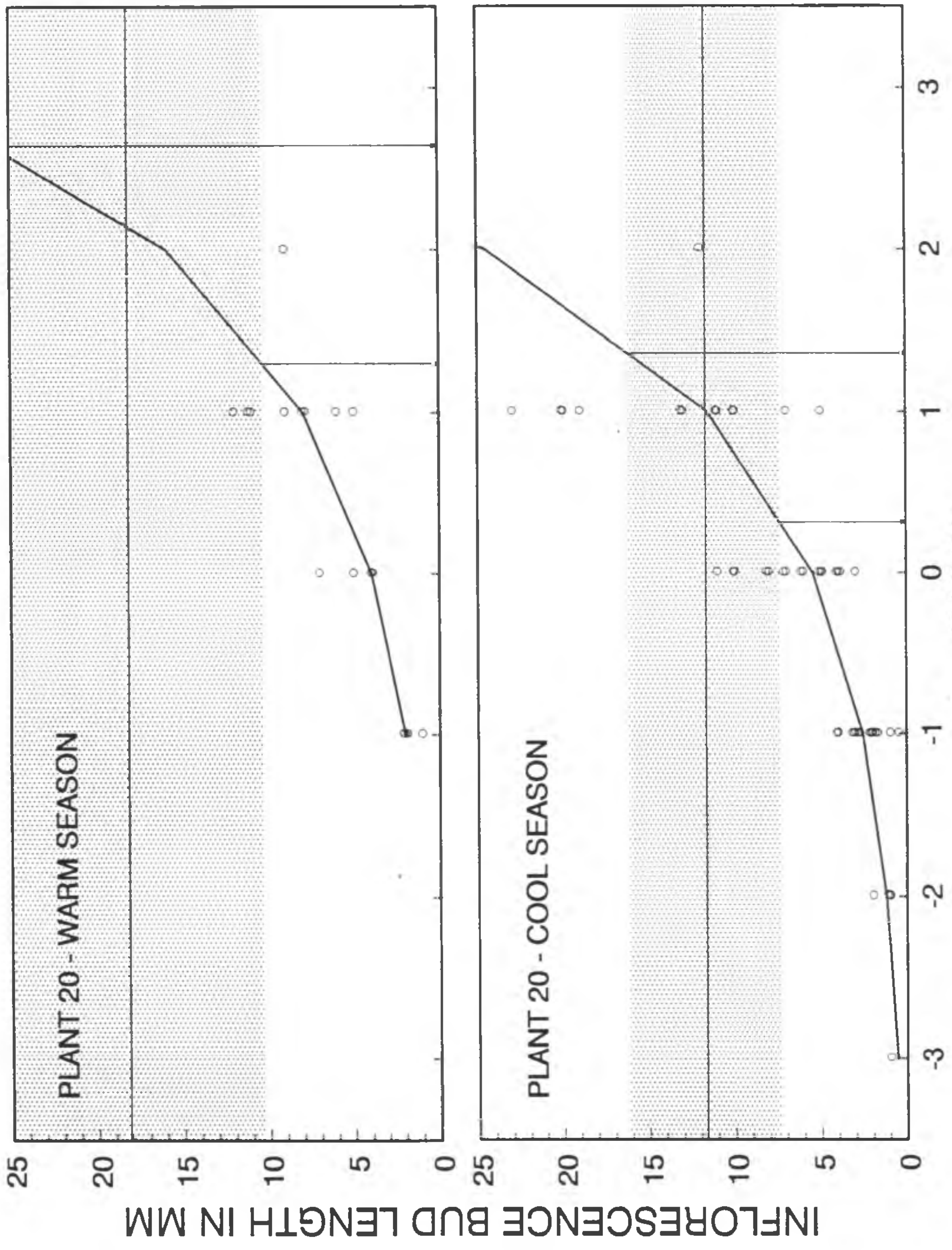


Figure 71. Comparison of the time at which inflorescence buds of Plant 20 became abortion-sensitive in 2 seasons. The exponential curve represented the inflorescence growth (Table 50) and the shaded area represented a range of aborting-sensitive size (mean ± SE, Table 51). The inflorescence buds reached abortion sensitive stage in the axils of the 2nd youngest emerged leaf in cool season (leaf number 1) while they reached abortion sensitive stage in the axils of the 3rd youngest leaf (leaf number 2) in warm season.

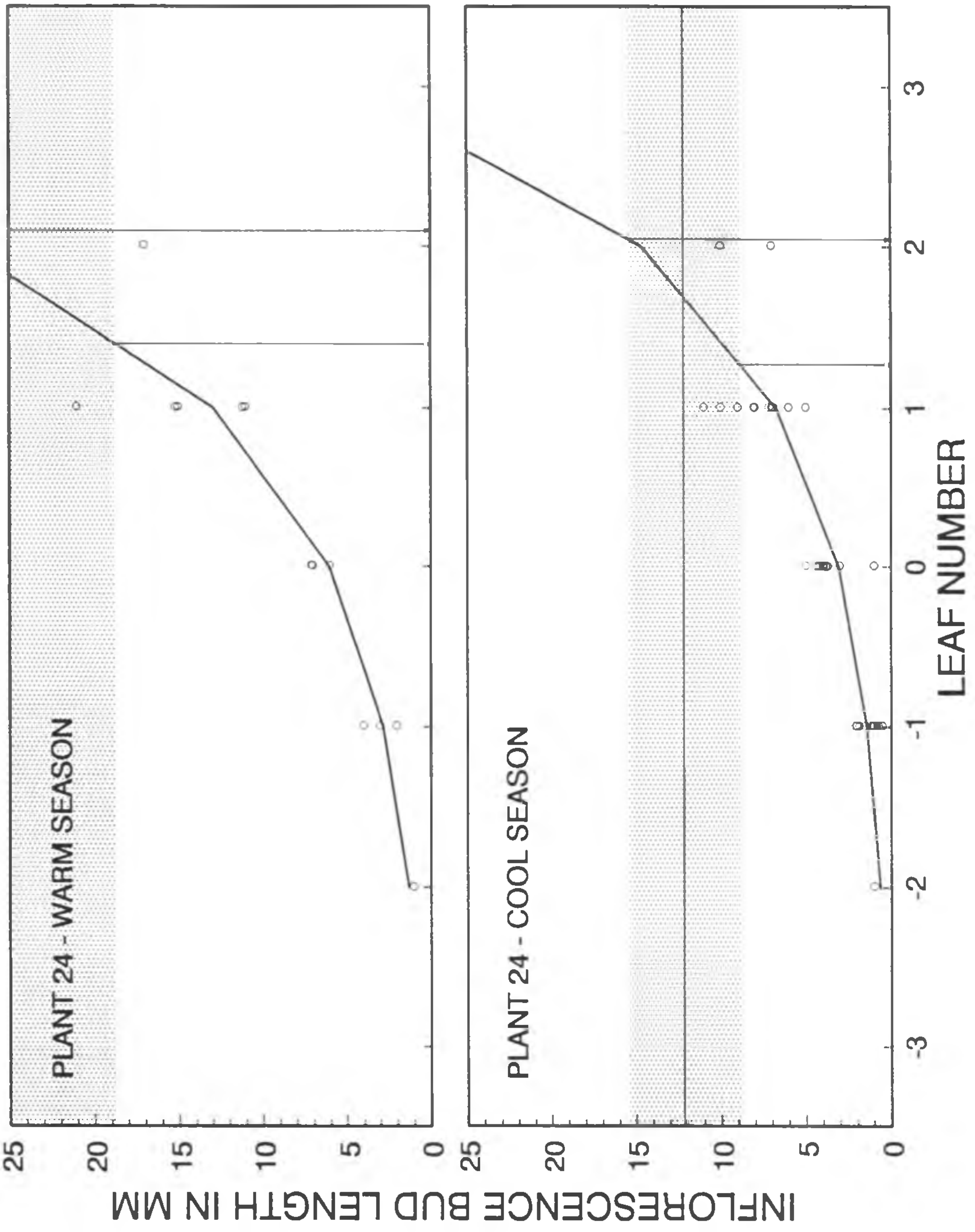
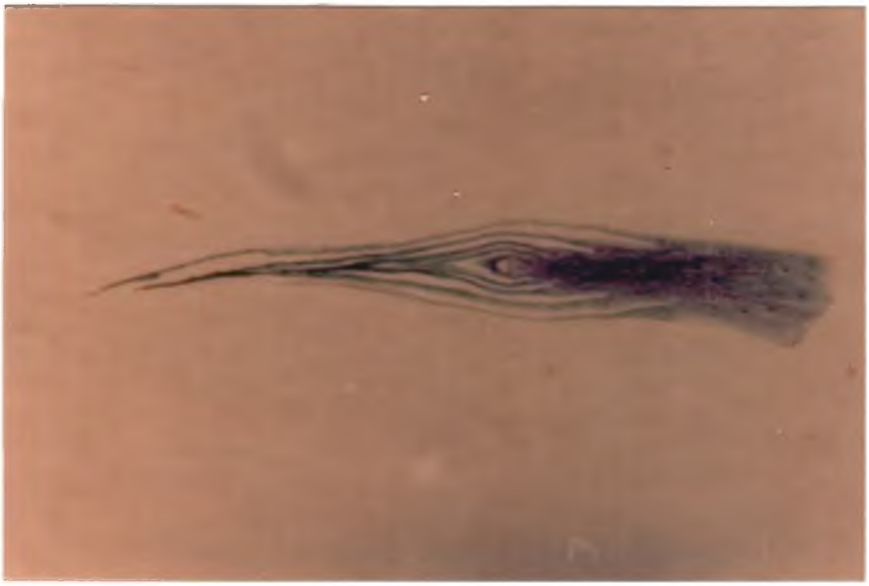


Figure 72. Comparison of the time at which inflorescence buds of Plant 24 became abortion-sensitive in 2 seasons. The exponential curve represented the inflorescence growth (Table 50) and the shaded area represented a range of aborting-sensitive size (mean ± SE, Table 51). The inflorescence buds reached abortion sensitive stage in the axils of the 3rd youngest emerged leaf (leaf number 2) in both warm and cool seasons.

A



B

Figure 73. Longitudinal sections of aborted inflorescence buds of bird of paradise. One of the smallest aborted bud of 6 mm long (A) still showed 6-7 leafy sheaths differentiated, while the 3 mm long aborted bud (B) showed only 3-4 leafy sheaths.

CHAPTER 6

MODELING TIME PERIOD AFTER LEAF EMERGENCE IN FLOWER GROWTH OF BIRD OF PARADISE

The flower growth of bird of paradise before leaf emergence (LE) was modeled in Chapter 5. In this chapter, the time period after LE to flowering (flower cut, FC) was modeled using heat unit accumulation to incorporate an environmental factor in the flower growth model.

6.1 Literature Review

Flower growth after leaf emergence. The time intervals after leaf emergence in bird of paradise flower growth varied geographically and seasonally in four production sites (Halevy, et al., 1987): for the leaf emergence to flower emergence (LEFE) the shortest was 150 days in Australia, and the longest was 324 days in California; for the flower emergence to flower cut (FEFC) the shortest was 55 days in Hawaii, and the longest was 196 days in South Africa. In Hawaii, although the LEFE and FEFC were assessed as relatively constant, 173-204 and 54-74 days, respectively (Criley and Kawabata, 1984), the sigmoidal growth patterns regressed for FEFC varied between cool and warm seasons, and the most influential environmental factor was air temperature (Kawabata, et al., 1984).

Although there was no other comparable study for the temperature effect on the plant growth rate in bird of paradise, in bananas, a high air temperature was related to faster growth. The maximum leaf extension occurred when the air temperature was maximum in the day (32-33°C) in Honduras (Barker, 1968); the largest daily gain of leaf dryweight would occur at the maximum air temperature above 30°C (Green and Kuhne, 1970); under-canopy sprinkling resulted in fewer LEs per month and extended FEFC for 70 days, and the cause was attributed to the decrease in pseudostem temperature by 3-5°C due to evaporative cooling in South Africa (Robinson and Alberts, 1987).

Since there was no comprehensive research done, it was necessary to model flower growth after LE to determine the magnitude of the seasonality in flower production of bird of paradise. A heat unit accumulation model (review by Wang, 1960) was suited for this purpose, because it would estimate the time period to flowering by temperature environment, and air temperature was the single most influential environmental variable (Kawabata, et al., 1984). Since the LEFC period in Hawaii spans over a half year period (238-255 days, Criley and Kawabata, 1984) and modeling entire LEFC in one period could mask seasonal differences in flower growth, breaking the period into 2 stages, LEFE and FEFC, would be preferred as the seasonal effect would become more evident in each of the period.

Heat unit models. The concept of heat unit accumulation, in which completion of a physiological process in plant would occur when an accumulation of temperature reaches a certain level, originated in 18th century. This modeling was widely used for predicting harvest dates in cereal and vegetable crops by 1950s (review by Wang, 1960) and was applied for predicting various other processes in plant: plant growth rate (Brown, 1960), chill requirement for the completion of rest (Richardson, et al., 1974), leaf area (Eisensmith, et al., 1982), and pest control and management (Wilson and Barnett, 1983). For ornamental crops, stages of Easter lily development were determined by heat unit models (O'Rourke and Branch, 1987).

A series of improvements was made to increase the accuracy of heat unit models. A high temperature threshold was introduced (Madariaga and Knott, 1951). Air temperature was measured at the crop height (Katz, 1952), and hourly temperature was used for the summation instead of daily (Lana and Haber, 1952). Negative values were accumulated for the day which the maximum temperature exceeded the upper threshold (Gilmore and Rogers, 1958). Heat unit accumulation for a certain developmental stage served for estimating the yield (Stauber, et al., 1968). Soil moisture (Kish, et al., 1972) and photoperiod (Coligado and Brown, 1975) were incorporated into the heat unit computation. Heat unit was expressed as a function of air temperature (Richardson, et al., 1975), and the degree growth stage was accumulated instead of temperature itself (Kobayashi, et al., 1982).

Although the heat unit modeling generally lacks precision due to its computational nature (Wang, 1960), selection of a best accumulation type out of many candidate models has resulted in satisfactory predictions (Perry, et al., 1986; Ashcroft, et al., 1977). Two other possible improvements for the model precision are a better model selection method and shorter intervals for temperature recording.

Base temperature. The heat unit modeling is based on the theory that, with the selection of a proper base temperature, a level of heat unit accumulation (sum of differences when actual temperature exceed a base temperature) can be found at which a plant process is completed regardless of the temperature fluctuation. Arnold (1959) discussed two types of errors associated with this modeling: errors in the accumulation of heat units, and the errors in time (days) between the actual and the predicted. He recommended the use of standard deviation (SD) or coefficient of variation (CV) of errors in time (days) rather than in accumulated heat units for determining the best base temperature. This practice is still followed today (Perry, 1986; Richardson, et al., 1974).

The use of errors in days should be encouraged as it would increase the precision of a model as Arnold indicated, however, the use of SD or CV for the selection of the base temperature is not always be optimal. Unlike the errors estimated by a linear regression model in which the mean of error would be always 0, the errors predicted by a heat unit accumulation model would not necessarily be 0. If the mean of errors should deviate from 0, SD or CV would indicate a smaller sum of squares than actual for an amount of the correction factor (or number of observation times square of error mean). Therefore, the uncorrected sum of squares (sum of squares of error without adjustment for the correction factor) would be the correct measurement for the performance of heat unit accumulation models. As a result, when the minimum uncorrected sum of squares is used for the base temperature selection, the accuracy of the estimates would increase.

Interval of temperature recording. Two means to increase accuracy of the daily temperature estimation are to build a better model and to measure temperature more often. The former has been studied more intensively than the latter probably because the latter was physically exhaustive and financially expensive.

Efforts to increase the accuracy in daily heat unit accumulations were made by interpolations assuming daily temperature fluctuated sinusoidally between daily maximum and minimum temperatures: corrections were made by sine-curve models when the minimum temperature fell below the base temperature (Arnold, 1961) and when the maximum temperature exceeded above the upper threshold (Baskerville and Emin, 1969); the heat unit accumulated was expressed as a function of air temperature (Logan and Boyland, 1983). Corrections were made by statistically fitting accumulations on maximum and minimum air temperatures (Aron, 1975).

To increase the precision of estimating daily temperature fluctuation, complex functions were produced: a combination of a truncated sine function for the day and an exponential decay function for the night fitted well for the daily air and soil temperatures (Parton and Logan, 1981); three mathematical models including the previous air temperature model were compared (Wann, et al., 1985).

Despite the sophistication of these temperature estimation models and heat unit accumulation models, their accuracy is still limited since the estimation was based on only two temperatures, daily maximum and minimum. In addition, the interference of a possible smooth daily air temperature fluctuation by variable cloud cover is ignored. This latter limitation makes the use of those mathematical models unrealistic in Hawaii (Ch. 2).

Studies for increasing the accuracy of heat unit accumulation by frequent observations are sparse. Although 3-hour intervals were claimed unnecessary (Gilmore and Rogers, 1958), the use of 1-hour intervals have been suggested (Andrew, et al., 1956) and the accuracy of daily temperature estimation increases when 1-hour intervals are used instead of 2- or 3-hour intervals (Wann, et al., 1985).

Since computers and computerized data collection equipment are available for a flexible data collection and fast analysis, it would be advantageous to take temperature in short intervals which would increase the accuracy of the heat unit accumulations estimates and also would reduce the error caused by passing cloud cover.

The objectives of this experiment were:

1. To model the LEFE and FEFC intervals in bird of paradise using heat unit models.
2. To determine the best heat unit accumulation model which could be used for both LEFE and FEFC periods.
3. To determine if short intervals for temperature measurement increase the accuracy in the heat unit accumulation estimates.
4. To determine if the leaf cooling effect on the LEFE and FEFC period by misting can be modeled by heat unit accumulation models.

6.2 Materials and Methods

Selecting flowers for the modeling. The time periods between LE and FE (LEFE) and FE and FC (FEFC) were collected from the MASTER data set (Ch. 3) in which LE and FE dates occurred July 1, 1984-December 31, 1985 and in which FC dates occurred July 1, 1984-June 30, 1986. With this selection method, 801 flowers with complete LE and FE dates were recorded for the control plants and 667 flowers for the misted plants for LEFE. For FEFC, 581 flowers were recorded for the control plants and 520 for the misted plants.

Although the data period spanned 3 years, many FE and FC data were incomplete (or flowers had not reached to the respective stages) at the end of July 1986 when the data collection was terminated. The selection procedure above allowed at least a year of complete LEFE and FEFC records for the modeling. Each flower was regarded as the experimental unit. Since the leaves and flowers emerged all year and the LE, FE, and FC dates were recorded weekly, this design permitted the seasonal fluctuation in the rate of flower growth to be represented almost continuously (52 weeks per year).

Collecting air temperature. The air temperature was recorded at 1.8 m above the ground by a computerized thermistor thermometer (Datapod, Appendix A) placed in the field for the entire period of this experiment, 1 July 1984-31 July 1986. The recording mode was set for an instantaneous reading at 10-min intervals. Solar radiation was also instantaneously monitored in the same time intervals.

Intermittent misting (Ch. 2) was applied to the misting plots for the periods August 20-November 2 in 1984 and June 14-October 2 in 1985. The leaf temperature was estimated by air temperature (1.8 m above the ground) and solar radiation using a regression equation:

$$T_{leaf} = 4.73 + 0.704 \cdot T_{air} + 0.026 \cdot RAD - 0.0000099 \cdot RAD \cdot RAD - 0.00023 \cdot T_{air} \cdot RAD \text{ ....Eq. 8}$$

where T_{leaf} was leaf temperature (°C), T_{air} was air temperature (°C), RAD was solar radiation ($J \cdot m^{-2} . s^{-1}$). This regression equation was derived from the leaf temperature model (Variance Sequence 2, Ch. 2) replacing the air temperature near the leaf by the air temperature 1.8 m above the ground.

Modeling with heat unit accumulation. A total of 12 types of heat unit accumulation (Table 53) were computed to give the combinations of recording intervals and heat unit types: DM, LDM, DH, LDH, DHI, LDHI, DDMIN, LDDMIN, DDMAX, LDDMAX, DDMEAN, and LDDMEA. The names starting with a letter D indicated the use of air temperature and starting with letters LD indicated the use of leaf temperature. The instantaneous readings were used for the DM, DHI, DDMAX, DDMIN and their leaf temperature equivalents; while mean temperatures were used for the DH and DDMEAN, with hourly and daily recording intervals respectively, and for their leaf temperature equivalents.

A SAS program ("DDESTIM.SAS", Program 4) was executed to proceed the following steps for modeling the LEFE and FEFC periods:

1. The temperatures of all 12 types were accumulated daily for a faster computation. (Since LE, FE, and FC were recorded by date, it was not necessary to compute heat units shorter than daily.)
2. Daily accumulations were summed for the period between LE and FE for LEFE (FE and FC for FEFC) for each flower.
3. A mean heat unit accumulation of all flowers was computed as the best estimate for the accumulation for each base temperature.
4. The estimated FE was computed for each flower using the actual LE date (FC and FE for FEFC, respectively) and the mean heat unit accumulation estimated in the step 3.
5. The steps 1-4 were repeated for the base temperatures 0-25°C, for all heat unit types, and for LEFE and FEFC.

The minimum value for the base temperature range, 0°C, was arbitrary. However, since a base temperature in the heat unit accumulation models is not necessarily equal to the temperature below which no growth takes place (Arnold, 1959), lower values than the minimum temperature at the experimental site (11.5°C) were included. The maximum base temperature was set to 25°C since many temperature types did not accumulate heat units at higher temperatures than 25°C.

Selection of the best model. The best model was selected as follows:

1. Checking for the correctness of the estimated FEs (and FCs for FEFC). This was done by applying 95% confidence intervals to the

mean residual (mean difference between estimated FEs and actual FEs for LEFE). If the confidence intervals should include 0, then the estimates would be determined as correct. The band width of confidence intervals also indicated the preciseness: the more precise the estimates were, the narrower the band would become. Heat unit accumulation types which did not estimate correctly at any base temperature were eliminated from the search for the best model.

2. Checking for the accuracy (performance) of the model. The accuracy of the model estimates was indicated by uncorrected sum of squares for error (USS). The more accurate the estimates were, the smaller the USS would become. The best base temperature was determined for each of the candidate model type.
3. The best model was determined from the models selected in step 2 by the consideration of USS and other factors.

Verification and validation of the models. Except for that the heat unit accumulation models were not linear models, the procedure for checking for the correctness of estimates, step 1 in the previous section, was exactly the same procedure as checking for the significance of explanatory variables in a regression model. Therefore, the procedure in step 1 served as the verification of models.

Since an equivalent data set was available for the plants in misting plot (but it was not used for the model building), the validation of the model was done by estimating LEFE (or FEFC) for the misted plants using the heat unit accumulations previously estimated for the control plants. If the difference between the estimated and the actual FEs for a LEFE model for the misted plants (or FCs for a FEFC model) was not significantly different from 0, then the model was said to be validated.

6.3 Results

6.3.1 Leaf Emergence to Flower Cut

Actual LEFE. Monthly means of the actual LEFE for control plants were plotted against month of LE for July 1984-December 1985 period (Fig. 74). The longest monthly mean of LEFE was 192 days for November 1984 and the shortest was 145 days for June 1985 which was comparable to a previous study (172-195 days for Hawaii, Halevy, et al., 1987). A seasonal fluctuation was observed for the period: long intervals in the cool season and short intervals in the warm season with a sinusoidal pattern between them. Since the data period was 17 month (not exactly 1 year) and a simple mean would not represent a correct mean, a sine-curve regression model was fit for the period (same procedure as for leaf emergence interval, Table 40). The result indicated the mean as 168 days.

The fluctuation pattern of LEFE for control plants was compared with the LEFE for misted plants (Fig. 75). The extension of LEFE by misting was observed 1-2 month after the start of mist application as the misting in August 20-November 2 in 1984 showed the extension of LEFE in October-December, and the misting in June 14-October 2 in 1985 also showed the extension of LEFE in July-December. The maximum difference was approximately 40 days for September 1985. Although an LEFE extending effect was seen in January-June period in 1985 the differences in the period was small. Therefore, a seasonal fluctuation existed in the LEFE intervals, and the effect of misting began appearing in 1-2 months after the start of misting in extending the intervals as long as 40 days.

Modeling LEFE with heat unit accumulation. The LFFE intervals were modeled by heat unit accumulations ("DDESTIM.SAS", Program 4) and residual patterns for control plants (Figs. 76-87) were produced. A study of the residual patterns indicated that, when the base temperature was chosen for 12°C or less, all models showed correct estimates as the residual means were within plus 2 days of estimates and the 95% confidence intervals for the mean residuals included 0. In these models, the estimates were always larger as much as 1 day, since any fractional remainder in the estimated FE was raised to the next largest integer. As a result, the mean errors were as small as 1 day. The CSS (corrected sum of squares for error) used for the confidence interval estimates represented the preciseness of estimates since it was adjusted for the mean.

On the other hand, the USS (uncorrected sum of squares for error) indicated the accuracy (or performance) of the estimates by the heat unit accumulation models as it was computed before the adjustment for the error mean. The USS (Figs. 76-87) was at the lowest level in the base temperature 0-12°C in each of the heat unit accumulation type.

Therefore, these results indicated that the estimates of LEFE by the temperature accumulation types used in this study were correct, and the best base temperature could be found for each temperature accumulation type.

Although all temperature accumulation types had acceptable base temperatures for LEFE for control, when the models were tested for predicting FE for misted plants (Figs. 88-97), only the leaf temperature accumulation types correctly estimated the FEs (Figs. 89, 91, 93, and 97) in the range of the base temperatures 11-17°C, except for the LDDMAX which showed acceptable base temperatures 0-9°C (Fig. 95).

All air temperature accumulation types estimated the FEs for misted plants approximately 10 days shorter (earlier) than the actual (Figs. 88, 90, 92, 94, and 96). These under-estimations occurred because when air temperatures were accumulated, estimates were not compensated for the leaf cooling effect given by misting, therefore, the FEs were predicted as if plants were not misted.

The errors of the DDMIN and LDDMIN models for the misted plants were not presented. Because the daily minimum temperature occurred at night when misting was not applied, the daily heat unit accumulations for these models became identical among the plots, control and misted. Therefore, the models were not subjected to the validation.

These results validated the use of heat unit accumulation for modeling the LEFE in bird of paradise. The use of leaf temperature was more useful than air temperature since the models using leaf temperature showed satisfactory LEFE estimates regardless of the leaf cooling effect by misting.

6.3.2 Flower Emergence to Flower Cut

Actual FEFC. Monthly means of the actual FEFC for control plants were plotted against months for January 1985-April 1986 period (Fig. 98). The longest LEFE was 68 days for November 1985 and the shortest was 53 days for June 1985 which was comparable to a previous study (55-75 days for Hawaii, Halevy, et al., 1987). A seasonal pattern appeared in which the FEFCs showed large values in the October-January period and relatively constant values between 53-60 days for the rest of the year. A sine-curve regression computed the mean for the period as 58 days.

The fluctuation pattern for FEFC for control plant was compared with FEFC for the misted plants (Fig. 99). While values for the FEFC misted were similar to the control, a period appeared in April-September 1985 in which FEFC for the misted plants did not drop down as much as for the control values (a maximum difference of 6 days for April 1985). Since the misting was started June 14, 1985, the period of the long FEFC in April-May 1985 could not have resulted from misting in 1985. The end of the long FEFC period September 1985 coincided with the termination of misting in October 2, 1985. Therefore, a seasonal fluctuation existed in the FEFC, and the effect of misting was observed immediately in extending the FEFC intervals. However, the difference was small and misting did not significantly alter the seasonal pattern.

Modeling FEFC with heat unit accumulation. Similar results for the LEFE period were obtained for the errors in the FEFC period (Figs. 100-111) as all heat unit models estimated the mean residuals within 1 day. The highest base temperature at which 95% confidence intervals for the mean residual included 0 varied from 10°C for the DDMIN (Fig. 106) to 25°C for the LDDMAX (Fig. 109). The estimations were accurate since the USS was at the lowest level (precise) in the base temperature range in which the confidence intervals included 0 mean (correct estimates).

Validating the heat unit accumulation models with the misted plants (Figs. 112-121), again, showed that all leaf temperature accumulation types (Figs. 113, 115, 117, and 121) correctly estimated FCs at base temperatures 0-13°C except for LDDMAX (Fig. 119), while air temperature accumulation types (Figs. 112, 114, 116, 118, and 120) under-estimated FCs by approximately 2 days which deviated significantly from the actual FCs.

These results indicated that the seasonal fluctuation in FEFC period, as with LEFE, could be estimated by the heat unit accumulation models using leaf temperatures.

6.4 Discussion

6.4.1 Characteristics in Error Variance

Two distinctive trends in error variance, previously reported by Arnold (1959), were also recognized in the USS plotted against the varying base temperature for all heat unit accumulation types in this study: a sharply increasing trend as base temperature was raised above the optimal and a slowly increasing trend as base temperature was lowered below the optimal (Figs. 76-87 for LEFE and Figs. 100-111 for FEFC). In the LDDMAX type, the optimal base temperature was indicated below 0°C. An explanation of the heat unit accumulation would be necessary to understand these characteristics.

A heat unit sum value has two components: one which is proportional and one which is variable. The proportional component can be simply computed by multiplying the temperature difference between the base and the minimum for the period with the number of days; and the variable component is a temperature sum above the minimum for the period. These components have different responses to the base temperature. When a base temperature is set below the minimum for the period, the magnitude of the proportional component changes accordingly (proportionally) to the temperature difference between the base and the minimum, while the variable component remains as a constant. On the other hand, when a base temperature is set above the minimum temperature, the proportional component is non-existent, while the variable component decreases.

In the flower growth of bird of paradise, USS increased rapidly when the base temperature was raised above approximately 15°C (a visual judgment). Because the relative magnitude of the variable component to the proportional component would increase as the base temperature was raised to the minimum temperature of the actual observation, the variance in the estimates of LEFE (or FEFC) also increased. This effect resulted in a increasingly large USS at high base temperatures above the optimal. In extreme cases, setting a high base temperature will develop no-estimation: the heat unit accumulation for some flowers never reached the critical sum value in the period (i.e. base temperatures above 20°C for LDDMIN, Fig. 83).

On the other hand, when the base temperature was lowered below 10°C, the USS remained at a nearly constant level or even slowly increased (i.e. DM, Fig. 76). This occurred because the proportional component increased while the variable component remained constant. This change caused the estimates of LEFE (or FEFC) to become more uniform and the USS to increase slowly. If the base temperature was sufficiently low, the estimates of LEFE (or FEFC) approached the mean of observed LEFEs (or FEFCs).

As a result of these two trends in both high and low temperature regions, the estimate which yields the lowest USS would be found between the two extreme base temperatures: high base temperatures which would result in highly variable estimations and the low base temperatures which would result in the highly uniform estimations. Most of the USS plots presented in this study exhibited the transition of the two trends (appearing as a valley on the plots of USS against base temperature) in the range of 10-15°C. This base temperature range coincided with the minimum temperature for the experimental site, 11.5°C.

A biological base temperature, below which no growth takes place, could vary from a base temperature for a heat unit accumulation model

(Arnold, 1959). Assuming that a biological base exists and it is equal to the base for the heat unit accumulation, these analyses indicate that the biological base temperature for the bird of paradise flower growth is 11.5°C. However, the lack of distinctive dip in the residual plots (USS on base temperature) indicats a better base below 11.5°C. This temperature is in accordance with a previous study which suggested a minimum air temperature below 13°C could retard flower development in bird of paradise (Halevy, et al., 1987).

Although the differences in performance among the models seemed small since the minimum USSs of different accumulation types did not vary greatly (approximately 700,000 for LEFE and 120,000 for FEFC). However, there would be differences among the models as the existence of large variations in USS at high base temperatures indicated the estimates were not identical. The smaller variation in the low base temperature range was also due to the high minimum temperature in the experimental site.

6.4.2 Determining Best Type of Heat Unit Accumulation

The best representative from each of the heat unit accumulation models was determined by the smallest USS, and the associated values were summarized in Table 54 for LEFE and Table 55 for FEFC. The values listed were: a) the smallest USS, b) the base temperature at which the smallest USS was observed, c) the range of base temperature in which the 95% confidence intervals of error mean included 0, d) whether temperatures on columns b and c had a same value, and e) the mean of heat unit accumulation for the base temperature in column b. For a comparison of heat unit accumulation among temperature types, mean sums for 12°C base temperature were listed, f.

The best heat unit accumulation type was selected by following criteria in a sequence using the Tables 54 and 55:

1. Choosing the types which resulted in correct estimations for both control and misting plots ("Yes" in column d). This criterion represented the correctness of the model. It eliminated all air temperature accumulation types since they significantly underestimated LEFE and FEFC for misted plants.
2. Choosing the types which resulted in low USSs (column a). This criterion represented the accuracy of the estimates. The candidate models were reduced to LDM, LDH, and LDDMEA. Among these, LDM and LDDMEA had identical and the smallest USSs, while LDH was the next best as it had a larger USS for LEFE in misted flowers than LDM or LDDMEA.
3. Considering overall performance. When the USSs were inspected over the entire base temperature range (Fig. 77 for LDM and Fig. 87 for LDDMEA), LDM had smaller USSs at high base temperatures than LDDMEA. This would indicate that the performance of LDM would not be reduced as much as LDDMEA when a base temperature other than the best was used.

Therefore, the LDM was selected as the best representative among the heat unit accumulation models.

6.4.3 Estimates of Leaf Degree-Minute Model

LEFE estimation by the LDM model. Monthly means of the estimated and actual LEFEs were plotted together against the month of LE (Fig. 122). The LDM model generally followed the seasonal trend in the actual LEFE. However, a possible phase shift for 1-2 months appeared: under-estimation in November-February and over-estimation in May-September.

The causes for the shift could be: 1) LE did not precisely indicate the beginning of the stage of flower growth, as FD (flower differentiation) which occurred during LEFE (Ch. 5) would have been a better indicator if it was observable; 2) FE also was not dependable since it was affected by the growth of the subtending leaf as the length of the petiole of channel through which the flower stalk elongates; and 3) the sigmoidal shape of flower stalk growth (Kawabata, et al., 1984) indicated that the rate of flower development varied according to the stage of flower development and the effect of a heat unit was not equal at all the flower development stages.

The residual plots (Fig. 123) reflected the effect of the shift by showing a gentle wave. The negative value side of the residuals seemed to have a larger scattering than the positive side. However, the plot did not have any other trend, and the test for the estimates indicated (confidence intervals for the mean residual, Fig. 77) that the trends did not significantly affect the estimates.

FEFC estimation by the LDM model. Monthly means of the estimated and actual FEFCs were plotted together against the month of FE (Fig.

124). The LDM model closely followed the trend in actual FEFC except for July-November in 1984 when the actual values exceeded the estimates. The longer FEFC intervals observed in the field were probably due to a drought before an irrigation system was installed in the field on 19 July 1984 (Ch. 4) as the same period in 1985 showed a satisfactory fit. The residual plots (Fig. 125) showed a scatter around 0 residual, and no apparent trend was found. The layering pattern appeared on the plot since the FEs and FCs were observed weekly while actual FEs and FCs occurred daily.

LDM models for bird of paradise flower growth after LE. Despite the existence of some unaccounted errors by the LDM models, the seasonal fluctuation in the flower growth was satisfactorily fit by the heat unit accumulation models using only leaf temperature. Since this leaf temperature was estimated from air temperature, the result supported the finding that the temperature was an influential variable for the variation in the yield in bird of paradise (Kawabata, et al., 1984).

The LEFEs and FEFCs were correctly estimated by various leaf temperature models (Table 53) even when plants were misted. Among the models, the most desirable model was the LDM: 4061024 heat units accumulation for LEFE when the leaf temperature was accumulated in 10-min intervals with the base temperature of 7°C (2327128 heat units with 14°C base temperature for the misted), and 1875172 heat units accumulation for FEFC with the base temperature of 2°C (1441858 heat units with 7°C base temperature for the misted). Three of these 4 base temperatures were lower than the minimum air temperature at Waimanalo, Hawaii. However, they were used in the models to achieve the best estimations in LEFE and FEFC, and they were not intended to indicate the biological base temperature for bird of paradise flower growth.

Selecting a single base temperature for the LEFE and FEFC periods would simplify the modeling as bases 0-12°C correctly estimated for both periods for control plants (Figs. 77 and 101). However, separate base temperature were chosen for each time period for better estimates, since the correct base for misting in LEFE showed a different range in 11-17°C (Fig. 89) from FEFC (0-12°C, Figs. 77, 101, and 113) despite an existence of narrow overlap in 11-12°C.

6.4.4 Alternative Models

Although the LDM was selected as the representative model for the bird of paradise flower growth, there were other useful alternative models. They were:

LDH: The performances of this type, both the correctness and preciseness in the estimates, were nearly identical to the LDM model. Computerized recording equipment would be suitable for this type as many have been programmed to record data hourly to reduce storage requirement.

LDDMEA: This type would require even less device requirement than the LDH model since only 1 number was stored a day. However, the error would become large at a lower base temperature (20°C, Fig. 87) than other alternative models.

DDMAX: This type estimated FEFC the best for control flowers, although it did not estimate correctly for the misted plants or FEFC.

6.4.5 Considerations for averaging temperature measurements

Previous to this study, a proper recording interval for averaging temperature measurements was not known. For shorter intervals, more data would have to be recorded. Although the quantity of data would not be a limiting factor as computers are available for data analysis, the storage capacity in the data recording equipment could be still limiting. For instance, if a data storage device had a capacity to store 1000 numbers (i.e. 1023 for the Datapod), the storage would last approximately 1 week (1008 records) by storing temperature every 10 min, 6 weeks (1008 records) by storing hourly averages, or 3 years (1095 records) by storing daily averages.

In this study, the temperature was measured and stored in 10-min intervals. Then, the data were transformed as 10-min instantaneous readings (DM), hourly averages (DH), or daily averages (DDMEAN) to compare the effect of intervals in averaging. (Another set could be found with the leaf temperature types, LDM, LDH, and LDDMEA, but only air temperature types were used as the representative.)

When the USSs for DM, DH, and DDMEAN were plotted together (Fig. 126), smaller USS were observed for the shorter intervals of averaging. While DDMEAN had higher USSs in the high base temperature range (16-25°C) than other two, the difference between DM and DH was small.

Therefore, choosing DM or DH over DDMEAN could be beneficial since better estimates were obtained, but choosing DM over DH might not sufficiently improve the model estimation at high base temperatures.

Therefore, if data storage capacity was limiting, accumulating temperature hourly would be recommended because of the lesser requirement for the storage capacity. If the storage was not limiting, then 10-min intervals would recommended as it would provide the most precise estimates. Daily accumulation could be recommended only when the capacity to record and store shorter intervals was not available.

6.5 Summary

1. The time intervals of the LEFE and FEFC in bird of paradise flower growth were estimated by the heat unit accumulations models, and the seasonal differences in the LEFE and FEFC periods were satisfactorily modeled (*t* test at 5% level) by temperature alone in Waimanalo, Oahu.
2. The LDM model, leaf temperature accumulated in 10-minute intervals, was determined as the best accumulation type. The best estimates for LEFE resulted from accumulating 4,061,024 heat units with 7°C base temerature and 2,327,128 heat units with 14°C base temperature for control and misting, respectively. The best estimates for FEFC resulted from 1,875,172 heat units with 2°C base temperature and 1,441,858 heat units with 7°C base temperature for control and misting, respectively.
3. While both the air and leaf temperature measurements could be used for the heat unit accumulation modeling for control plots, only

the leaf temperature was satisfactory in estimating LEFE and FEFC periods for the misted plants because leaf temperature accounted for the leaf cooling effect by misting.

4. The estimates were better using a shorter average intervals for the heat unit accumulation models among the intervals of 10 minutes, 1 hour, and 1 day.
5. The characteristics in the errors and the estimates of the heat unit accumulation models were discussed. A set of better base temperatures would have been found if the plants were exposed to a lower air temperature than 11.5°C, the minimum for the experimental site.

Table 53. Heat unit accumulation types used for estimating LEFE and FEFC in bird of paradise in Oahu, Hawaii. Base temperatures 0-25°C were applied to each of the type in search of the least sum of squares for error.

Label	Type of temperature accumulation
DM	Degree-minute. Air temperature was measured and recorded instantaneously in 10-min intervals. Each reading was multiplied by 10 to represent degree-minute accumulation.
LDM	Leaf degree-minute. Same as DM except leaf temperature was accumulated.
DH	Degree-hour. Air temperature was measured instantaneously in 10-min intervals and hourly means were recorded.
LDH	Leaf degree-hour. Same as DH except leaf temperature was accumulated.
DHI	Degree-hour, instantaneous. Air temperature was measured and recorded instantaneously at the beginning of each hour.
LDHI	Leaf degree-hour, instantaneous. Same as DHI except leaf temperature was accumulated.
DDMIN	Degree-day, minimum. Daily minimum of air temperature was determined from the measurements in 10-min intervals and recorded daily.
LDDMIN	Leaf degree-day, minimum. Same as DDMIN except leaf temperature was accumulated.
DDMAX	Degree-day, maximum. Daily maximum of air temperature was determined from the measurements in 10-min intervals and recorded daily.
LDDMAX	Leaf degree-day, maximum. Same as DDMAX except leaf temperature was accumulated.
DDMEAN	Degree-day, mean. Air temperatures measured in 10-min intervals were averaged and recorded daily.
LDDMEA	Leaf degree-day, mean. Same as DDMEAN except leaf temperature was accumulated.

Table 54. The heat unit accumulation models fitted for the LEFE period of bird of paradise in Waimanalo, Oahu. The columns indicated followings: a, the smallest uncorrected sum of squares (USS); b, the base temperature at which the smallest USS was observed (°C); c, the range of base temperature (°C) in which 95% confidence intervals of error mean included 0; d, whether b and c occurred at the same base temperature; e, mean of heat unit accumulations for the base at b; and f, mean of heat unit accumulations for the base at 12°C.

Type	Column					
	a	b	c	d	e	f
			Modeling with control plants			
DM	702328	9	0-25	Yes	3626822	2883698 °min
LDM	733241	7	0-12	Yes	4061024	2822309 °min
DH	702448	9	0-25	Yes	60450	48064 °hr
LDH	733241	7	0-12	Yes	67687	47041 °hr
DHI	702837	9	0-25	Yes	60459	48073 °hr
LDHI	735143	6	0-12	Yes	71806	47031 °hr
DDMIN	728940	2	0-10	Yes	3060	1340 °day
LDDMIN	732647	4	0-11	Yes	2526	1150 °day
DDMAX	694288	12	0-25	Yes	2956	2956 °day
LDDMAX	709175	19	0-25	Yes	2433	3638 °day
DDMEAN	702448	9	0-24	Yes	2519	2003 °day
LDDMEA	733241	7	0-12	Yes	2820	1960 °day
			Validating models with misted plants			
DM	677016	12	-	No	2883698	
LDM	703623	14	11-17	Yes	2327128	
DH	676864	12	-	No	48064	
LDH	703849	14	11-17	Yes	38787	
DHI	676515	12	-	No	48073	Same as above
LDHI	705526	13	11-17	Yes	42903	
DDMIN	-	-	-	-	-	
LDDMIN	-	-	-	-	-	
DDMAX	724698	14	-	No	2612	
LDDMAX	894499	0	0- 9	Yes	5702	
DDMEAN	677016	12	-	No	2003	
LDDMEA	703623	14	11-17	Yes	1616	

Table 55. The heat unit accumulation models fitted for the FEFC period of bird of paradise in Waimanalo, Oahu. The columns indicated followings: a, the smallest uncorrected sum of squares (USS); b, the base temperature at which the smallest USS was observed (°C); c, the range of base temperature (°C) in which 95% confidence intervals of error mean included 0; d, whether b and c occurred at the same base temperature; e, mean of heat unit accumulations for the base at b; and f, mean of heat unit accumulations for the base at 12°C.

Type	Column a	 b	 c	 d	 e	 f
Modeling with control plants						
DM	121415	1	0-14	Yes	1987847	1034595 °min
LDM	117090	2	0-14	Yes	1875172	1008552 °min
DH	121366	1	0-14	Yes	33132	17244 °hr
LDH	117090	2	0-14	Yes	31254	16810 °hr
DHI	121274	0	0-14	Yes	34578	17247 °hr
LDHI	117090	3	0-14	Yes	29800	16801 °hr
DDMIN	121897	1	0- 9	Yes	1149	487 °day
LDDMIN	120504	0	0-11	Yes	1137	415 °day
DDMAX	124382	1	0-20	Yes	1715	1053 °day
LDDMAX	118755	14	0-25	Yes	1166	1286 °day
DDMEAN	121415	0	0-14	Yes	1441	718 °day
LDDMEA	117090	3	0-14	Yes	1242	700 °day
Validating models with misted plants						
DM	71130	0	16-19	No	2074510	
LDM	65910	7	0-13	Yes	1441858	
DH	71060	0	16-19	No	34576	
LDH	65910	7	0-13	Yes	24032	
DHI	71176	0	16-19	No	34587	Same as above
LDHI	66023	7	0-13	Yes	24023	
DDMIN	-	-	-	-	-	
LDDMIN	-	-	-	-	-	
DDMAX	72047	1	18-22	No	1715	
LDDMAX	84243	0	-	No	2008	
DDMEAN	71130	0	15-18	No	1441	
LDDMEA	65910	7	0-18	Yes	1001	

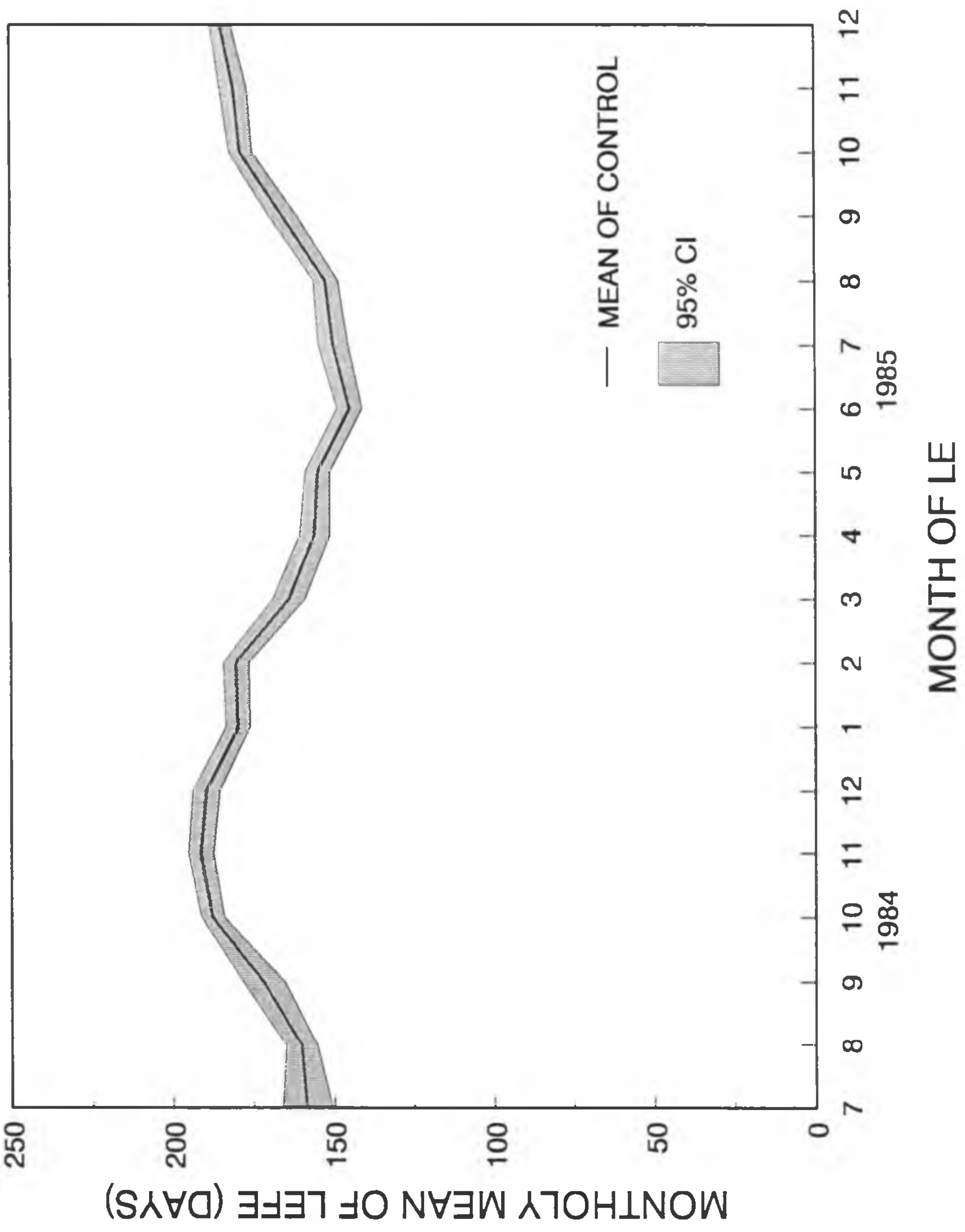


Figure 74. Monthly mean of LEFE (number of days between leaf emergence and flower emergence) in bird of paradise flower growth on the axis of the month of LE for the June 1984-December 1985 period in Hawaii. Fluctuating in 145-192 days with a mean of 168 days, the LEFE exhibited a gentle seasonal fluctuation.

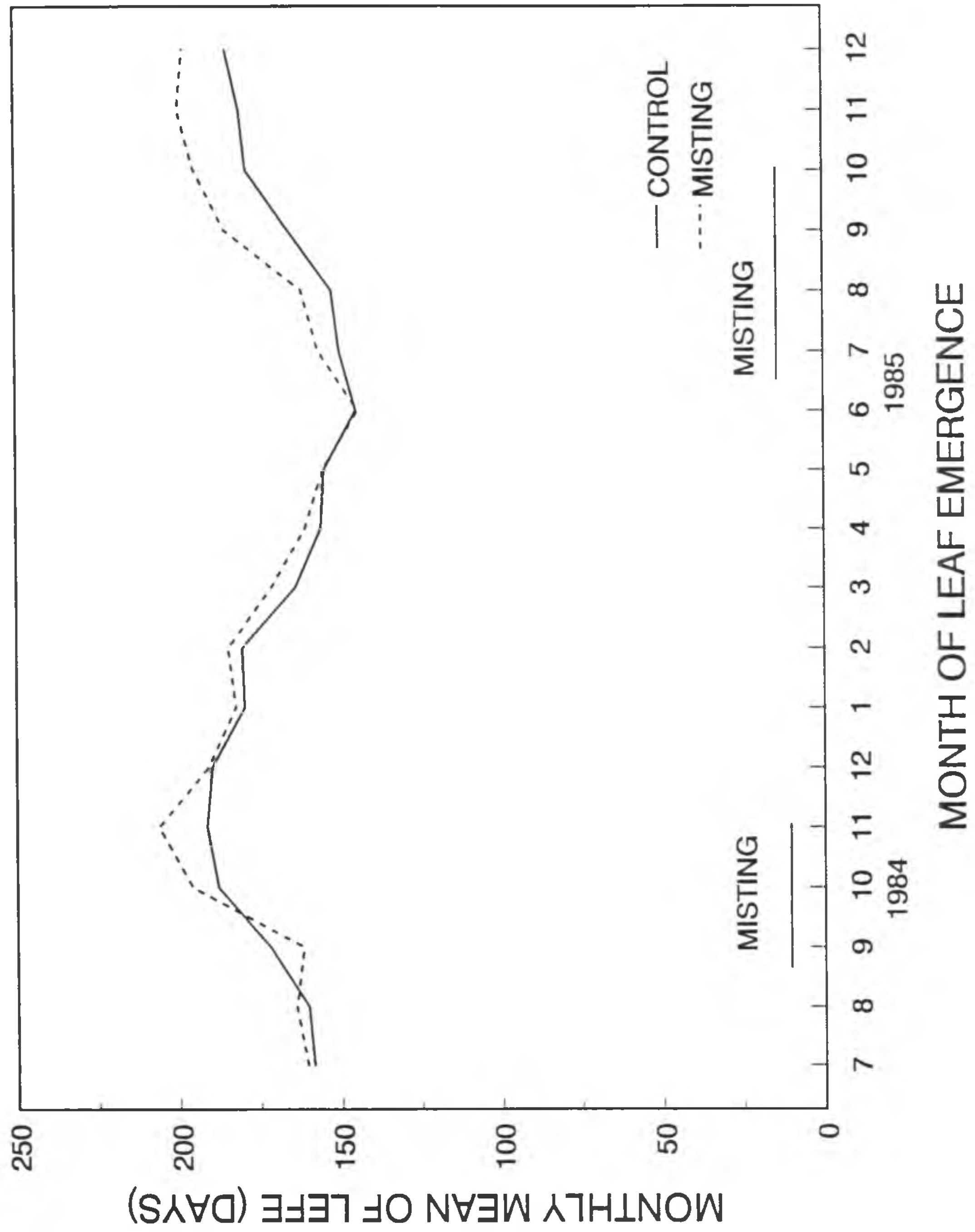


Figure 75. The comparison of LEFE in bird of paradise flower growth with or without the application of intermittent misting (misting and control, respectively). The misting, applied in August 20-November 2 in 1984 and June 14-October 2 in 1985, extended the LEFE intervals as many as 30 days.

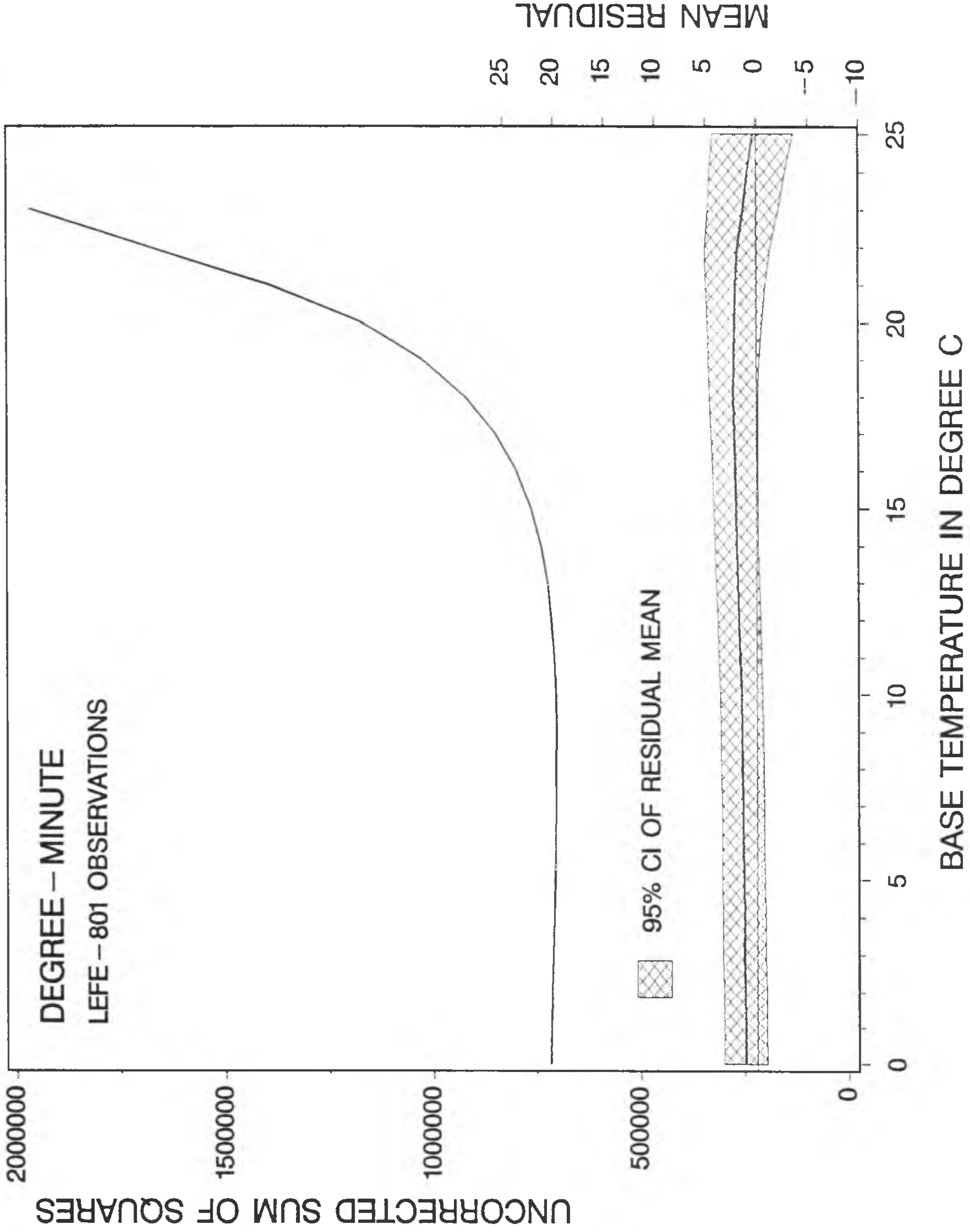


Figure 76. The uncorrected sum of squares for error (USS) and the mean residual of the DM model (degree-minute, Table 53) estimated for the LEFE period in bird of paradise flower growth. The inclusion of 0 mean residual by the confidence limits in the range of base temperatures of low USS indicated that the model was satisfactory.

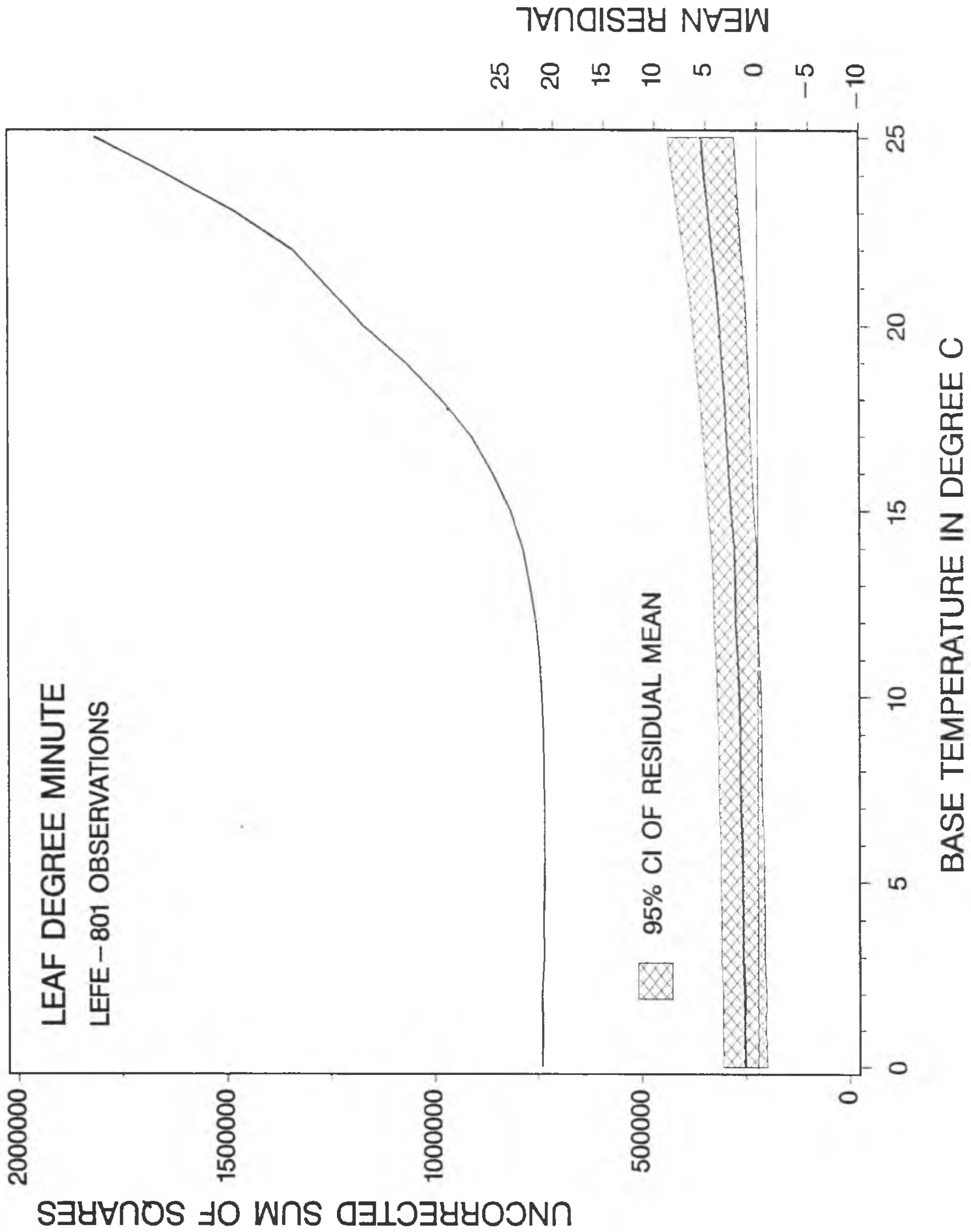


Figure 77. The uncorrected sum of squares for error (USS) and the mean residual of the LDM model (leaf degree-minute, Table 53) estimated for the LEFE period in bird of paradise flower growth. The inclusion of 0 mean residual by the confidence limits in the range of base temperatures of low USS indicated that the model was satisfactory.

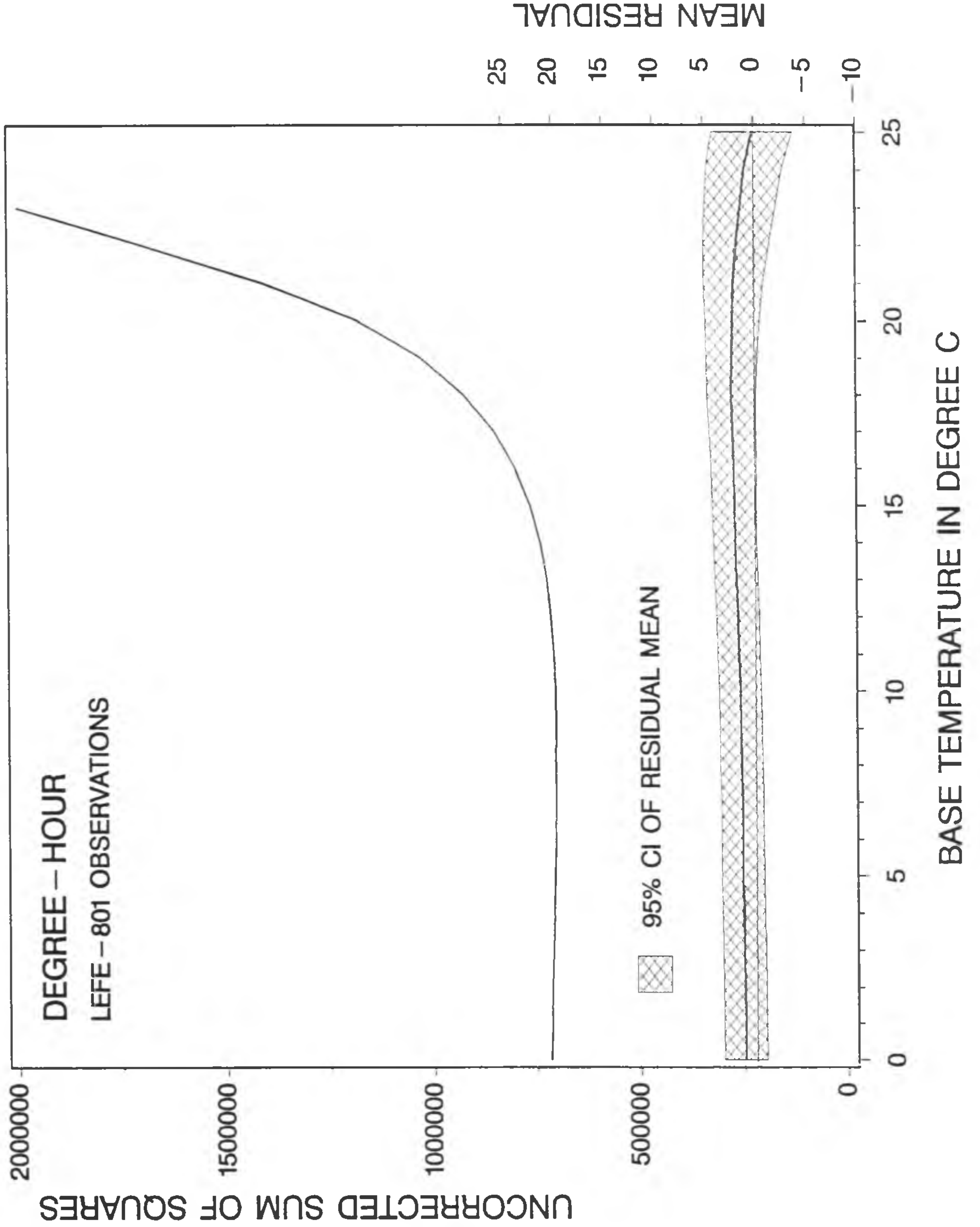


Figure 78. The uncorrected sum of squares for error (USS) and the mean residual of the DH model (degree-hour, Table 53) estimated for the LEFE period in bird of paradise flower growth. The inclusion of 0 mean residual by the confidence limits in the range of base temperatures of low USS indicated that the model was satisfactory.

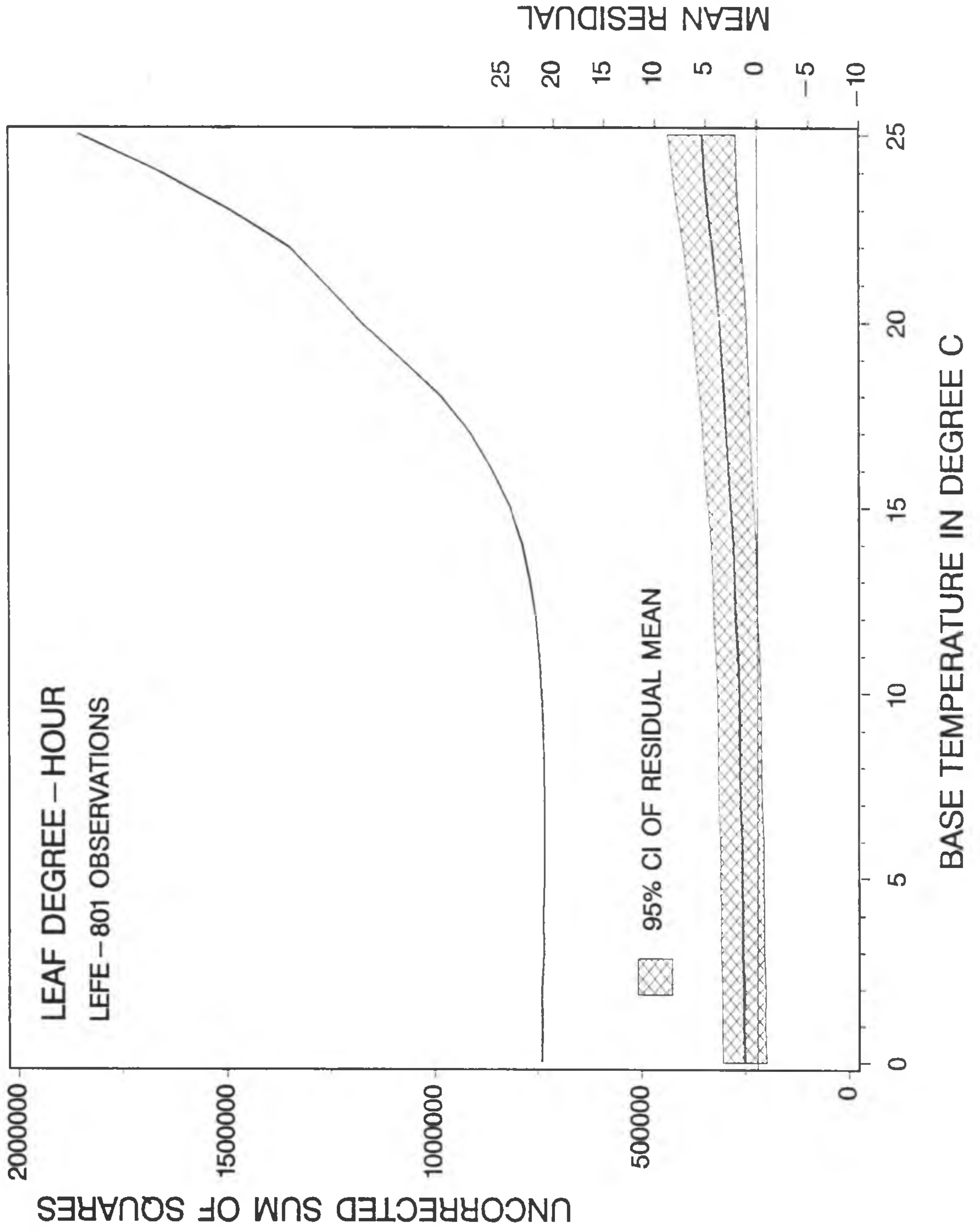


Figure 79. The uncorrected sum of squares for error (USS) and the mean residual of the LDH model (leaf degree-hour, Table 53) estimated for the LEFE period in bird of paradise flower growth. The inclusion of 0 mean residual by the confidence limits in the range of base temperatures of low USS indicated that the model was satisfactory.

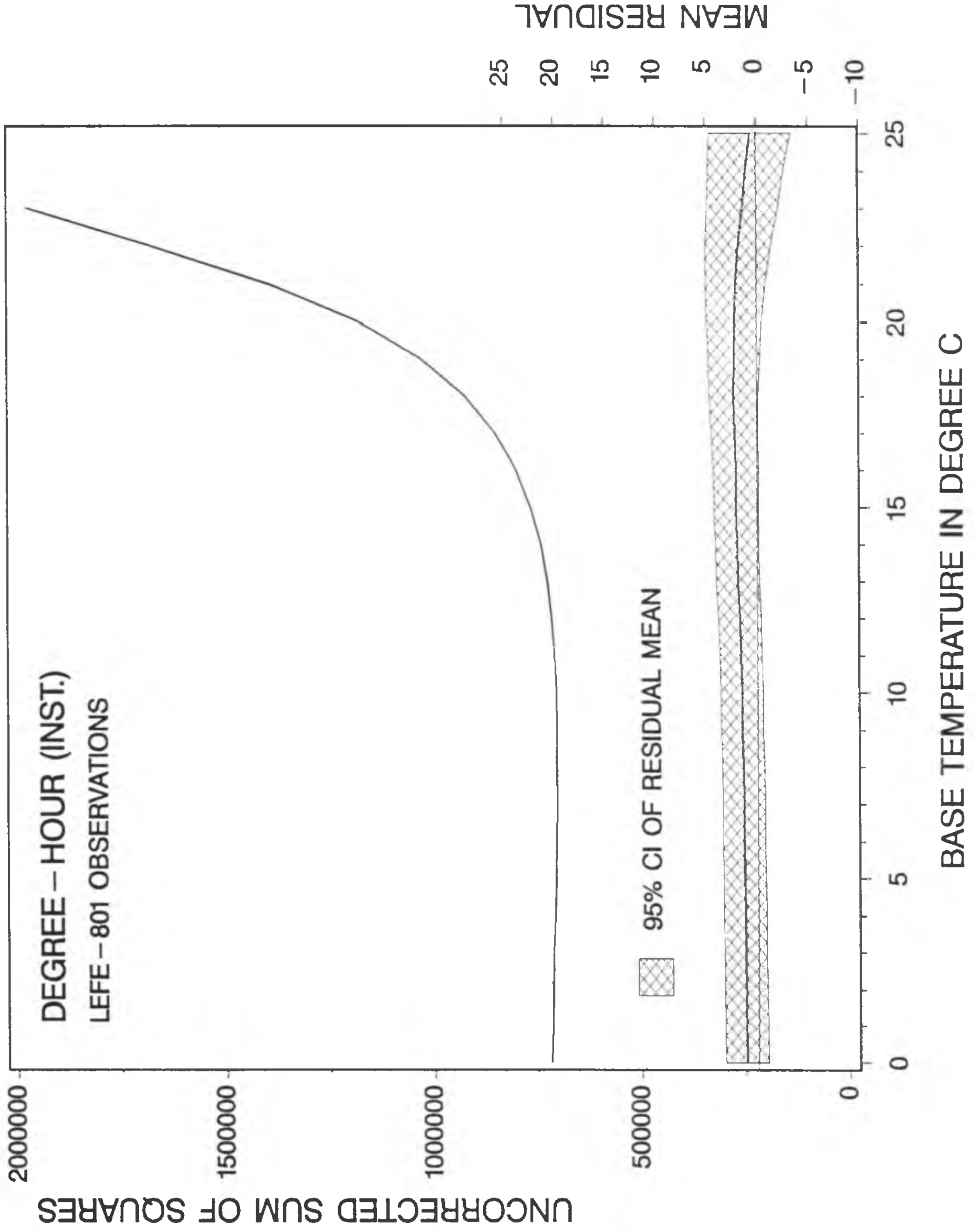


Figure 80. The uncorrected sum of squares for error (USS) and the mean residual of the DHI model (degree-hour, instantaneous, Table 53) estimated for the LEFE period in bird of paradise flower growth. The inclusion of 0 mean residual by the confidence limits in the range of base temperatures of low USS indicated that the model was satisfactory.

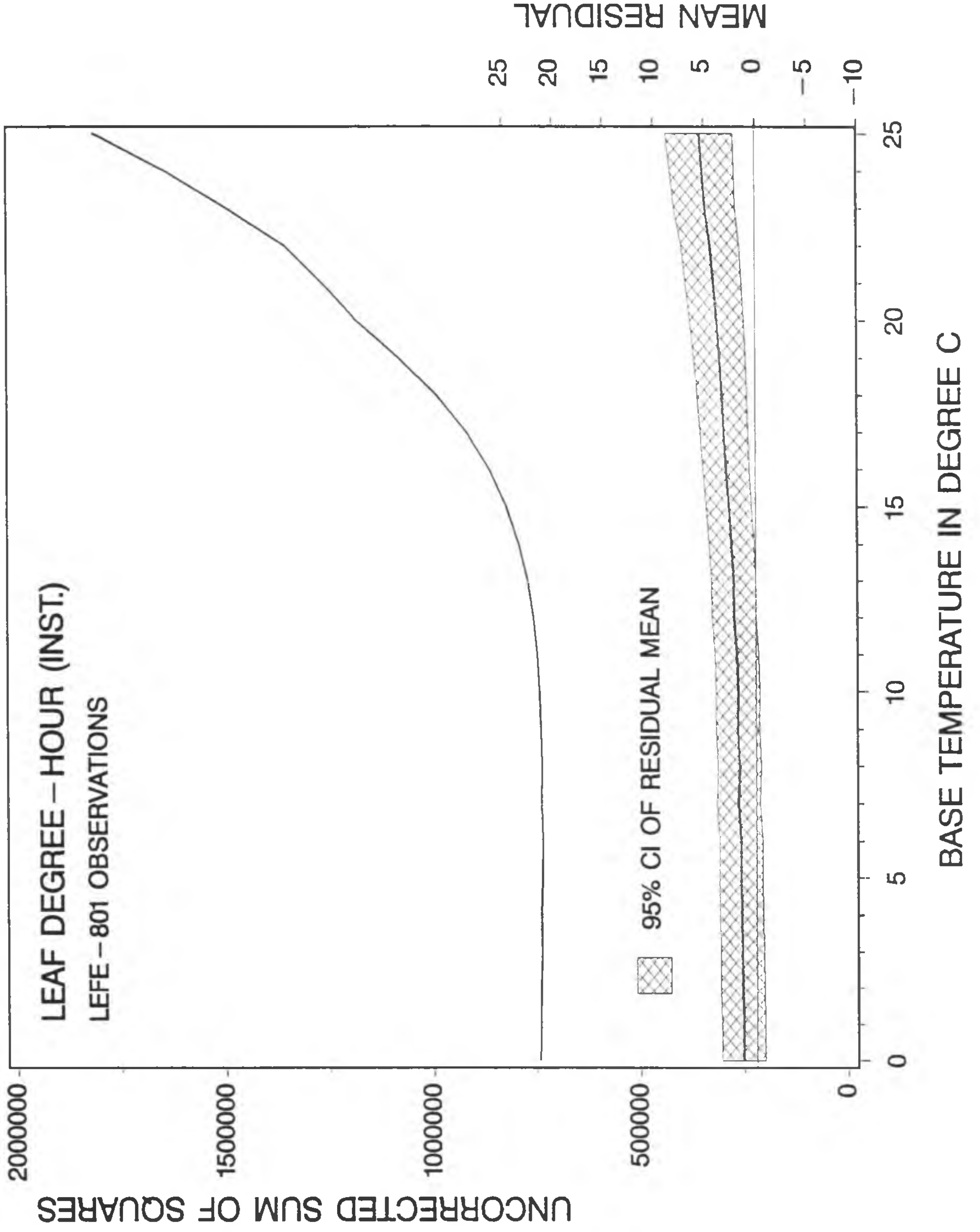


Figure 81. The uncorrected sum of squares for error (USS) and the mean residual of the LDHI model (leaf degree-hour, instantaneous, Table 53) estimated for the LEFE period in bird of paradise flower growth. The inclusion of 0 mean residual by the confidence limits in the range of base temperatures of low USS indicated that the model was satisfactory.

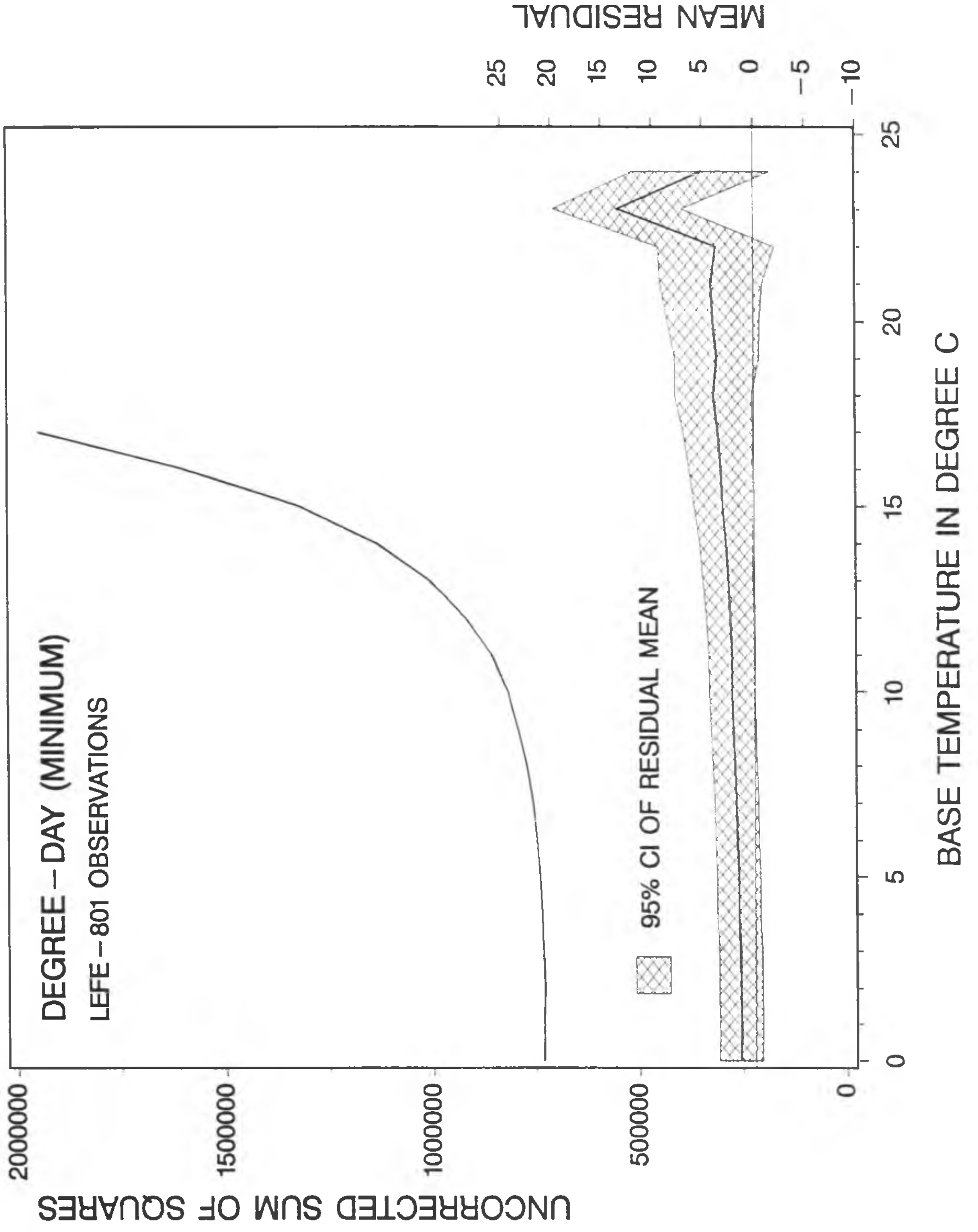


Figure 82. The uncorrected sum of squares for error (USS) and the mean residual of the DDMIN model (degree-day, minimum, Table 53) estimated for the LEFE period in bird of paradise flower growth. The inclusion of 0 mean residual by the confidence limits in the range of base temperatures of low USS indicated that the model was satisfactory.

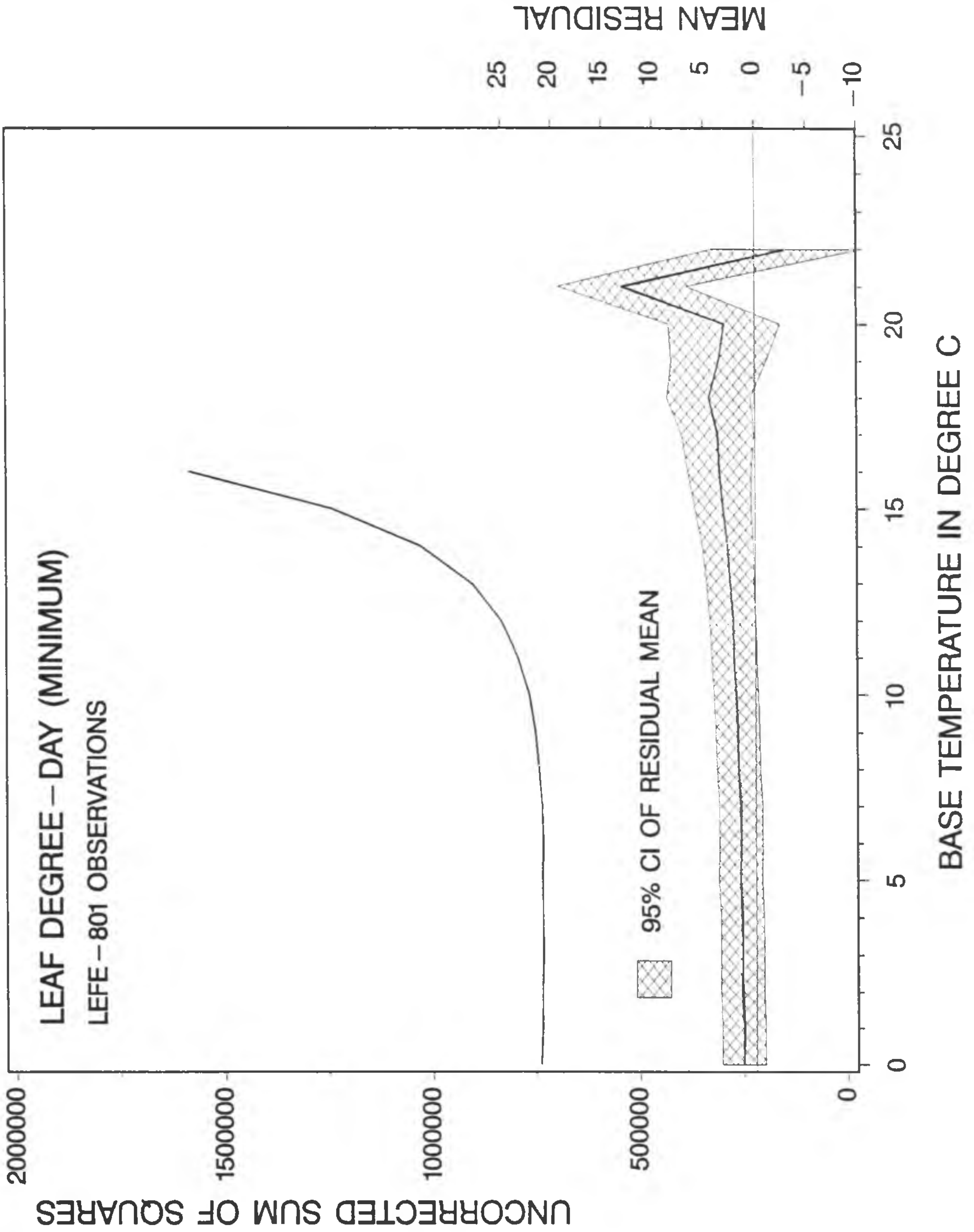


Figure 83. The uncorrected sum of squares for error (USS) and the mean residual of the LDDMIN model (leaf degree-day, minimum, Table 53) estimated for the LEFE period in bird of paradise flower growth. The inclusion of 0 mean residual by the confidence limits in the range of base temperatures of low USS indicated that the model was satisfactory.

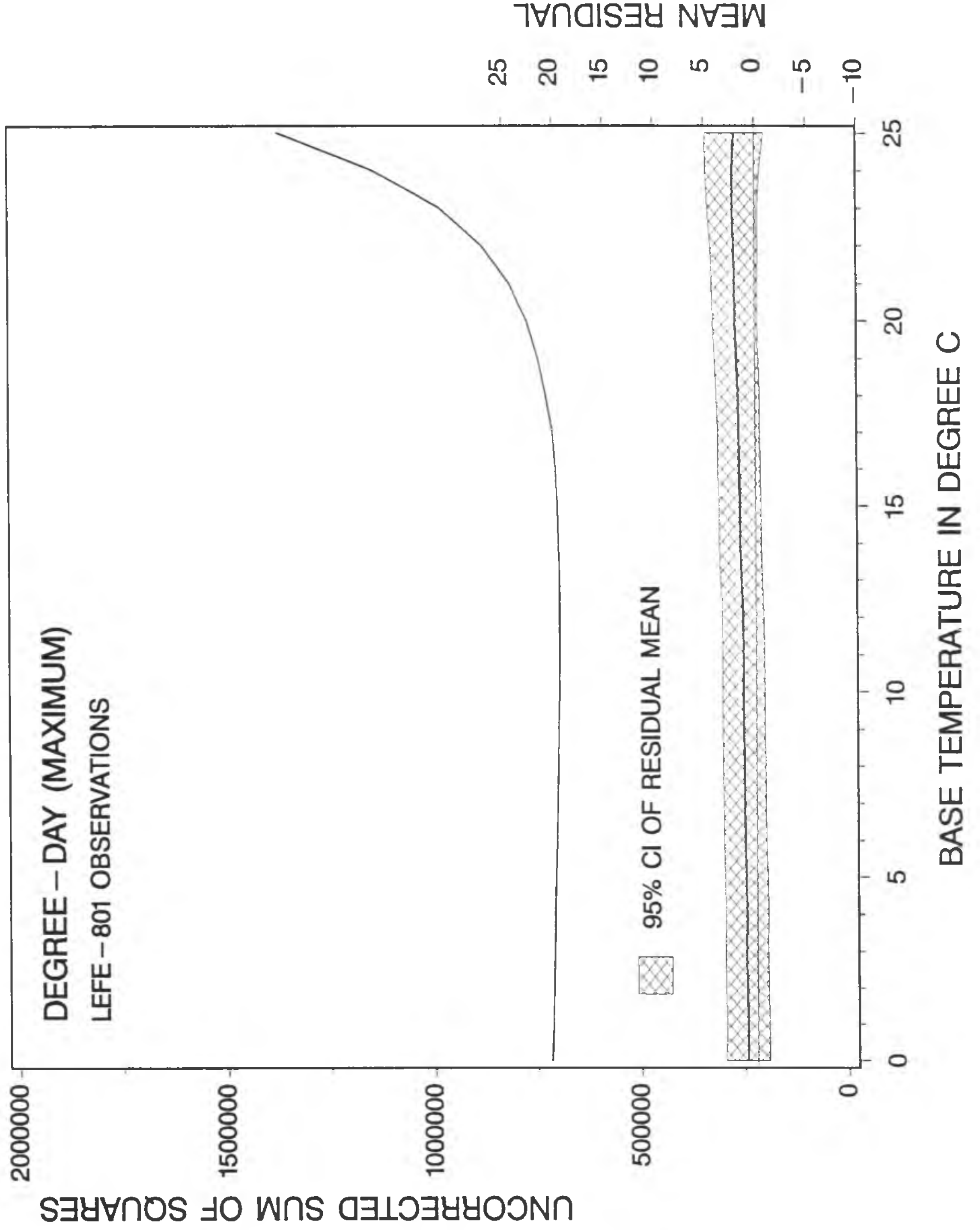


Figure 84. The uncorrected sum of squares for error (USS) and the mean residual of the DDMAX model (degree-day, maximum, Table 53) estimated for the LEFE period in bird of paradise flower growth. The inclusion of 0 mean residual by the confidence limits in the range of base temperatures of low USS indicated that the model was satisfactory.

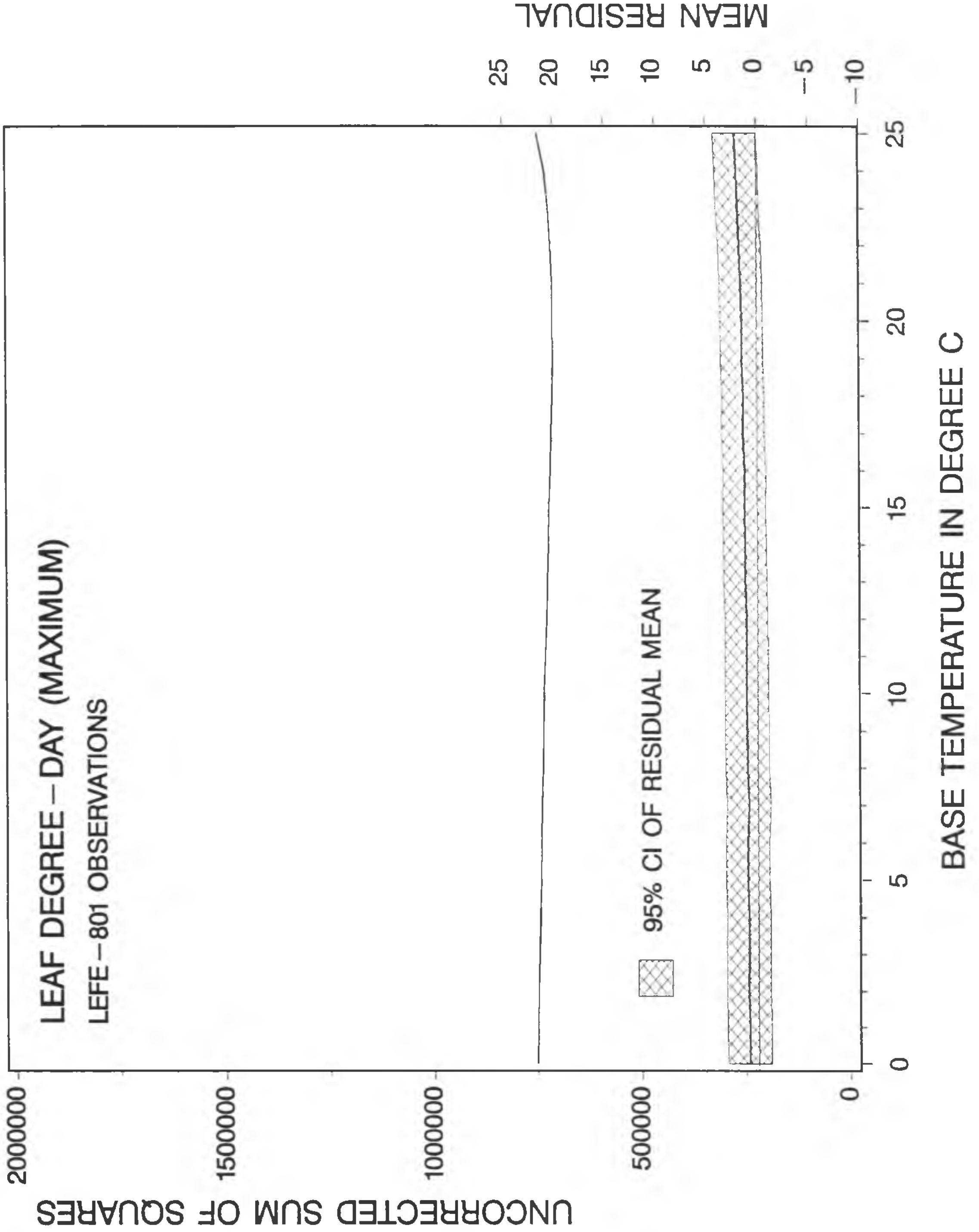


Figure 85. The uncorrected sum of squares for error (USS) and the mean residual of the LDDMAX model (leaf degree-day, maximum, Table 53) estimated for the LEFE period in bird of paradise flower growth. The inclusion of 0 mean residual by the confidence limits in the range of base temperatures of low USS indicated that the model was satisfactory.

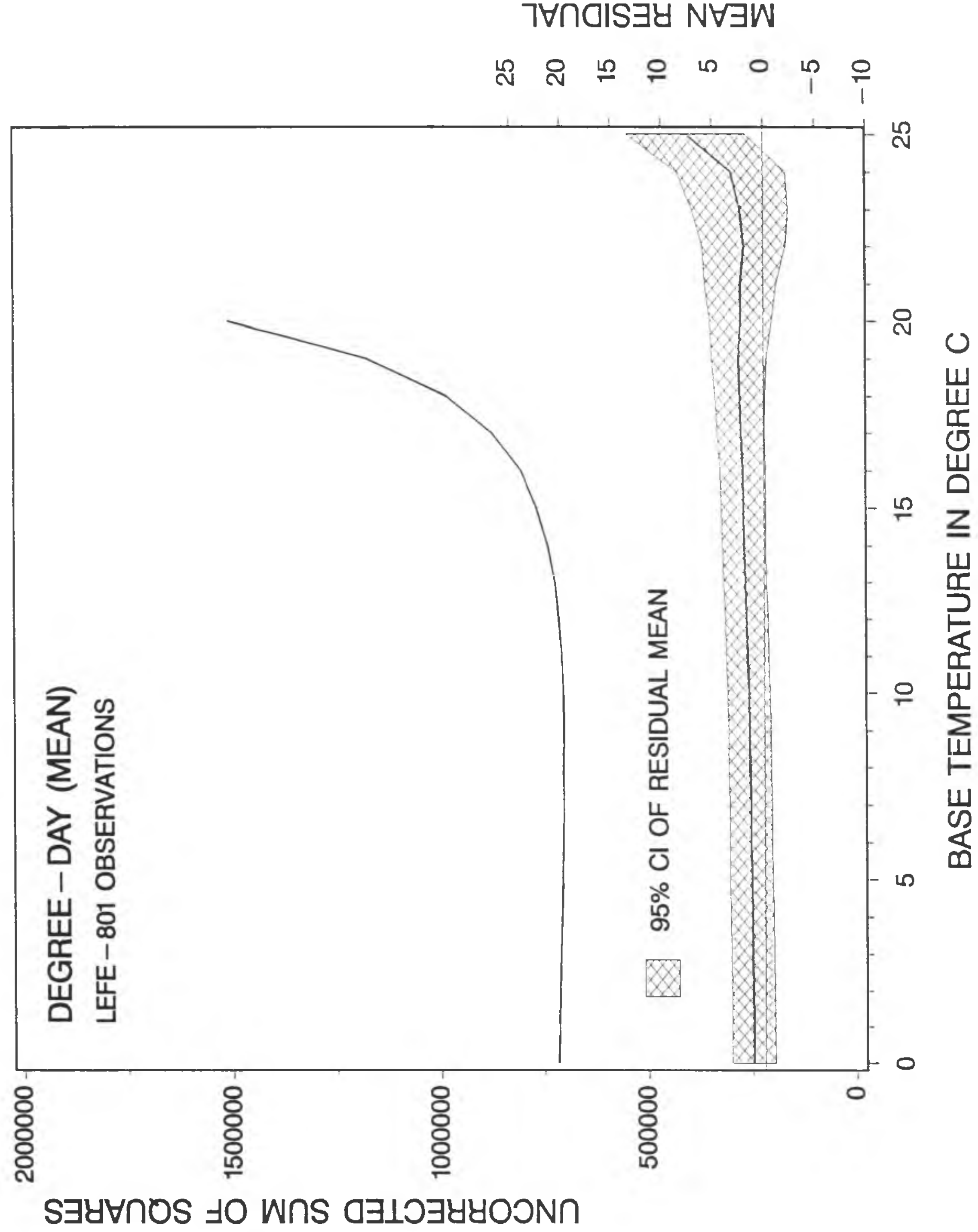


Figure 86. The uncorrected sum of squares for error (USS) and the mean residual of the DDMEAN model (degree-day, mean, Table 53) estimated for the LEFE period in bird of paradise flower growth. The inclusion of 0 mean residual by the confidence limits in the range of base temperatures of low USS indicated that the model was satisfactory.

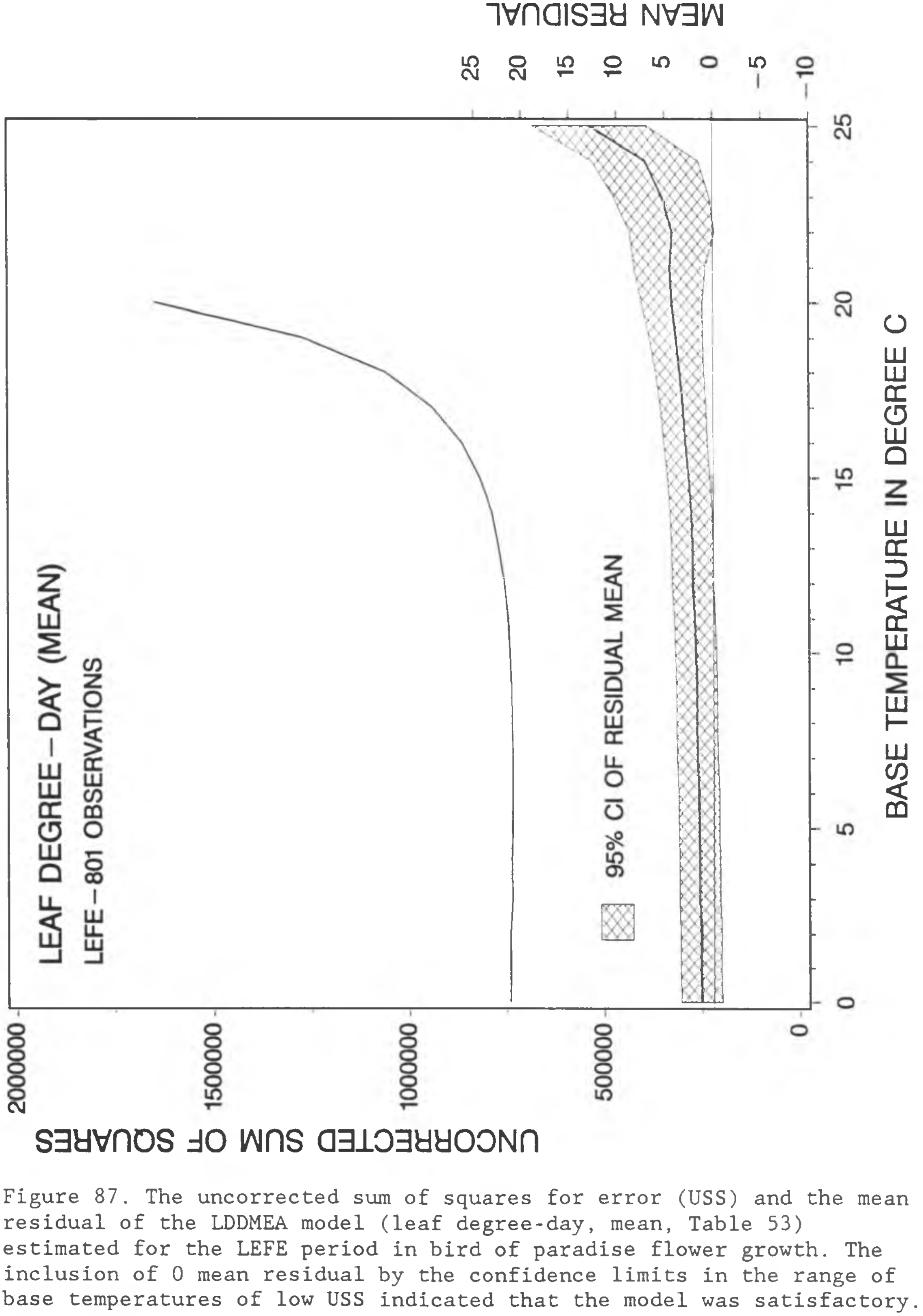


Figure 87. The uncorrected sum of squares for error (USS) and the mean residual of the LDDMEA model (leaf degree-day, mean, Table 53) estimated for the LEFE period in bird of paradise flower growth. The inclusion of 0 mean residual by the confidence limits in the range of base temperatures of low USS indicated that the model was satisfactory.

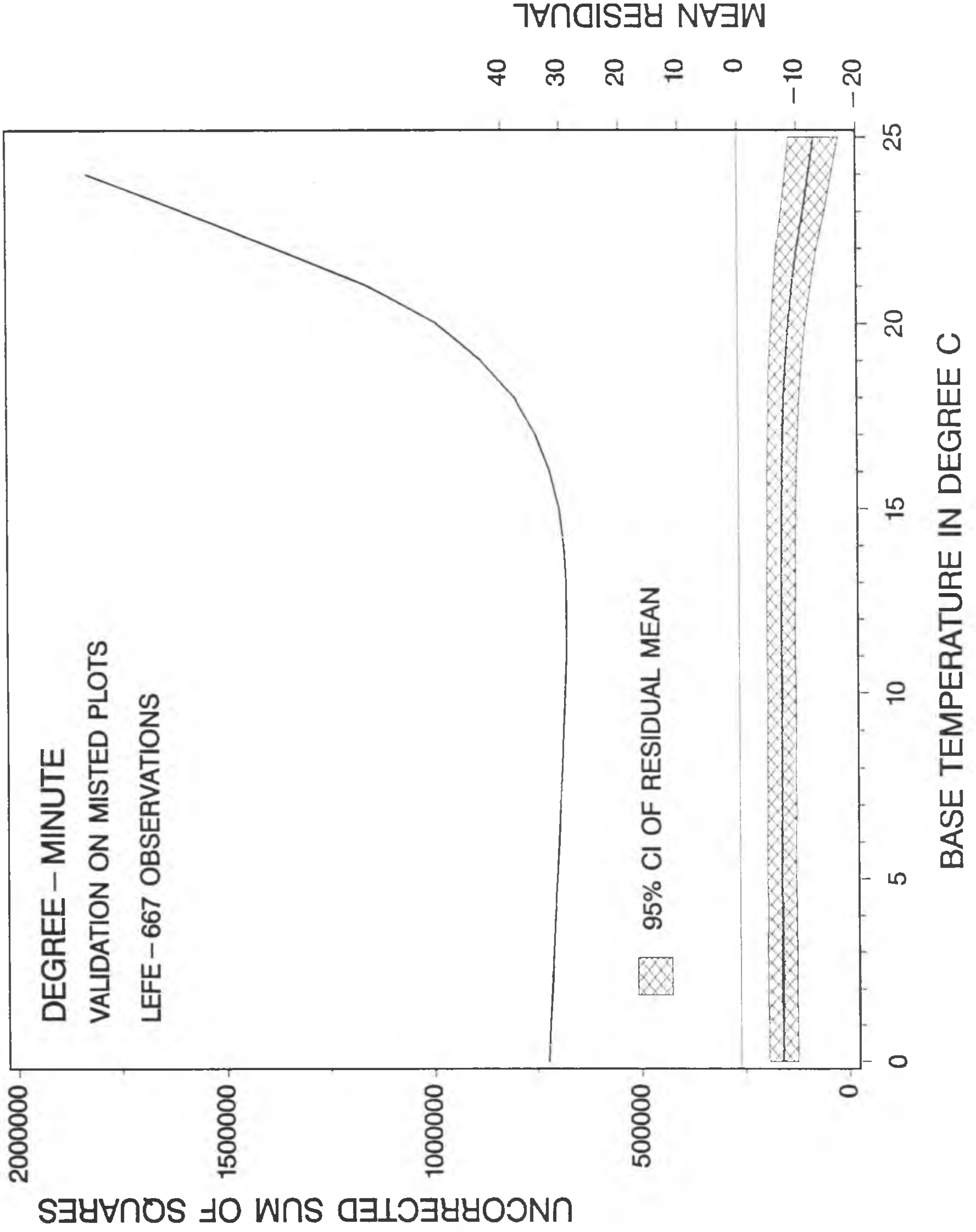


Figure 88. Validation of the DM model (degree-minute, Table 54). The mean heat units accumulated for control plants were used to estimate the FE for misted plants. The exclusion of 0 mean residual by the confidence limits indicated that the model was not satisfactory.

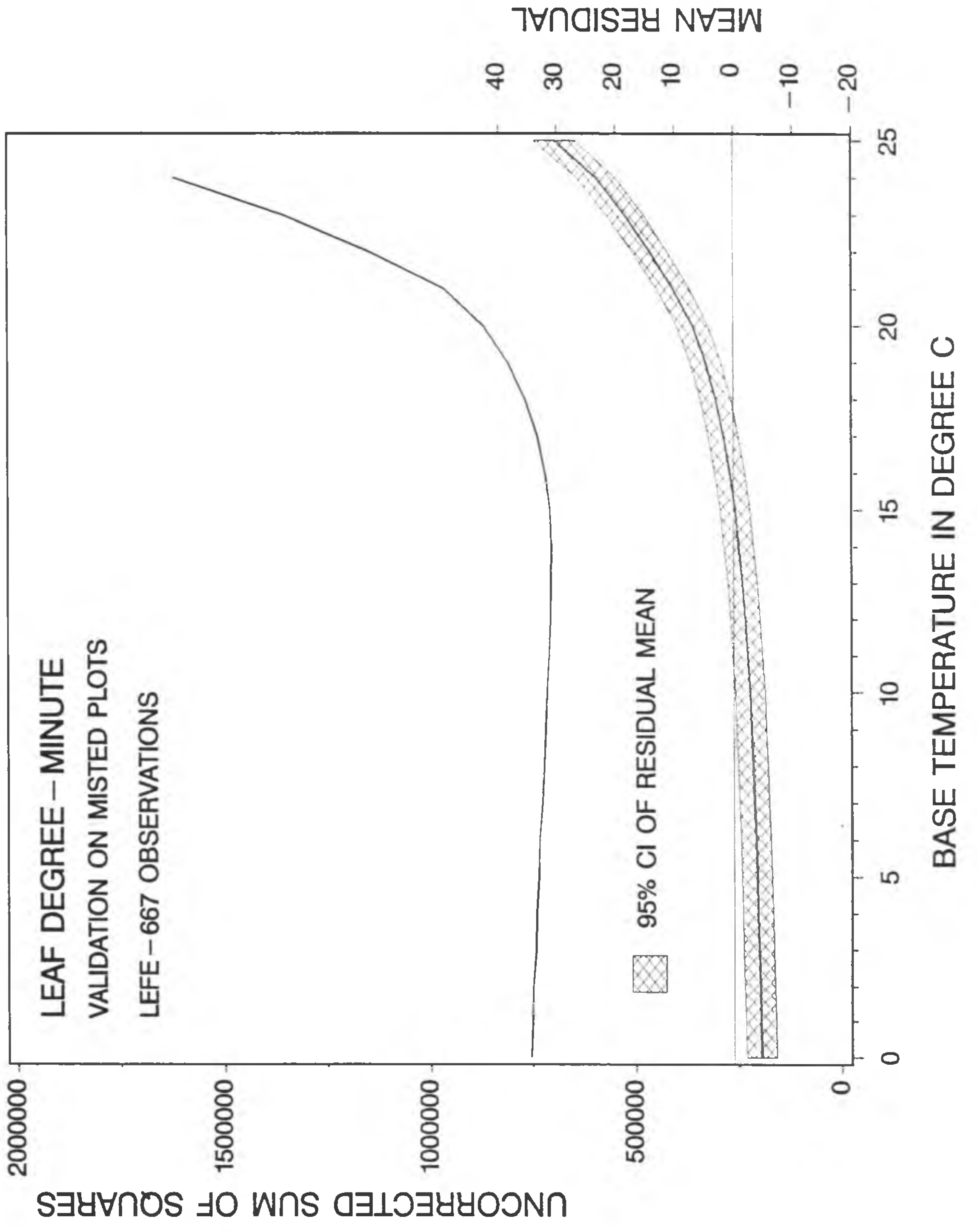


Figure 89. Validation of the LDM model (leaf degree-minute, Table 54). The mean heat units accumulated for control plants were used to estimate the FE for misted plants. The inclusion of 0 mean residual by the confidence limits at the base temperature for the minimum uncorrected sum of squares indicated that the model was satisfactory within the 10-18°C base temperature range.

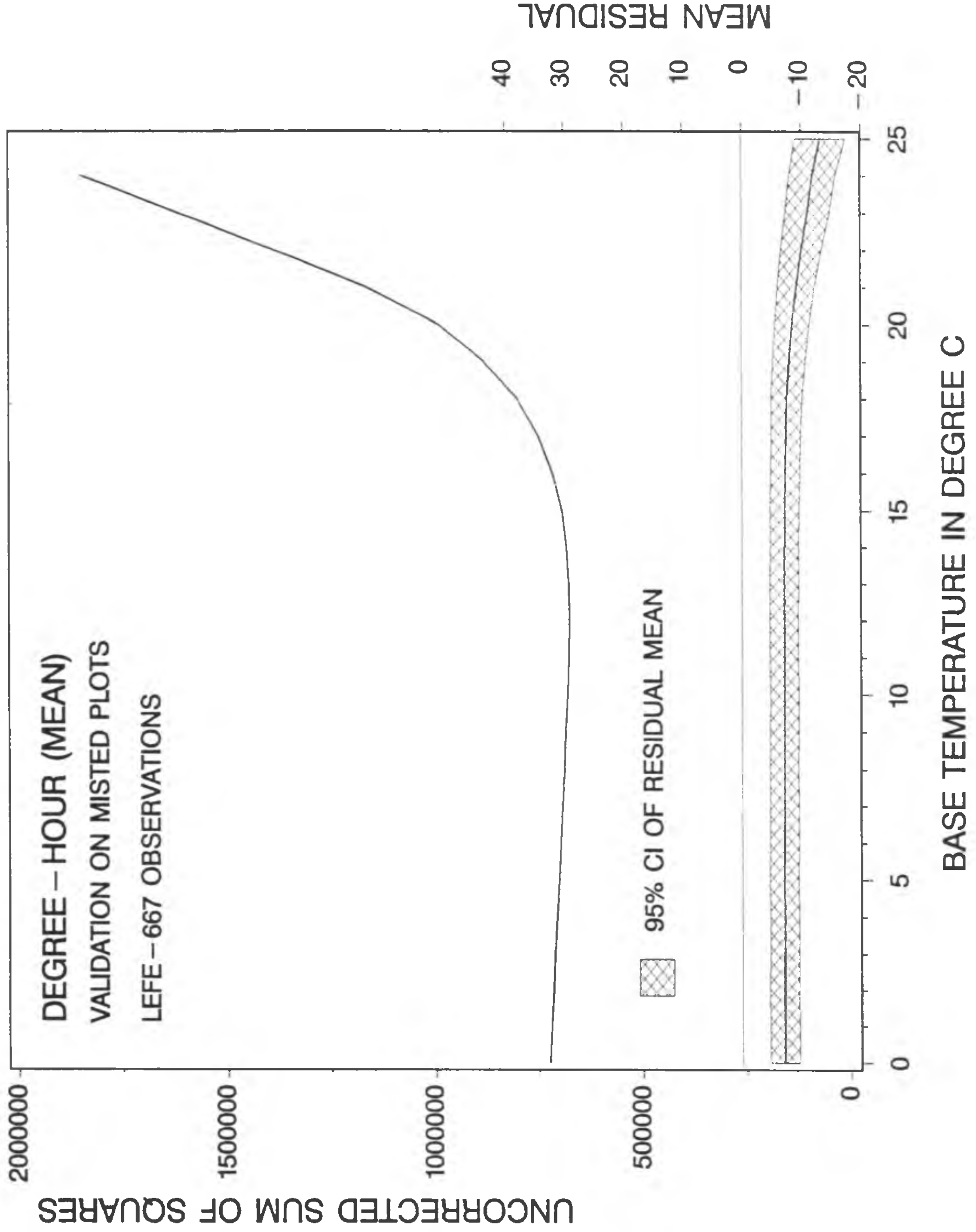


Figure 90. Validation of the DH model (degree-hour, Table 54). The mean heat units accumulated for control plants were used to estimate the FE for misted plants. The exclusion of 0 mean residual by the confidence limits indicated that the model was not satisfactory.

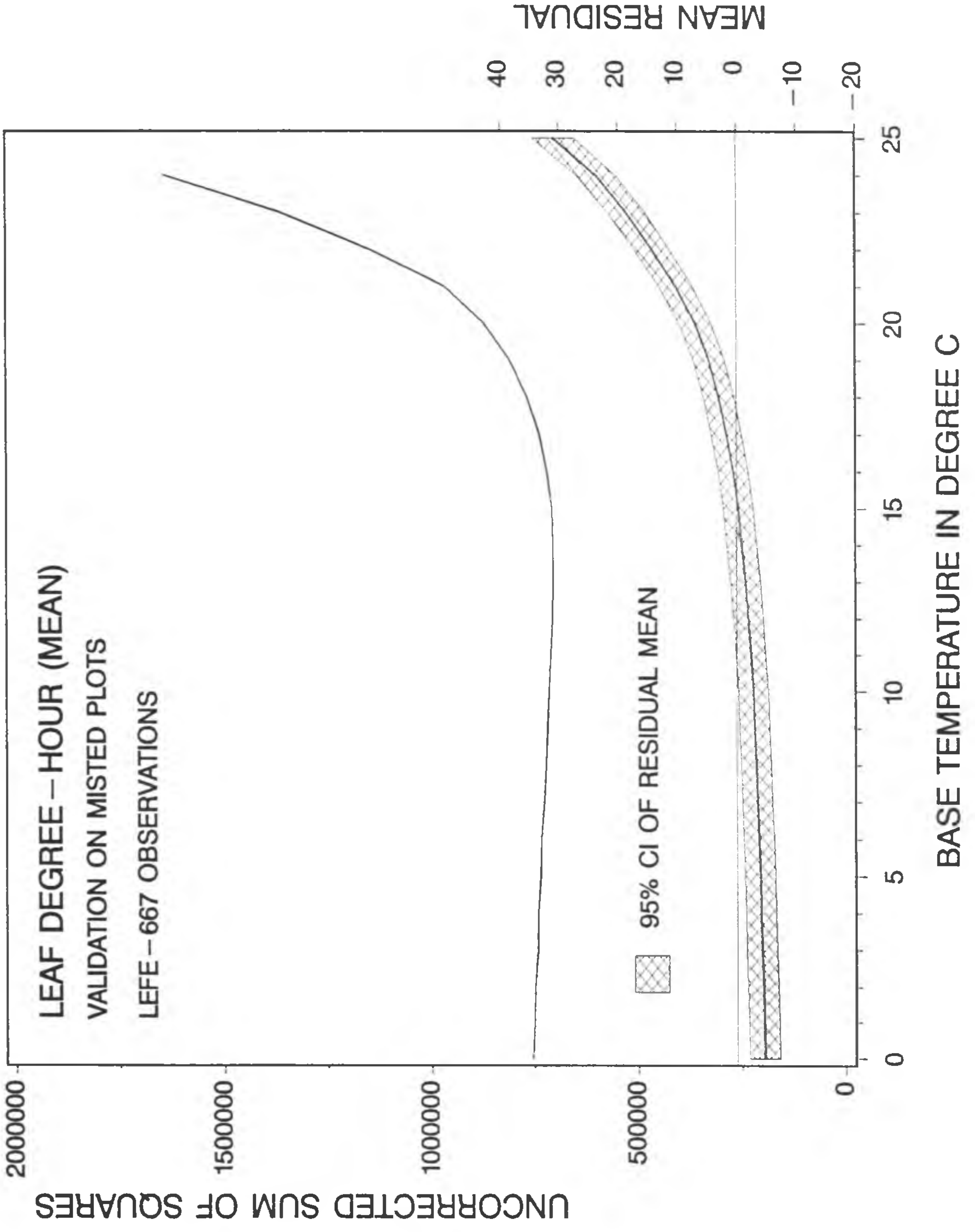


Figure 91. Validation of the LDH model (leaf degree-hour, Table 54). The mean heat units accumulated for control plants were used to estimate the FE for misted plants. The inclusion of 0 mean residual by the confidence limits at the base temperature for the minimum uncorrected sum of squares indicated that the model was satisfactory.

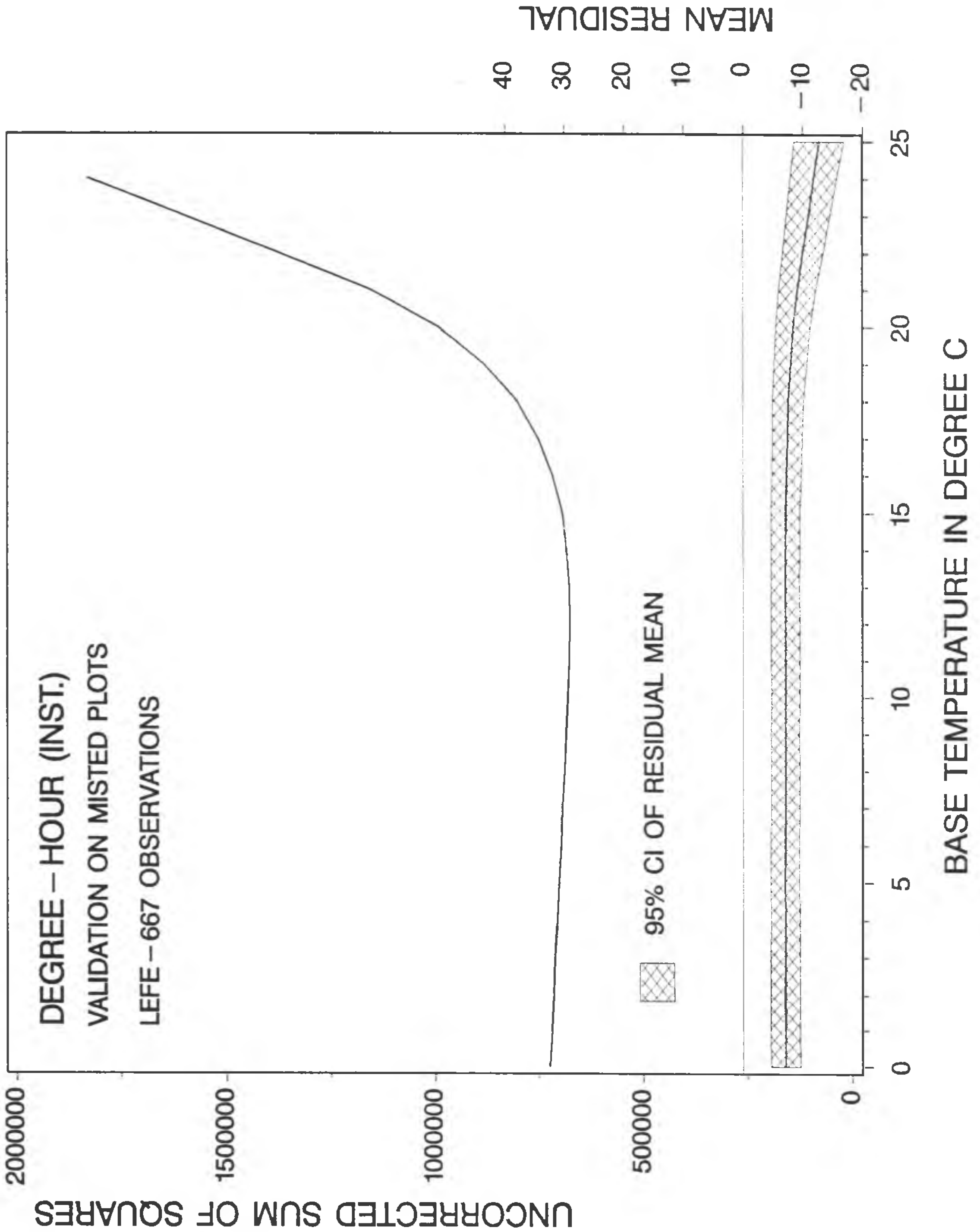


Figure 92. Validation of the DHI model (degree-hour, instantaneous, Table 54). The mean heat units accumulated for control plants were used to estimate the FE for misted plants. The exclusion of 0 mean residual by the confidence limits indicated that the model was not satisfactory.

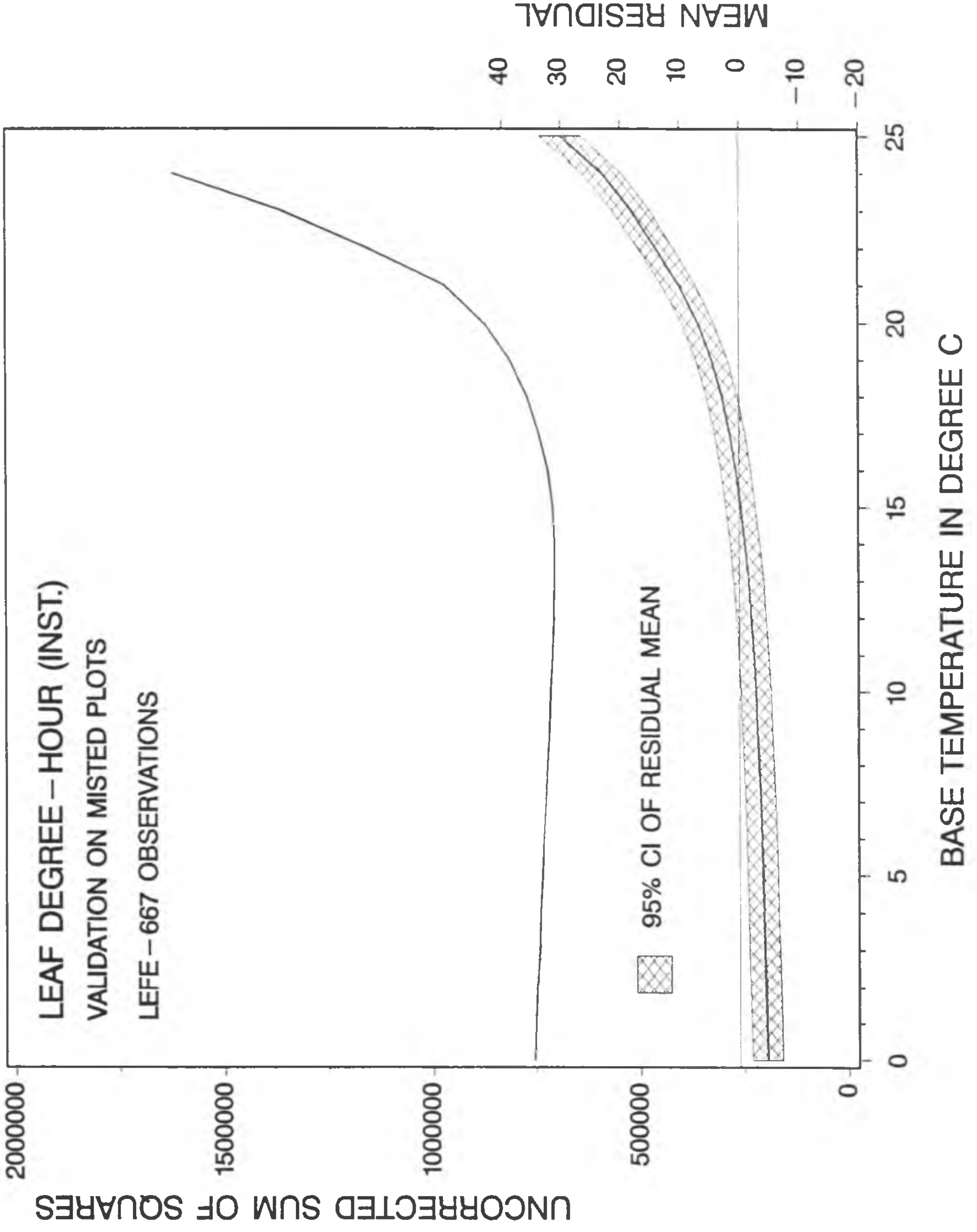


Figure 93. Validation of the LDHI model (leaf degree-hour, instantaneous, Table 54). The mean heat units accumulated for control plants were used to estimate the FE for misted plants. The inclusion of 0 mean residual by the confidence limits at the base temperature for the minimum uncorrected sum of squares indicated that the model was satisfactory.

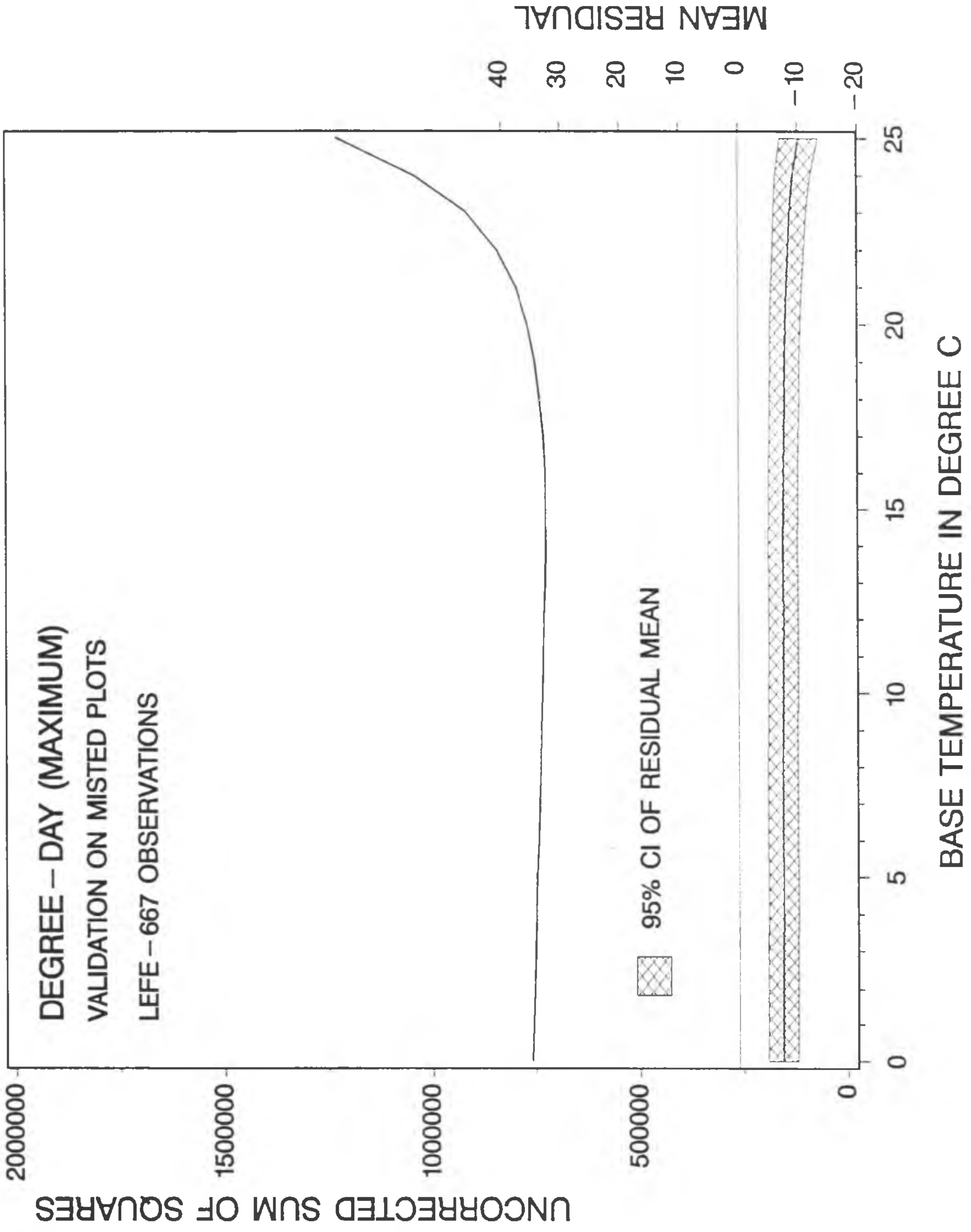


Figure 94. Validation of the DDMAX model (degree-day, maximum, Table 54). The mean heat units accumulated for control plants were used to estimate the FE for misted plants. The exclusion of 0 mean residual by the confidence limits indicated that the model was not satisfactory.

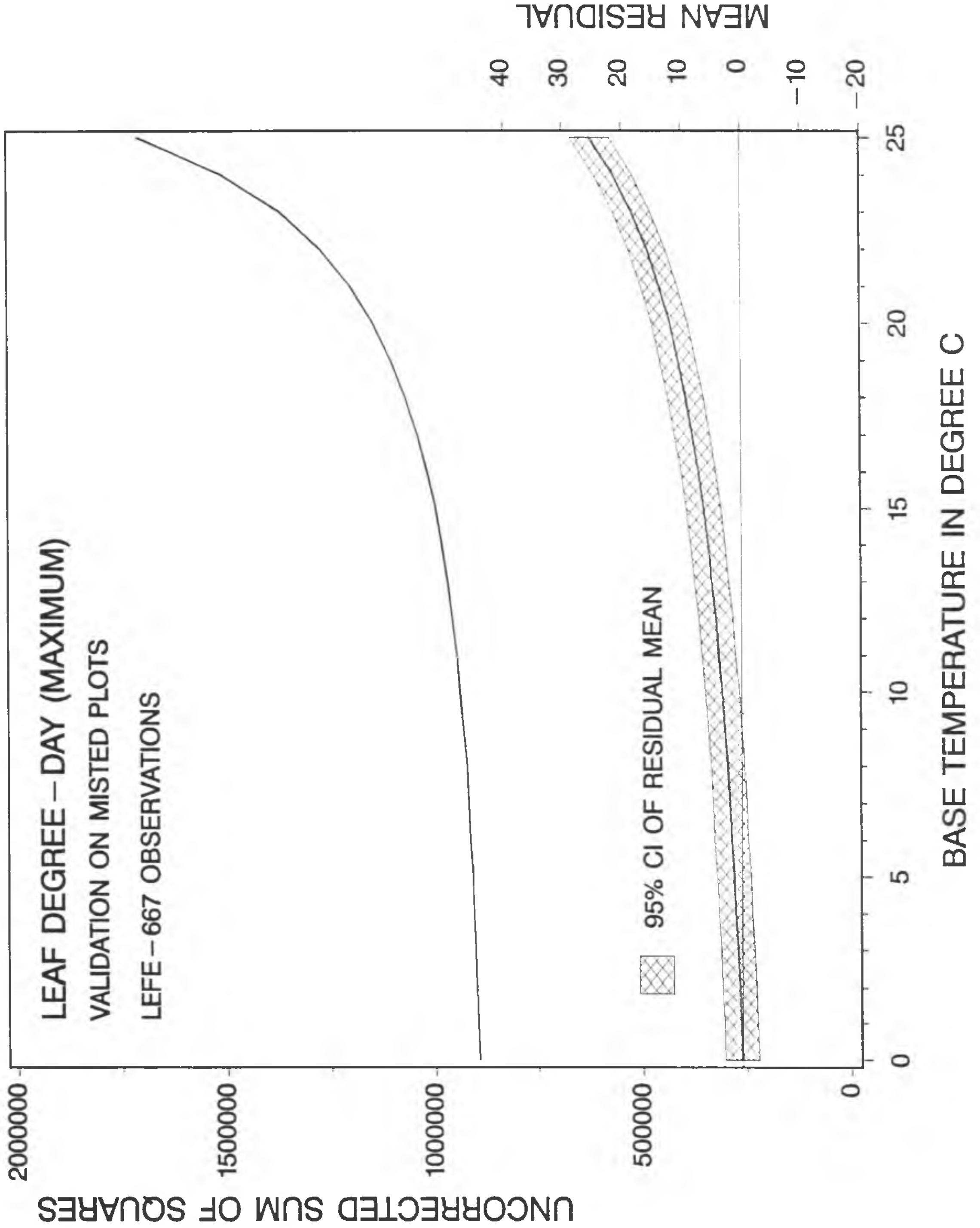


Figure 95. Validation of the LDDMAX model (leaf degree-day, maximum, Table 54). The mean heat units accumulated for control plants were used to estimate the FE for misted plants. The inclusion of 0 mean residual by the confidence limits at the base temperature for the minimum uncorrected sum of squares indicated that the model was satisfactory.

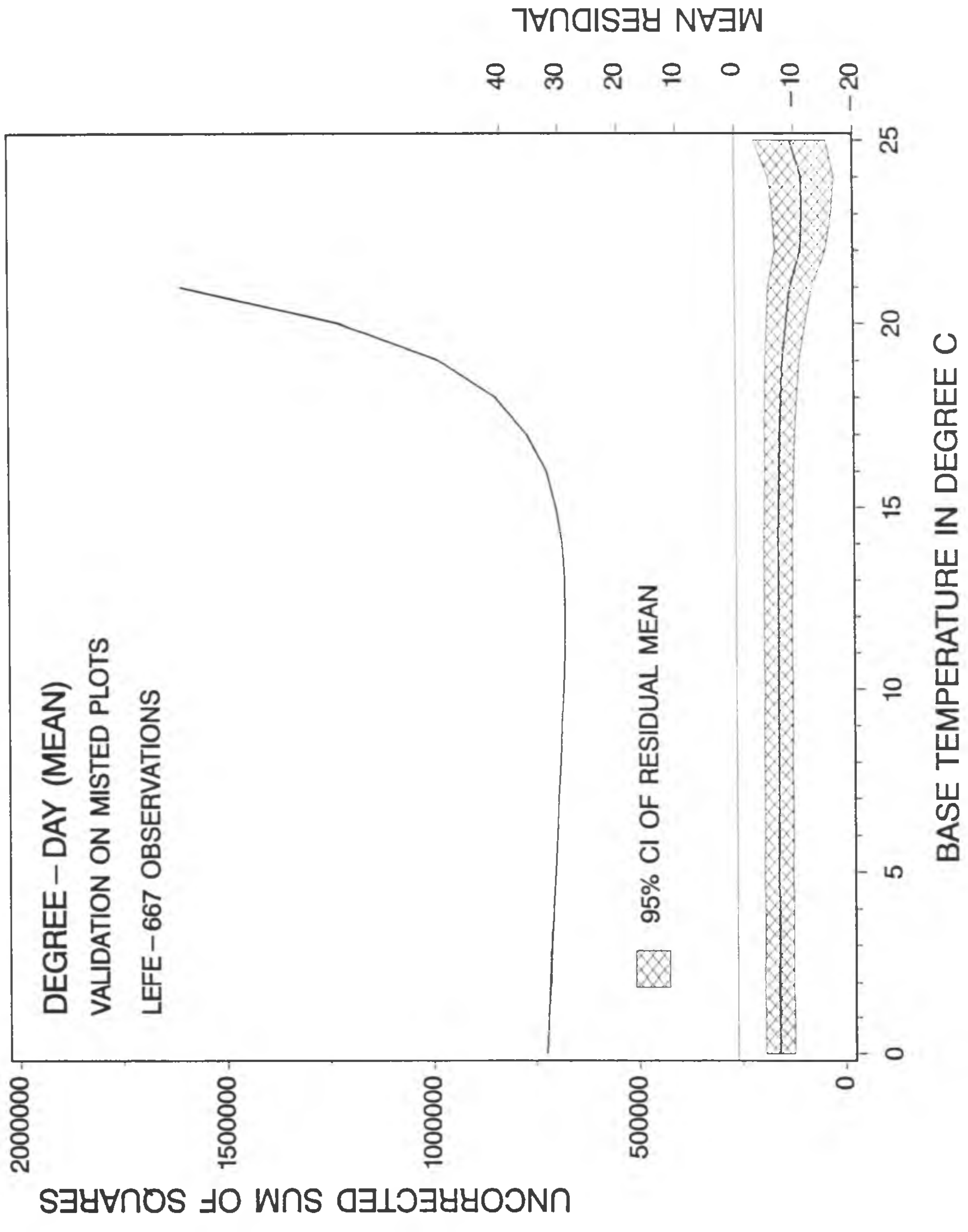


Figure 96. Validation of the DDMEAN model (degree-day, mean, Table 54). The mean heat units accumulated for control plants were used to estimate the FE for misted plants. The exclusion of 0 mean residual by the confidence limits indicated that the model was not satisfactory.

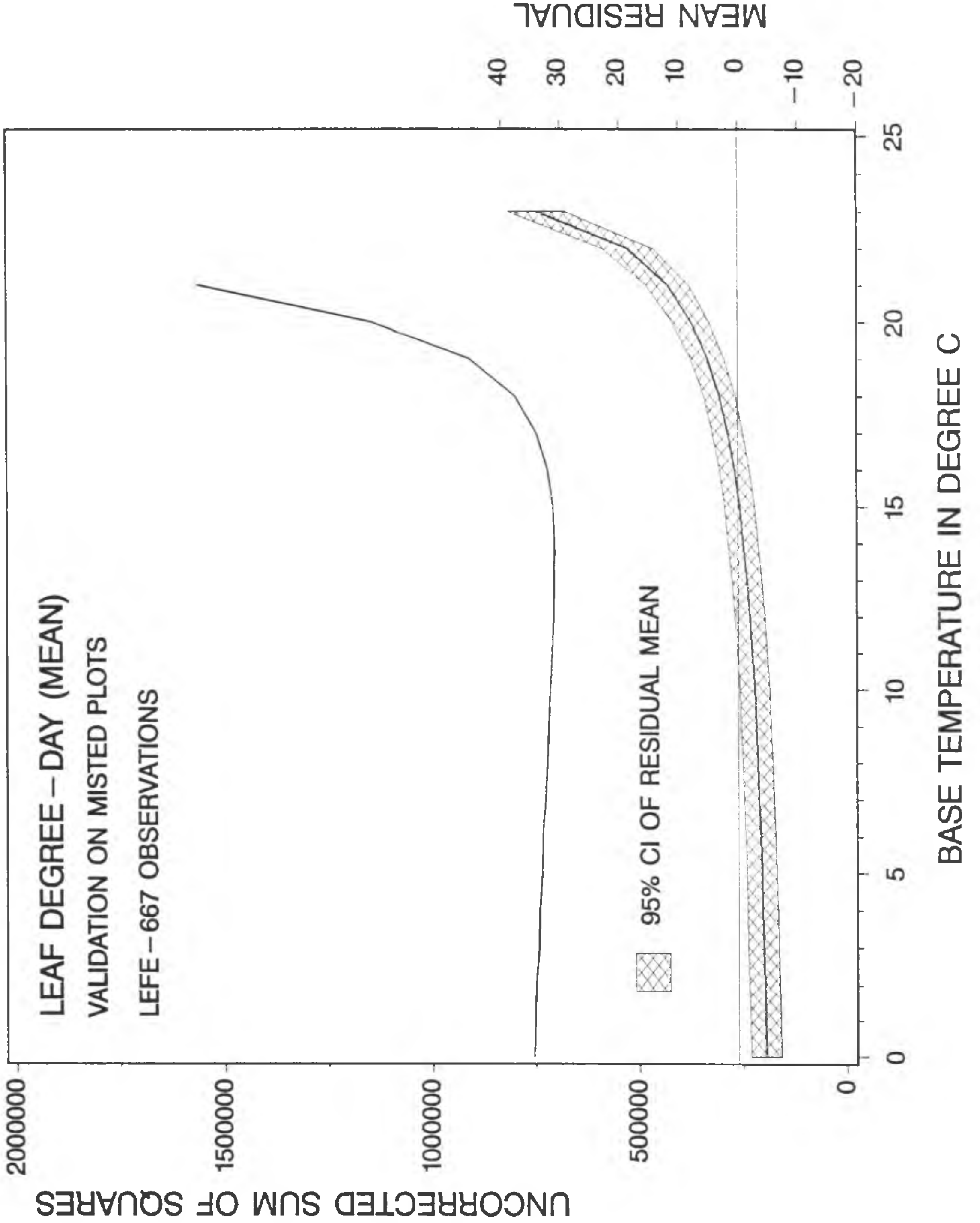


Figure 97. Validation of the LDDMEA model (leaf degree-day, mean, Table 54). The mean heat units accumulated for control plants were used to estimate the FE for misted plants. The inclusion of 0 mean residual by the confidence limits at the base temperature for the minimum uncorrected sum of squares indicated that the model was satisfactory.

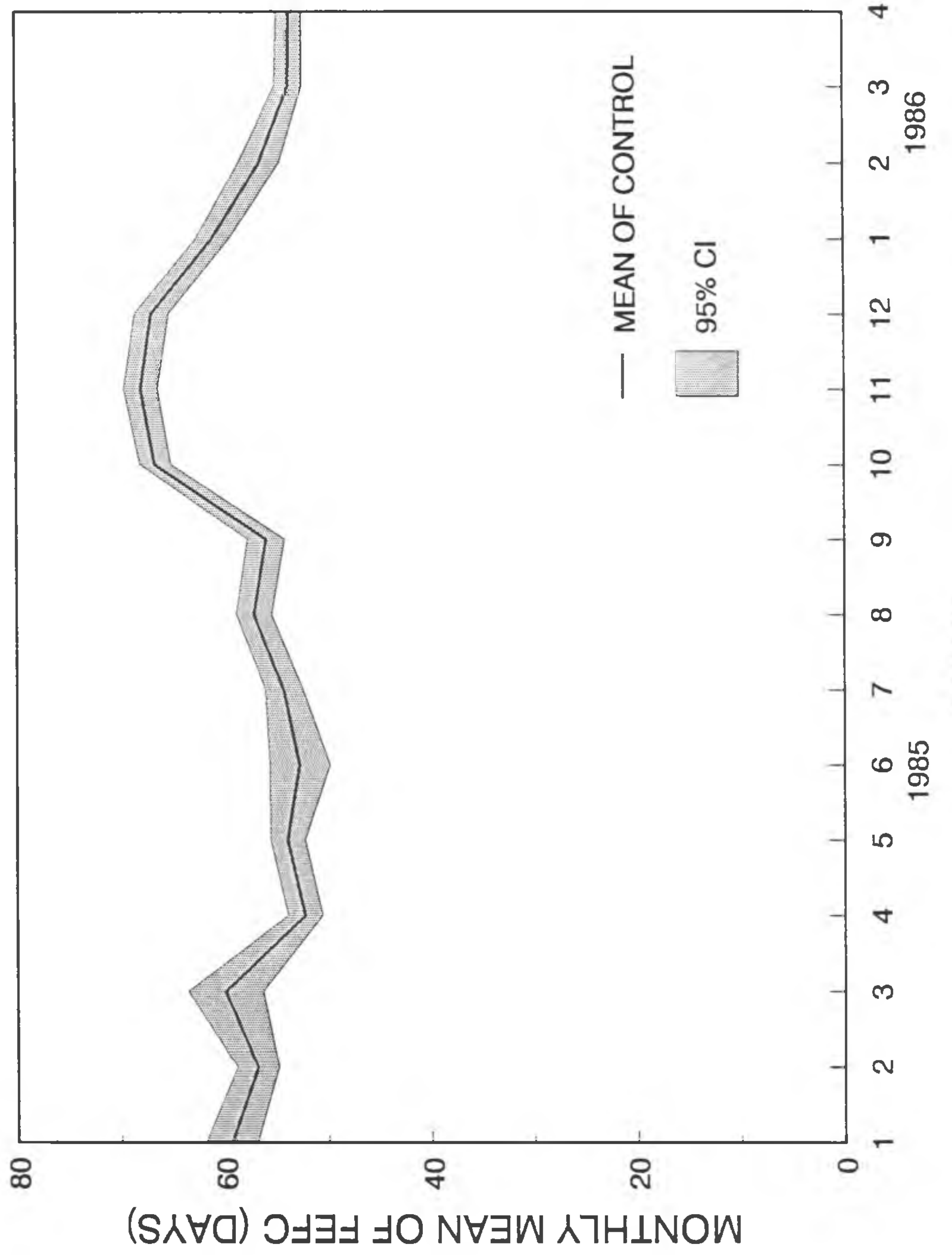


Figure 98. Monthly mean of FEFC (number of days between flower emergence and flower cut) in bird of paradise flower growth on the axis of the month of FE for the January 1985-December 1986 period in Hawaii. Fluctuating in 53-68 days with a mean of 58 days, the FEFC exhibited a slightly long period in cool season.

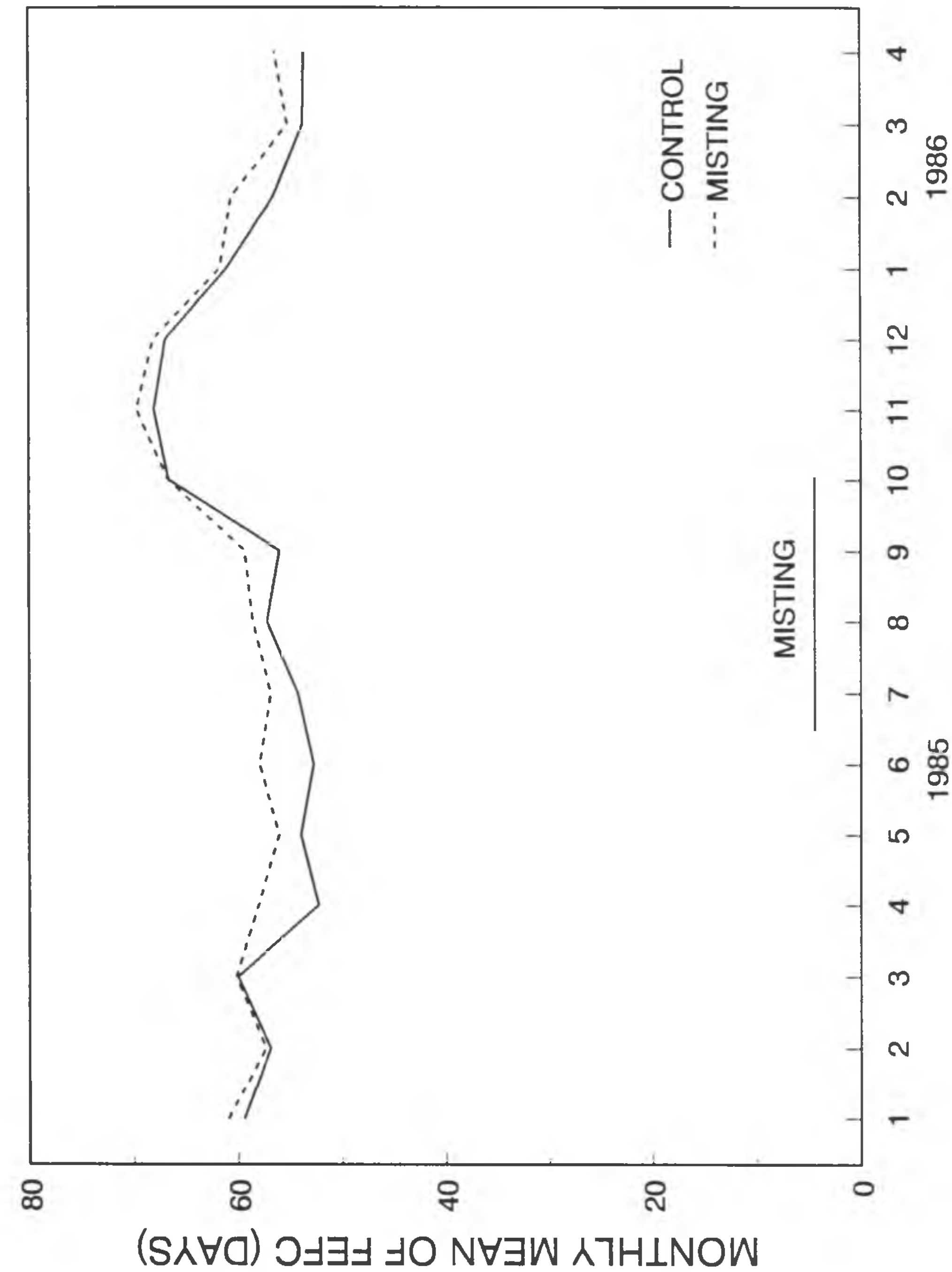


Figure 99. The comparison of FEFC (number of days between flower emergence and flower cut) in bird of paradise flower growth with or without the application of intermittent misting (misting and control, respectively). The misting, applied August 22-November 2 in 1984 and June 14-October 2 in 1985, extended the FEFC intervals, however, the difference was small and no immediate effect was observed on the seasonal pattern.

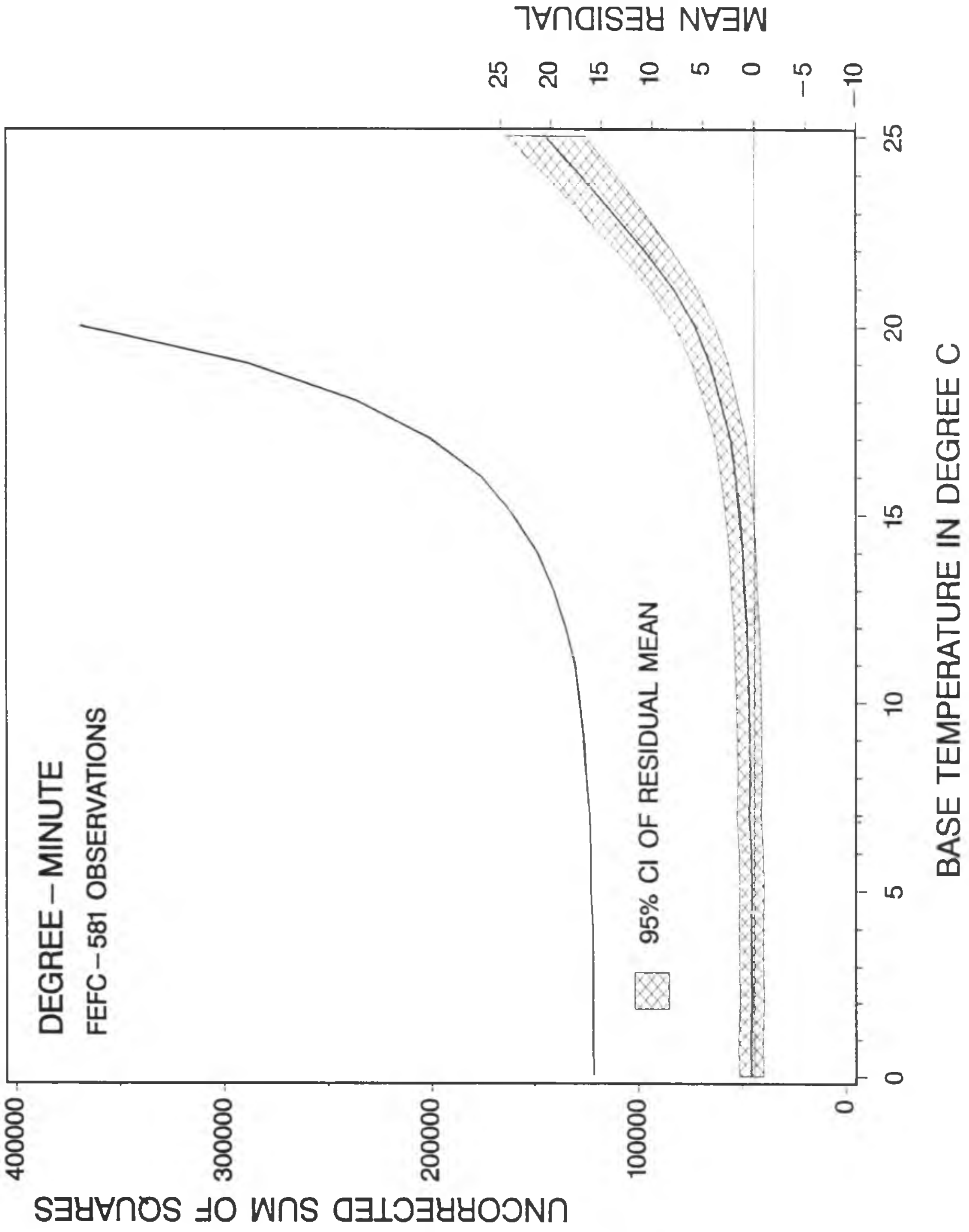


Figure 100. The uncorrected sum of squares for error (USS) and the mean residual of the DM model (degree-minute, Table 53) estimated for the FEFC period in bird of paradise flower growth. The inclusion of 0 mean residual by the confidence limits in the range of base temperatures of low USS indicated that the model was satisfactory.

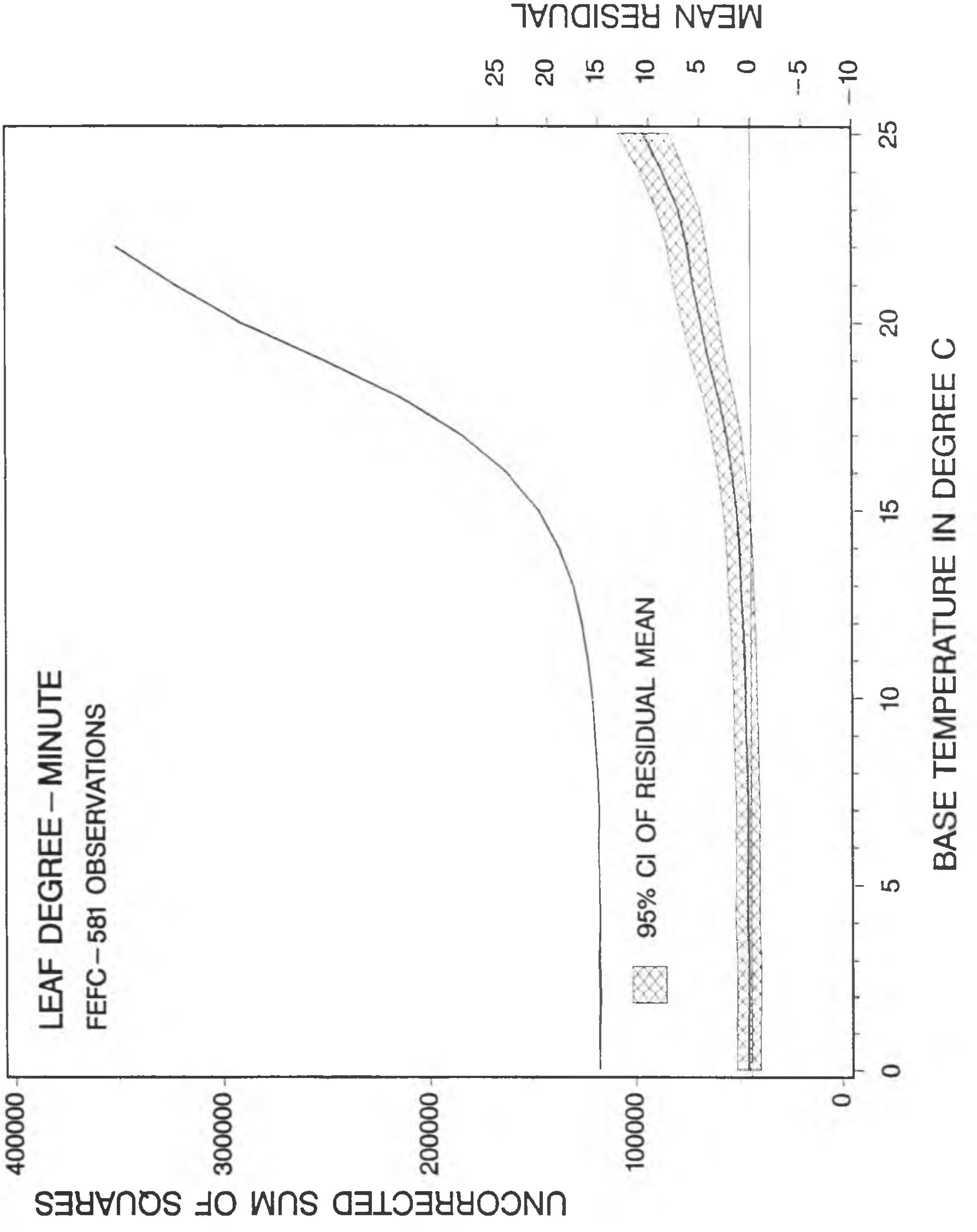


Figure 101. The uncorrected sum of squares for error (USS) and the mean residual of the LDM model (leaf degree-minute, Table 53) estimated for the FEFC period in bird of paradise flower growth. The inclusion of 0 mean residual by the confidence limits in the range of base temperatures of low USS indicated that the model was satisfactory.

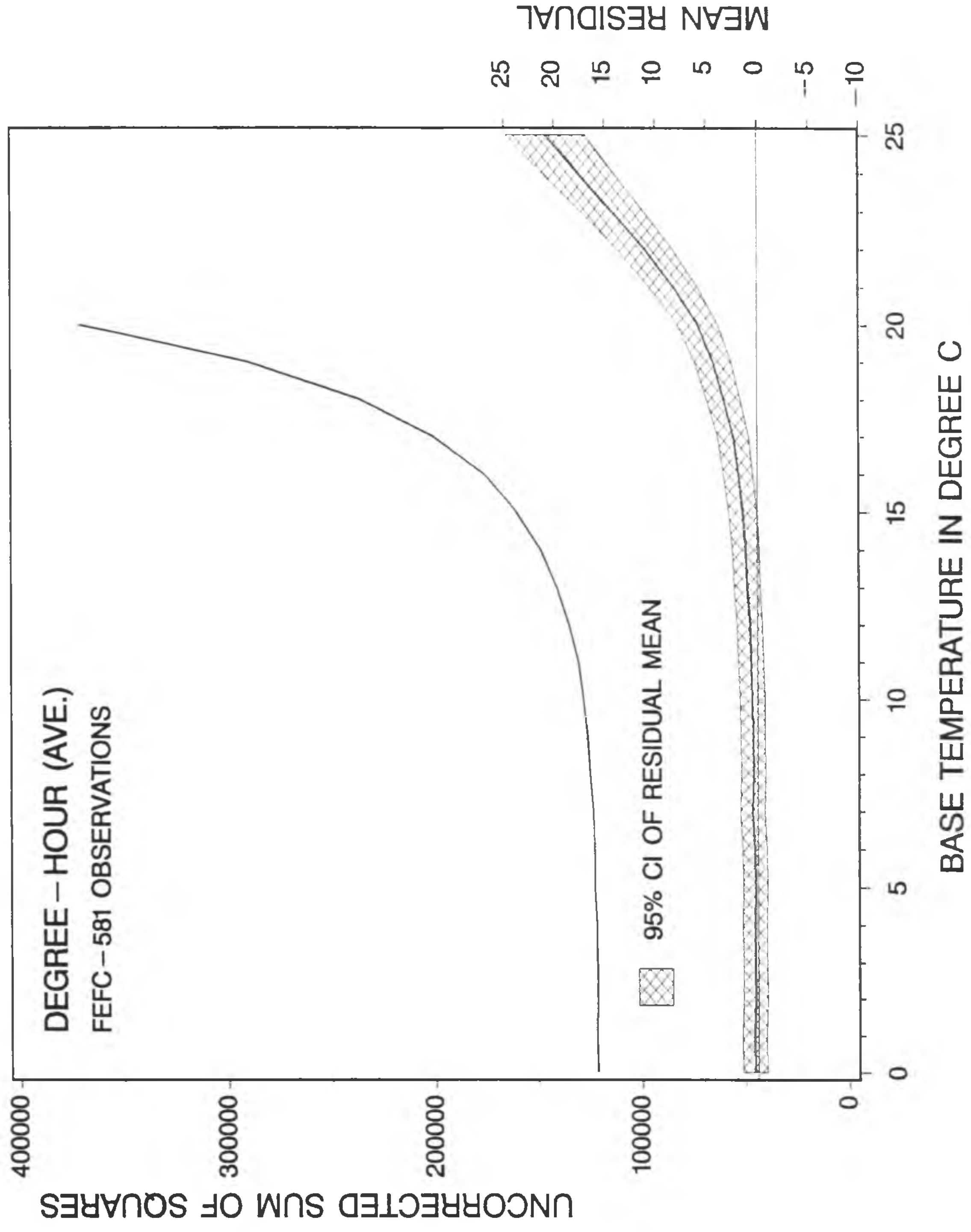


Figure 102. The uncorrected sum of squares for error (USS) and the mean residual of the DH model (degree-hour, Table 53) estimated for the FEFC period in bird of paradise flower growth. The inclusion of 0 mean residual by the confidence limits in the range of base temperatures of low USS indicated that the model was satisfactory.

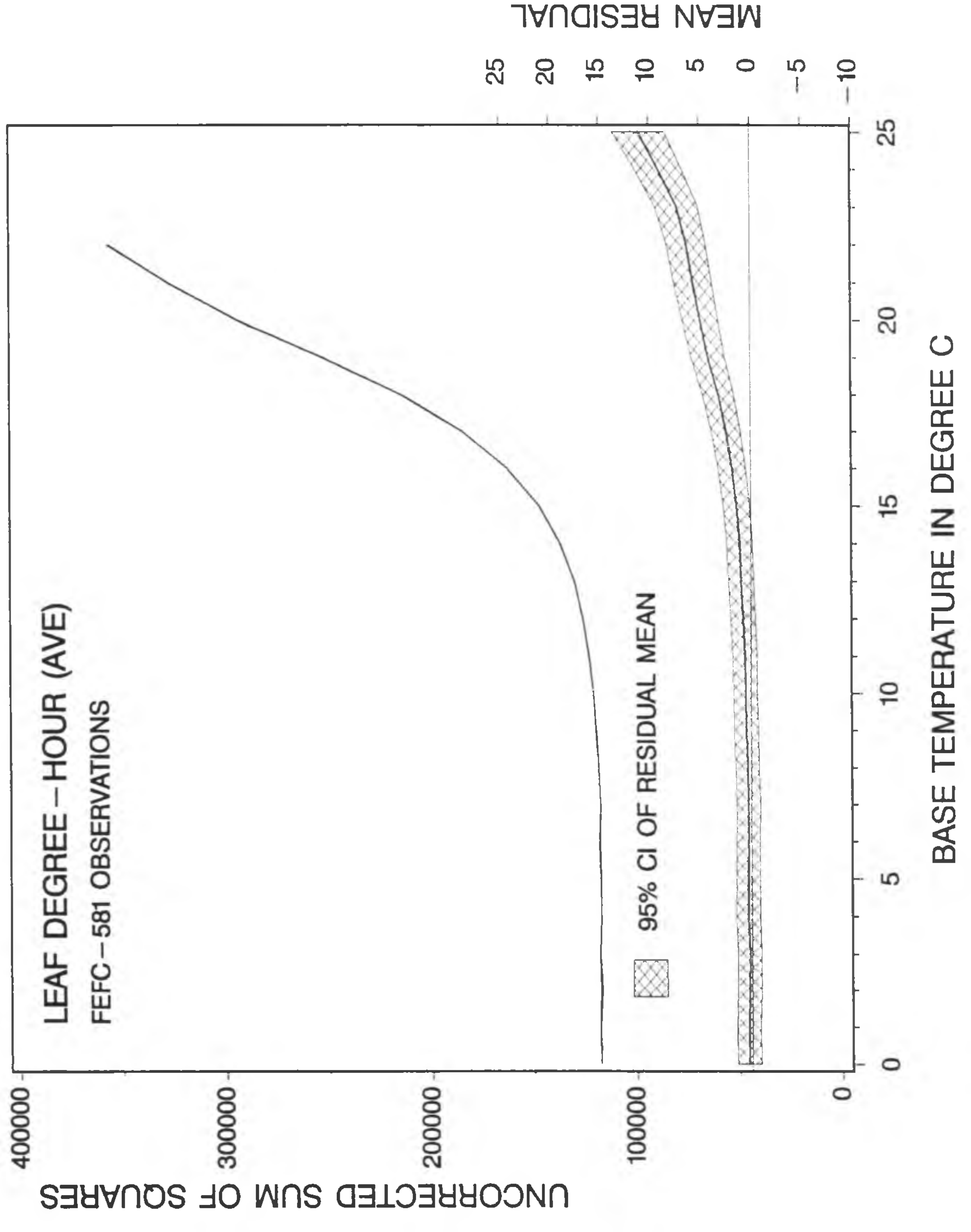


Figure 103. The uncorrected sum of squares for error (USS) and the mean residual of the LDH model (leaf degree-hour, Table 53) estimated for the FEFC period in bird of paradise flower growth. The inclusion of 0 mean residual by the confidence limits in the range of base temperatures of low USS indicated that the model was satisfactory.

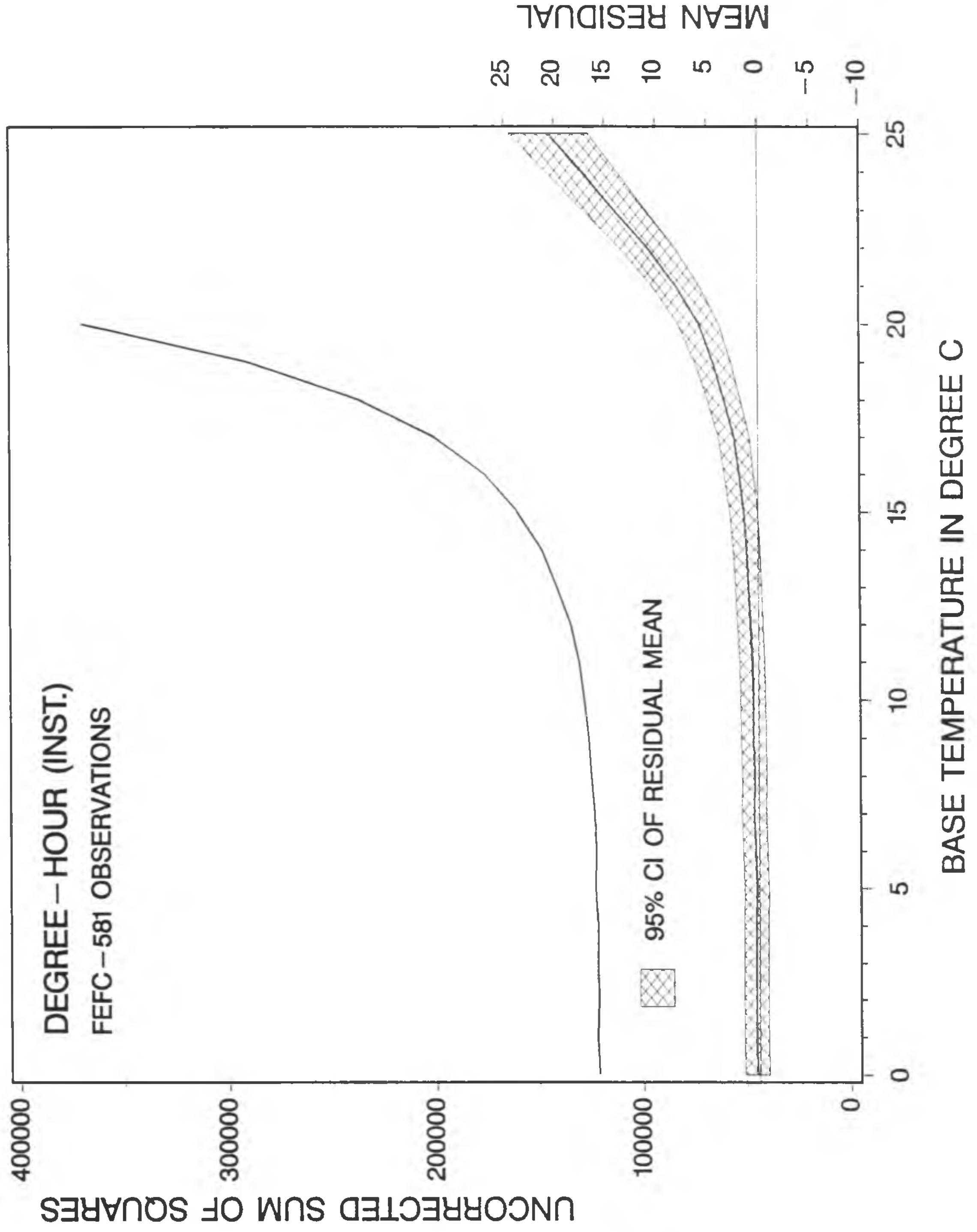


Figure 104. The uncorrected sum of squares for error (USS) and the mean residual of the DHI model (degree-hour, instantaneous, Table 53) estimated for the FEFC period in bird of paradise flower growth. The inclusion of 0 mean residual by the confidence limits in the range of base temperatures of low USS indicated that the model was satisfactory.

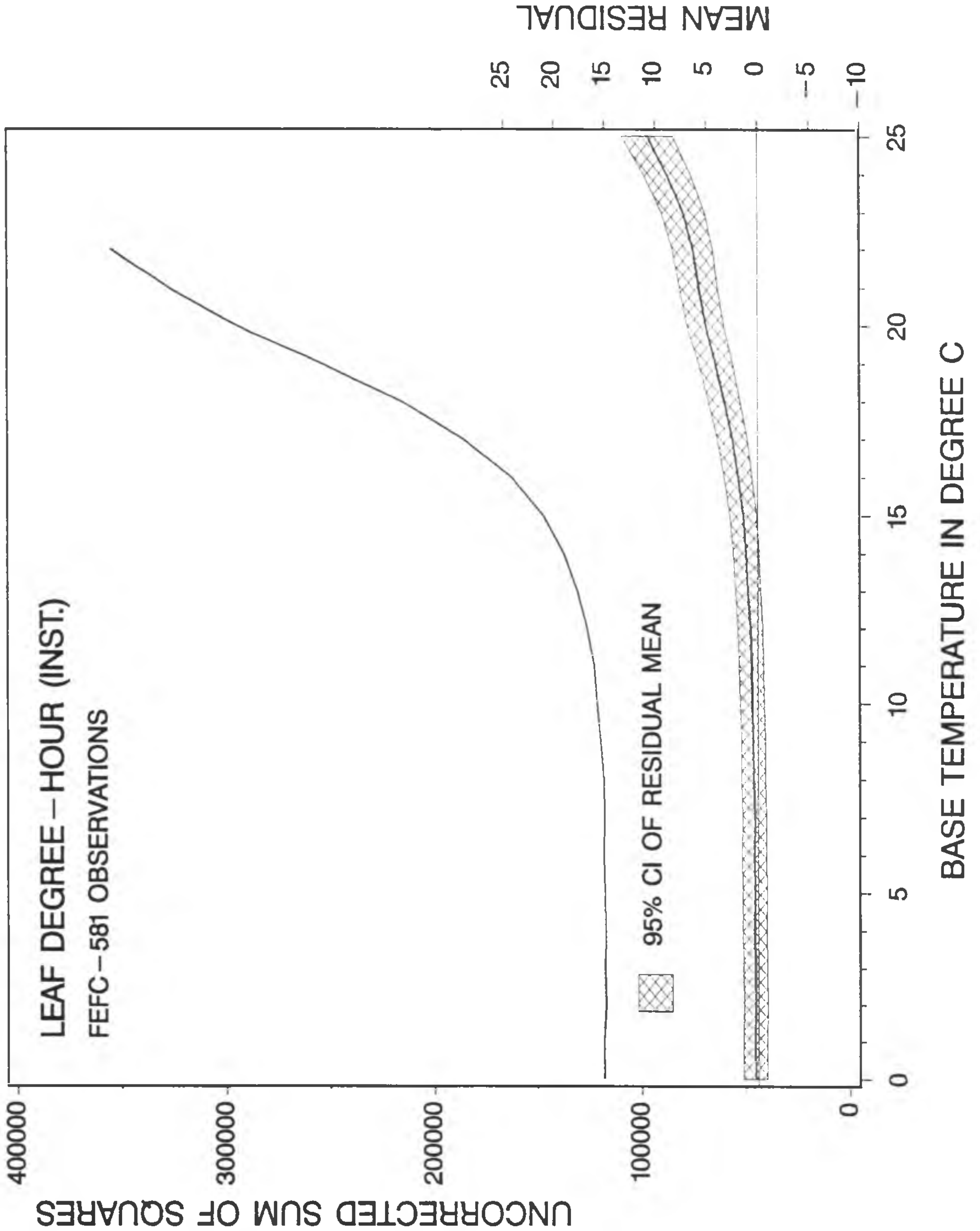


Figure 105. The uncorrected sum of squares for error (USS) and the mean residual of the LDHI model (leaf degree-hour, instantaneous, Table 53) estimated for the FEFC period in bird of paradise flower growth. The inclusion of 0 mean residual by the confidence limits in the range of base temperatures of low USS indicated that the model was satisfactory.

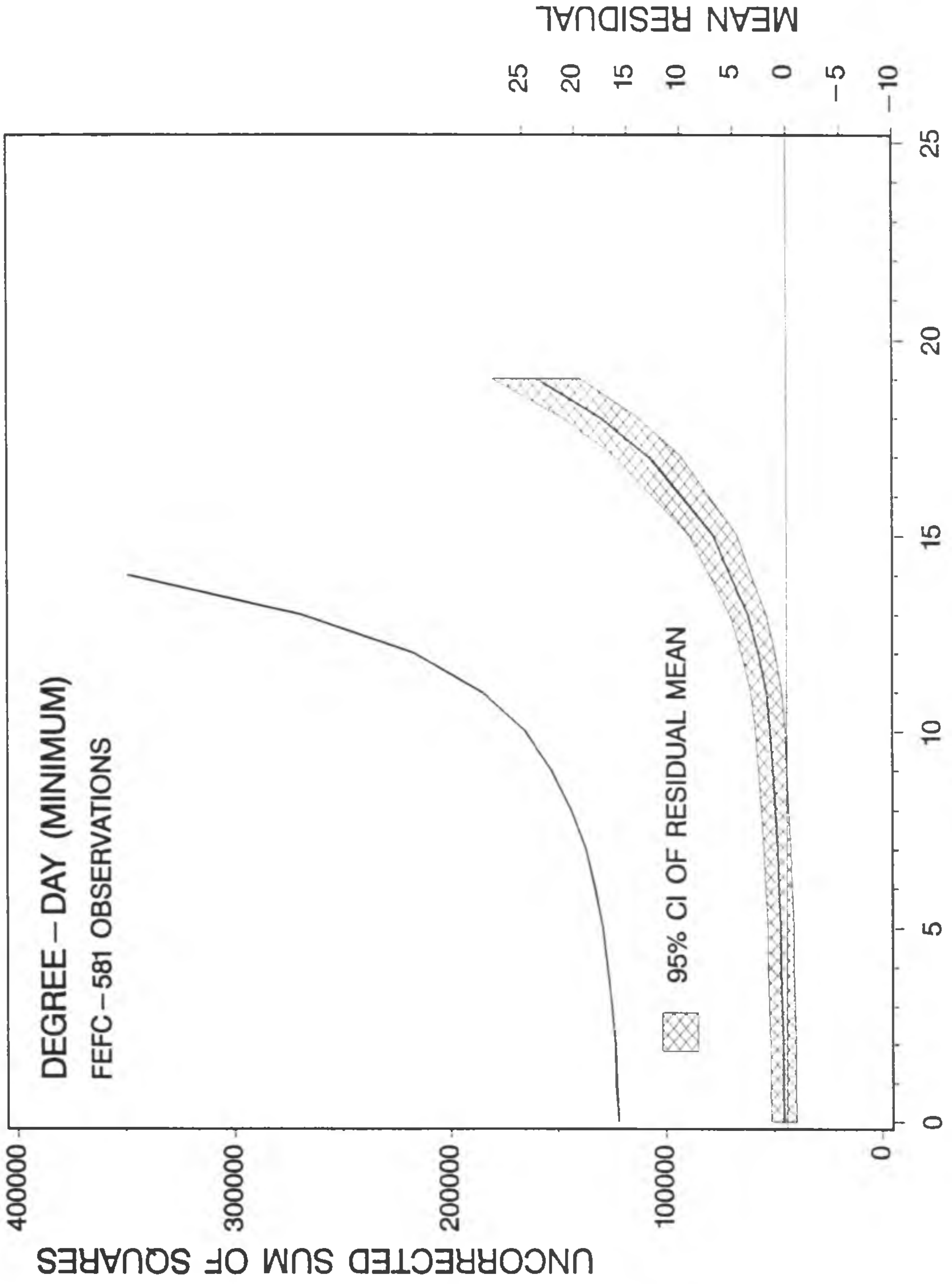


Figure 106. The uncorrected sum of squares for error (USS) and the mean residual of the DDMIN model (degree-day, minimum, Table 53) estimated for the FEFC period in bird of paradise flower growth. The inclusion of 0 mean residual by the confidence limits in the range of base temperatures of low USS indicated that the model was satisfactory.

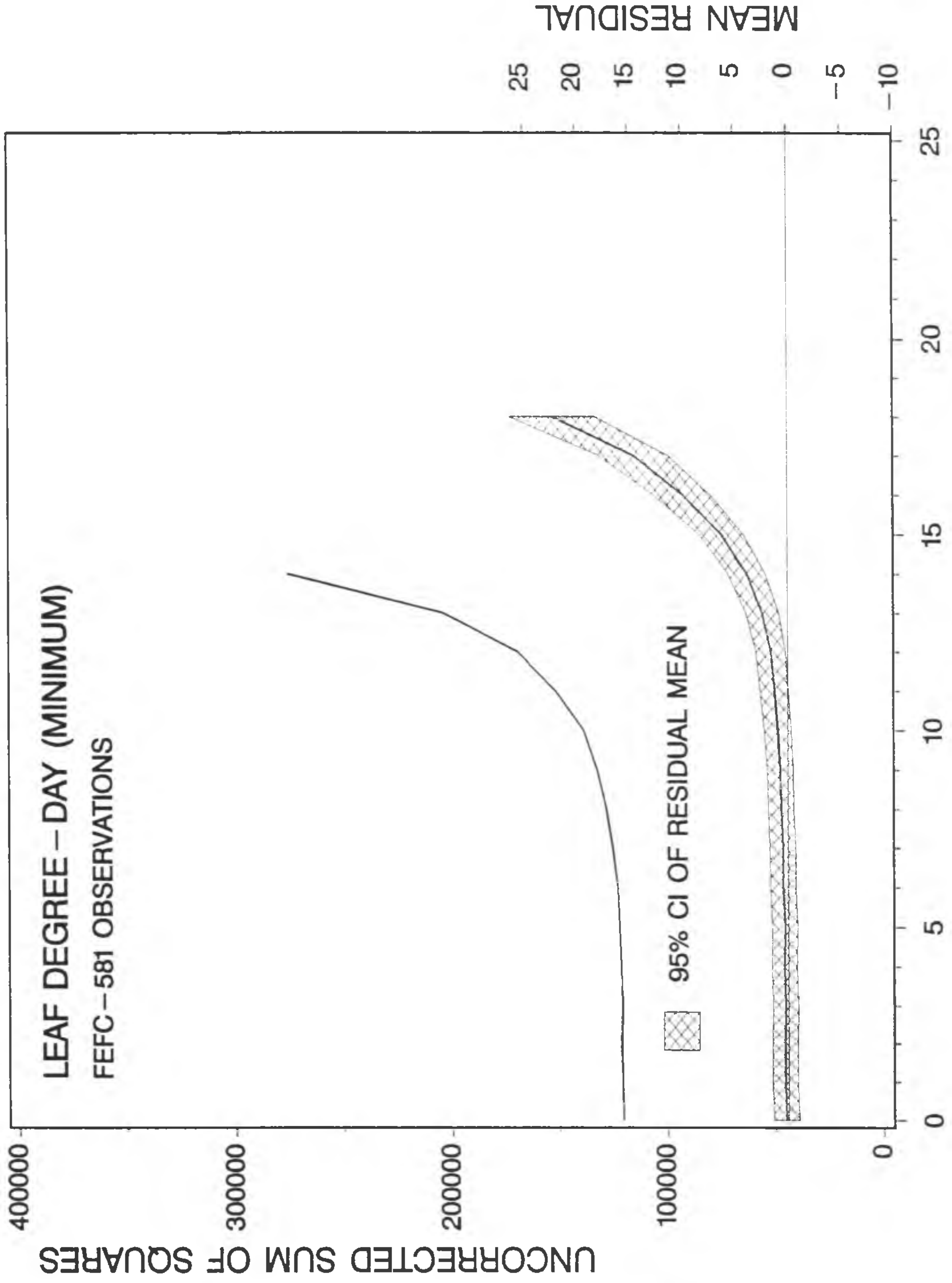


Figure 107. The uncorrected sum of squares for error (USS) and the mean residual of the LDDMIN model (leaf degree-day, minimum, Table 53) estimated for the FEFC period in bird of paradise flower growth. The inclusion of 0 mean residual by the confidence limits in the range of base temperatures of low USS indicated that the model was satisfactory.

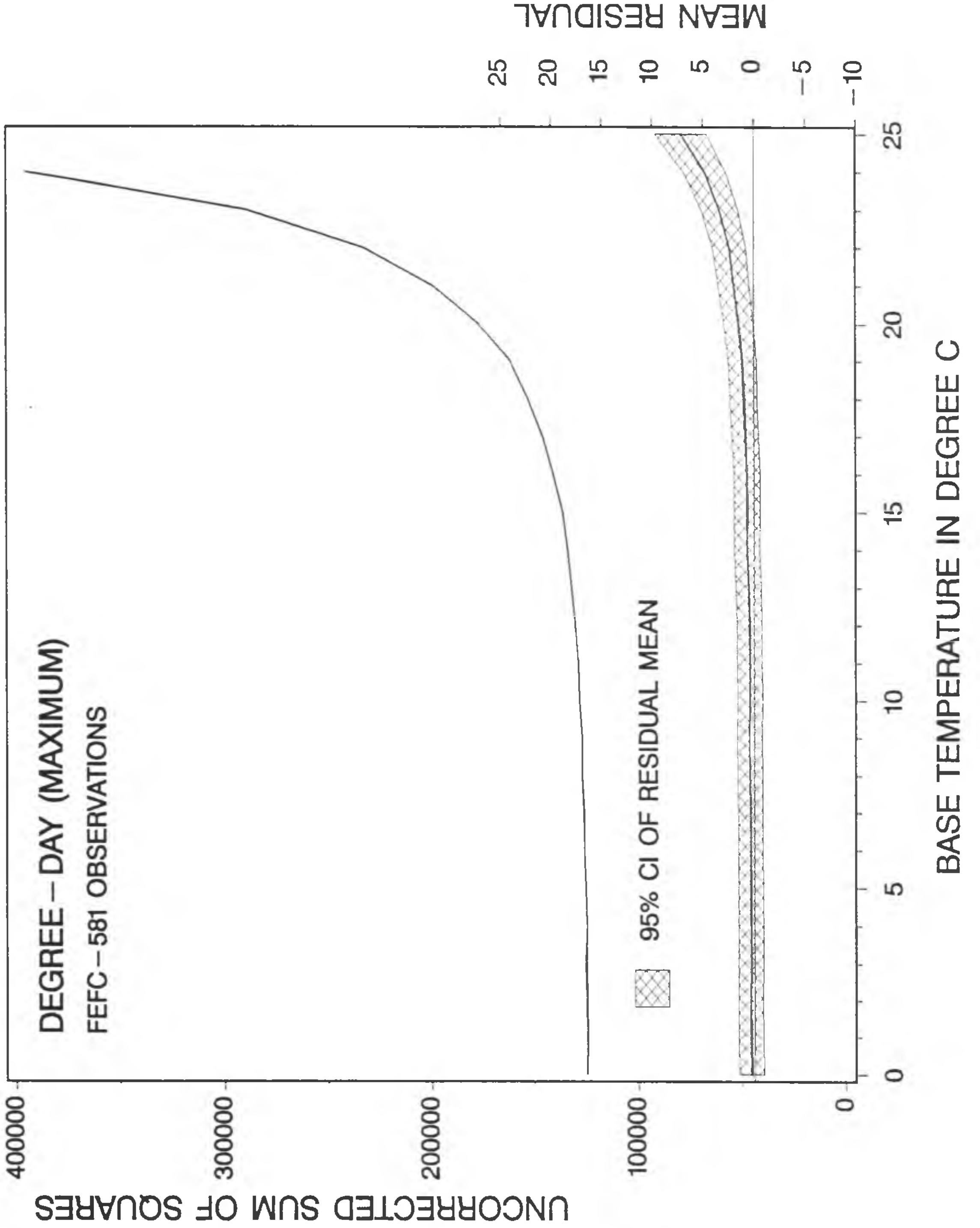


Figure 108. The uncorrected sum of squares for error (USS) and the mean residual of the DDMAX model (degree-day, maximum, Table 53) estimated for the FEFC period in bird of paradise flower growth. The inclusion of 0 mean residual by the confidence limits in the range of base temperatures of low USS indicated that the model was satisfactory.

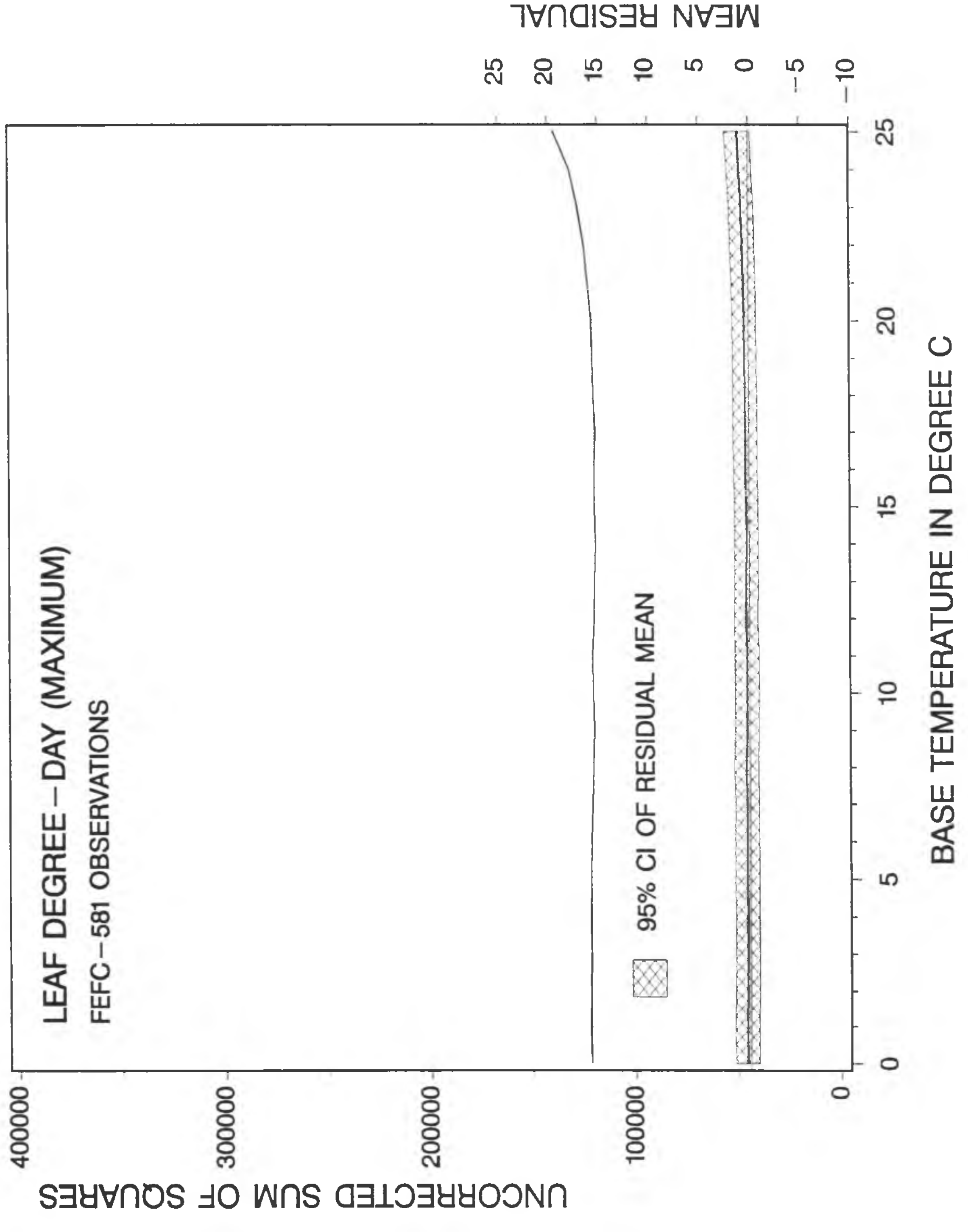


Figure 109. The uncorrected sum of squares for error (USS) and the mean residual of the LDDMAX model (leaf degree-day, maximum, Table 53) estimated for the FEFC period in bird of paradise flower growth. The inclusion of 0 mean residual by the confidence limits in the range of base temperatures of low USS indicated that the model was satisfactory.

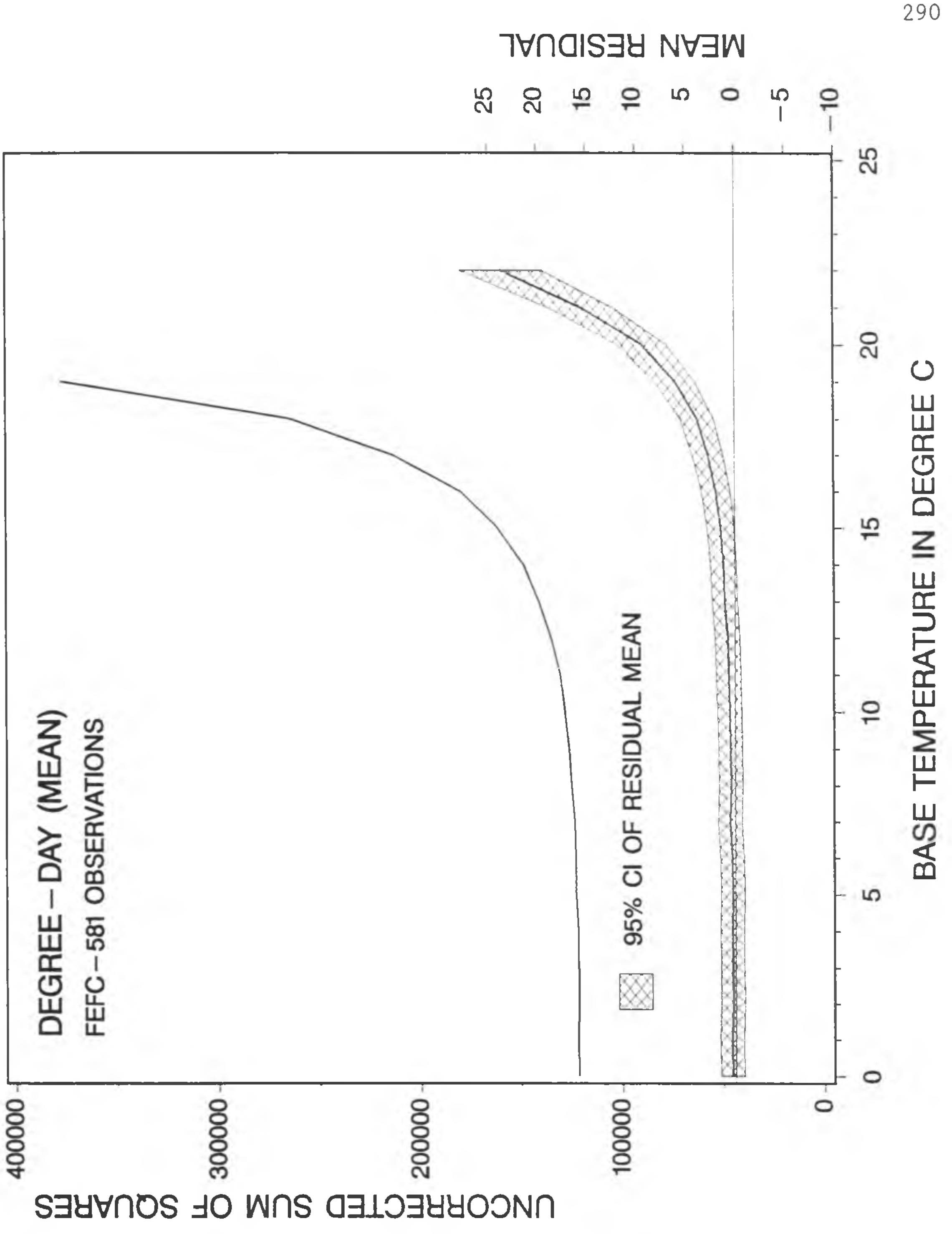


Figure 110. The uncorrected sum of squares for error (USS) and the mean residual of the DDMEAN model (degree-day, mean, Table 53) estimated for the FEFC period in bird of paradise flower growth. The inclusion of 0 mean residual by the confidence limits in the range of base temperatures of low USS indicated that the model was satisfactory.

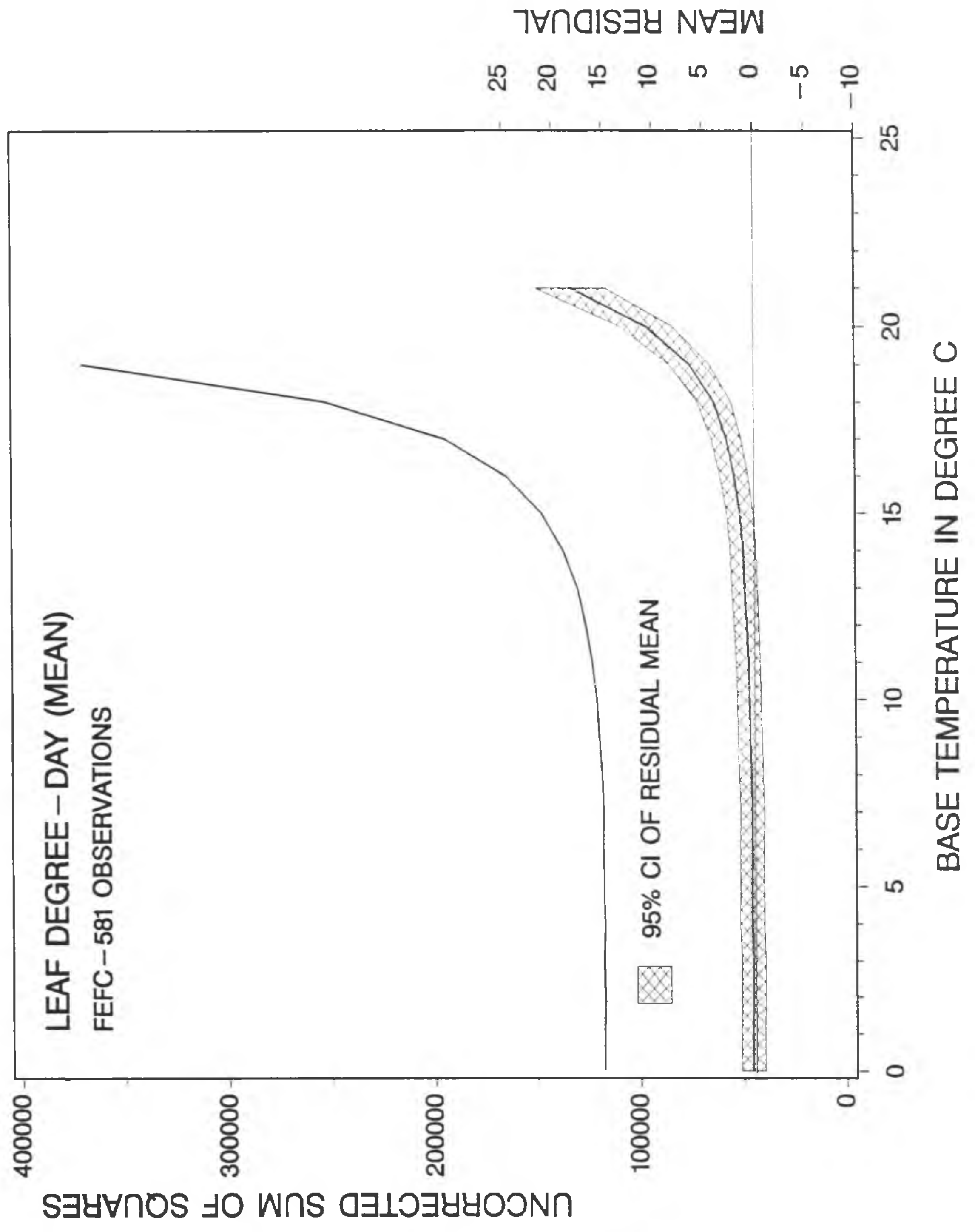


Figure 111. The uncorrected sum of squares for error (USS) and the mean residual of the LDDMEA model (leaf degree-day, mean, Table 53) estimated for the FEFC period in bird of paradise flower growth. The inclusion of 0 mean residual by the confidence limits in the range of base temperatures of low USS indicated that the model was satisfactory.

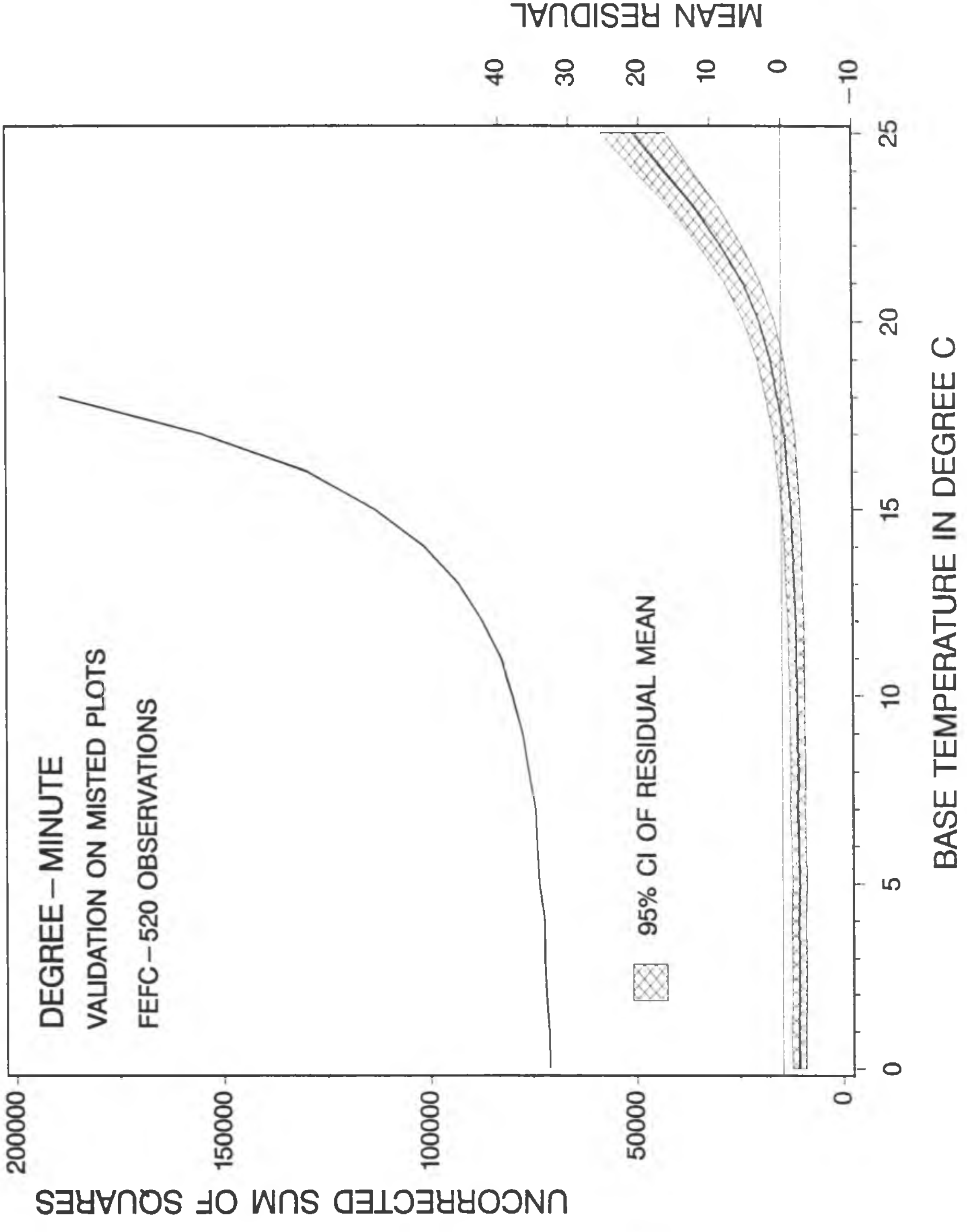


Figure 112. Validation of the DM model (degree-minute, Table 55). The mean heat units accumulated for control plants were used to estimate the FE for misted plants. The exclusion of 0 mean residual by the confidence limits at the base temperature for the minimum uncorrected sum of aquares indicated that the model was not satisfactory.

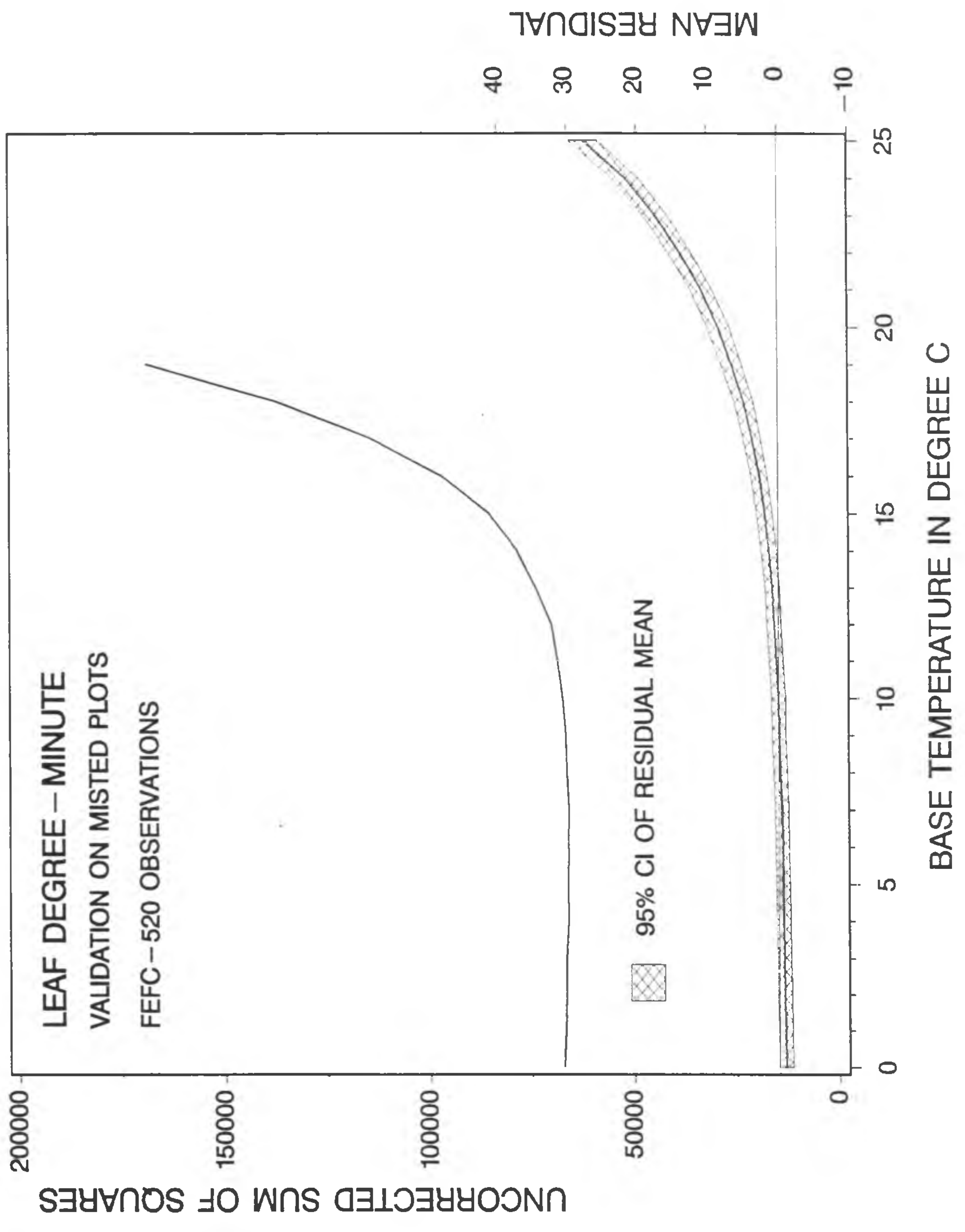


Figure 113. Validation of the LDM model (leaf degree-minute, Table 55). The mean heat units accumulated for control plants were used to estimate the FE for misted plants. The inclusion of 0 mean residual by the confidence limits at the base temperature for the minimum uncorrected sum of squares indicated that the model was satisfactory.

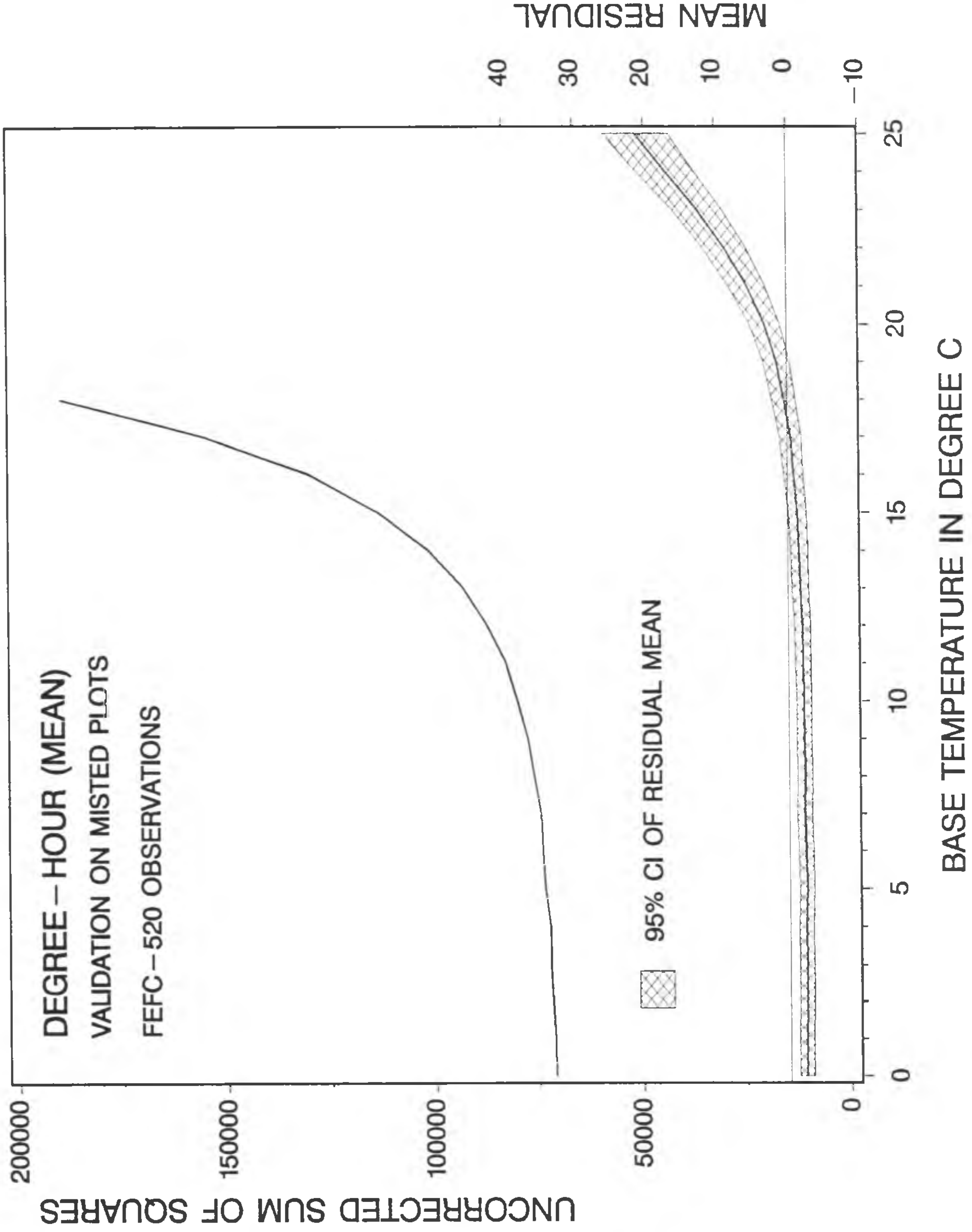


Figure 114. Validation of the DH model (degree-hour, Table 55). The mean heat units accumulated for control plants were used to estimate the FE for misted plants. The exclusion of 0 mean residual by the confidence limits at the base temperature for the minimum uncorrected sum of squares indicated that the model was not satisfactory.

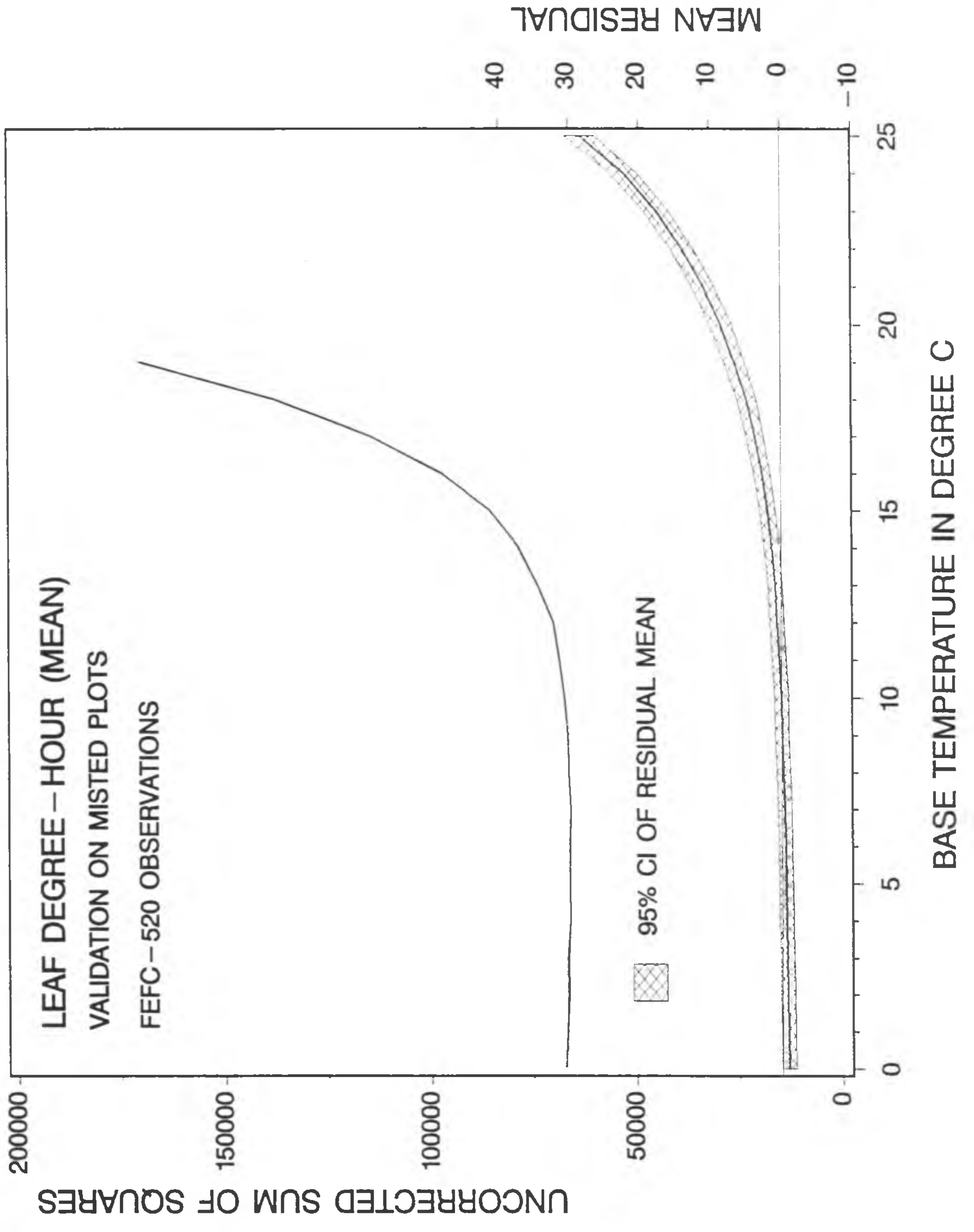


Figure 115. Validation of the LDH model (leaf degree-hour, Table 55). The mean heat units accumulated for control plants were used to estimate the FE for misted plants. The inclusion of 0 mean residual by the confidence limits at the base temperature for the minimum uncorrected sum of squares indicated that the model was satisfactory.

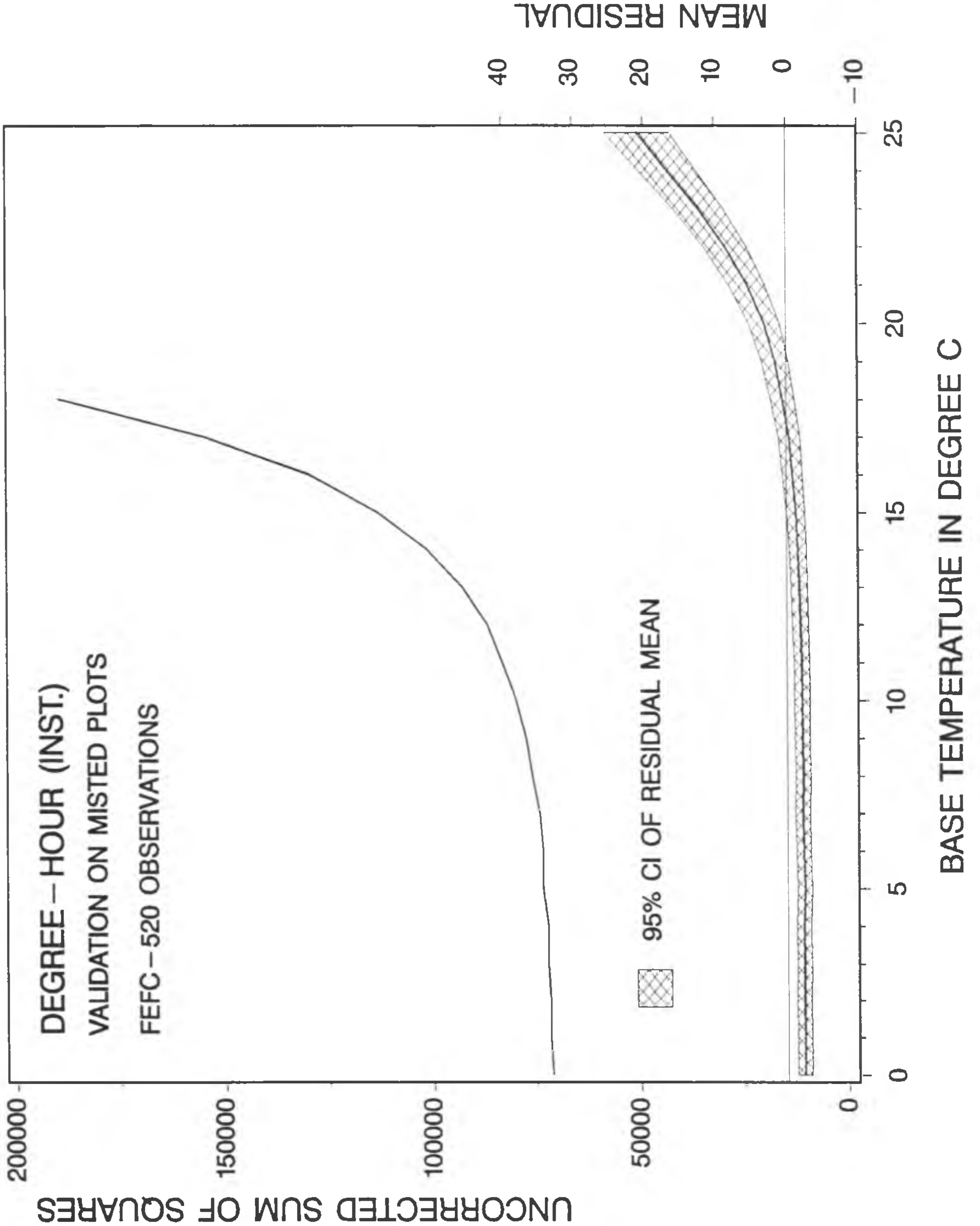


Figure 116. Validation of the DHI model (degree-hour, instantaneous, Table 55). The mean heat units accumulated for control plants were used to estimate the FE for misted plants. The exclusion of 0 mean residual by the confidence at the base temperature for the minimum uncorrected sum of squares limits indicated that the model was not satisfactory.

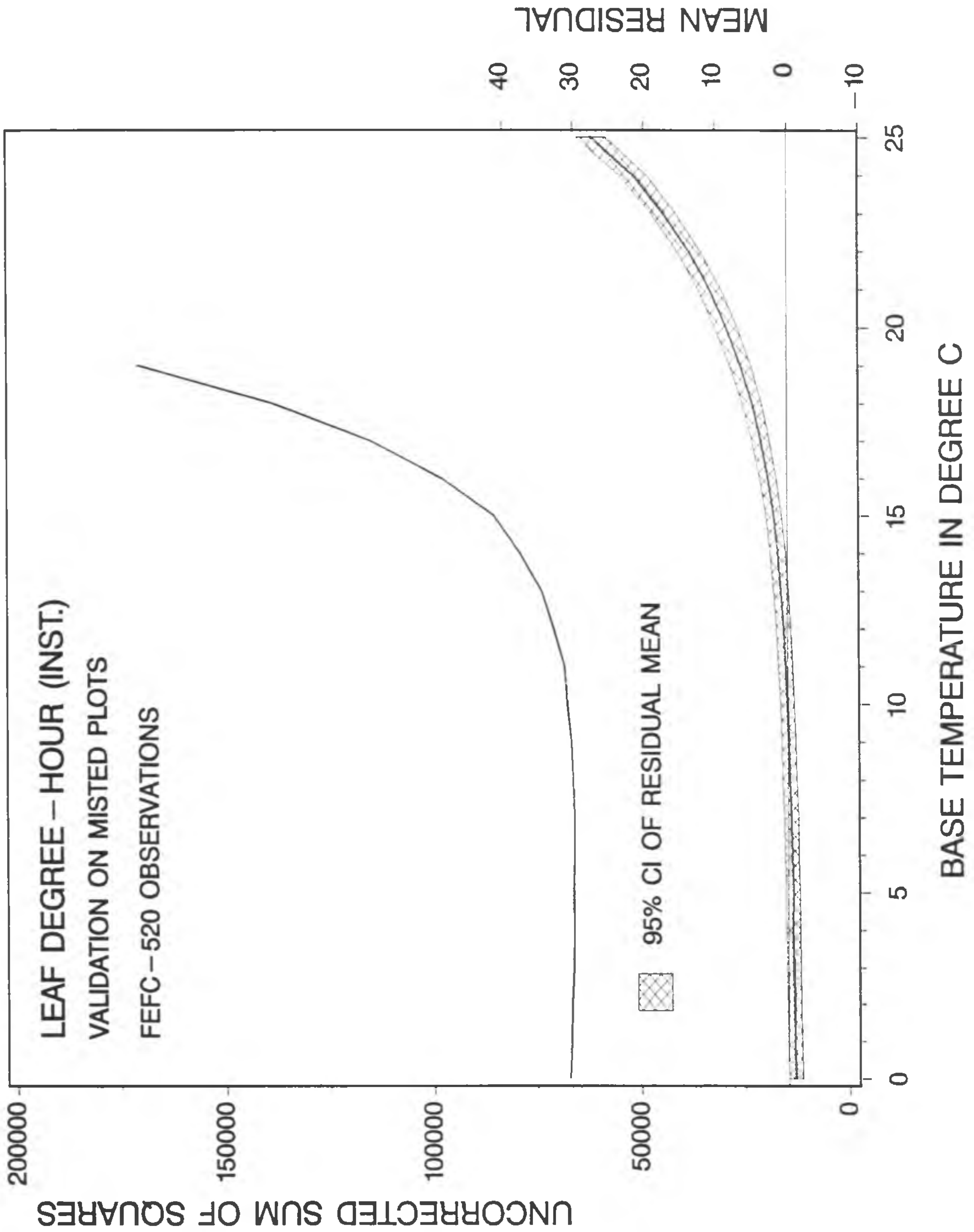


Figure 117. Validation of the LDHI model (leaf degree-hour, instantaneous, Table 55). The mean heat units accumulated for control plants were used to estimate the FE for misted plants. The inclusion of 0 mean residual by the confidence limits at the base temperature for the minimum uncorrected sum of squares indicated that the model was satisfactory.

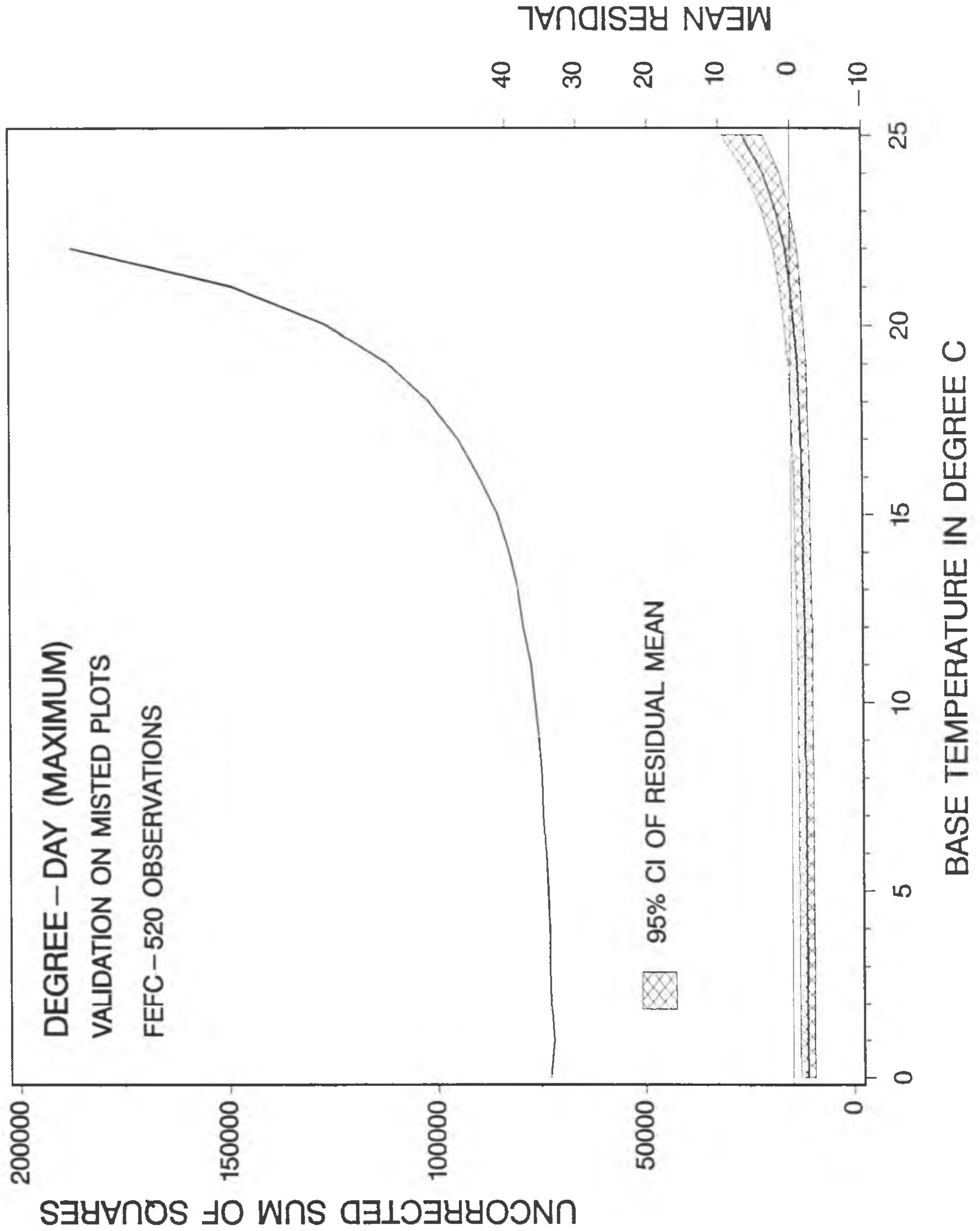


Figure 118. Validation of the DDMAX model (degree-day, maximum, Table 55). The mean heat units accumulated for control plants were used to estimate the FE for misted plants. The exclusion of 0 mean residual by the confidence at the base temperature for the minimum uncorrected sum of squares limits indicated that the model was not satisfactory.

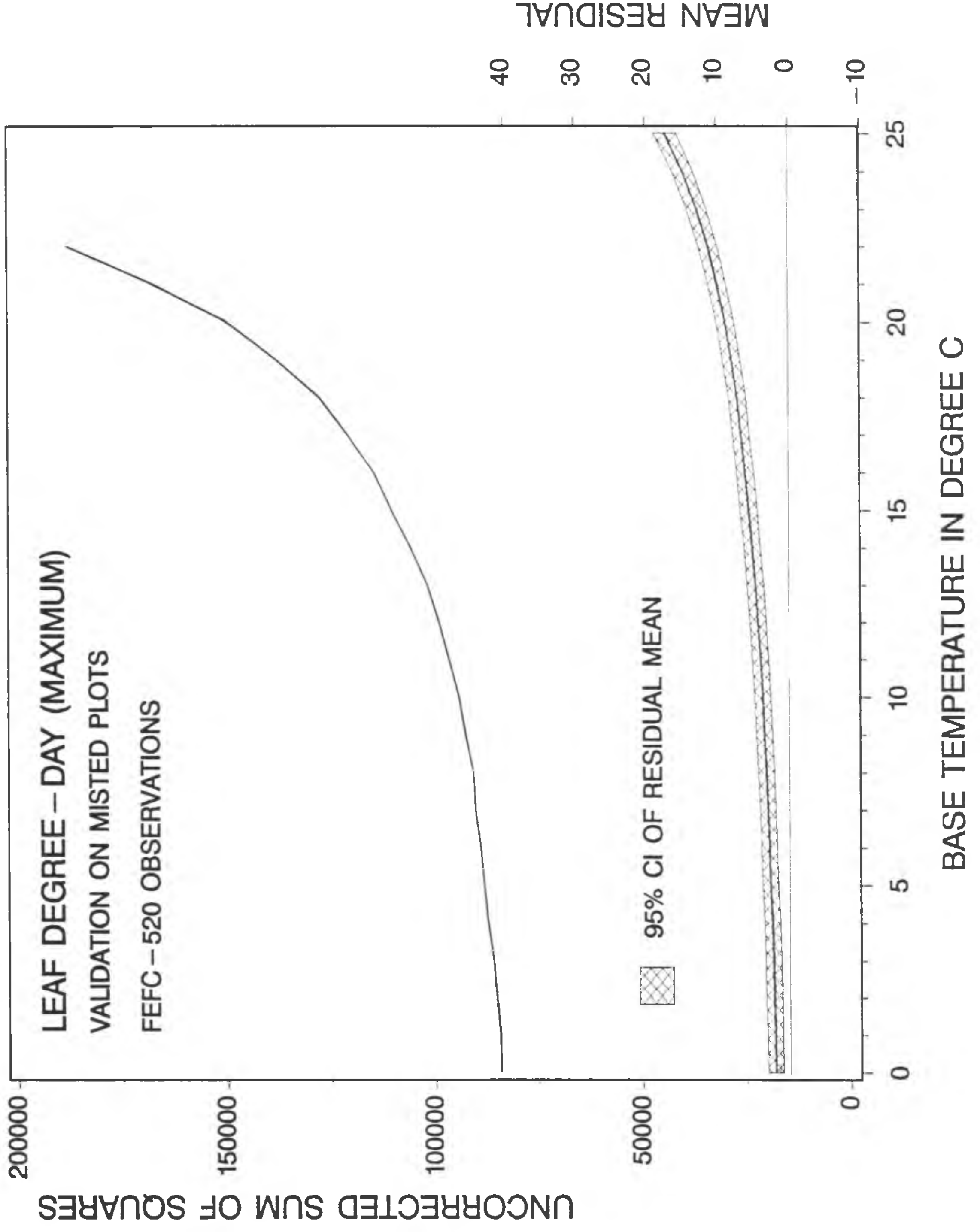


Figure 119. Validation of the LDDMAX model (leaf degree-day, maximum, Table 55). The mean heat units accumulated for control plants were used to estimate the FE for misted plants. The exclusion of 0 mean residual by the confidence at the base temperature for the minimum uncorrected sum of squares limits indicated that the model was not satisfactory.

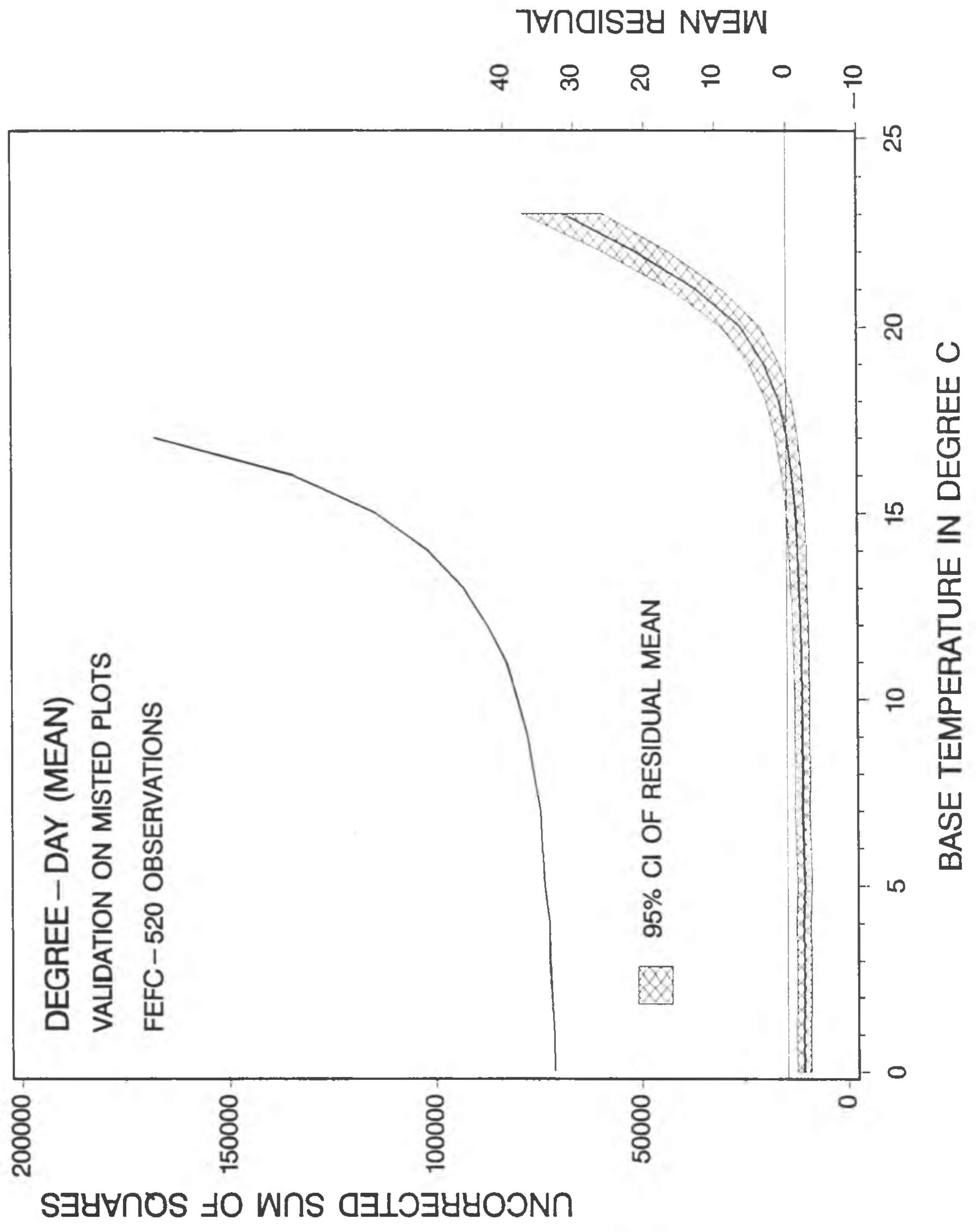


Figure 120. Validation of the DDMEAN model (degree-day, mean, Table 55). The mean heat units accumulated for control plants were used to estimate the FE for misted plants. The exclusion of 0 mean residual by the confidence at the base temperature for the minimum uncorrected sum of squares limits indicated that the model was not satisfactory.

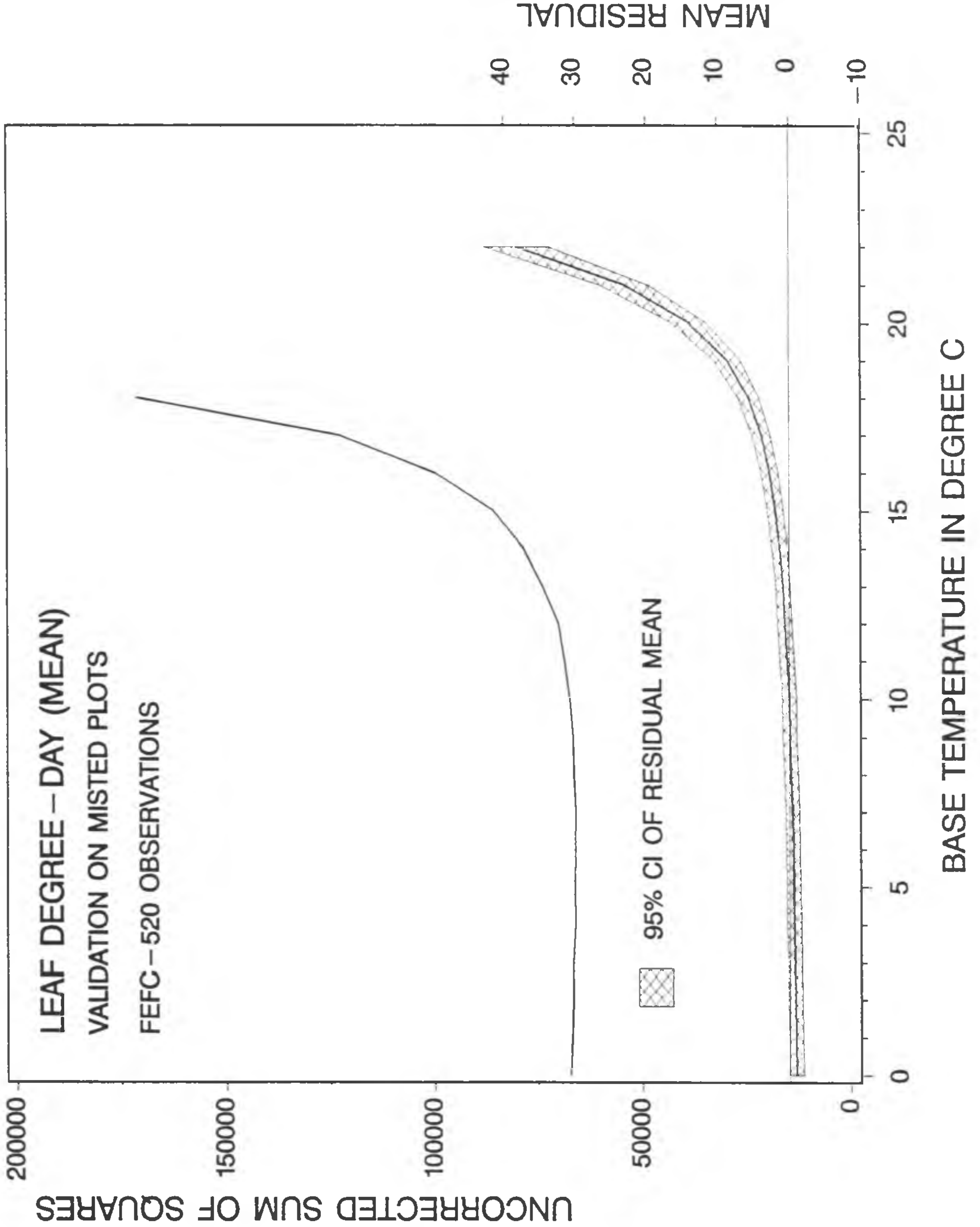


Figure 121. Validation of the LDDMEA model (leaf degree-day, mean, Table 55). The mean heat units accumulated for control plants were used to estimate the FE for misted plants. The inclusion of 0 mean residual by the confidence limits at the base temperature for the minimum uncorrected sum of squares indicated that the model was satisfactory.

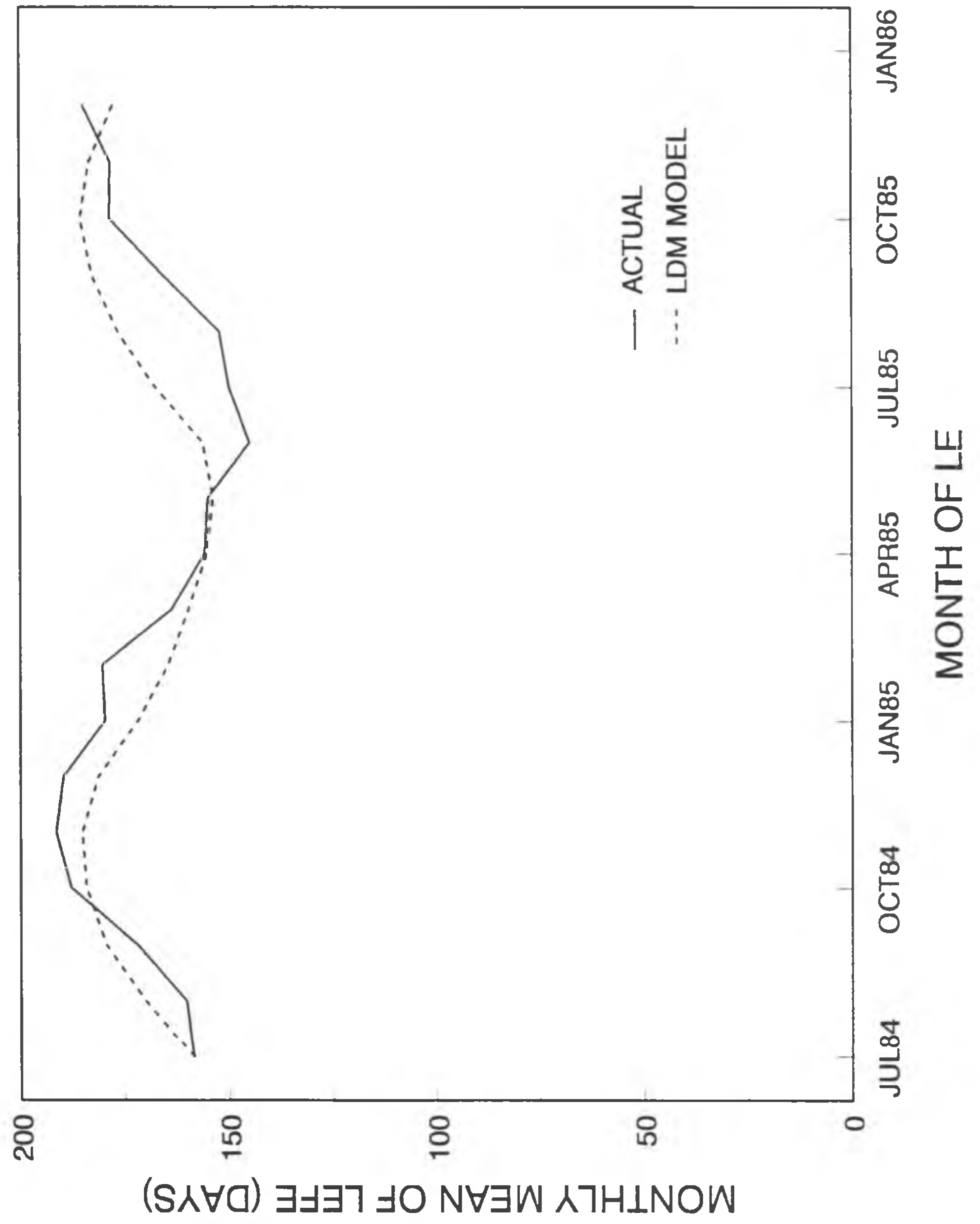


Figure 122. Comparison of the monthly mean of estimated and actual LEFE (time period between leaf emergence and flower emergence) for control in bird of paradise flower growth in Hawaii. Although a shift in the phase was observed, the LDM model (7°C base temperature, Table 54) satisfactorily estimated the LEFE (significant at 5% level, Fig. 77) and the seasonal fluctuationg trend.

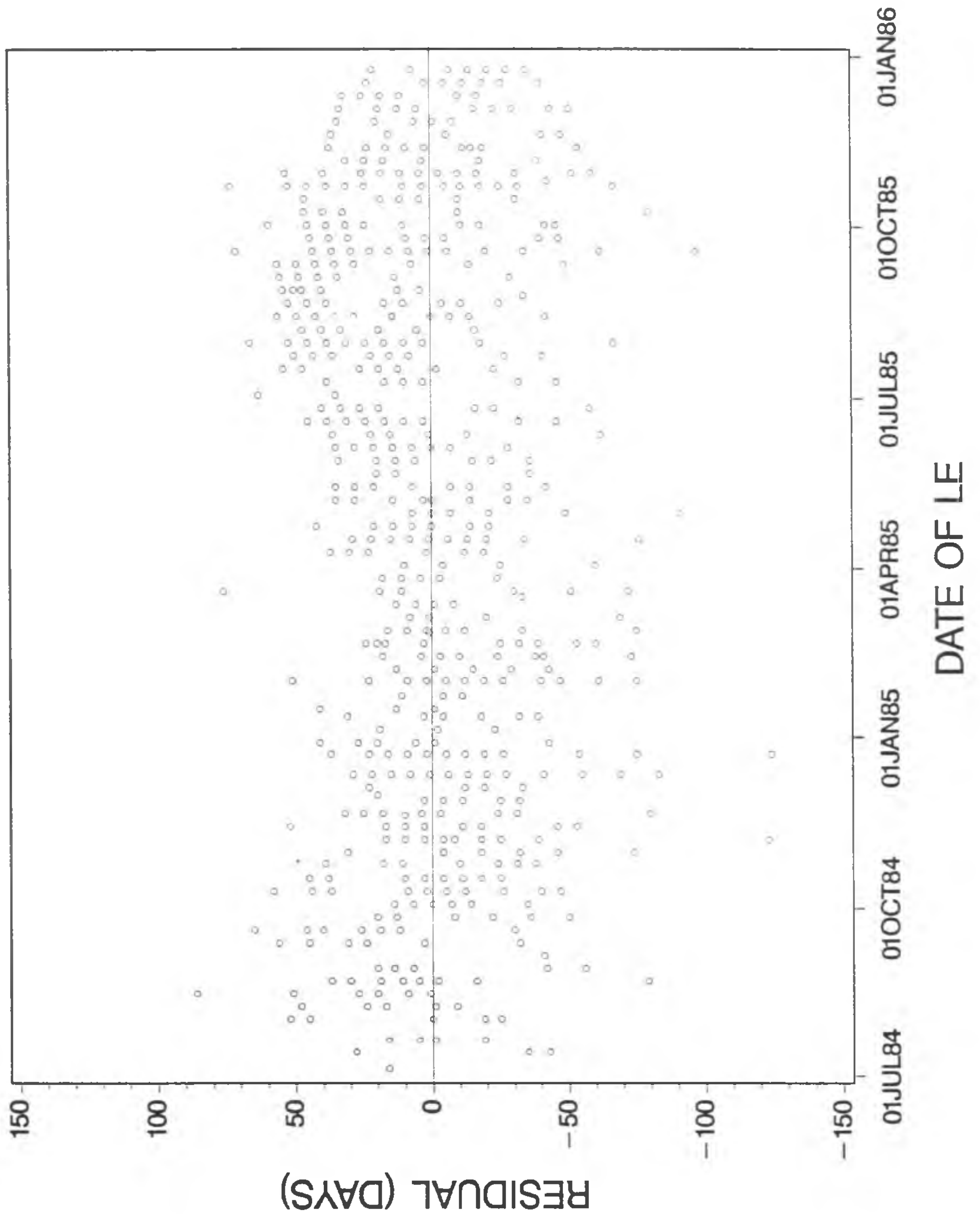


Figure 123. Residual plots for the LDM model for the LEFE (time period between leaf emergence and flower emergence) in bird of paradise flower growth in Hawaii. A gentle wave indicated the existence of the phase shift in the estimates (Fig. 122), however, the shift did not cause significant difference in the LEFE estimates (Fig. 77).

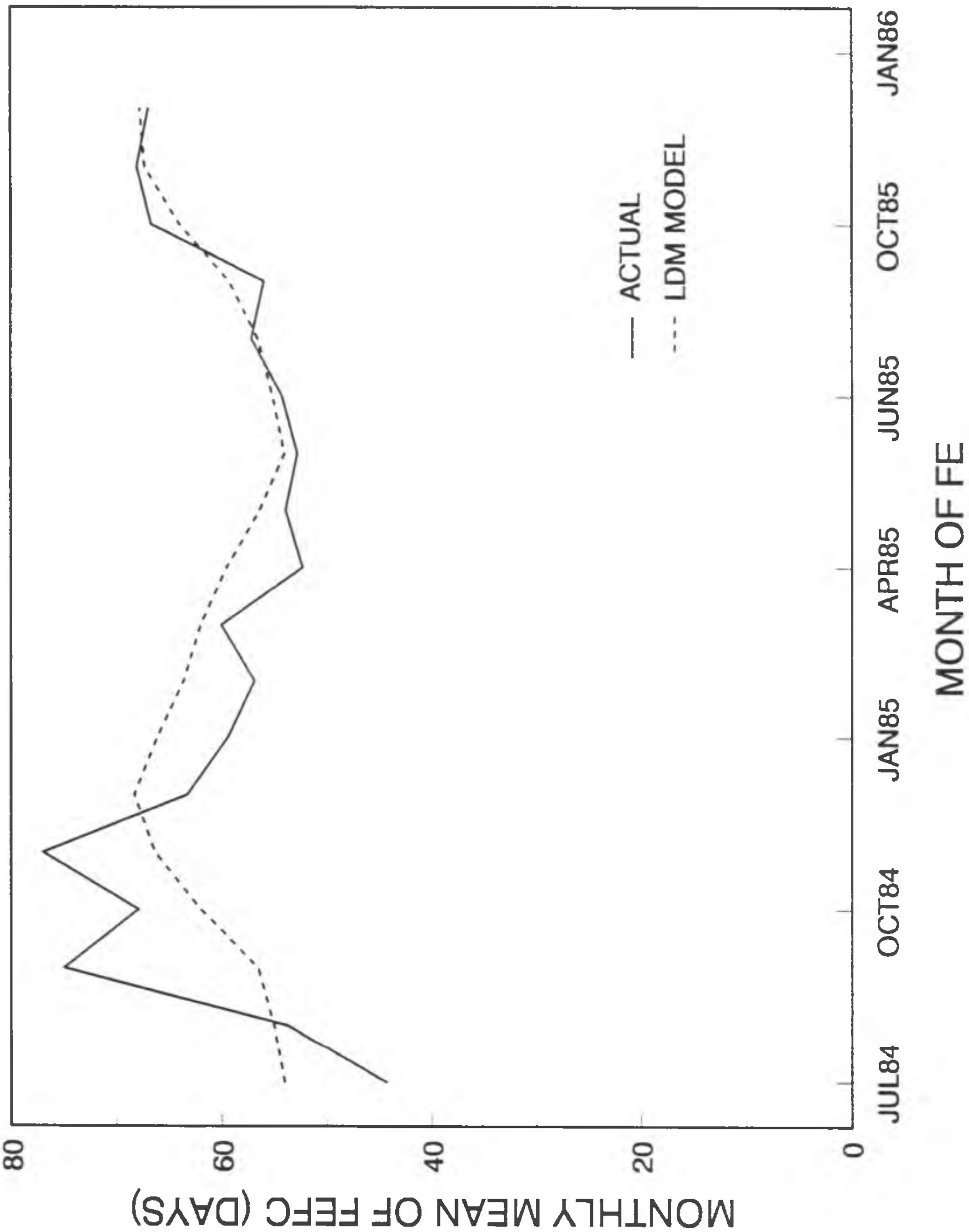


Figure 124. Comparison of the monthly mean of estimated and actual FEFC (time period between flower emergence and flower cut) for control in bird of paradise flower growth in Hawaii. The LDM model (2°C base temperature, Table 55) satisfactorily estimated the seasonal trend in the LEFE (significant at 5% level, Fig. 101). The large discrepancy in 1984 was attributed to the drought in the year until an irrigation system was installed on 19 July 1984.

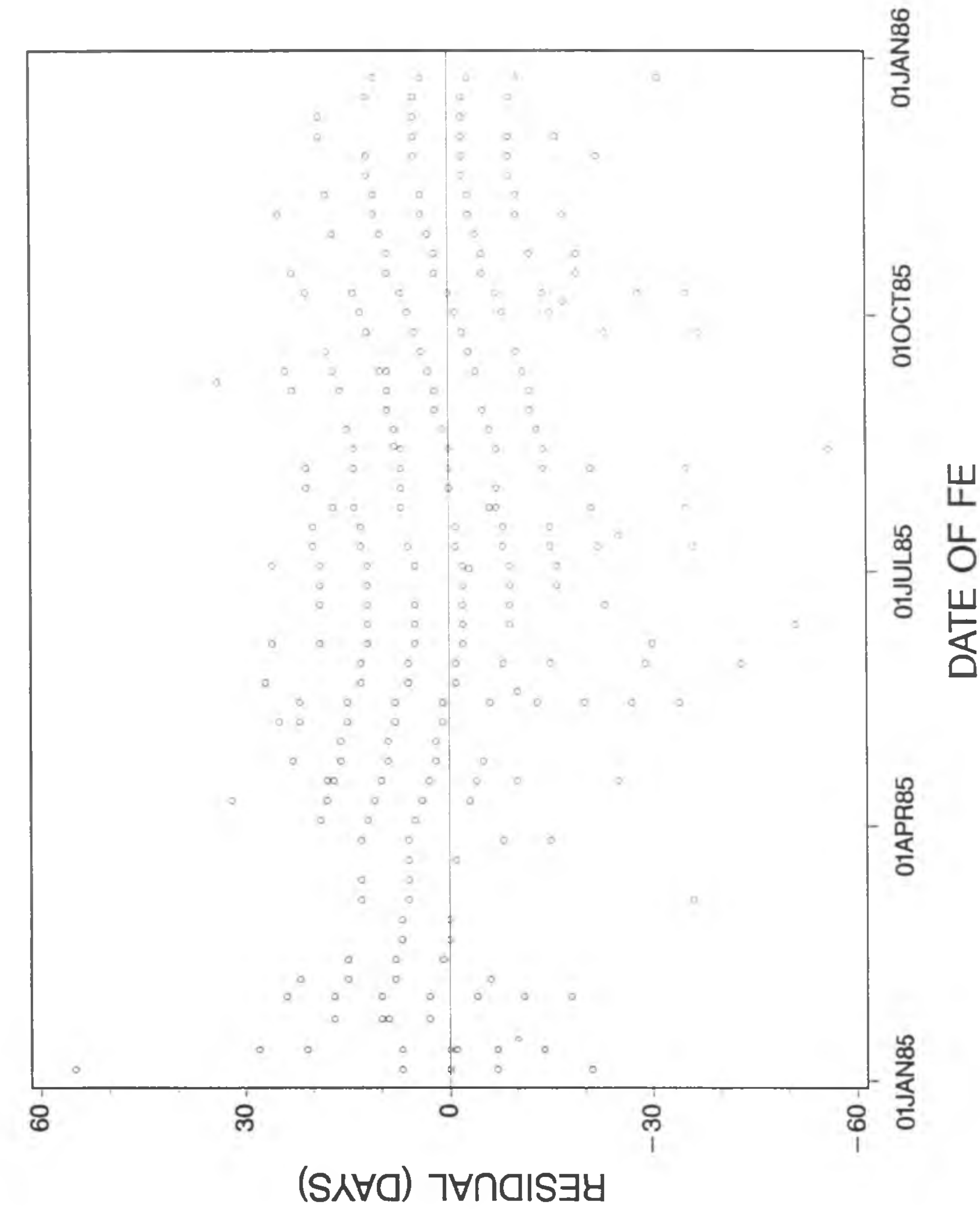


Figure 125. Residual plots for the LDM model for the FEFC (time period between flower emergence and flower cut) in bird of paradise flower growth in Hawaii. While a larger scatter could be seen on the negative residual side, no other trend was observed.

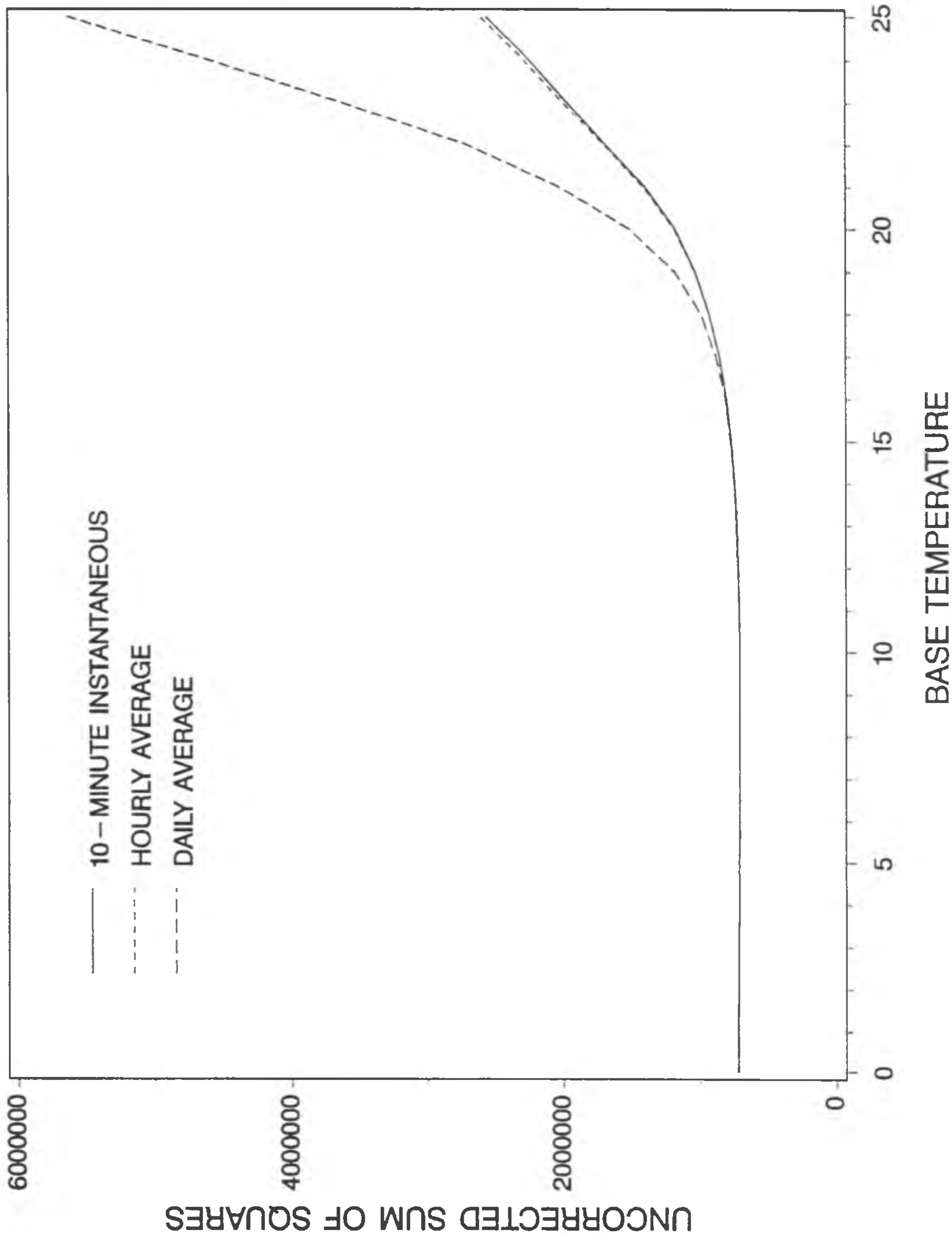


Figure 126. The effect of averaging intervals on the estimates of heat unit accumulation. Errors for the DM, DH, and DDMEAN (10-minute, hourly, and daily recording intervals, respectively) on the LEFE in bird of paradise was compared. Ten-minute and hourly intervals resulted in smaller errors than daily intervals at the high base temperature range while they were nearly identical in the low range.

CHAPTER 7

PREDICTING FLOWER PRODUCTION PATTERN OF BIRD OF PARADISE BY MODELING LEFE AND FEFC PERIODS WITH HEAT UNIT ACCUMULATION MODELS

Flower growth periods in bird of paradise, LEFE and FEFC, were modeled with heat unit accumulation models using leaf temperature in Chapter 6. In this chapter, the flower production pattern for control was predicted using the actual LE data and the flower growth period model; then the effects of misting and flower abortion on the flower production patterns were determined.

7.1 Literature Review

Two possible causes for the fluctuation in flower production of bird of paradise were proposed (Kawabata, et al., 1984): seasonal differences in the rate of flower growth and in flower abortion.

For the flower growth, while the number of occurrences of LE was seasonal as indicated by a seasonal fluctuation in LE intervals (Fig. 49, Ch. 4), the seasonal difference in the inflorescence bud size occurred only after LE (Table 49, Ch. 5) and the earliest seasonal difference in the inflorescence size was observed in the LEFD (between leaf emergence and flower differentiation) stage (Table 52, Ch. 5). The seasonal flower growth period after LE was successfully modeled with heat unit accumulation (Tables 54 and 55, Ch. 6). Therefore, since LE dates of all flowers and temperature data are available, the flower yield pattern and the effect of leaf cooling (Ch. 2) can be modeled.

For the flower abortion, a large number of the occurrences was previously suggested (Criley and Kawabata, 1984). In the present study, a total of 37% of the control leaves failed to subtend flowers (Ch. 3), while 3.4% of the leaves might not have had flowers initiated at their leaf axils (Ch. 5). Despite the large number of flower abortions, the effect of flower abortion on the seasonal fluctuation pattern could not be determined, because aborted flowers did not have FC (flower cut) and the date of the expected harvest day could not be determined. One method to clarify the abortion effect on the flower production pattern was to simulate the flower growth starting at LE and to estimate hypothetical FCs. Since such a model would have FC date regardless of the occurrence of flower abortion, the comparison of flower production patterns with or without flower abortion was possible.

The objectives of this experiment were:

1. To predict the seasonal flower production pattern by heat unit accumulation models (Ch. 6).
2. To determine the effects of flower abortion and leaf cooling by misting on the seasonal flower production pattern.

7.2 Materials and Methods

LE and temperature data. The data for LE, FE, and FC for control were acquired from the MASTER data set (Ch. 3) by selecting for flowers which 1) the LE occurred in July 1, 1984-December 31, 1985, 2) the FE occurred in July 1, 1984-April 30, 1986, or aborted, and 3) the FC occurred before 1 August 1986 if they were not aborted. These selection procedures were necessary since the MASTER data set included missing data, and the new data set included whole population of flowers which were complete with LE, FE, and FC for the normal flowers and LE only for the aborted. A total of 1282 flowers were accounted for in the control plots. The temperature data to build the heat unit accumulation models were used again in this simulation.

Effect of flower abortion on the flower production pattern. For each control flower, an expected FC was computed in two steps ("LEFCABRT.SAS", Program 5). First, the LEFE period (and FE date) was estimated using the LDM model for 7°C base temperature (Table 54) and the actual LE date. Then, the FEFC period (and FC date) was estimated using the LDM model for 2°C base temperature (Table 55) and the expected FE computed in the previous step.

Monthly totals were computed and the patterns of the monthly sums of estimated FC with or without considering the occurrence of flower abortion. The resulting patterns were compared each other for the size and time (month) of the occurrence of peaks. Since FCs were estimated from actual LEs, the expected FC was present for each flower regardless of the occurrence of flower abortion. (The actual dates of FCs were missing for the aborted flowers.)

Effect of misting on the flower production pattern. For each LE of the control flower, a hypothetical FC date under misting was simulated on a program ("LEFCMIST.SAS" Program 6). First, the LEFE period (and FE date) was estimated using LDM model (Table 54) for 14°C base temperature and the actual LE. Then, the FEFC period was estimated by the LDM model for 7°C base temperature (Table 55) and the expected FE.

This procedure made it possible to estimate the expected FCs as if the plants were misted. Then, monthly totals were computed, and the patterns of monthly sum of the estimated FCs with or without misting were compared for the size and time (month) of the occurrence of peaks.

The patterns created for these comparisons were derived from the same data set for control. Therefore, the comparison of the resulting flower production patterns were free from errors due to the variation in plots and plants, and the differences represented only the treatment effects.

7.3 Results and Discussion

7.3.1 Comparison of Actual and Estimated Flower Production

The performance of the LDM models on the estimation of the flower production pattern was examined by comparing the monthly totals of the FCs (Fig. 127).

The actual FC exhibited a seasonal flower production pattern (Fig 127), however, it was not as strong as previously reported (Kawabata, et al., 1984). Since the plants in this study were young, 4-5 years old, and they were still rapidly increasing in plant size, an annual reduction of flower yield in late fall and winter could have been masked by the gradual increase in FCs (long term increase due to plant growth). This narrowly fluctuating pattern was also seen in the previous study (Kawabata, et al., 1984) in which relatively small fluctuation was observed for the 4-5 years old plants (production record for 1973-1974, Kawabata, et al., 1984).

While four peaks appeared for the monthly total of the actual FCs, the estimated FC had three peaks and generally followed the pattern for the actual FC. Peaks in July 1985, January 1986 and April 1986 were estimated for the same months by the two patterns. For the peak in October 1985 for the actual, the model predicted one month early resulting in a wide peak in July-September 1985.

A probable cause for the one month shift was the under-estimating characteristics by the LDM model for the LEFE for October 1984-February 1985 period (Fig. 122). The maximum under-estimation of LEFE for 16 days (180 days for the actual and 164 days for the estimated) occurred in February 1985. Flowers for which LEs occurred in February 1985 had FEs mainly in August 1985 as mean LEFE was approximately six month, then they had FCs in October 1985 as FEFC was approximately two months (Fig. 124). Therefore, October 1985 peak in the actual FC pattern resulted mainly from long LEs occurred in February 1985, and the 16 days under-estimation of LEFE by the heat unit models resulted in the one month shift of October peak of the actual FC to September for the predicted FC. These analysis showed that the flower production pattern created by the heat unit models were satisfactory in predicting the occurrence of peaks despite the existence of a small shift (1 month).

Another error was created by the harvesting intervals. The actual FC was recorded weekly, while the estimated FC was computed daily.

Since these FCs were summed monthly, there would be discrepancies in harvest months to flowers which FCs occurred within 1 week to the end of month. While an estimated FC was recorded in the present month, the actual FC would have been recorded in the following months. Therefore, the weekly harvest could have created 1 month error in FC dates for some of the flowers.

Although the predicted flower production pattern did not exactly match the actual, the error in predicting peaks were small and this modeling was useful for studying the effects of flower abortion and misting on the flower production patterns.

7.3.2 Effect of Flower Abortion on Flower Production Pattern

Monthly totals of estimated FCs for control, with or without flower abortion, were plotted together along with the differences among them for 1 year period starting May 1985 (Fig. 128). Although the amplitude of the fluctuations were small, these estimated FC patterns showed the typical seasonal flower production patterns in Hawaii: high production in summer-fall and low in winter. On the other hand, the differences of the two totals, which estimate of monthly totals of flower abortion, were not as seasonal as the estimated yield. Except for the May-July 1985 period in which plants showed large numbers of abortion probably due to a drought in the previous year (Ch. 3), the estimated number of flowers aborted showed a gradual increase (30-42) for the rest of the year.

When the 1 year total of estimates were computed for May 1985-April 1986 period, 428 flowers were aborted among 956 flowers initiated or 45% of the total. The number of non-bearing leaves (3.4% of the total leaves) could reduce the percentage to 42%. Although the percentage abortion was reasonable as up to 50% flower abortion was predicted by the previous study (Criley and Kawabata, 1984), the flower abortion was not as seasonal as expected.

Kawabata, et al. (1984) suggested that the flower abortion could have been caused by high air temperatures in warm season which resulted in the sharp reduction in the flower production in late summer-fall period in Hawaii. However, present study indicates a sharp increase in the occurrence of flower abortion expected in late summer-fall period was absent in this irrigated experiment while flower abortion occurred all year (DIFFERENCE, Fig. 128). The cause for the sharp production drops in the previous study could be attributed to the drought conditions in the field (Ch. 4).

Plots of monthly totals of LEs, FEs, and FCs (Fig. 129) shows a gradual change in the production patterns. The LE pattern shows a sharp peak in October 1984. The corresponding peak in the FE pattern shifts to a wider peak in June-July 1985. The totals for FEs are lower than for LEs due to the flower abortion. The peak further widens to July-September 1985 in the FC pattern. These changes in patterns was the result of seasonal difference in plant development rate as a response to the seasonal temperature fluctuation which was modeled by heat unit accumulation models for LEFE and FEFC.

These results indicated that, although the flower abortion caused a large loss of flower production (45% of the total), its contribution to the seasonal difference in flower production was small. The majority of seasonality in the flower production can be attributed to the seasonal difference in the number of LEs and in the flower growth rate after LE (or FD, fower parts differentiatyion, Ch.4).

7.3.3 Relative Number vs. Absolute Number in Expressing the Magnitude of Flower Abortion

The gadual increase in monthly totals of flower abortion (Fig. 128) seemed to be inconsistent with the finding that percent flowering seasonally fluctuated as it had low values for March-October 1985 in the present study (Fig. 39) or for April-August in the previous study (Criley and Kawabata, 1984).

However, plots of monthly totals of LEs and flowers aborted (Fig. 130) displays the reason for the inconsistency. While monthly totals of LEs (LE in A, Fig. 130) has a seasonal fluctuation, flowers aborted (ABORTED in A, Fig. 130) do not have the seasonality. Both totals have gradual increases with time which represents plant growth. When these monthly totals are expressed as percent flowering (B, Fig. 130), a period of low values appeares in the March-October 1985 period.

Therefore, the seasonal fluctuation appeared in the percent flowering (Fig. 39) does not indicate the seasonal fluctuation in monthly totals of flower abortions but it represents the existence of seasonal fluctuation in monthly totals of LEs. Unlike the samplings used in the previous study (Criley and Kawabata, 1984) the study on population in this research made this comparison possible.

7.3.4 Effect of Misting on Flower Production Pattern

Monthly totals of estimated FCs, with or without simulated misting, were plotted together for March 1985-May 1986 (Fig. 131). Both patterns showed the beginning of high production period in summer in the same months, June-July 1985. Since the intermittent misting was not applied until 14 June, 1985, the beginning of the summer production peak was not affected by the misting.

However, the peak period for the FC with misting lasted until October 1985 while the FC without misting lasted only to September 1985. This extension of flowering peak for 1 month was probably due to the slow flower stalk growth caused by the evaporative cooling of plants (Fig. 75 for LEFE and Fig. 99 for FEFC).

An identical extension of the flower yield peak, September 1985 to October 1985, was also found for the estimates in which no flower abortion was assumed (Fig. 132). These flower production patterns estimated by the model indicated that misting in summer could extend the high production peak in summer for 1 month while flower abortion would have no measurable effect on the production pattern.

Actual time for the occurrence of the delays in peaks could be off (as long as 1 month, discussed in this chapter) due to the phase shift observed in the LDM model (Ch. 6). However, the comparison of peaks among the predicted patterns were not affected, because both patterns were estimated from the same LE data and the LDM models. Thus, the estimates were subjected to the phase shift equally.

7.4 Summary

1. The seasonal fluctuation in the flower production of bird of paradise was satisfactorily modeled by the environmental temperature alone using heat unit accumulation.
2. The percentage of flower abortion was determined to 45% (including 3.4% of non-bearing leaves) of the potential flowers in 4-5 year old plants when flower harvests were summed in May 1985-April 1986. Despite the frequent occurrence of flower abortion, the monthly sum of estimated FCs showed only a gradual increase in the abortion pattern which represented the plant growth.
3. The frequent occurrence of flower abortion induced by a high temperature threshold of 27°C (Kawabata, et al., 1984) was not verified a sharp increase in flower abortion expected in late summer-fall period was not observed.
4. The model estimated that intermittent misting in summer extended the peak flower harvesting period for 1 month due to slowed flower growth in LEFC intervals.

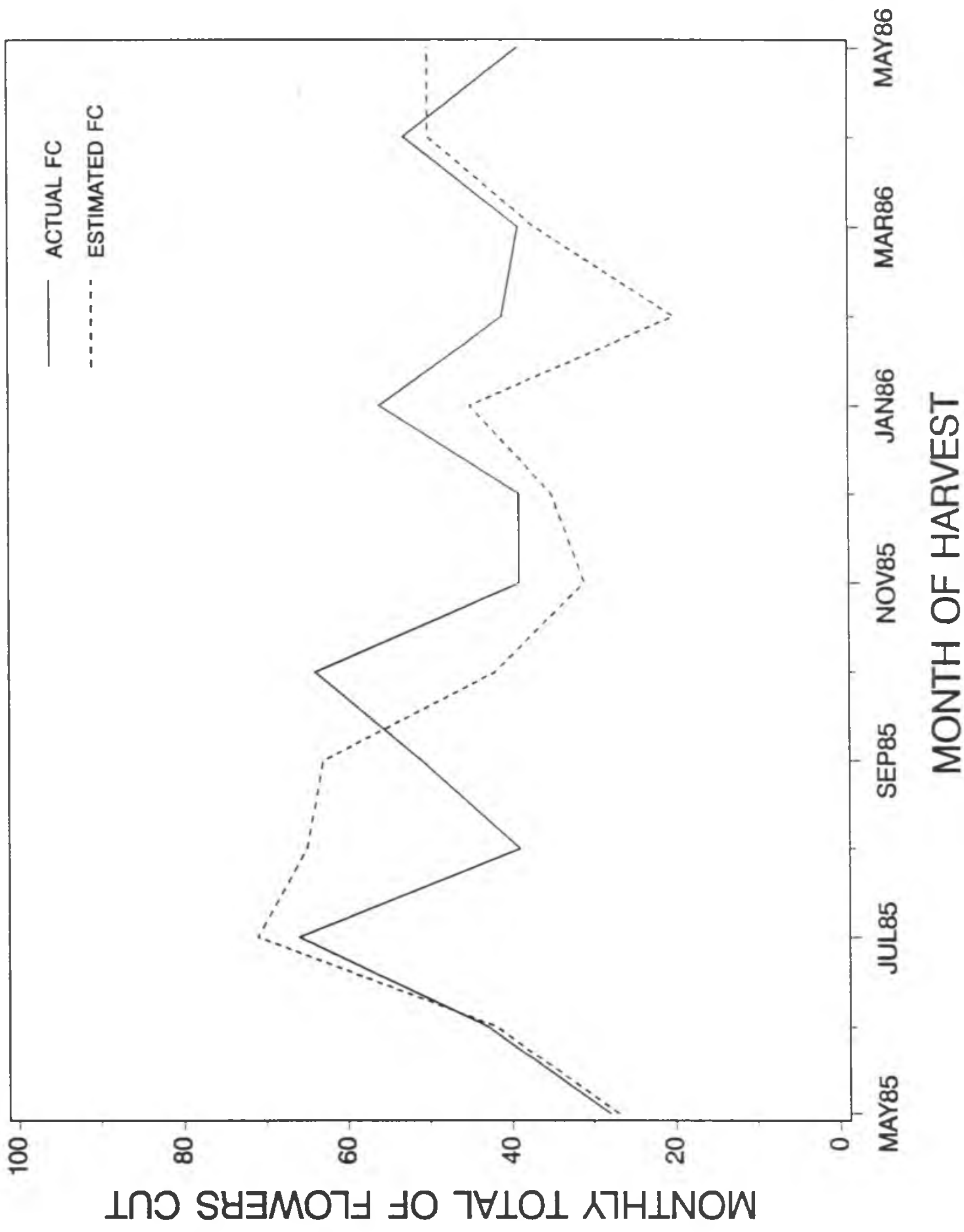


Figure 127. Comparison of the monthly totals for the actual and the estimated flowers cut (FC) in 17 non-misted birds of paradise (5-year-old) in Oahu, Hawaii. The pattern for the estimated FC was produced by the heat unit accumulation models (LDM, Tables 54 and 55) using leaf temperature. Although the estimated monthly totals of flowers cut did not precisely follow the actual, the model simulated the fluctuation pattern in the actual monthly totals of flowers cut.

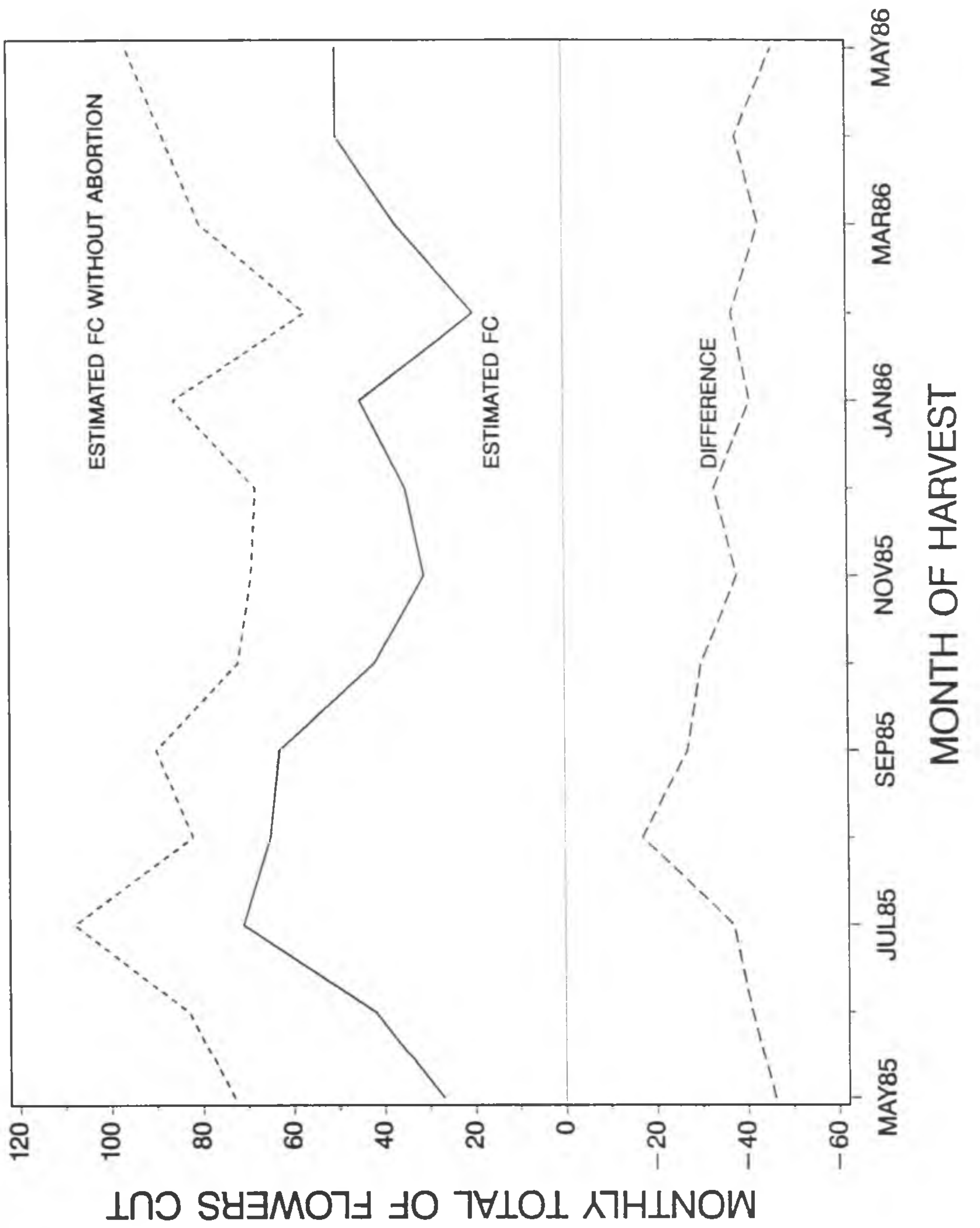


Figure 128. Comparison of the monthly totals for the estimated flower cuts (FC) by heat unit accumulation models in bird of paradise in Oahu, Hawaii. While the flower production patterns, with or without flower abortion, showed relatively large seasonal fluctuations, the difference of the two or the monthly total of flower abortion did not fluctuate as much as the production patterns.

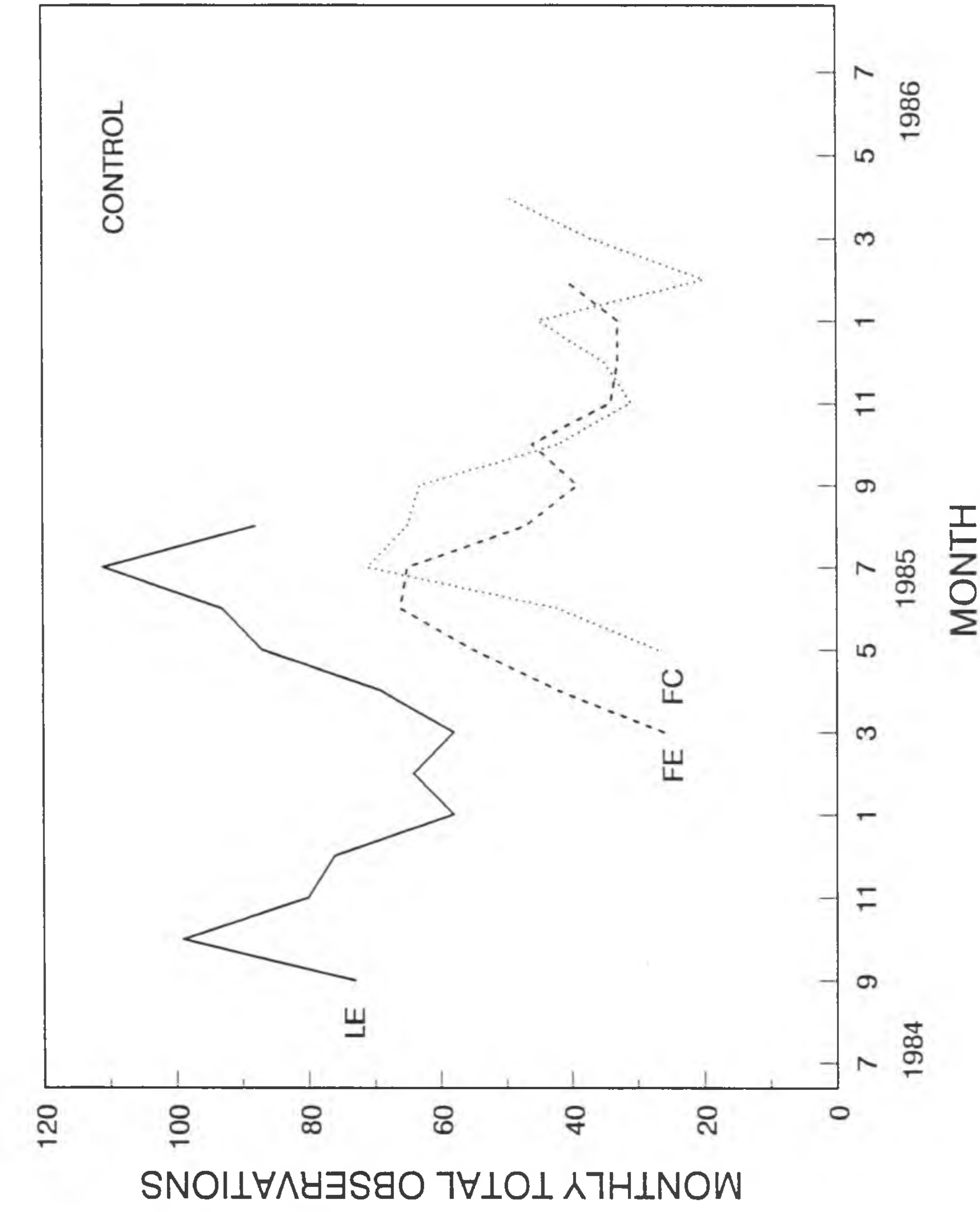


Figure 129. Comparison of the patterns of monthly totals for the actual leaf emergences (LE) and estimated flower emergences (FE) and flowers cut (FC) by heat unit accumulation models in bird of paradise in Oahu, Hawaii. Modified by fluctuating environmental temperature, a sharp October 1984 peak for LE became a broad, July-September 1985 peak for FC resulting from the cumulative effect of fluctuating plant growth rate.

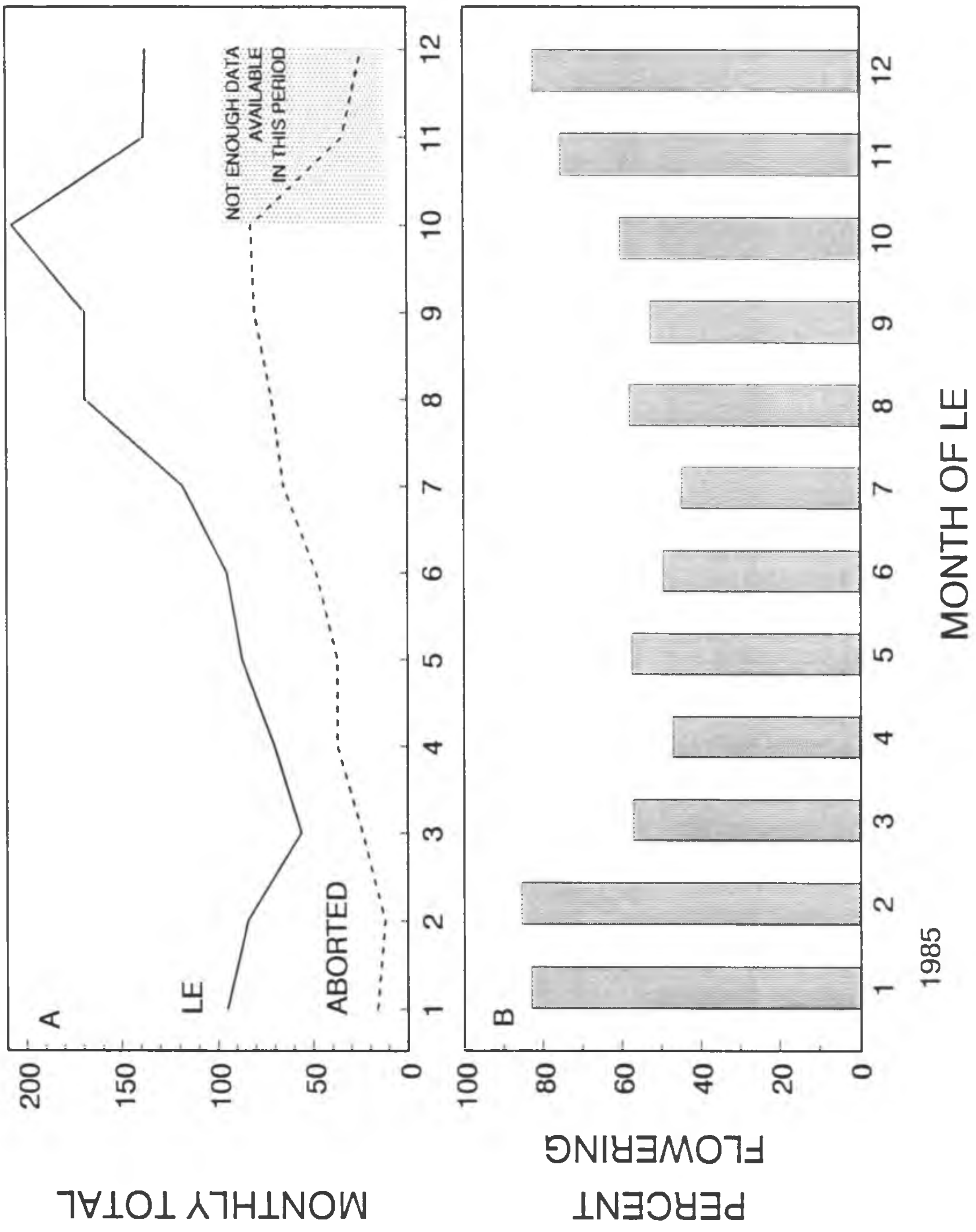


Figure 130. Comparison of the occurrences of flower abortion in bird of paradise expressed as absolute and relative numbers. While monthly totals of leaf emergences (LE in A) and flower abortion (ABORTED in A) both shows gradual increases which represent the plant growth, the ABORTED does not have a seasonal fluctuation. When these two absolute counts are expressed as percentages, a period of low values for March-October 1985 appeared (B). However, the seasonal fluctuation reflects only the seasonal fluctuation in LE but not in the flowers aborted.

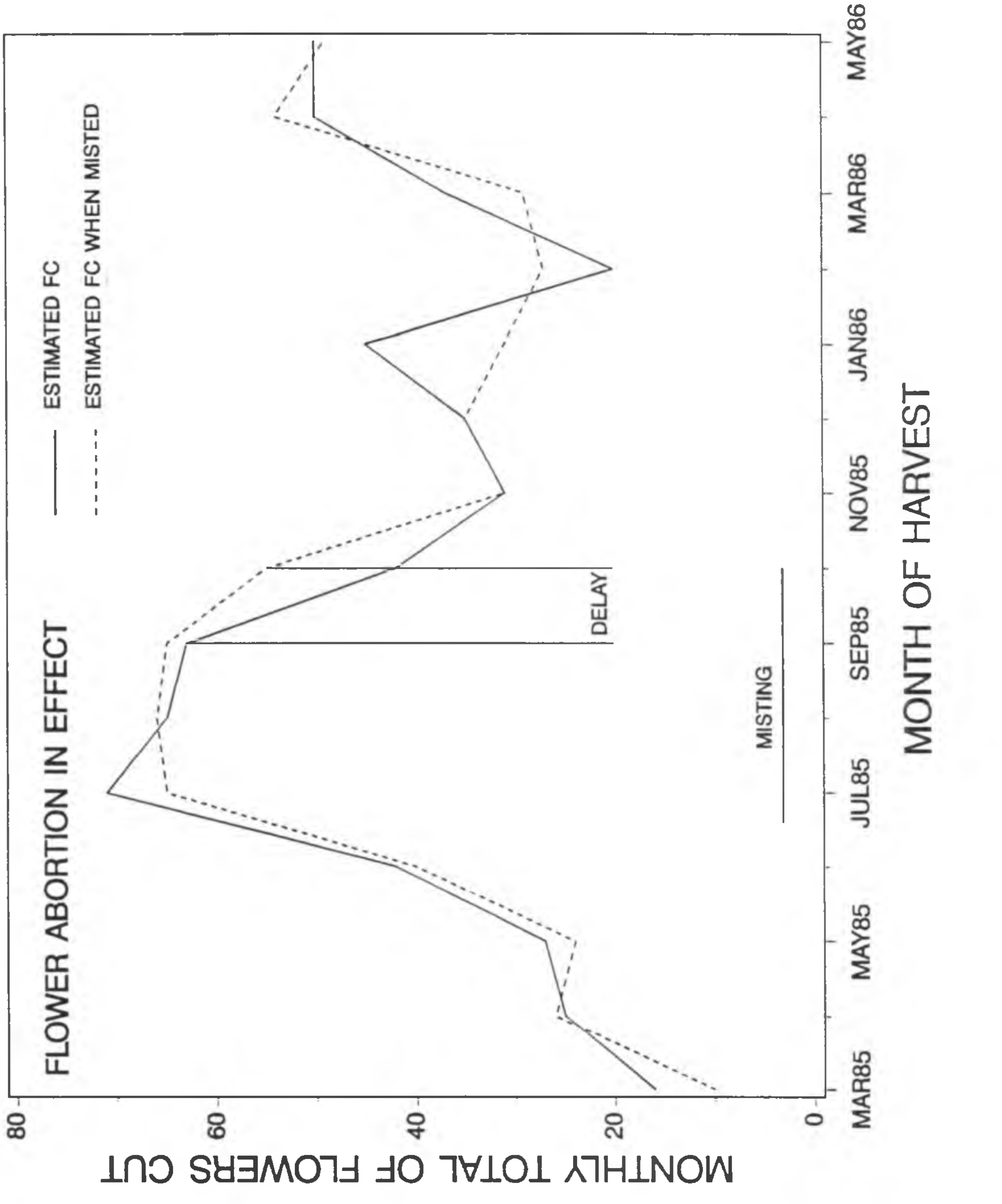


Figure 131. Comparison of the monthly totals of the estimated flower cuts (FC) by heat unit accumulation models in bird of paradise in Oahu, Hawaii. The pattern for the mist (intermittent misting June 14-October 2 in 1985) showed the extension of the end of the peak flowering period in summer 1985 for 1 month due to slow flower growth and the delay of the beginning of the summer peak for the following year (Figs. 75) . The actual records were used for the occurrences of flower abortions.

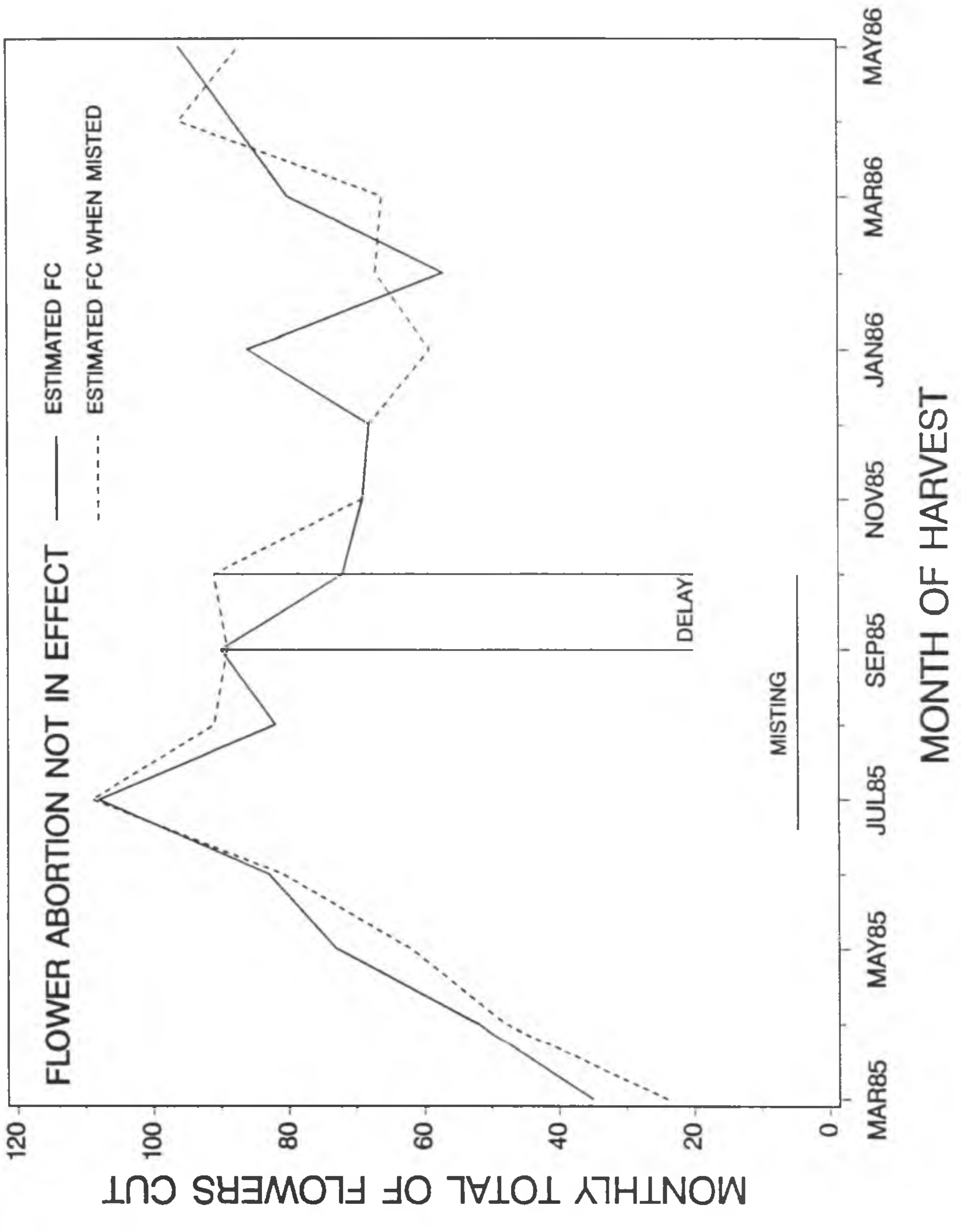


Figure 132. Comparison of the monthly totals of the estimated flower cuts (FC) by heat unit accumulation models in bird of paradise in Oahu, Hawaii. The patterns, estimated under assumption that no flower abortion occurred, showed the same characteristics as the patterns with the flower abortion in the previous figure.

CHAPTER 8

CONCLUSIONS

A problem existed in the occurrence of seasonal fluctuation pattern in flower yield of bird of paradise in Hawaii. A previous study indicated the possible causes to be seasonal differences in the rate of flower growth and in the occurrence of inflorescence bud abortion (Kawabata, et al., 1984). The effect of each possible cause on the flower production pattern was investigated systematically.

In Chapter 2, Leaf temperature models were produced. Air temperature 5 mm away from the bird of paradise leaves and solar radiation (Variable Sequence 2) accounted for 79 percent of the variation in the leaf temperature (Table 9). While mean leaf temperature for summer afternoons was 33.3°C, intermittent misting and 30 percent shading significantly reduced the leaf temperature by 4.6 and 3.2°C, respectively (Figs. 31 and 33).

These results suggested that if the rate of inflorescence bud and flower stalk elongation were dependent on leaf temperature, leaf cooling treatments possibly would show an effect on the flower production pattern by extending the flower growth period. The reduction of leaf temperature by the treatments was also a means to investigate inflorescence abortion as a rise in air temperature beyond 27°C in spring was suggested to be associated with the beginning of the high-abortion-rate period on the flower production record in late summer-fall (Kawabata, et al., 1984).

In Chapter 3, the effect of leaf cooling treatments was determined for actual flower production records. While 63 percent of control leaves subtended inflorescences (Fig. 38), contrary to expectation, neither misting or shading treatments increased the total flower yield over whole observation period (Table 26). This result indicated flower abortion in bird of paradise was not directly caused by a high leaf temperature. The existence of shifts in the peaks in monthly total harvest showed that the rate of flower growth could be modified by the leaf cooling treatments, and modeling of flower production pattern was possible.

In Chapter 4, the characteristics in the branch development and the interactions with leaf cooling treatments were parameterized. It was necessary to determine if the rate of branch development was altered by leaf cooling treatments in addition to the rate of inflorescence development, since a long term increase pattern in flower production (over the life cycle of a plant) was dependent on the rate of leaf production which, in turn, was determined by the development of branches (fans).

The results (Table 42) showed that no significant difference was detected for the parameters in the branch development: total number of splits per plant, split interval, number of daughter fans per split, and number of leaves per fan. Leaf emergence interval was the only variable which showed a significant difference among leaf cooling treatments. Since other characteristics were not modified, leaf emergence interval would affect only the seasonal fluctuation pattern, and it would not change the long term flower production increase. Therefore, leaf cooling treatments did not interact with the branch development, and the differences in seasonal fluctuation patterns among leaf cooling treatments represented only the differences in leaf emergence intervals and the rate of inflorescence growth.

In Chapter 5, it was determined that seasonal difference in the rate of inflorescence occurred in a period between leaf emergence and flower parts differentiation at the earliest (Figs. 70-72). An analysis indicated that, if the rate of the occurrence of leaf emergence were known, modeling of the flower growth period in bird of paradise could be started from leaf emergence in order to predict the seasonal fluctuation in flower production pattern, and that modeling branch development was not necessary.

In Chapter 6, the seasonal difference in inflorescence growth periods, leaf emergence to flower emergence and flower emergence to anthesis, were significantly accounted for (significant at 5% level, Figs. 77 and 101) by leaf degree-minute models (Table 53) with an assumption that an increase in leaf temperature (11.5°C, minimum; and 33°C, average maximum) linearly increased the rate of flower development. Base temperatures were chosen at 7°C for leaf emergence to flower emergence and 2°C for flower emergence to anthesis (Table 54 and 55). Shorter observation intervals, 10-minute compared with hourly or daily, increased the precision of heat unit accumulation models (Fig. 126).

In Chapter 7, flower production patterns for May 1985-May 1986 period were simulated using actual non-misted leaf emergence records, actual flower abortion records, and leaf degree-minute models for inflorescence growth periods after leaf emergence (Ch. 7). Accumulating leaf temperature, instead of air temperature, made it possible to account for the slowing effect of mist treatment on flower stalk growth. The models satisfactorily predicted the occurrences of 4 peaks in May 1985-May 1986 within 1 month of discrepancy (Fig. 127), and the effect of misting in summer on the pattern was determined as extending peak flowering period for 1 month, from July-September to July-October in 1985, regardless of flower abortion (Figs. 131 and 132).

The magnitude of flower abortion was determined as 45 percent (including possible 3.4 percent non-bearing leaves, Ch. 5) of the total leaf production in Hawaii for the 4-5 year old plants. Despite the frequent occurrences, monthly totals of flower abortion showed a only a small seasonal fluctuation with the minimum observed in August 1985 (Fig. 128). Nutritional competition between rapidly growing flower stalks and inflorescence buds at FD stage and insufficient available water were suggested for possible causes of abortion. A 27°C threshold air temperature (Kawabata, et al., 1984) could not be linked to the abortion and seasonal fluctuation pattern in flower production.

In conclusion, flower development in bird of paradise after leaf emergence was estimable using response surface regression models for leaf temperature and heat unit accumulation models for intervals between leaf emergence and anthesis. The use of these models along with the records of leaf emergences made a simulation of flower production possible. The use of leaf temperature for the modeling enabled estimations for the effects of leaf cooling by the intermittent misting and the occurrences of flower abortions on the flower production pattern. Present study suggests a modeling of leaf emergences will improve the applicability of these models and the nutritional competition is a possible cause for the flower abortion.

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APPENDIX A

EQUIPMENT

List of equipment used

Name and model	Description	Manufacturer
	Data collection devices	
Datapod DP-211	A 2-Channel electronic data logger	Omnidata Logan, Utah
Easylogger EL824-GP	A multichannel electronic data logger	Omnidata Logan, Utah
SolaSpray Model 3	An electric misting and irrigation controller	Anabil Enterprise Mustang, Okla.
	Sensors	
Pyranometer LI-200S	A pyranometer for use with Datapod	LI-COR Lincoln, Neb.
Thermistor TP-10V	A thermistor for use with Datapod	Omnidata Logan, Utah
Thermistor ON-909-44008	An epoxy encapsulated ±0.2°C interchangeable thermistor	Omega Stamford, Conn.
Slidewarmer Cat. No. 26000	A slidewarmer with a mercury thermometer	Chicago Surgical and Electrical Melrose Park, Ill.
	Computer hardware	
IBM 3081 3081D	A mainframe computer	IBM Boca Raton, Fla.
IBM PC/AT Personal Computer AT	A microcomputer	IBM Boca Raton, Fla.
Laser printer LaserJet Series II	A laser jet printer for microcomputers	Hewlett Packard Corvallis, Ore.
Plotter Zeta 3600	A four pen plotter for computers	Nicolet

Computer software

Freelance Version 2.0	A graphics program for microcomputers	Lotus Development Cambridge, Mass.
Graphwriter Version 4.30	A graphics program for microcomputers	Lotus Development Cambridge, Mass.
PC SAS Version 6.02	A statistical program for microcomputers	SAS Institute Cary, N. C.
SAS Version 5.16	A statistical program for mainframe computers	SAS Institute Cary, N. C.
Stan Version II.0	A statistical program for microcomputers	Statistical Consultants Lexington, Ky.
Quick BASIC Version 3.0	A BASIC compiler for micro computers	Microsoft Seattle, Wash.

APPENDIX B

PROGRAMS

Program 1. A BASIC program "EZREADER.EZR" for retrieving and managing data from Datapod data logging equipment. This program stores data files in a binary form and writes as an ASCII file including the time variable in the SAS datetime format.

```
==========================================================================
1 'PROGRAM EZREADER.EZR
2 'THIS PROGRAM READS DATAPOD 211 WITH SOLAR RADIATION AND TEMPERATURE
3 'SENSORS, STORES, AND OUTPUTS THE DATA.
4 'VARIABLES   DESCRIPTION
5 '========    ===========================================================
6 'A$          ARRAY (256) OF FILE NAMES
7 'A%          2 DIMENSIONAL (1024 X 2) ARRAY FOR OBSERVATION VARIABLES
8 'C%          NUMBER OF CHARACTERS
9 'CEXT$       NUMBER OF CHARACTERS IN EXTENSION USED FOR FILE SEARCH
10 'CNAM$      NUMBER OF CHARACTERS IN FILE NAME USED FOR FILE SEARCH
11 'D%         UNFORMATTED DATA LINE READ FROM READER
12 'DD$        DAY VALUE
13 'DD%        DAY VALUE (NUMERIC)
14 'DIRECT$    DIRECTORY NAME TO WHICH FILES ARE WRITTEN
15 'DT$        SAS DATETIME VALUE
16 'EXT$       EXTENSION OF DATA FILES
17 'EXTI$      TEMPORARY EXTENSION FOR FILING
18 'HH$        HOUR VALUE
19 'HH%        HOUR VALUE (NUMERIC)
20 'HM%        STARTING MINUTE VALUE IN A DAY
21 'I%         COUNTER FOR INPUT LINES, PAGE, FILE, AND DATA NUMBER
22 'INDI$      TEMPORARY INTERVAL OF OBSERVATION FOR FILING
23 'INL%       INTERVAL OF OBSERVATIONS IN MINUTES
24 'J%         COUNTER FOR INPUT COLUMNS, OUTPUT PAGE NUMBER
25 'L$         LENGTH OF FILE NAME, MEMO
26 'M%         DATA NUMBER IN A FILE
27 'MEM$       MEMO ATTACHED TO FILES
28 'MEMI$      TEMPORARY MEMO FOR FILING
29 'MM$        MINUTE VALUE
30 'MM%        MINUTE VALUE (NUMERIC)
31 'MON2%      TEMPORARY MONTH VALUE (NUMERIC)
32 'MON$       MONTH VALUE
33 'MON%       MONTH VALUE (NUMERIC)
34 'N%         COUNTER FOR NUMBER OF OBSERVATIONS
35 'N%         NUMBER OF OBSERVATIONS
36 'NAM$       NAME OF DATA FILES
37 'NAMI$      TEMPORARY FILE NAME FOR FILING
38 'OBS%       NUMBER OBSERVATIONS
39 'OBSI$      TEMPORARY NUMBER OF OBSERVATIONS FOR FILING
40 'P%         COUNTER FOR OUTPUT PAGE NUMBER
41 'R$         INPUT BUFFER FOR SOLAR RADIATION READING
42 'RAD!       SOLAR RADIATION RECORD
43 'S$         TEMPORARY VARIABLE FOR SELECTION
44 'S%         SELECTION OF A FILE NUMBER
```

```
45 'STD$        STARTING DATE OF DATA FILES
46 'STDI$       TEMPORARY STARTING TIME FOR FILING
47 'T$          INPUT BUFFER FOR TEMPERATURE READING
48 'TEMP!       TEMPERATURE RECORD
49 'YY$         YEAR VALUE
50 'YY%         YEAR VALUE (NUMERIC)
51 '====================================================================
52 'DATA FILES INDEX.EZR AND LASTFILE.EZR ARE NEEDED FOR THE MOST
53 'RECENT INFORMATION
54 '
55 '
60 DIM A$(256),A%(1024,2)
70 COMMON A%(), N%, NAM$, EXT$, STD$, INL%, MEM$
80 NAM$="FILENAME": EXT$="EXT"
90 STD$="MM/DD/YY-HH:MM": INL%=999: MEM$="MEMO"
100 CLS: PRINT "*** DATA STEP ***           EZREADER by Osamu Kawabata"
110 PRINT: PRINT
120 PRINT "DATA INPUT & UTILITY SELECTION"
130 PRINT
140 PRINT "   <D>atapod  reader"
150 PRINT "   <R>etrieve file"
160 PRINT "   <K>eyboard entry"
170 PRINT "   <I>ndex    files"
175 PRINT
180 PRINT "Select a <K>ey for a desirable operation. ";
190 S$=INKEY$: IF S$="" THEN 190
200 IF S$="D" OR S$="d" THEN GOSUB 1000: GOTO 250
210 IF S$="R" OR S$="r" THEN GOSUB 2000: GOTO 250
220 IF S$="K" OR S$="k" THEN GOSUB 3000: GOTO 250
230 IF S$="I" OR S$="i" THEN GOSUB 4000: GOTO 250
232 IF S$="G" OR S$="g" THEN 100
240 GOTO 100
245 '
250 CLS: PRINT "*** PROCEDURE STEP ***"
260 PRINT: PRINT
270 PRINT "PROCEDURE SELECTION"
280 PRINT
290 PRINT "   <F>ile    data to disk"
300 PRINT "   <C>orrect data on screen"
310 PRINT "   <V>iew    data on screen"
320 PRINT "   <L>ist    data to printer"
355 PRINT "   <A>SCII   conversion"
360 PRINT "   <B>ack    to DATA STEP"
370 PRINT "   <E>xit    from EZREADER"
380 PRINT
390 PRINT "Select a <K>ey for a desirable procedure. ";
400 S$=INKEY$: IF S$="" THEN 400
410 IF S$="F" OR S$="f" THEN GOSUB 11000: GOTO 500
420 IF S$="C" OR S$="c" THEN GOSUB 12000: GOTO 500
430 IF S$="V" OR S$="v" THEN GOSUB 13000: GOTO 500
```

```
440 IF S$="L" OR S$="l" THEN GOSUB 14000: GOTO 500
450 IF S$="D" OR S$="d" THEN GOSUB 15000: GOTO 500
460 IF S$="P" OR S$="p" THEN GOSUB 16000: GOTO 500
470 IF S$="S" OR S$="s" THEN GOSUB 17000: GOTO 500
475 IF S$="A" OR S$="a" THEN GOSUB 18000: GOTO 500
480 IF S$="B" OR S$="b" THEN 100
490 IF S$="E" OR S$="e" THEN GOTO 900
500 GOTO 250
900 CLS: PRINT "*** END ***"
910 END
920 '
930 '
999 '==================================== DATAPOD READING =============
1000 CLS: PRINT "DATAPOD READER - MODEL 217"
1010 PRINT: PRINT
1020 PRINT "Set up READER as follows."
1030 PRINT
1040 PRINT "   1. Connect READER to PC."
1050 PRINT "   2. Power READER on."
1060 PRINT "   3. Insert an EPROM."
1070 PRINT "   4. Reset READER."
1080 PRINT
1090 PRINT "Press <RETURN> when set up. ";
1100 S$=INKEY$: IF S$="" THEN 1100
1105 CLOSE: OPEN "COM1:9600,E,7,1,RS,CS65535,DS,CD" AS #1
1110 CLS: PRINT "Press <TRANSMIT RAW DATA> on READER to start. "
1120 FOR I%=1 TO 256
1130 LOCATE 23
1140 LINE INPUT #1,A$(I%)
1150 PRINT A$(I%);"   <--";I%
1170 NEXT I%
1180 CLOSE: CLS
1190 PRINT "End of retrieval.  Wait for a beep for next step."
1200 N%=0
1210 FOR I%=1 TO 256
1215 PRINT ".";
1217 IF I%><1 THEN A$(I%)=MID$(A$(I%),2,64)
1220 FOR J%=1 TO 64 STEP 16
1230 N%=N%+1
1240 RAD$=MID$(A$(I%),J%,8): A%(N%,1)=VAL(RAD$)
1250 TEMP$=MID$(A$(I%),J%+8,8): A%(N%,2)=VAL(TEMP$)
1300 IF N%=1023 THEN J%=65
1310 NEXT J%
1330 NEXT I%
1340 BEEP
1360 RETURN
1370 '
1380 '
1999 '==================================== DATA RETRIEVAL ===============
2000 P%=1
```

```
2010 IF P%<1 THEN P%=1
2020 CLS
2030 PRINT "RETRIEVING A FILE"
2040 PRINT ".#.FILENAME.EXT.MM/DD/YY-HH.MM.#OBS.INTL.";
2050 PRINT "............MEMO............"
2060 OPEN "I",#1,"INDEX.EZR"
2070 FOR I%=1 TO P%*20
2080 IF EOF(1) THEN PRINT "=== END OF FILE ===": GOTO 2180
2090 IF P%*20-I%>20 THEN LINE INPUT#1, D$: GOTO 2170
2100 INPUT#1, NAM$, EXT$, STD$, INL%, OBS%, MEM$
2110 PRINT USING "## ";I%;
2120 PRINT USING "\      \";NAM$;
2122 PRINT ".";
2125 PRINT USING "\ \";EXT$;
2127 PRINT " ";
2130 PRINT USING "\            \";STD$;
2140 PRINT USING " ####";OBS%;
2150 PRINT USING " #### ";INL%;
2160 PRINT MEM$
2170 NEXT I%
2180 CLOSE
2185 I%=I%-1
2190 PRINT "=== Select <N>ext page, <P>revious page, or <R>etrieve ";
2195 PRINT "a file. ";
2200 S$=INKEY$: IF S$="" THEN 2200
2210 IF S$="P" OR S$="p" THEN P%=P%-1: GOTO 2010
2220 IF S$="R" OR S$="r" THEN GOSUB 5000: BEEP: GOTO 2470
2230 IF S$="N" OR S$="n" THEN P%=P%+1: GOTO 2010
2240 GOTO 2200
2470 RETURN
2480 '
2490 '
2999 '==================================== KEYBOARD ENTRY ==============
3000 CLS
3010 PRINT "KEYBOARD ENTRY"
3020 PRINT
3030 ON ERROR GOTO 3035: GOTO 3040
3035 RESUME 3040
3040 INPUT "Total length of data: ", N%
3050 ON ERROR GOTO 0
3060 FOR I%=1 TO N%
3070 PRINT "Observation =============== #";I%
3080 ON ERROR GOTO 3085: GOTO 3090
3085 RESUME 3090
3090 INPUT "Radiation in mV  :  ",RAD!
3100 INPUT "Temperature in C : ",TEMP!
3110 A%(I%,1)=RAD!*5: A%(I%,2)=TEMP!*2+100
3120 ON ERROR GOTO 0
3130 PRINT
3140 NEXT I%
```

```
3150 PRINT "Press <RETURN> for procedure steps. ";
3160 S$=INKEY$: IF S$="" THEN 3160
3170 RETURN
3180 '
3190 '
3999 '=================================== FILE INDEXING ===============
4000 CLS: PRINT "INDEXING DATA FILES"
4010 CNAM$="NAM": CEXT$="EXT"
4030 PRINT
4040 PRINT "Select indexing by file <N>ame or <E>xtension. ";
4050 S$=INKEY$: IF S$="" THEN 4050
4060 IF S$="N" OR S$="n" THEN 4090
4070 IF S$="E" OR S$="e" THEN 4110
4080 GOTO 4000
4090 PRINT
4095 INPUT "Type first n char. for indexing and press <RETURN>: ",CNAM$
4100 C%=LEN(CNAM$): GOTO 4130
4110 PRINT
4115 INPUT "Type first n char. for indexing and press <RETURN>: ",CEXT$
4120 C%=LEN(CEXT$)
4125 '
4130 P%=1
4135 I%=0: J%=0
4140 IF P%<1 THEN P%=1
4142 CLS: PRINT "INDEXING FILES"
4144 PRINT ".#.filename.ext.mm.dd.yy.hh.mm.#obs.intl.";
4146 PRINT "............memo............"
4148 OPEN "I",#1,"INDEX.EZR"
4149 I%=I%+1
4150 IF EOF(1) THEN PRINT "=== END OF FILE ===": GOTO 4310
4160 INPUT #1, NAM$, EXT$, STD$, INL%, OBS%, MEM$
4170 IF LEFT$(NAM$,C%)=CNAM$ EQV LEFT$(EXT$,C%)=CEXT$ THEN 4149
4180 IF P%*20-J%>20 THEN GOTO 4280
4190 PRINT USING "## ";I%;
4200 PRINT USING "\      \";NAM$;
4210 PRINT ".";
4220 PRINT USING "\ \";EXT$;
4230 PRINT " ";
4240 PRINT USING "\            \";STD$;
4250 PRINT USING " ####";OBS%;
4260 PRINT USING " #### ";INL%;
4270 PRINT MEM$
4280 J%=J%+1
4290 IF J%=P%*20 THEN 4310
4300 GOTO 4149
4310 CLOSE
4315 '
4320 PRINT "=== Select <N>ext/<P>rev. page, <G>et/<E>rase a file, or ";
4325 PRINT "<D>ATA STEP. ";
4330 S$=INKEY$: IF S$="" THEN 4330
```

```
4340 IF S$="N" OR S$="n" THEN P%=P%+1: GOTO 4135
4350 IF S$="P" OR S$="p" THEN P%=P%-1: GOTO 4135
4360 IF S$="G" OR S$="g" THEN GOSUB 5000: BEEP: GOTO 4390
4365 IF S$="E" OR S$="e" THEN GOSUB 6000: GOTO 4135
4370 RETURN 100
4390 RETURN
4400 '
4410 '
4999 '================================== READING DATAPOD ============
5000 ON ERROR GOTO 5005: GOTO 5010
5005 RESUME 5020
5010 PRINT
5020 INPUT "=== Type a file number (#) and press <RETURN>: ",S%
5030 IF S%<1 OR S%>I% THEN 5010
5040 ON ERROR GOTO 0
5050 OPEN "I",#1,"INDEX.EZR"
5060 FOR I%=1 TO S%-1
5070 LINE INPUT#1, D$
5080 NEXT I%
5090 INPUT#1, NAM$, EXT$, STD$, INL%, OBS%, MEM$
5100 CLOSE
5110 FILENAME$=NAM$+"."+EXT$
5120 CLS: PRINT "Retrieving "; FILENAME$;"."
5130 OPEN "R",#1,FILENAME$,4
5140 FIELD #1, 2 AS R$, 2 AS T$
5150 FOR N%=1 TO OBS%
5160 GET #1,N%
5170 A%(N%,1)=CVI(R$): A%(N%,2)=CVI(T$)
5180 NEXT N%
5190 N%=N%-1
5200 CLOSE
5210 RETURN
5220 '
5230 '
5999 '=================================== FILE DELETION ==============
6000 ON ERROR GOTO 6005: GOTO 6010
6005 RESUME 6010
6010 PRINT
6020 INPUT "=== Type a file num. (#) to erase and press <RETURN>: ",S%
6030 IF S%<1 OR S%>I% THEN 6010
6040 ON ERROR GOTO 0
6045 PRINT "=== Erasing a file."
6050 OPEN "I",#1,"INDEX.EZR"
6060 OPEN "O",#2,"COPY.EZR"
6070 FOR I%=1 TO S%-1
6080 LINE INPUT#1, D$
6090 PRINT#2, D$
6100 NEXT I%
6110 INPUT#1,NAM$,EXT$,STD$,INL%,OBS%,MEM$
6120 IF EOF(1) THEN 6160
```

```
6130 LINE INPUT#1, D$
6140 PRINT#2, D$
6150 GOTO 6120
6160 CLOSE
6170 KILL "INDEX.EZR"
6180 NAME "COPY.EZR" AS "INDEX.EZR"
6185 KILL NAM$+"."+EXT$
6190 RETURN
6200 '
6210 '
10999 '================================ FILE STORAGE ===============
11000 CLS
11010 PRINT "DATA FILING PROCEDURE"
11020 PRINT
11030 'PRINT "   < >iew index"
11040 PRINT "   <L>ist files"
11050 PRINT "   <F>ile data"
11060 PRINT
11070 PRINT "Select a <K>ey for a desirable procedure. ";
11080 S$=INKEY$: IF S$="" THEN 11080
11090 IF S$="V" OR S$="v" THEN GOSUB 20000: GOTO 11000
11100 IF S$="L" OR S$="l" THEN FILES: PRINT: PRINT: GOTO 11010
11120 OPEN "I",#1,"LASTFILE.EZR"
11130 INPUT#1, NAM$, EXT$, STD$, INL%, OBS%, MEM$
11140 CLOSE
11145 '
11150 CLS
11160 PRINT "INDEX INFORMATION          DATA LENGTH: ";N%;" POINTS"
11170 PRINT "  * A change is required to one of these (*) names."
11180 PRINT
11190 PRINT "  *<1> File name . . . . . . : ";NAM$
11200 PRINT "  *<2> Extension . . . . . . : ";EXT$
11210 PRINT "   <3> Starting date & time  : ";STD$
11220 PRINT "   <4> Interval  . . . . . . : ";INL%
11230 PRINT "   <5> Memo  . . . . . . . . : ";MEM$
11240 PRINT "   <9> Start filing"
11250 PRINT
11260 PRINT "Select <K>eys to change, then press <9> to start filing."
11270 S$=INKEY$: IF S$="" THEN 11270
11280 IF ASC(S$)<49 OR ASC(S$)>57 THEN 11260
11290 S=ASC(S$)-48
11300 ON S GOTO 11310,11360,11390,11410,11630,11660,11660,11660,11660
11305 '
11310 PRINT: INPUT "Type new filename and <RETURN>: ",NAM$
11320 L%=LEN(NAM$)
11321 IF L%=0 THEN PRINT "Type at least one character.": GOTO 11310
11322 FOR I%= 1 TO L%
11323 S$=MID$(NAM$,I%,1)
11324 IF ASC(S$)=32 THEN PRINT "No space allowed.": GOTO 11310
11325 NEXT I%
```

```
11326 IF L%>8 THEN NAM$=LEFT$(NAM$,8)
11330 S$=LEFT$(NAM$,1)
11340 IF ASC(S$)>47 AND ASC(S$)<58 THEN PRINT "START WITH A-Z.": GOTO
      11310
11350 GOTO 11150
11355 '
11360 PRINT: INPUT "Type new extension and <RETURN>: ",EXT$
11370 IF LEN(EXT$)<>3 THEN PRINT "GIVE 3 CHARACTERS.": GOTO 11360
11380 GOTO 11150
11385 '
11390 PRINT: INPUT "Type starting MM/DD/YR-HH:MM and <RETURN>: ",STD$
11400 GOTO 11150
11405 '
11410 PRINT
11415 PRINT "INTERVAL BETWEEN OBSERVATIONS"
11420 PRINT
11430 PRINT "   <1>    1 Minute"
11440 PRINT "   <2>    2 Minutes"
11450 PRINT "   <3>    5 Minutes"
11460 PRINT "   <4>   10 Minutes"
11470 PRINT "   <5>   30 Minuteqs"
11480 PRINT "   <6>   60 Minutes or 1 hour"
11490 PRINT "   <7>  120 Minutes or 2 hours"
11500 PRINT "   <8> 1440 Minutes or 1 day"
11510 PRINT
11520 PRINT "Select a <K>ey. ";
11530 S$=INKEY$: IF S$="" THEN 11530
11540 IF S$="1" THEN INL%=1: GOTO 11150
11550 IF S$="2" THEN INL%=2: GOTO 11150
11560 IF S$="3" THEN INL%=5: GOTO 11150
11570 IF S$="4" THEN INL%=10: GOTO 11150
11580 IF S$="5" THEN INL%=30: GOTO 11150
11590 IF S$="6" THEN INL%=60: GOTO 11150
11600 IF S$="7" THEN INL%=120: GOTO 11150
11610 IF S$="8" THEN INL%=1440: GOTO 11150
11620 GOTO 11410
11625 '
11630 PRINT: INPUT "Write a memo ( <30 and no special char.): ",MEM$
11631 L%=LEN(MEM$)
11632 FOR I%=1 TO L%
11633 S$=MID$(MEM$,I%,1)
11634 IF ASC(S$)=34 THEN 11630
11635 NEXT I%
11640 MEM$=LEFT$(MEM$,30)
11650 GOTO 11150
11655 '
11660 CLS: PRINT "Checking and writing an index file."
11670 OPEN "I",#1,"INDEX.EZR"
11680 OPEN "O",#2,"COPY.EZR"
11690 IF EOF(1) THEN 11800
```

```
11700 INPUT#1, NAMI$, EXTI$, STDI$, INLI%, OBSI%, MEMI$
11710 IF NAMI$<>NAM$ OR EXTI$<>EXT$ THEN 11780
11720 CLOSE
11730 KILL "COPY.EZR"
11740 PRINT "Make an unique filename.ext combination."
11750 PRINT "Press <RETURN> to continue."
11760 S$=INPUT$(1)
11770 GOTO 11000
11775 '
11780 WRITE#2, NAMI$, EXTI$, STDI$, INLI%, OBSI%, MEMI$
11790 GOTO 11690
11800 WRITE#2, NAM$, EXT$, STD$, INL%, N%, MEM$
11805 CLOSE: KILL "INDEX.EZR"
11810 NAME "COPY.EZR" AS "INDEX.EZR"
11820 OPEN "O",#1,"LASTFILE.EZR"
11830 WRITE#1, NAM$, EXT$, STD$, INL%, N%, MEM$
11840 CLOSE
11850 PRINT "Writing ";NAM$;".";EXT$;" on a disk."
11855 FILENAME$=NAM$+"."+EXT$
11860 OPEN "R",#1,FILENAME$,4
11870 FIELD #1, 2 AS R$, 2 AS T$
11880 FOR I%=1 TO N%
11890 RSET R$=MKI$(A%(I%,1))
11900 RSET T$=MKI$(A%(I%,2))
11910 PUT #1,I%
11920 NEXT I%
11930 CLOSE: BEEP: RETURN
11960 '
11970 '
11999 '================================== DATA CORRECTION =============
12000 P%=0
12010 PRINT: GOSUB 21000
12020 PRINT "=== Select <S>pecific page, <C>orrect data, or <E>xit. ";
12030 S$=INKEY$: IF S$="" THEN 12030
12040 IF S$="E" OR S$="e" THEN RETURN
12050 IF S$="C" OR S$="c" THEN 12080
12060 IF S$="S" OR S$="s" THEN 12190
12065 PRINT
12070 P%=P%+1: GOTO 12010
12075 '
12080 ON ERROR GOTO 12105
12085 PRINT
12090 INPUT "Type a data number (#) and press <RETURN>: ",S%
12100 IF S%>M% OR S%<M%-80 THEN GOTO 12090
12104 ON ERROR GOTO 0: GOTO 12120
12105 RESUME 12090
12120 ON ERROR GOTO 12164
12130 INPUT "Type new radiation: ",RAD!
12140 A%(S%,1)=RAD!*5
12150 INPUT "Type new temperature: ",TEMP!
```

```
12160 A%(S%,2)=TEMP!*2+100
12162 ON ERROR GOTO 0: GOTO 12010
12164 RESUME 12130
12180 '
12190 ON ERROR GOTO 12224
12195 PRINT
12200 INPUT "=== Go to page: ",S%
12210 P%=S%-1
12220 ON ERROR GOTO 0: GOTO 12010
12224 RESUME 12200
12240 '
12250 '
12999 '==================================== PAGE SELECTION ==============
13000 P%=0
13010 PRINT: GOSUB 21000
13140 PRINT "=== Select <N>ext page, <P>revious page, or <E>xit. ";
13150 S$=INPUT$(1)
13160 IF S$="P" OR S$="p" THEN P%=P%-1: GOTO 13010
13170 IF S$="E" OR S$="e" THEN GOTO 13190
13180 P%=P%+1: GOTO 13010
13190 RETURN
13200 '
13210 '
13999 '==================================== PRINTING DATA ===============
14000 CLS: PRINT "LISTING DATA"
14010 PRINT
14020 PRINT "Turn on a printer, and press <RETURN>. ";
14030 S$=INKEY$: IF S$="" THEN 14030
14035 PRINT: PRINT "Press any key to interrupt printing."
14045 M%=0: P%=1
14050 LPRINT NAM$;".";EXT$;" ";STD$;" ";N%;"OBS. ";
14055 LPRINT INL%;
14056 LPRINT "MIN. ";MEM$
14060 LPRINT TAB(66) "PAGE ";P%
14070 LPRINT "     #   RAD  TEMP     #   RAD  TEMP";
14080 LPRINT "     #   RAD  TEMP     #   RAD  TEMP"
14090 J%=0
14095 S$=INKEY$: IF S$><"" THEN 14250
14100 FOR I%=1 TO 4
14110 M%=M%+1
14120 IF M%>N% THEN LPRINT "  == END OF DATA ==": GOTO 14240
14130 RAD!=A%(M%,1)/5: TEMP!=(A%(M%,2)-100)/2
14140 LPRINT USING "  ####"; M%;
14150 LPRINT USING "  ##.#"; RAD!; TEMP!;
14160 NEXT I%
14170 LPRINT
14180 J%=J%+1
14190 IF J%=54 THEN GOTO 14210
14200 GOTO 14100
14210 LPRINT CHR$(27)+"&l0H"
```

```
14220 P%=P%+1: GOTO 14050
14240 BEEP
14250 RETURN
14260 '
14270 '
15000 CLS: RETURN
16000 CLS: RETURN
17000 CLS: RETURN
17010 '
17020 '
17999 '================================== ASCII CONVERSION ============
18000 CLS: PRINT "CONVERTING DATA TO AN ASCII FILE"
18010 PRINT
18020 PRINT "New ASCII file will have .ASC extension."
18030 PRINT "New file name will not be verified for the uniqueness."
18032 PRINT
18035 PRINT "You may specify a destination directory using : and \."
18040 INPUT "Otherwise press <RETURN>. -->",DIRECT$
18042 PRINT "Include SAS datetime in output? (Y/N) "
18044 S$=INKEY$: IF S$="" THEN 18044
18046 IF S$="Y" OR S$="y" THEN 18300
18048 PRINT: PRINT "SAS datetime will not be printed."
18050 PRINT "Press <RETURN> to start the conversion."
18060 S$=INKEY$: IF S$="" THEN 18060
18070 CLOSE: OPEN "O",#1,DIRECT$+NAM$+".ASC"
18080 PRINT #1,NAM$;".ASC";" ";STD$;" ";N%;"OBS. ";
18090 PRINT #1,INL%;
18100 PRINT #1,"MIN. ";MEM$
18110 FOR I%=1 TO N%
18120 RAD!=A%(I%,1)/5: TEMP!=(A%(I%,2)-100)/2
18125 IF A%(I%,1)=255 THEN I%=N%+1: GOTO 18140
18130 PRINT #1,USING "  ##.#"; RAD!; TEMP!
18140 NEXT I%
18150 CLOSE: BEEP: PRINT: PRINT "New file is created.  Press <RETURN>."
18160 S$=INPUT$(1)
18170 RETURN
18180 '
18190 '
18299 '================================== SAS DATETIME CONVERSION =====
18300 DATA "JAN","FEB","MAR","APR","MAY","JUN","JUL","AUG","SEP","OCT"
18310 DATA "NOV","DEC"
18315 PRINT: PRINT "SAS datetime will be printed."
18320 PRINT "Press <RETURN> to start the conversion."
18330 S$=INKEY$: IF S$="" THEN 18330
18340 CLOSE: OPEN "O",#1,DIRECT$+NAM$+".ASC"
18350 MON$=MID$(STD$,1,2): MON%=VAL(MON$): GOSUB 18810: MON2%=MON%
18360 DD$ =MID$(STD$,4,2): DD% =VAL(DD$)
18370 YY$ =MID$(STD$,7,2): YY% =VAL(YY$)
18380 HH$ =MID$(STD$,10,2):HH% =VAL(HH$)
18390 MM$ =MID$(STD$,13,2):MM% =VAL(MM$)
```

```
18400 HM%=HH%*60+MM%-INL%
18410 FOR I%=1 TO N%
18420 HM%=HM%+INL%
18430 IF HM%<1440 THEN GOTO 18560
18440 HM%=HM%-1440: DD%=DD%+1
18450 IF DD%=<28 THEN 18560
18460 IF MON%><2 THEN 18490
18470 IF DD%=29 AND (YY% MOD 4)=0 THEN 18560
18480 DD%=1: MON%=3: GOTO 18560
18490 IF DD%=<30 THEN 18560
18500 IF DD%=32 THEN 18540
18510 IF MON%=4 OR MON%=6  THEN MON%=MON%+1: DD%=1: GOTO 18560
18520 IF MON%=9 OR MON%=11 THEN MON%=MON%+1: DD%=1: GOTO 18560
18530 GOTO 18560
18540 MON%=MON%+1: DD%=1
18550 IF MON%=13 THEN MON%=1: DD%=1: YY%=YY%+1
18560 RAD!=A%(I%,1)/5: TEMP!=(A%(I%,2)-100)/2
18570 IF A%(I%,1)=255 THEN I%=N%+1: GOTO 18720
18580 IF MON%=MON2% THEN 18630
18590 GOSUB 18810
18630 MON2%=MON%
18640 DD$=STR$(DD%): DD$=MID$(DD$,2): IF LEN(DD$)=1 THEN DD$="0"+DD$
18650 YY$=STR$(YY%): YY$=MID$(YY$,2)
18660 HH%=HM%\60: MM%=HM% MOD 60
18670 HH$=STR$(HH%): HH$=MID$(HH$,2): IF LEN(HH$)=1 THEN HH$="0"+HH$
18680 MM$=STR$(MM%): MM$=MID$(MM$,2): IF LEN(MM$)=1 THEN MM$="0"+MM$
18690 DT$=DD$+MON$+YY$+":"+HH$+":"+MM$
18700 PRINT #1,DT$;
18710 PRINT #1,USING "  ##.#"; RAD!; TEMP!
18720 NEXT I%
18730 CLOSE: BEEP: PRINT: PRINT "New file is created. Press <RETURN>."
18740 S$=INPUT$(1)
18750 RETURN
18760 '
18800 '
18810 RESTORE
18820 FOR J%=1 TO MON%
18830 READ MON$
18840 NEXT J%
18850 RETURN
18860 '
18870 '
19999 '================================= OUTPUT IN COLUMN ===========
20000 CLS: RETURN
21000 IF P%<0 THEN P%=0
21010 CLS
21020 PRINT "DATA    page ";
21025 PRINT USING "## ";P%+1;
21030 PRINT "  file ";NAM$;
21035 PRINT ".";EXT$;
```

```
21040 PRINT "  intv’l ";INL%;
21045 PRINT " min.  start ";STD$
21050 PRINT "     #   RAD  TEMP     #   RAD  TEMP";
21060 PRINT "     #   RAD  TEMP     #   RAD  TEMP"
21070 M%=P%*80
21080 FOR I%=1 TO 20
21090 FOR J%=1 TO 4
21100 M%=M%+1
21110 IF M%>N% THEN PRINT: PRINT "END OF DATA": GOTO 21190
21120 RAD!=A%(M%,1)/5: TEMP!=(A%(M%,2)-100)/2
21130 PRINT USING "  ####"; M%;
21140 PRINT USING "  ##.#"; RAD!; TEMP!;
21150 NEXT J%
21160 PRINT
21170 NEXT I%
21180 PRINT
21190 RETURN
21200 ’
=======================================================================
```

Program 2. A SAS program "MASTER.SAS" which reads bird of paradise data recoreded on the data collection forms (Append. and a sample input file listed at the end of the program) and build a master data set for further analysis. Univariate statistics were performed for testing the variables created.

```
=========================================================================
*---------------------------------------------------*
PROGRAM 'MASTER.SAS'

THIS PROGRAM CONVERTS BIRD OF PARADISE DATA RECORDED IN THE
DATA COLLECTION FORM INTO VALUES OF VARIABLES WHICH CAN BE
SUBJECTED FOR FURTHER ANALYSIS.

INPUT FILE:     RAW.ALL
OUTPUT FILE:    MASTER
DIRECTORY USED: SAVE

VARIABLE    TYPE        DESCRIPTION
========    ========    =============================================

BENT        Numeric     Bent flower stalk: 1, bent; 0, normal
BRO         Numeric     Original fan, always had a value 1
BR1-BR7     Numeric     Branch number for the nth generation split
COL         Numeric     Column number in the field
DOUBLE      Numeric     Double flower on a stalk: 1, double; 0, normal
EARLYSHW    Numeric     Early LE due to abnormally open leaf sheath:
                        1, early; 0, normal
FAN         Numeric     Fan identification which includes plant and
                        branch identifications
FC          Numeric     Date for flower cut
FCINT       Numeric     Interval between successive FCs, missing if FC
                        for the previous leaf is missing
FCPREV      Numeric     FC for the previous leaf
FE          Numeric     Date for flower emergence
FEFC        Numeric     Interval between FE and FC
FEINT       Numeric     Interval between successive FEs, missing if FE
                        for the previous leaf is missing
FEPREV      Numeric     FE for the previous leaf
INCOMP      Numeric     Completion of a fan at the termination of data
                        collection: 1, incomplete; 0, complete
LE          Numeric     Date for leaf emergence
LEAF        Numeric     Leaf number starting 0 for split leaf
LEAFDEF     Numeric     Leaf deformation: 1, deformed; 0, normal
EFC       Numeric     Interval between LE and FC
LEFE        Numeric     Interval between LE and FE
LEINT       Numeric     Interval between successive LEs, missing for
                        the split leaf
LEPREV      Numeric     LE for the previous leaf
MULTFL      Numeric     Multiple flower stalk: 1, multiple; 0, normal
```

```
NOTE         Numeric      Other notes taken: 1, yes; 0, no
PLANT        Numeric      Plant identification which includes row and
                          column number in the field
ROW          Numeric      Row number in the field
SIDEMERG     Numeric      FE from the side of a fan: 1, side; 0, normal
SPLIT        Numeric      Emergence of split leaves: 1, yes; 0, no
STEMLEN      Numeric      Stalk length in cm
TRT          Character    Treatments: control, mist, shade, or border
X            Character    Temporary variable
================================================================
*---------------------------------------------*;

DATA SAVE.MASTER;
   INFILE 'ROW.ALL';
   MISSING A B M;          /* A; ABORTED: B; BLASTED: M; MISSING */
   INPUT FAN @;
   BR0=1;
   INPUT @1 PLANT 3. @4 BR1 1. @5 BR2 1. @6 BR3 1.
        @7 BR4 1. @8 BR5 1. @9 BR6 1. @10 BR7 1.;
   ROW=INT(PLANT/100);
   COL=PLANT-ROW*100;
   IF 1<=COL AND COL<=6 THEN TRT='S';
      ELSE IF  8<=COL AND COL<=13 THEN TRT='C';
      ELSE IF 15<=COL AND COL<=20 THEN TRT='M';
      ELSE TRT='B';
   LEAF=-1;
   SPLIT=0; INCOMP=0;
   LEPREV=.; FEPREV=.; FCPREV=.;
   DO WHILE(SPLIT NE 1);
      LEAF=LEAF+1;
      STEMLEN=.; BENT=.; SIDEMERG=.; EARLYSHW=.; MULTFL=.; DOUBLE=.;
         LEAFDEF=0; NOTE=0;
      INPUT @1 LE MMDDYY8. @10 FE MMDDYY8. @19 FC MMDDYY8. +1 @;
      LEFE=FE-LE;
      FEFC=FC-FE;
      LEFC=FC-LE;
      LEINT=LE-LEPREV;
      FEINT=FE-FEPREV;
      FCINT=FC-FCPREV;
      IF FE>.M THEN DO;
         BENT=0; SIDEMERG=0; EARLYSHW=0; DOUBLE=0; MULTFL=0; END;
      IF FC>.M THEN DO;
         INPUT STEMLEN @; END;
      X='*';
      DO WHILE(X NE ' ');
         INPUT X $CHAR1. @;
         IF      X='S' THEN SPLIT=1;
         ELSE IF X='I' THEN DO; SPLIT=1; INCOMP=1; END;
         ELSE IF X='B' THEN BENT=1;
         ELSE IF X='D' THEN DOUBLE=1;
```

```
         ELSE IF X='E' THEN EARLYSHW=1;
         ELSE IF X='L' THEN LEAFDEF =1;
         ELSE IF X='M' THEN MULTFL=1;
         ELSE IF X='N' THEN NOTE=1;
         ELSE IF X='R' THEN SIDEMERG=1;
         ELSE IF X NE ' ' THEN DO; PUT FAN LEAF X X X; END;
      END;
      INPUT;
      OUTPUT;
      LEPREV=LE;
      FEPREV=FE;
      FCPREV=FC;
   END;
   FORMAT LE FE FC LEPREV FEPREV FCPREV MMDDYY8.;
   RUN;
PROC UNIVARIATE PLOT NORMAL;
   VAR LE FE FC LEINT FEINT FCINT LEFE FEFC LEFC STEMLEN;
   RUN;
PROC UNIVARIATE FREQ;
   VAR BENT SIDEMERG EARLYSHW MULTFL DOUBLE LEAFDEF;
   QUIT;

/* A SAMPLE INFILE DATA FOR FAN 10911
1234567890123456789112345678921234567894
========================================
10911
110784   A
120584   051585   073185   83.5 E
012385   070285   082885   97.5
031385   080785   100285   108.0
042485   092585   111385   101.5
060585   A
070385   A
081485   021986   042386   115.0
100985   042386   061886   105.0
121185   062586
022686
040986
052886                     S
*/
=========================================================================
```

Program 3. A SAS program "BRANCH.SAS" which makes a new data set BRANCH from the MASTER data set created in Ch. 3. The BRANCH data set extracts branching characteristics in bird of paradise.

```
=======================================================================
*-------------------------------------------------*
PROGRAM 'BRANCH.SAS'

THIS PROGRAM EXTRACTS BRANCHING CHARACTERISTICS
FROM 'SAVE.MASTER' DATA SET.

INPUT FILE:     MASTER
OUTPUT FILE:    BRANCH
DIRECTORY USED: SAVE

   VARIBLE    TYPE      DESCRIPTION
   ========   =======   ===========================================
 * COL        NUMERIC   COLUMN NUMBER IN THE FIELD
 * FAN        NUMERIC   FAN ID
   FANS[]     NUMERIC   LIST OF FAN ID IN A PLANT
 * FIRSTLE    NUMERIC   LE DATE FOR THE FIRST LEAF IN A FAN
 * GEN        NUMERIC   GENERATION NUMBER OF A BRANCH (FAN)
   HI         NUMERIC   TEMPORARY VARIABLE TO DETERMINE FANS[]
   J          NUMERIC   COUNTER
 * LASTLE     NUMERIC   LE DATA FOR THE LAST LEAF IN A FAN
   LE         NUMERIC   DATE OF LEAF EMERGENCE
 * LEAF       NUMERIC   NUMBER OF LEAVES SUBTENDED BY A FAN
   LO         NUMERIC   TEMPORARY VARIABLE TO DETERMINE FANS[]
   N          NUMERIC   COUNTER
 * NSPLIT     NUMERIC   NUMBER OF DAUGHTER FANS CREATED FROM A FAN
 * PLANT      NUMERIC   PLANT ID
 * ROW        NUMERIC   ROW NUMBER IN THE FIELD
 * SPLITINT   NUMRRIC   SPLIT INTERVAL IN DAYS
 * TRT        DISCRETE  TREATMENTS - LEVELS C: CONTROL
                                            M: MISTING
                                            S: SHADING
   X1-X100    NUMERIC   ELEMENTS IN FANS[]
   ================================================================
 * DENOTES VARIABLES INCLUDED IN 'BRANCH' DATA SET.

*-------------------------------------------------*;

DATA ONE;                               /* GET FIRSTLE AND LASTLE */
   SET SAVE.MASTER;
   BY FAN NOTSORTED;
   KEEP TRT ROW PLANT COL FAN FIRSTLE LASTLE LEAF;
   LASTLE=LE;
   IF FIRST.FAN THEN FIRSTLE=LE;
   RETAIN FIRSTLE;
   IF LAST.FAN THEN OUTPUT;
```

```
   RUN;
DATA TWO;
   SET;
   GEN=INT(LOG10(FAN))-1;                   /* COMPUTES GEN AND SPLITINT */
   SPLITINT=LASTLE-FIRSTLE;
   FORMAT FIRSTLE LASTLE MMDDYY8.;
   RUN;
DATA THREE;                                 /* GET NSPLIT */
   ARRAY FANS[100] X1-X100;
   KEEP FAN NSPLIT;
   SET;
   BY PLANT NOTSORTED;
   IF FIRST.PLANT THEN N=0;
   RETAIN N X1-X100;
   N=N+1;
   FANS[N]=FAN;
   IF LAST.PLANT THEN DO;
      DO I=1 TO N;                          /* SEARCH SAME PARENT ID */
         NSPLIT=0;                          /* IN A PLANT FOR NSPLIT */
         LO=FANS[I]*10;
         HI=LO+10;
         DO J=I TO N;
            IF LO<FANS[J]<HI THEN NSPLIT=NSPLIT+1;
         END;
         FAN=FANS[I];
         OUTPUT THREE;
      END;
   END;
   RUN;
DATA SAVE.BRANCH;
   MERGE TWO THREE;
   IF NSPLIT NE 0;
   RUN;
PROC CONTENTS;
   RUN;
PROC PRINT;
   VAR FAN PLANT TRT GEN NSPLIT FIRSTLE LASTLE SPLITINT LEAF;
   RUN;
```

Program 4. A SAS program "DDESTIM.SAS" used to estimate the LEFE (time period between leaf emergence and flower emergence) in bird of paradise in Hawaii by heat unit accumulation models, and the sample outputs from the program

```
======================================================================
*---------------------------------------------------*
PROGRAM 'DDESTIM.SAS' FOR LEFE

THIS PROGRAM ESTIMATES LEFE PERIOD IN BIRD OF PARADISE IN HAWAII USING
HEAT UNIT ACCUMULATION MODELS AND COMPARES THE ERRORS FOR BASE
TEMPERATURES 0-25°C ALONG WITH A SINE-CURVE REGRESSION MODEL.

FOR FEFC ESTIMATION DO FOLLOWINGS.
  1. CHANGE EQUATION FOR EST27 TO
        EST27=59.00+7.91*SIN(2*PI*(TIME+130)/AVEYEAR).
  2. CHANGE NUMBER OF LEAVES (801 FOR LEFE, 581 FOR FEFC).
  3. CHANGE ALL OCCURRENCES OF "LEFE" TO "FEFC".
  4. CHANGE ALL OCCURRENCES OF "FE" TO "FC".
  5. CHANGE ALL OCCURRENCES OF "LE" TO "FE".

TO REDUCE THE SIZE OF DISK OUTPUTS, 12 HEAT UNIT ACCUMULATION TYPES ARE
EXECUTED SEPARATELY. THE FOLLOWING VARIABLES AND TABLES ARE REPLACED IN
EACH EXECUTION OF THIS PROGRAM. THE TABLES CONTAIN DAILY HEAT UNIT
ACCUMULATION.  /* XXX */ IN THE PROGRAM INDICATES THE STATEMENTS WHICH
REQUIRE CHANGES.

     VARIABLE   TABLE       VARIABLE   TABLE
     ================       =======================
     DM         DDT1        LDM        DDT2,DDT2M*
     DH         DDT5        LDH        DDT6,DDT6M
     DDMAX      DDT7        LDDMAX     DDT8,DDT8M
     DDMEAN     DDT9        LDDMEA     DDT10,DDT10M
     DHI        DDT11       LDHI       DDT12,DDT12M
     DDMIN      DDT13       LDDMIN     DDT14,DDT14M
     ----------------       -----------------------
     *M IN THE TABLE DENOTES THE HEAT UNIT ACCUMULATION UNDER MISTING.
      TO ESTIMATE UNDER MISTING, CHANGE NUMBER OF LEAVES (667 FOR LEFE,
      520 FOR FEFC).

DATASETS NEEDED:          DDTn         DAILY HEAT UNIT ACCUMULATION TABLE
                          LEFE_C       FILE OF LE AND FE DATES
NUMBER OF LEAVES:         801          NUMBER OF LEAVES
NUMBER OF DD VARIABLES:   27           BASES 0-25 AND A SINE CURVE MODEL
OUTPUT FILES:             S_DM         HEAT UNIT SUMS IN DM MODEL
                          M_DM         MEAN OF HEAT UNIT SUMS IN DM MODEL
                          E_DM         ESTIMATES OF LEFE BY DM MODEL
                          D_DM         ERRORS IN DM MODEL
DIRECTORIES USED:         S, M, E, D, SAVE, DDTSAVE
TEMPORARY FILES USED:     ONE, TWO, THREE, FOUR, FIVE
```

```
VARIABLE              DESCRIPTION
===============       ===================================================
ABS_MDIF              MEAN ABSOLUTE DIFFERENCE OF ESTIMATED & ACTUAL FE
ADIFF1-ADIFF27        ABSOLUTE DIFFERENCE OF ESTIMATED AND ACTUAL FE
ADIFF[27]             ARRAY NAME FOR THE VARIABLES ADIFF1-ADIFF27
AVEYEAR               AVERAGE DAYS IN A YEAR
BOTTOM                MAXIMUM VALUE FOR THE ITERATION IN DAYS
COL1-COL4             VARIABLES CREATED BY TRANSPOSING
CONF_INT              CONFIDENCE INTERVAL FOR THE ERROR MEAN
DDSUM1-DDSUM26        HEAT UNIT ACCUMULATION FOR BASES 0-25°C
DDSUM[26]             ARRAY NAME FOR THE VARIABLES DDSUM1-DDSUM26
DD[26]                ARRAY NAME FOR THE VARIABLES DM0-DM25
DIFF1-DIFF27          DIFFERENCE OF ESTIMATED AND ACTUAL FE
DIFF[27]              ARRAY NAME FOR THE VARIABLES DIFF1-DIFF27
DM0-DM25              DAILY HEAT UNIT VALUE OF THE DM FOR BASES 0-25°C
EST1-EST26            ESTIMATED LEFE IN DAYS
EST[26]               ARRAY NAME FOR THE VARIABLES EST1-EST26
EST27                 SINE-CURVE REGRESSION MODEL ESTIMATES
FE                    DATE OF FLOWER EMERGENCE
I, J, K, L            COUNTER
LE                    DATE OF LEAF EMERGENCE
LEFE                  NUMBER OF DAYS BETWEEN LE AND FE
MADIFF1-MADIFF27      MEAN ABSOLUTE DIFFERENCE FOR BASES 0-25°C
MDIFF1-MDIFF27        MEAN DIFFERNCE FOR BASES 0-25°C
MEAN_DIF              MEAN DIFFERENCE OF ESTIMATED AND ACTUAL FE
MSUM1-MSUM26          MEAN OF HEAT UNIT ACCUMLATIONS FOR BASES 0-25°C
MSUM[26]              ARRAY NAME FOR THE VARIABLES MSUM1-MSUM26
N1-N54                NUMBER OF OBSERVATIONS
NEW1-NEW27            TEMPORARY VARIABLE FOR THE BASE TEMPERATURE
NEW[27]               ARRAY NAME FOR THE VARIABLES NEW1-NEW27
N_OBS                 NUMBER OF OBSERVATIONS
ORG[108]              ARRAY NAME FOR THE VARIABLES FOR PRINTED OUTPUT
PI                    3.1416
SE                    STANDARD ERROR FOR THE ERROR MEAN
SOURCE                LABEL FOR THE BASE TEMPERATURE
SSADIF1-SSADIF27      UNCORRECTED SS FOR THE VARIABLES ADIFF1-ADIFF27
SSDIF1-SSDIF27        UNCORRECTED SS FOR THE VARIABLES DIFF1-DIFF27
SUM1-SUM26            SUM VARIABLE FOR HEAT UNIT ACCUMULATION
SUM[26]               ARRAY NAME FOR THE VALUABLES SUM1-SUM26
TIME                  NUMBER OF DAYS FROM DECEMBER 31, 1983
TOT                   COUNTER FOR THE NUMBER OF BASES COMPLETED SUMMATION
UNCR_SSD              UNCORRECTED SUM OF SQUARES FOR ERROR
===============       ===================================================

*------------------------------------------------*;
```

```
   TITLE 'DM0-DM25';                    /* XXX */
*-------------------------------------------------*
THIS MODULE COMPUTES HEAT UNIT ACCUMULATION FOR
EACH LEAF AND BASE TEMPERATURE, TAKES MEANS AS THE
BEST ESTIMATES, AND COMPUTES ESTIMATED LEFE.
*-------------------------------------------------*;
DATA S.S_DM;                            /* XXX */
   ARRAY DDSUM[26] DDSUM1-DDSUM26;
   ARRAY DD[26] DM0-DM25;               /* XXX */
   SET SAVE.LEFE_C;
   DO I=1 TO 26;                        /* INITIALIZE SUM VARS */
      DDSUM[I]=0;
   END;
   DO I=LE-'30JUN84'D TO FE-'30JUN84'D;
      SET DDTSAVE.DDT1 POINT=I;         /* XXX */
      DO J=1 TO 26;
         DDSUM[J]=DDSUM[J]+DD[J];       /* ACCUMULATE SUM VALUES */
      END;
   END;
   OUTPUT;                              /* ACCUMULATIONS TO A FILE */
   KEEP LE FE DDSUM1-DDSUM26;
   RUN;
PROC MEANS MEAN NOPRINT;                /* MEANS TO A FILE */
   VAR DDSUM1-DDSUM26;
   OUTPUT OUT=M.M_DM                    /* XXX */
          MEAN=MSUM1-MSUM26;
   RUN;
DATA E.E_DM;                            /* XXX */
   ARRAY MSUM[26] MSUM1-MSUM26;
   ARRAY DD[26]   DM0-DM25;             /* XXX */
   ARRAY SUM[26]  SUM1-SUM26;
   ARRAY EST[26]  EST1-EST26;
   I=1;                                 /* READ ESTIMATED DD SUMS */
   SET M.M_DM POINT=I;                  /* XXX */
   DO I=1 TO 801;
      DO J=1 TO 26;
         SUM[J]=0;                      /* INITIALIZE SUM VARS */
         EST[J]=0;
      END;
      TOT=0;
      SET SAVE.LEFE_C POINT=I;
      BOTTOM='31JUL886'D-'30JUN84'D;
      DO J=LE-'30JUN84'D TO BOTTOM;
         SET DDTSAVE.DDT1 POINT=J;      /* XXX */
         DO K=1 TO 26;
            IF SUM[K]<MSUM[K] THEN DO;  /* ACCUMULATE SUM VALUES */
               SUM[K]=SUM[K]+DD[K];
               EST[K]=EST[K]+1;
               IF SUM[K]>=MSUM[K] THEN TOT=TOT+1;
            END;
```

```
         END;
         IF TOT=26 THEN J=BOTTOM;
      END;
      OUTPUT;                           /* ESTIMATES TO A FILE */
   END;
   KEEP LE FE EST1-EST26;
   STOP;
   RUN;
*-----------------------------------------------*
THIS MODULE COMPUTES DIFFERENCES BETWEEN ACTUAL
AND ESTIMATED LEFC INCLUDING A SINE-CURVE MODEL.
STATISTICS ARE TAKEN FOR COMPARE DIFFERENT TYPES.
*-----------------------------------------------*;
DATA D.D_DM;                            /* XXX */
   ARRAY ADIFF[27] ADIFF1-ADIFF27;
   ARRAY DIFF[27]  DIFF1-DIFF27;
   ARRAY EST[27]   EST1-EST27;
   SET E.E_DM;                          /* XXX */
   PI=3.1416;
   AVEYEAR=365.25;
   TIME=INTCK('DAY','31DEC83'D,LE);
   EST27=167.53+21.58*SIN(2*PI*(TIME+110)/AVEYEAR);
   EST27=CEIL(EST27);
   LEFE=FE-LE;
   DO I=1 TO 27;
      DIFF[I]=EST[I]-LEFE-1;
      ADIFF[I]=ABS(DIFF[I]);
   END;
   KEEP LE FE LEFE EST1-EST27 DIFF1-DIFF27 ADIFF1-ADIFF27;
   RUN;
PROC MEANS N MEAN USS NOPRINT;          /* MEANS AND SS */
   VAR DIFF1-DIFF27 ADIFF1-ADIFF27;
   OUTPUT OUT=ONE N=   N1-N54
                  MEAN=MDIFF1-MDIFF27 MADIFF1-MADIFF27
                  USS= SSDIF1-SSDIF27 SSADIF1-SSADIF27;
   RUN;
*-----------------------------------------------*
THIS MODULE PRODUCES AN OUTPUT OF STATISTICS IN
COLUMNS INCLUDING PLOTS FOR THE UNCORRECTED SUM
OF SQUARES FOR ERROR.
*-----------------------------------------------*;
DATA ONE;
   ARRAY NEW[27]  NEW1-NEW27;
   ARRAY ORG[108] N1-N27 MDIFF1-MDIFF27
                  MADIFF1-MADIFF27 SSADIF1-SSADIF27;
   I=1;
   DO J=1 TO 4;
      SET ONE POINT=I;
      DO K=1 TO 27;
         NEW[K]=ORG[(J-1)*27+K];
```

```
        END;
        OUTPUT;
     END;
     STOP;
     KEEP NEW1-NEW27;
     RUN;
  PROC TRANSPOSE OUT=TWO;
     RUN;
  DATA THREE;
     INPUT SOURCE $ @@;
     CARDS;
        BASE0 BASE1 BASE2 BASE3 BASE4
        BASE5 BASE6 BASE7 BASE8 BASE9
        BASE10 BASE11 BASE12 BASE13 BASE14
        BASE15 BASE16 BASE17 BASE18 BASE19
        BASE20 BASE21 BASE22 BASE23 BASE24
        BASE25 SINE
     ;
     RUN;
  DATA FOUR;
     MERGE TWO THREE;
     DROP _NAME_;
     RUN;
  DATA FIVE;
     SET;
     N_OBS=COL1;
     MEAN_DIF=COL2;
     ABS_MDIF=COL3;
     UNCR_SSD=COL4;
     SE=SQRT((UNCR_SSD-N_OBS*MEAN_DIF**2)/(N_OBS*(N_OBS-1)));
     CONF_INT=2.617*SE;
     DROP COL1-COL4;
     RUN;
  PROC PRINT;
     VAR SOURCE N_OBS MEAN_DIF CONF_INT ABS_MDIF UNCR_SSD;
     RUN;
  PROC TIMEPLOT MAXDEC=0;
     PLOT UNCR_SSD='*';
     ID SOURCE;
     QUIT;
```

```
*-----------------------------------------------------------------*
A sample output listing of "DDESTIM.SAS" program for the LDHI model.
*-----------------------------------------------------------------*

                          LDHI0-LDHI25                              1

OBS    SOURCE    N_OBS    MEAN_DIF    CONF_INT    ABS_MDIF    UNCR_SSD

  1    BASE0      667     -4.5922     3.37978     25.6027      754981
  2    BASE1      667     -4.4363     3.37470     25.5547      751817
  3    BASE2      667     -4.2849     3.36928     25.5082      748568
  4    BASE3      667     -4.0975     3.35665     25.3688      742009
  5    BASE4      667     -3.9475     3.35512     25.3688      740539
  6    BASE5      667     -3.8171     3.34478     25.2714      735370
  7    BASE6      667     -3.6702     3.33971     25.2444      732438
  8    BASE7      667     -3.4648     3.32967     25.1619      727117
  9    BASE8      667     -3.2429     3.32267     25.1169      723105
 10    BASE9      667     -2.9280     3.31455     25.0960      718311
 11    BASE10     667     -2.7481     3.30939     25.0600      715413
 12    BASE11     667     -2.3508     3.30157     25.0315      710710
 13    BASE12     667     -1.9445     3.29682     25.0300      707511
 14    BASE13     667     -1.5202     3.29447     25.0705      705526
 15    BASE14     667     -0.9190     3.29708     25.1499      705665
 16    BASE15     667     -0.1829     3.30644     25.3373      709132
 17    BASE16     667      0.5952     3.33327     25.6567      720903
 18    BASE17     667      1.6192     3.37981     26.1259      742678
 19    BASE18     667      2.8861     3.43533     26.7151      771029
 20    BASE19     667      4.6057     3.51075     27.6012      813602
 21    BASE20     667      6.9175     3.60453     28.7496      874652
 22    BASE21     667     10.1064     3.73026     30.4273      970675
 23    BASE22     667     13.9940     3.97278     33.1364     1154340
 24    BASE23     667     18.0765     4.20275     35.9115     1363617
 25    BASE24     667     23.0195     4.42390     38.9865     1622856
 26    BASE25     667     30.0615     4.69139     43.4648     2030325
 27    SINE       667      0.5307     3.08752     22.7526      618508
```

```
*---------------------------------------------------------------------*
A sample output plot of the "DDESTIM.SAS" program for the LDHI model.
*---------------------------------------------------------------------*

                            LDHIO-LDHI25                              2

SOURCE      UNCR_SSD      min                                       max
                          618508                                2030325
                         *--------------------------------------------*
BASE0           754981   |    *                                       |
BASE1           751817   |    *                                       |
BASE2           748568   |    *                                       |
BASE3           742009   |    *                                       |
BASE4           740539   |    *                                       |
BASE5           735370   |    *                                       |
BASE6           732438   |   *                                        |
BASE7           727117   |   *                                        |
BASE8           723105   |   *                                        |
BASE9           718311   |   *                                        |
BASE10          715413   |   *                                        |
BASE11          710710   |   *                                        |
BASE12          707511   |   *                                        |
BASE13          705526   |   *                                        |
BASE14          705665   |   *                                        |
BASE15          709132   |   *                                        |
BASE16          720903   |   *                                        |
BASE17          742678   |    *                                       |
BASE18          771029   |     *                                      |
BASE19          813602   |      *                                     |
BASE20          874652   |        *                                   |
BASE21          970675   |           *                                |
BASE22         1154340   |                *                           |
BASE23         1363617   |                        *                   |
BASE24         1622856   |                                *           |
BASE25         2030325   |                                           *|
SINE            618508   |*                                           |
                         *--------------------------------------------*;

========================================================================
```

Program 5. A SAS program "LEFCABRT.SAS" for estimating FC date from the actual LE date and the heat unit models.

```
========================================================================
*---------------------------------------------------*
PROGRAM 'LEFCABRT.SAS'

THIS PROGRAM ESTIMATES LEFE AND FEFC IN SUCCESSION THEN PREDICTS FC
DATE IN BIRD OF PARADISE FLOWER GROWTH.

DATASETS NEEDED:       M_LDM         MEAN HEAT UNIT ACCUMULATIONS
                       LEFEFC_C      DATES OF LE, FE, AND FC
                       DDTn          DAILY HEAT UNIT ACCUMULATION TABLE
NUMBER OF FLOWERS:     1282
OUTPUT FILES:          LEFC_SIM      ESTIMATED AND ACTUAL FE AND FC
DIRECTORY USED:        DDTSAVE       LOCATION OF DDTn FILES
                       LEFESAVE      LOCATION OF M_LDM FILES FOR LEFE
                       FEFCSAVE      LOCATION OF M_LDM FILES FOR FEFC
                       SAVE          LOCATION OF OUTPUT FILES
TEMPORARY FILES USED:  ONE TWO

============        ===================================================
BOTTOM              MAXIMUM VALUE FOR THE ITERATION IN DAYS
DD[26]              ARRAY NAME FOR THE VARIABLES LDM1-LDM26
EST                 SUM VARIABLE FOR LEFE OR FEFC
E_FC                ESTIMATED FC DATE
E_FE                ESTIMATED FE DATE
I, J                COUNTER
K                   BASE TEMPERATURE (PLUS 1)
LDM1-LDM26          DAILY HEAT UNIT VALUE FOR THE LDM FOR BASES 0-25°C
LE                  ACTUAL LE DATE
MSUM1-MSUM26        MEAN OF HEAT UNIT ACCUMULATIONS FOR BASES 0-25°C
MSUM[26]            ARRAY NAME FOR THE VARIABLES MSUM1-MSUM26
N                   NUMBER OF FLOWERS
SUM                 SUM VARIABLE FOR HEAT UNIT ACCUMULATION
============        ===================================================
*---------------------------------------------------*;

TITLE 'LEFEABRT.SAS';
*---------------------------------------------------*
THIS MODULE ESTIMATES FE DATE FROM THE ACTUAL LE.
*---------------------------------------------------*;

DATA ONE;
   ARRAY MSUM[26] MSUM1-MSUM26;
   ARRAY DD[26]   LDM0-LDM25;
   I=1;
   N=1282;                              /* NUMBER OF LEAVES */
   K=8;                                 /* BASE TEMPERATURE */
   SET LEFESAVE.M_LDM POINT=I;          /* GET DD CRITERION */
```

```
   DO I=1 TO N;
      SUM=0;                              /* INITIALIZE VARS */
      EST=0;
      SET SAVE.LEFEFC_C POINT=I;          /* GET LE */
      BOTTOM='31JUL86'D-'30JUN84'D;
      DO J=LE-'30JUN84'D TO BOTTOM;
         SET DDTSAVE.DDT2 POINT=J;        /* GET DD VALUE */
         IF SUM<MSUM[K] THEN DO;
            SUM=SUM+DD[K];                /* ACCUMULATE DD */
            EST=EST+1;
            IF SUM>=MSUM[K] THEN J=BOTTOM;
         END;
      END;
      E_FE=LE+EST;
      PUT LE E_FE;
      OUTPUT;                             /* FILE ESTIMATES */
   END;
   STOP;
   KEEP E_FE;
   FORMAT E_FE MMDDYY8.;
   RUN;

*-----------------------------------------------*
THIS MODULE ESTIMATES FC DATE FROM THE ESTIMATED FE.
*-----------------------------------------------*;

DATA TWO;
   ARRAY MSUM[26] MSUM1-MSUM26;
   ARRAY DD[26]   LDM0-LDM25;
   I=1;
   N=1282;                                /* NUMBER OF LEAVES */
   K=3;                                   /* BASE TEMPERATURE */
   SET FEFCSAVE.M_LDM POINT=I;            /* GET DD CRITERION */
   DO I=1 TO N;
      SUM=0;                              /* INITIALIZE VARS */
      EST=0;
      SET ONE POINT=I;                    /* GET E_FE */
      BOTTOM='31JUL86'D-'30JUN84'D;
      DO J=E_FE-'30JUN84'D TO BOTTOM;
         SET DDTSAVE.DDT2 POINT=J;        /* GET DD VALUE */
         IF SUM<MSUM[K] THEN DO;
            SUM=SUM+DD[K];                /* ACCUMULATE DD */
            EST=EST+1;
            IF SUM>=MSUM[K] THEN J=BOTTOM;
         END;
      END;
      E_FC=E_FE+EST;
      OUTPUT;                             /* FILE ESTIMATES */
   END;
   STOP;
```

```
   KEEP E_FC;
   FORMAT E_FC MMDDYY8.;
   RUN;

DATA SAVE.LEFC_SIM;                        /* MERGE DATA SETS */
   MERGE SAVE.LEFEFC_C ONE TWO;
   RUN;

PROC CONTENTS;
   RUN;
PROC PRINT;
   RUN;

=========================================================================
```

Program 6. A SAS program "LEFCMIST.SAS" for estimating the date of FC under simulated misting from the actual LE date and the heat unit models.

```
========================================================================
*--------------------------------------------------*
PROGRAM 'LEFCMIST.SAS'

THIS PROGRAM ESTIMATES LEFE AND FEFC IN SUCCESSION THEN PREDICTS FC
DATE IN BIRD OF PARADISE FLOWER GROWTH. MISTING IS SIMULATED IN THE
HEAT UNIT ACCUMULATION.

DATASETS NEEDED:       M_LDM        MEAN HEAT UNIT ACCUMULATIONS
                       LEFEFC_C     DATES OF LE, FE, AND FC
                       DDTn         DAILY HEAT UNIT ACCUMULATION TABLE
NUMBER OF FLOWERS:     1282
OUTPUT FILES:          LEFC_SIM     ESTIMATED AND ACTUAL FE AND FC
DIRECTORY USED:        DDTSAVE      LOCATION OF DDTn FILES
                       LEFESAVE     LOCATION OF M_LDM FILES FOR LEFE
                       FEFCSAVE     LOCATION OF M_LDM FILES FOR FEFC
                       SAVE         LOCATION OF OUTPUT FILES
TEMPORARY FILES USED:  ONE TWO

============        ===================================================
BOTTOM              MAXIMUM VALUE FOR THE ITERATION IN DAYS
DD[26]              ARRAY NAME FOR THE VARIABLES LDM1-LDM26
EST                 SUM VARIABLE FOR LEFE OR FEFC
E_FC                ESTIMATED FC DATE
E_FE                ESTIMATED FE DATE
I, J                COUNTER
K                   BASE TEMPERATURE (PLUS 1)
LDM1-LDM26          DAILY HEAT UNIT VALUE FOR THE LDM FOR BASES 0-25°C
LE                  ACTUAL LE DATE
MSUM1-MSUM26        MEAN OF HEAT UNIT ACCUMULATIONS FOR BASES 0-25°C
MSUM[26]            ARRAY NAME FOR THE VARIABLES MSUM1-MSUM26
N                   NUMBER OF FLOWERS
SUM                 SUM VARIABLE FOR HEAT UNIT ACCUMULATION
============        ===================================================
*--------------------------------------------------*;

TITLE 'LEFCMIST.SAS';
*--------------------------------------------------*
THIS MODULE ESTIMATE FE DATE FROM THE ACTUAL LE.
*--------------------------------------------------*;

DATA ONE;
   ARRAY MSUM[26] MSUM1-MSUM26;
   ARRAY DD[26]   LDM0-LDM25;
   I=1;
   N=1282;                            /* NUMBER OF LEAVES */
```

```
   K=15;                                  /* BASE TEMPERATURE */
   SET LEFESAVE.M_LDM POINT=I;            /* GET DD CRITERION */
   DO I=1 TO N;
      SUM=0;                              /* INITIALIZE VARS */
      EST=0;
      SET SAVE.LEFEFC_C POINT=I;          /* GET LE */
      BOTTOM='31JUL86'D-'30JUN84'D;
      DO J=LE-'30JUN84'D TO BOTTOM;
         SET DDTSAVE.DDT2M POINT=J;       /* GET DD VALUE */
         IF SUM<MSUM[K] THEN DO;
            SUM=SUM+DD[K];                /* ACCUMULATE DD */
            EST=EST+1;
            IF SUM>=MSUM[K] THEN J=BOTTOM;
         END;
      END;
      E_FE=LE+EST;
      PUT LE E_FE;
      OUTPUT;                             /* FILE ESTIMATES */
   END;
   STOP;
   KEEP E_FE;
   FORMAT E_FE MMDDYY8.;
   RUN;

*---------------------------------------------------*
THIS MODULE ESTIMATES FC DATE FROM THE ESTIMATED FE.
*---------------------------------------------------*;

DATA TWO;
   ARRAY MSUM[26] MSUM1-MSUM26;
   ARRAY DD[26]   LDM0-LDM25;
   I=1;
   N=1282;                                /* NUMBER OF LEAVES */
   K=8;                                   /* BASE TEMPERATURE */
   SET FEFCSAVE.M_LDM POINT=I;            /* GET DD CRITERION */
   DO I=1 TO N;
      SUM=0;                              /* INITIALIZE VARS */
      EST=0;
      SET ONE POINT=I;                    /* GET E_FE */
      BOTTOM='31JUL86'D-'30JUN84'D;
      DO J=E_FE-'30JUN84'D TO BOTTOM;
         SET DDTSAVE.DDT2M POINT=J;       /* GET DD VALUE */
         IF SUM<MSUM[K] THEN DO;
            SUM=SUM+DD[K];                /* ACCUMULATE DD */
            EST=EST+1;
            IF SUM>=MSUM[K] THEN J=BOTTOM;
         END;
      END;
      E_FC=E_FE+EST;
      OUTPUT;                             /* FILE ESTIMATES */
```

```
   END;
   STOP;
   KEEP E_FC;
   FORMAT E_FC MMDDYY8.;
   RUN;

DATA SAVE.LEFCMSIM;                        /* MERGE DATA SETS */
   MERGE SAVE.LEFEFC_C ONE TWO;
   RUN;

PROC CONTENTS;
   RUN;
PROC PRINT;
   RUN;

=======================================================================
```

APPENDIX C

DATA COLLECTION FORM

A data collection form for recording the bird of paradise growth in Waimanalo, Oahu. Each fan was given the form as the first leaf emerged. While the plant was identified by the row and column number in the field, the fan was identified by the relative location to the sister fans, and each leaf was identified by the sequence of the leaf emergence. Dates of leaf emergence (LE), flower emergence (FE), flower cut (FC), and other attributes were recorded in the form.

APPENDIX D

BRANCH DATA

Listing of the BRANCH data set which contains branch characteristics in bird of paradise.

OBS	FAN	PLANT	TRT	GEN	NSPLIT	FIRSTLE	LASTLE	SPLITINT	LEAF
1	101	101	S	1	2	M	07/28/83	.	4
2	1011	101	S	2	2	07/28/83	01/06/84	162	4
3	10111	101	S	3	2	01/06/84	10/31/84	299	5
4	101111	101	S	4	2	10/31/84	08/07/85	280	5
5	10112	101	S	3	2	01/06/84	10/10/84	278	4
6	1012	101	S	2	2	07/28/83	12/15/83	140	4
7	10121	101	S	3	2	12/15/83	10/25/84	315	6
8	101211	101	S	4	2	10/25/84	07/24/85	272	6
9	10122	101	S	3	2	12/15/83	09/05/84	265	4
10	101221	101	S	4	2	09/05/84	10/10/84	35	1
11	101222	101	S	4	2	09/05/84	06/19/85	287	7
12	102	102	S	1	2	M	02/02/84	.	8
13	1022	102	S	2	2	02/02/84	04/10/85	433	9
14	103	103	S	1	2	M	08/25/83	.	5
15	1031	103	S	2	2	08/25/83	06/14/84	294	8
16	10311	103	S	3	2	06/14/84	04/03/85	293	6
17	10312	103	S	3	2	06/14/84	01/22/86	587	12
18	1032	103	S	2	2	08/25/83	06/08/84	288	7
19	10321	103	S	3	2	06/08/84	04/10/85	306	5
20	10322	103	S	3	2	06/08/84	10/31/84	145	3
21	104	104	S	1	2	M	12/01/83	.	9
22	1041	104	S	2	2	12/01/83	10/25/84	329	8
23	1042	104	S	2	2	12/01/83	10/17/84	321	8
24	105	105	S	1	2	M	10/27/83	.	6
25	1051	105	S	2	2	10/27/83	09/26/84	335	7
26	1052	105	S	2	2	10/27/83	09/12/84	321	6
27	106	106	S	1	2	M	08/11/83	.	5
28	1061	106	S	2	2	08/11/83	07/21/84	345	11
29	10612	106	S	3	2	07/21/84	02/19/86	578	15
30	1062	106	S	2	2	08/11/83	05/10/84	273	8
31	107	107	B	1	2	M	07/21/83	.	3
32	1071	107	B	2	2	07/21/83	04/05/84	259	8
33	10712	107	B	3	2	04/05/84	12/12/84	251	7
34	1072	107	B	2	2	07/21/83	01/19/84	182	6
35	10721	107	B	3	2	01/19/84	08/01/84	195	5
36	107211	107	B	4	2	08/01/84	08/14/85	378	8
37	107212	107	B	4	2	08/01/84	04/24/85	266	6
38	10722	107	B	3	2	01/19/84	08/29/84	223	6
39	107221	107	B	4	2	08/29/84	08/21/85	357	7
40	107222	107	B	4	2	08/29/84	09/04/85	371	8
41	108	108	C	1	2	M	03/28/84	.	11
42	1082	108	C	2	2	03/28/84	09/18/85	539	12
43	109	109	C	1	3	M	12/01/83	.	8
44	1091	109	C	2	2	12/02/83	11/07/84	341	8

```
OBS     FAN PLANT TRT GEN NSPLIT  FIRSTLE   LASTLE SPLITINT LEAF

 45    1092  109   C   2     2   12/01/83 06/22/84    204     4
 46   10921  109   C   3     2   06/22/84 02/20/85    243     5
 47    1093  109   C   2     2          M 03/20/85     .      9
 48   10931  109   C   3     2   03/20/85 05/15/85     56     1
 49     110  110   C   1     2          M 08/11/83     .      5
 50    1101  110   C   2     2   08/11/83 02/09/84    182     6
 51   11011  110   C   3     2   02/09/84 10/03/84    237     4
 52   11012  110   C   3     2   02/09/84 09/26/84    230     4
 53  110122  110   C   4     2   09/26/84 02/26/86    518     9
 54    1102  110   C   2     2   08/11/83 04/20/84    253     8
 55   11021  110   C   3     2   04/21/84 02/20/85    305     6
 56   11022  110   C   3     2   04/20/84 10/25/84    188     4
 57  110222  110   C   4     2   10/25/84 03/19/86    510     9
 58     111  111   C   1     2          M 09/21/83     .      6
 59    1111  111   C   2     2   09/21/83 08/01/84    315     6
 60   11111  111   C   3     2   08/01/84 02/13/85    196     5
 61    1112  111   C   2     2   09/21/83 08/22/84    336     7
 62   11121  111   C   3     2   08/22/84 02/12/86    539    13
 63     112  112   C   1     3          M 07/28/83     .      6
 64    1121  112   C   2     2   07/28/83 08/29/84    398    10
 65   11211  112   C   3     2   08/29/84 05/08/85    252     6
 66   11212  112   C   3     2   09/19/84 11/14/84     56     2
 67  112122  112   C   4     2   11/14/84 11/13/85    364     8
 68    1122  112   C   2     2   07/28/83 03/22/84    238     6
 69   11221  112   C   3     2   03/22/84 05/24/84     63     1
 70  112212  112   C   4     2          M 05/08/85     .      7
 71   11222  112   C   3     2   03/22/84 10/17/84    209     4
 72  112221  112   C   4     2   10/17/84 01/29/86    469    11
 73    1123  112   C   2     2   07/28/83 08/15/84    384     8
 74   11231  112   C   3     2   08/15/84 02/06/85    175     5
 75   11232  112   C   3     2   08/15/84 01/31/85    169     5
 76     113  113   C   1     5          M 10/27/83     .      9
 77    1131  113   C   2     3   10/27/83 05/10/84    196     5
 78   11311  113   C   3     2   05/10/84 01/23/85    258     5
 79   11312  113   C   3     2   06/10/84 11/20/85    528    14
 80   11313  113   C   3     2   06/28/84 11/07/84    132     3
 81  113132  113   C   4     2   11/07/84 08/14/85    280     6
 82     114  114   B   1     2          M 08/18/83     .      5
 83    1141  114   B   2     2   08/18/83 01/06/84    141     5
 84   11411  114   B   3     2   01/06/84 08/08/84    215     3
 85  114111  114   B   4     2   08/08/84 07/10/85    336     7
 86  114112  114   B   4     2   08/08/84 05/25/85    290     6
 87   11412  114   B   3     2   01/06/84 09/12/84    250     4
 88  114121  114   B   4     2   09/12/84 01/12/85    122     3
 89  114122  114   B   4     2   09/19/84 06/12/85    266     6
 90    1142  114   B   2     2   08/18/83 08/22/84    370    10
 91   11421  114   B   3     2   08/22/84 08/21/85    364     9
 92   11422  114   B   3     2   08/22/84 10/16/85    420    12
```

OBS	FAN	PLANT	TRT	GEN	NSPLIT	FIRSTLE	LASTLE	SPLITINT	LEAF
93	115	115	M	1	3	M	08/18/83	.	5
94	1151	115	M	2	4	08/18/83	M	.	7
95	11511	115	M	3	2	M	10/25/84	.	5
96	115111	115	M	4	2	10/25/84	08/07/85	286	5
97	115112	115	M	4	2	10/25/84	10/09/85	349	7
98	11512	115	M	3	2	M	12/12/84	.	5
99	11513	115	M	3	2	08/08/84	08/14/85	371	7
100	1152	115	M	2	2	08/18/83	04/20/84	246	8
101	11521	115	M	3	2	04/20/84	12/12/84	236	5
102	115212	115	M	4	2	12/12/84	08/21/85	252	4
103	11522	115	M	3	2	04/20/84	08/29/84	131	2
104	115221	115	M	4	2	08/29/84	01/31/85	155	3
105	1153	115	M	2	2	09/21/83	09/12/84	357	6
106	11531	115	M	3	2	09/12/84	10/10/84	28	1
107	115311	115	M	4	2	10/10/84	08/24/85	318	6
108	115312	115	M	4	2	10/10/84	09/18/85	343	5
109	116	116	M	1	2	M	07/21/83	.	4
110	1161	116	M	2	2	07/21/83	01/06/84	169	6
111	11611	116	M	3	2	01/06/84	08/21/85	593	15
112	116112	116	M	4	2	08/21/85	03/26/86	217	5
113	11612	116	M	3	2	01/06/84	09/12/84	250	4
114	116121	116	M	4	2	09/12/84	09/25/85	378	10
115	116122	116	M	4	2	09/12/84	04/03/85	203	4
116	1161222	116	M	5	2	04/03/85	03/19/86	350	8
117	1162	116	M	2	2	07/21/83	01/06/84	169	6
118	11621	116	M	3	2	01/06/84	11/21/84	320	7
119	116211	116	M	4	3	11/21/84	12/04/85	378	10
120	116212	116	M	4	2	11/21/84	01/15/86	420	11
121	11622	116	M	3	2	01/06/84	06/22/84	168	3
122	116221	116	M	4	2	06/22/84	09/11/85	446	11
123	116222	116	M	4	2	06/22/84	01/05/85	197	4
124	1162221	116	M	5	2	01/05/85	11/13/85	312	7
125	1162222	116	M	5	2	01/05/85	03/12/86	431	10
126	117	117	M	1	3	M	01/27/84	.	11
127	1171	117	M	2	2	01/27/84	09/11/85	593	15
128	1172	117	M	2	2	01/27/84	03/06/85	404	9
129	1173	117	M	2	2	M	10/31/84	.	6
130	119	119	M	1	2	M	10/05/83	.	8
131	1191	119	M	2	3	10/05/83	03/28/84	175	5
132	11911	119	M	3	2	03/28/84	11/07/84	224	5
133	119111	119	M	4	2	11/07/84	10/02/85	329	8
134	119112	119	M	4	2	11/07/84	12/04/85	392	10
135	11912	119	M	3	2	03/28/84	07/24/85	483	10
136	11913	119	M	3	2	03/28/84	10/10/84	196	4
137	119131	119	M	4	2	10/10/84	12/11/85	427	10
138	1192	119	M	2	2	10/05/83	04/05/84	183	5
139	11921	119	M	3	2	04/05/84	10/03/84	181	3
140	119211	119	M	4	2	10/03/84	11/13/85	406	11

OBS	FAN	PLANT	TRT	GEN	NSPLIT	FIRSTLE	LASTLE	SPLITINT	LEAF
141	11922	119	M	3	2	04/05/84	11/07/84	216	5
142	120	120	M	1	3	M	08/25/83	.	7
143	1201	120	M	2	2	08/25/83	03/28/84	216	6
144	12011	120	M	3	2	03/28/84	04/10/85	378	8
145	120111	120	M	4	2	04/10/85	01/08/86	273	7
146	12012	120	M	3	2	03/28/84	05/01/85	399	8
147	1202	120	M	2	2	08/25/83	10/20/83	56	2
148	12021	120	M	3	2	10/20/83	03/01/84	133	2
149	120211	120	M	4	2	03/01/84	10/25/84	238	5
150	1202112	120	M	5	2	10/25/84	07/10/85	258	6
151	120212	120	M	4	2	03/01/84	11/07/84	251	6
152	12022	120	M	3	2	10/20/83	05/15/85	573	12
153	1203	120	M	2	2	09/14/83	11/28/84	441	10
154	12032	120	M	3	2	11/28/84	01/29/86	427	8
155	201	201	S	1	2	M	08/18/83	.	8
156	2011	201	S	2	2	08/18/83	05/31/84	287	8
157	20111	201	S	3	2	05/31/84	05/01/85	335	8
158	201111	201	S	4	2	05/01/85	01/15/86	259	6
159	20112	201	S	3	2	05/31/84	01/22/86	601	14
160	2012	201	S	2	2	08/18/83	04/27/84	253	7
161	20121	201	S	3	2	04/27/84	12/05/84	222	6
162	201211	201	S	4	2	12/05/84	02/26/86	448	8
163	201212	201	S	4	2	12/05/84	03/26/86	476	9
164	20122	201	S	3	2	04/27/84	11/21/84	208	6
165	201221	201	S	4	2	11/21/84	02/19/86	455	9
166	201222	201	S	4	2	11/21/84	08/15/85	267	5
167	202	202	S	1	2	M	06/01/83	.	1
168	2021	202	S	2	2	06/01/83	05/02/84	336	9
169	2022	202	S	2	2	06/01/83	06/14/84	379	10
170	203	203	S	1	3	M	09/28/83	.	5
171	2031	203	S	2	2	09/28/83	11/23/83	56	1
172	20311	203	S	3	2	11/23/83	11/23/83	0	0
173	203112	203	S	4	2	M	M	.	1
174	20312	203	S	3	2	11/23/83	06/05/85	560	9
175	2032	203	S	2	2	09/28/83	11/23/83	56	1
176	20321	203	S	3	2	11/23/83	03/27/85	490	4
177	204	204	S	1	2	M	08/25/83	.	5
178	2041	204	S	2	2	08/25/83	04/10/85	594	11
179	2042	204	S	2	2	08/25/83	09/19/84	391	7
180	205	205	S	1	3	M	09/21/83	.	5
181	2051	205	S	2	2	09/21/83	11/07/84	413	8
182	20511	205	S	3	2	11/07/84	01/22/86	441	9
183	2052	205	S	2	2	M	01/23/85	.	9
184	2053	205	S	2	2	01/12/84	12/25/85	713	14
185	206	206	S	1	3	M	09/18/83	.	5
186	2061	206	S	2	2	08/18/83	05/17/84	273	5
187	20611	206	S	3	2	05/17/84	10/17/84	153	4
188	206111	206	S	4	3	10/17/84	03/05/86	504	11

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 OBS     FAN  PLANT TRT GEN NSPLIT  FIRSTLE   LASTLE  SPLITINT LEAF

 189   20612   206   S   3     2   05/17/84 11/13/85     545    13
 190    2062   206   S   2     3   08/18/83 06/08/84     295     6
 191   20621   206   S   3     2   06/08/84 04/17/85     313     8
 192  206211   206   S   4     2   04/17/85 02/12/86     301     6
 193  206212   206   S   4     2   04/17/85 02/12/86     301     6
 194   20622   206   S   3     2   06/08/84 09/26/84     110     3
 195  206221   206   S   4     2   09/26/84 11/13/85     413     8
 196  206222   206   S   4     2   09/26/84 09/04/85     343     7
 197    2063   206   S   2     2   08/18/83 10/17/84     426    10
 198   20631   206   S   3     2   10/17/84 01/15/86     455    10
 199   20632   206   S   3     2   10/17/84 07/24/85     280     6
 200  206322   206   S   4     2   07/24/85 01/15/86     175     4
 201     207   207   B   1     1          M 07/21/83       .     4
 202    2071   207   B   2     2   07/21/83 08/15/84     391    10
 203   20711   207   B   3     2   08/15/84 12/25/85     497    11
 204   20712   207   B   3     2   08/15/84 09/19/84      35     1
 205  207121   207   B   4     2   09/19/84 03/12/86     539    11
 206  207122   207   B   4     1   09/19/84 11/06/85     413     9
 207    2072   207   B   2     2   07/21/83 09/07/83      48     2
 208   20721   207   B   3     2   08/11/83 09/05/84     391     9
 209  207211   207   B   4     2   09/05/84 06/05/85     273     6
 210  207212   207   B   4     2   09/05/84 12/04/85     455    10
 211   20722   207   B   3     2   09/07/83 05/10/84     246     6
 212  207221   207   B   4     2   05/10/84 09/26/84     139     3
 213  207222   207   B   4     2   05/10/84 11/28/84     202     5
 214     208   208   C   1     2          M 09/07/83       .     4
 215    2081   208   C   2     2   09/07/83 04/20/84     226     5
 216   20811   208   C   3     2   04/20/84 09/26/84     159     4
 217  208112   208   C   4     2   09/26/84 02/19/86     511    11
 218   20812   208   C   3     2   04/20/84 10/31/85     559    13
 219    2082   208   C   2     2   09/07/83 04/12/84     218     5
 220   20821   208   C   3     2   04/12/84 12/12/84     244     6
 221  208211   208   C   4     2   12/12/84 01/29/86     413     8
 222   20822   208   C   3     2   04/12/84 10/23/85     559    14
 223     209   209   C   1     2          M 07/14/83       .     3
 224    2091   209   C   2     3   07/14/83 03/01/84     231     6
 225   20911   209   C   3     2   03/01/84 06/22/84     113     2
 226  209111   209   C   4     2   06/22/84 03/27/85     278     5
 227  209112   209   C   4     2   06/22/84 05/08/85     320     5
 228   20912   209   C   3     2   03/01/84 09/26/84     209     4
 229   20913   209   C   3     2          M 12/05/84       .     6
 230    2092   209   C   2     2   07/14/83 01/06/84     176     5
 231   20921   209   C   3     2   01/06/84 10/03/84     271     6
 232  209211   209   C   4     2   10/03/84 01/08/86     462    11
 233  209212   209   C   4     2   10/03/84 08/14/85     315     6
 234   20922   209   C   3     2   01/06/84 10/17/84     285     6
 235  209221   209   C   4     2   10/17/84 03/19/86     518     9
 236     211   211   C   1     2          M 10/12/83       .     6
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OBS	FAN	PLANT	TRT	GEN	NSPLIT	FIRSTLE	LASTLE	SPLITINT	LEAF
237	2111	211	C	2	2	10/12/83	04/12/84	183	3
238	21112	211	C	3	3	04/12/84	08/01/84	111	1
239	2112	211	C	2	2	10/12/83	08/15/84	308	6
240	21121	211	C	3	2	08/15/84	04/16/86	609	14
241	21122	211	C	3	2	08/15/84	M	.	8
242	211221	211	C	4	2	M	03/19/86	.	4
243	212	212	C	1	2	M	08/25/83	.	4
244	2121	212	C	2	2	08/25/83	05/02/84	251	4
245	21211	212	C	3	2	05/02/84	10/02/85	518	11
246	21212	212	C	3	2	05/02/84	10/31/84	182	4
247	2122	212	C	2	2	08/25/83	10/10/84	412	8
248	21221	212	C	3	2	10/10/84	02/12/86	490	10
249	21222	212	C	3	2	10/10/84	03/06/85	147	3
250	213	213	C	1	2	M	05/02/84	.	7
251	2131	213	C	2	2	05/02/84	06/19/85	413	8
252	2132	213	C	2	2	06/02/84	01/16/85	228	5
253	214	214	B	1	2	M	09/14/83	.	6
254	2141	214	B	2	2	09/14/83	10/03/84	385	10
255	21411	214	B	3	2	10/03/84	10/25/84	22	1
256	21412	214	B	3	2	10/03/84	08/28/85	329	6
257	2142	214	B	2	2	09/14/83	09/12/84	364	9
258	21421	214	B	3	2	09/12/84	02/05/86	511	11
259	215	215	M	1	2	M	08/18/83	.	4
260	2151	215	M	2	2	08/18/83	04/20/84	246	7
261	21511	215	M	3	2	04/20/84	07/10/85	446	8
262	21512	215	M	3	2	04/27/84	06/12/85	411	7
263	2152	215	M	2	3	08/25/83	01/16/84	144	2
264	21521	215	M	3	2	01/16/84	09/26/84	254	3
265	21522	215	M	3	2	01/16/84	06/22/84	158	2
266	215222	215	M	4	2	06/22/84	02/20/86	608	9
267	21523	215	M	3	2	M	02/13/85	.	4
268	216	216	M	1	2	M	08/04/83	.	5
269	2161	216	M	2	2	08/04/83	12/08/83	126	4
270	21611	216	M	3	2	12/08/83	06/22/84	197	4
271	216111	216	M	4	2	06/22/84	01/08/86	565	10
272	21612	216	M	3	2	12/08/83	09/19/84	286	5
273	216121	216	M	4	2	09/19/84	03/06/85	168	3
274	216122	216	M	4	2	09/19/84	07/17/85	301	5
275	2162	216	M	2	2	08/04/83	04/12/84	252	7
276	21621	216	M	3	2	04/12/84	10/25/84	196	3
277	21622	216	M	3	2	04/12/84	11/28/84	230	4
278	216221	216	M	4	2	11/28/84	06/05/85	189	2
279	2162211	216	M	5	2	06/05/85	07/31/85	56	1
280	216222	216	M	4	2	11/28/84	07/31/85	245	3
281	217	217	M	1	3	M	02/23/84	.	11
282	2171	217	M	2	2	02/23/84	05/24/84	91	3
283	21711	217	M	3	2	05/24/84	10/03/84	132	3
284	217112	217	M	4	2	10/03/84	04/03/85	182	3

OBS	FAN	PLANT	TRT	GEN	NSPLIT	FIRSTLE	LASTLE	SPLITINT	LEAF
285	2172	217	M	2	2	02/23/84	09/11/85	566	12
286	2173	217	M	2	2	02/23/84	05/10/84	77	2
287	21731	217	M	3	2	05/10/84	03/06/85	300	4
288	21732	217	M	3	2	05/10/84	09/19/84	132	3
289	218	218	M	1	4	M	09/28/83	.	6
290	2181	218	M	2	2	09/28/83	10/10/84	378	7
291	21811	218	M	3	2	10/17/84	03/06/85	140	2
292	2182	218	M	2	2	09/28/83	08/01/84	308	6
293	21821	218	M	3	2	08/01/84	06/26/85	329	6
294	21822	218	M	3	2	08/01/84	07/17/85	350	6
295	2183	218	M	2	2	10/27/83	01/12/85	443	8
296	2184	218	M	2	2	M	01/15/86	.	14
297	219	219	M	1	3	M	08/31/83	.	4
298	2191	219	M	2	2	08/31/83	02/13/85	532	10
299	2192	219	M	2	2	08/31/83	09/21/83	21	1
300	21921	219	M	3	2	09/21/83	09/12/84	357	7
301	219211	219	M	4	2	09/12/84	06/19/85	280	4
302	21922	219	M	3	2	10/27/83	05/15/85	566	9
303	2193	219	M	2	2	08/31/83	08/31/83	0	0
304	21931	219	M	3	2	M	03/27/85	.	5
305	21932	219	M	3	2	M	12/23/84	.	4
306	220	220	M	1	2	M	11/23/83	.	7
307	2201	220	M	2	2	11/23/83	04/20/84	149	4
308	22011	220	M	3	2	04/20/84	06/05/85	411	11
309	220111	220	M	4	2	06/05/85	02/12/86	252	7
310	220112	220	M	4	2	06/05/85	12/25/85	203	6
311	22012	220	M	3	2	04/20/84	10/17/84	180	4
312	220121	220	M	4	2	10/17/84	09/04/85	322	7
313	220122	220	M	4	2	10/17/84	09/25/85	343	9
314	2202	220	M	2	2	11/23/83	06/08/84	198	5
315	22021	220	M	3	2	06/08/84	11/07/84	152	4
316	220211	220	M	4	2	11/07/84	11/06/85	364	9
317	220212	220	M	4	3	11/07/84	10/30/85	357	8
318	22022	220	M	3	2	06/08/84	12/12/84	187	5
319	220221	220	M	4	2	12/12/84	12/25/85	378	9
320	220222	220	M	4	2	12/12/84	02/05/86	420	9
321	303	303	S	1	2	M	02/23/84	.	10
322	3031	303	S	2	2	02/23/84	10/25/84	245	5
323	3032	303	S	2	2	02/23/84	10/31/84	251	5
324	305	305	S	1	2	M	12/17/83	.	8
325	3051	305	S	2	2	12/17/83	08/08/84	235	5
326	30512	305	S	3	2	08/08/84	01/16/85	161	4
327	305121	305	S	4	2	01/16/85	03/26/86	434	10
328	3052	305	S	2	2	12/17/83	07/05/84	201	4
329	30521	305	S	3	2	07/05/84	04/03/85	272	7
330	30522	305	S	3	2	07/05/84	09/18/85	440	12
331	306	306	S	1	2	M	01/05/84	.	9
332	3061	306	S	2	2	01/05/84	08/01/84	209	4

OBS	FAN	PLANT	TRT	GEN	NSPLIT	FIRSTLE	LASTLE	SPLITINT	LEAF
333	30611	306	S	3	2	08/01/84	01/08/86	525	15
334	30612	306	S	3	2	09/01/84	09/11/85	375	11
335	3062	306	S	2	2	01/05/84	10/10/84	279	6
336	30621	306	S	3	2	10/10/84	11/20/85	406	10
337	307	307	B	1	2	M	01/27/84	.	9
338	3071	307	B	2	2	01/27/84	08/01/84	187	4
339	30711	307	B	3	2	08/01/84	01/22/86	539	13
340	30712	307	B	3	3	08/01/84	03/12/86	588	14
341	3072	307	B	2	2	01/27/84	10/10/84	257	6
342	30721	307	B	3	2	10/10/84	10/16/85	371	11
343	309	309	C	1	2	M	12/08/83	.	5
344	3091	309	C	2	2	12/08/83	01/16/85	405	12
345	30911	309	C	3	2	01/16/85	10/23/85	280	8
346	30912	309	C	3	2	01/16/85	10/16/85	273	8
347	3092	309	C	2	2	12/08/83	08/22/84	258	7
348	30921	309	C	3	2	08/22/84	12/18/85	483	12
349	30922	309	C	3	2	08/22/84	10/23/85	427	13
350	310	310	C	1	3	M	01/19/84	.	9
351	3101	310	C	2	2	01/19/84	09/26/84	251	5
352	31011	310	C	3	2	09/26/84	01/29/86	490	12
353	3102	310	C	2	2	01/19/84	08/24/84	218	4
354	31021	310	C	3	2	08/29/84	04/17/85	231	5
355	31022	310	C	3	2	08/29/84	02/27/85	182	4
356	3103	310	C	2	2	03/22/84	10/17/84	209	4
357	312	312	C	1	2	M	10/27/83	.	8
358	3121	312	C	2	2	10/27/83	05/24/84	210	5
359	31211	312	C	3	2	05/24/84	08/15/84	83	2
360	312111	312	C	4	2	08/15/84	03/13/85	210	6
361	312112	312	C	4	3	08/15/84	03/26/86	588	16
362	31212	312	C	3	2	05/24/84	12/29/84	219	7
363	312121	312	C	4	2	12/29/84	12/25/85	361	10
364	312122	312	C	4	2	12/29/84	09/18/85	263	7
365	3122	312	C	2	2	10/27/83	03/15/84	140	3
366	31221	312	C	3	2	03/15/84	06/14/84	91	2
367	312211	312	C	4	2	06/14/84	01/01/86	566	15
368	312212	312	C	4	3	06/14/84	02/05/86	601	17
369	31222	312	C	3	2	03/15/84	09/05/84	174	4
370	312221	312	C	4	2	09/05/84	03/26/86	567	15
371	313	313	C	1	2	M	08/18/83	.	7
372	3131	313	C	2	2	08/18/83	04/12/84	238	7
373	31312	313	C	3	3	04/12/84	11/20/85	587	17
374	3132	313	C	2	2	08/18/83	03/15/84	210	6
375	31321	313	C	3	2	03/15/84	11/20/85	615	18
376	31322	313	C	3	3	03/15/84	12/18/85	643	19
377	314	314	B	1	3	M	01/19/84	.	10
378	3141	314	B	2	2	01/19/84	10/17/84	272	6
379	31412	314	B	3	2	10/17/84	07/24/85	280	6
380	3142	314	B	2	2	01/19/84	11/06/85	657	16

OBS	FAN	PLANT	TRT	GEN	NSPLIT	FIRSTLE	LASTLE	SPLITINT	LEAF
381	3143	314	B	2	2	M	10/25/84	.	4
382	31432	314	B	3	2	10/25/84	09/25/85	335	7
383	315	315	M	1	2	M	12/17/83	.	11
384	3151	315	M	2	2	12/17/83	06/08/84	174	5
385	31511	315	M	3	2	06/08/84	06/05/85	362	9
386	31512	315	M	3	2	06/08/84	01/31/85	237	6
387	3152	315	M	2	3	12/17/83	07/21/84	217	6
388	31522	315	M	3	2	07/21/84	06/26/85	340	7
389	31523	315	M	3	2	07/21/84	04/02/86	620	13
390	316	316	M	1	2	M	03/22/84	.	10
391	3161	316	M	2	2	04/05/84	08/01/84	118	3
392	31611	316	M	3	2	08/01/84	12/29/84	150	4
393	31612	316	M	3	2	08/01/84	12/23/84	144	4
394	3162	316	M	2	2	M	08/15/84	.	3
395	31621	316	M	3	2	08/15/84	10/02/85	413	10
396	31622	316	M	3	2	08/15/84	12/04/85	476	12
397	317	317	M	1	2	M	10/20/83	.	8
398	3171	317	M	2	2	10/20/83	07/14/84	268	7
399	31711	317	M	3	2	07/14/84	08/14/85	396	11
400	31712	317	M	3	2	07/14/84	04/10/85	270	8
401	317121	317	M	4	2	04/10/85	10/30/85	203	5
402	317122	317	M	4	2	04/10/85	01/22/86	287	7
403	3172	317	M	2	2	10/27/83	03/01/84	126	3
404	31721	317	M	3	2	03/01/84	02/27/85	363	9
405	317211	317	M	4	2	02/27/85	11/27/85	273	8
406	31722	317	M	3	2	03/01/84	04/10/85	405	8
407	318	318	M	1	2	M	10/27/83	.	9
408	3181	318	M	2	2	10/27/83	05/02/84	188	6
409	31811	318	M	3	2	05/02/84	09/26/84	147	3
410	31812	318	M	3	2	05/02/84	10/31/84	182	4
411	318121	318	M	4	2	10/31/84	09/11/85	315	6
412	3182	318	M	2	2	10/27/83	06/20/84	237	5
413	31821	318	M	3	2	04/20/84	11/07/84	201	5
414	318211	318	M	4	2	11/07/84	08/28/85	294	6
415	31822	318	M	3	2	04/20/84	11/07/84	201	6
416	318221	318	M	4	2	11/07/84	01/01/86	420	9
417	319	319	M	1	2	M	08/25/83	.	5
418	3191	319	M	2	2	08/25/83	05/29/85	643	20
419	3192	319	M	2	2	08/25/83	04/20/84	239	7
420	31921	319	M	3	2	04/20/84	10/09/85	537	14
421	31922	319	M	3	2	04/20/84	09/04/85	502	11
422	320	320	M	1	2	M	09/21/83	.	7
423	3201	320	M	2	2	09/21/83	06/22/84	275	5
424	32011	320	M	3	2	06/22/84	02/13/85	236	5
425	32012	320	M	3	2	06/22/84	08/15/84	54	1
426	320121	320	M	4	2	08/15/84	11/14/84	91	2
427	320122	320	M	4	2	08/15/84	02/12/86	546	12
428	3202	320	M	2	2	09/21/83	03/22/84	183	4

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 OBS     FAN  PLANT  TRT  GEN  NSPLIT   FIRSTLE    LASTLE  SPLITINT  LEAF

 429   32021   320    M    3      2    03/22/84  10/10/84     202       4
 430   32022   320    M    3      2    03/22/84  10/25/84     217       5
 431     401   401    S    1      3           M  03/01/84       .      10
 432    4011   401    S    2      2    06/08/84  11/20/85     530      14
 433    4012   401    S    2      2    04/20/84  10/10/84     173       4
 434   40122   401    S    3      2    10/10/84  12/29/84      80       1
 435    4013   401    S    2      2           M  11/27/85       .      15
 436     402   402    S    1      2           M  08/04/83       .       4
 437    4021   402    S    2      2    08/04/83  04/05/84     245       5
 438   40211   402    S    3      2    04/05/84  11/21/84     230       5
 439  402111   402    S    4      2    11/21/84  04/02/86     497      11
 440   40212   402    S    3      2    04/05/84  11/07/84     216       5
 441    4022   402    S    2      2    08/04/83  06/08/84     309       6
 442   40221   402    S    3      2    06/08/84  09/26/84     110       2
 443   40222   402    S    3      2    06/08/84  09/26/84     110       3
 444  402222   402    S    4      2    09/26/84  04/02/86     553      13
 445     403   403    S    1      2           M  09/14/83       .       6
 446    4031   403    S    2      2    09/14/83  04/20/84     219       5
 447   40311   403    S    3      2    04/20/84  08/01/84     103       2
 448  403112   403    S    4      2    08/01/84  10/30/85     455       9
 449   40312   403    S    3      2    04/20/84  06/14/84      55       1
 450  403121   403    S    4      2    06/14/84  11/13/85     517      10
 451  403122   403    S    4      2    06/14/84  01/23/85     223       4
 452    4032   403    S    2      2    09/14/83  04/12/84     211       5
 453   40321   403    S    3      2    04/12/84  08/01/84     111       2
 454  403211   403    S    4      2    08/01/84  06/05/85     308       5
 455  403212   403    S    4      2    09/12/84  03/19/86     553      10
 456   40322   403    S    3      2    04/12/84  09/12/84     153       3
 457  403222   403    S    4      2    09/12/84  02/20/85     161       3
 458     405   405    S    1      2           M  05/02/84       .      12
 459    4051   405    S    2      2    05/02/84  08/15/84     105       1
 460   40511   405    S    3      2    08/15/84  10/17/84      63       1
 461  405111   405    S    4      2    10/17/84  04/17/85     182       3
 462   40512   405    S    3      2    08/15/84  09/12/85     393       5
 463    4052   405    S    2      2    05/02/84  01/12/85     255       5
 464   40521   405    S    3      2    01/12/85  02/19/86     403       8
 465   40522   405    S    3      2    01/12/85  02/26/86     410       8
 466     408   408    C    1      2           M  10/27/83       .       8
 467    4081   408    C    2      2    10/27/83  06/14/84     231       4
 468   40812   408    C    3      2    06/14/84  09/04/85     447      10
 469    4082   408    C    2      2    10/27/83  04/12/84     168       3
 470   40821   408    C    3      2    04/12/84  10/03/84     174       4
 471   40822   408    C    3      3    04/12/84  08/15/84     125       2
 472  408223   408    C    4      2           M  04/17/85       .       2
 473     410   410    C    1      3           M  12/22/83       .       9
 474    4101   410    C    2      2    02/16/84  10/10/84     237       4
 475    4102   410    C    2      2           M  10/31/84       .       5
 476    4103   410    C    2      2           M  01/01/86       .      13
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OBS	FAN	PLANT	TRT	GEN	NSPLIT	FIRSTLE	LASTLE	SPLITINT	LEAF
477	411	411	C	1	2	M	09/14/83	.	7
478	4111	411	C	2	2	09/14/83	03/08/84	176	4
479	41111	411	C	3	2	03/08/84	09/19/84	195	5
480	411111	411	C	4	2	09/19/84	03/12/86	539	11
481	411112	411	C	4	2	09/19/84	02/27/85	161	4
482	41112	411	C	3	2	03/08/84	08/29/84	174	4
483	4112	411	C	2	2	09/14/83	04/05/84	204	5
484	41121	411	C	3	2	04/05/84	09/19/84	167	4
485	41122	411	C	3	2	04/05/84	09/26/84	174	5
486	412	412	C	1	2	M	01/12/84	.	9
487	4121	412	C	2	2	01/12/84	09/05/84	237	6
488	41211	412	C	3	2	09/05/84	01/01/86	483	15
489	412111	412	C	4	2	01/01/86	02/19/86	49	1
490	41212	412	C	3	3	09/05/84	01/01/86	483	15
491	4122	412	C	2	3	01/12/84	03/28/84	76	1
492	41221	412	C	3	2	M	11/07/84	.	3
493	413	413	C	1	2	M	09/07/83	.	6
494	4131	413	C	2	2	09/07/83	M	.	7
495	41311	413	C	3	2	M	10/25/84	.	4
496	413111	413	C	4	2	10/25/84	01/22/86	454	11
497	413112	413	C	4	2	10/25/84	07/24/85	272	5
498	41312	413	C	3	2	M	06/22/84	.	1
499	413121	413	C	4	2	06/22/84	M	.	10
500	413122	413	C	4	2	06/22/84	04/03/85	285	6
501	4131221	413	C	5	2	04/03/85	02/12/86	315	6
502	4132	413	C	2	3	09/07/83	04/27/84	233	6
503	41321	413	C	3	2	04/27/84	05/08/85	376	8
504	413212	413	C	4	2	05/08/85	01/22/86	259	6
505	41322	413	C	3	2	04/21/84	09/25/85	522	10
506	41323	413	C	3	2	M	09/12/84	.	2
507	413231	413	C	4	2	09/12/84	10/25/84	43	1
508	413232	413	C	4	2	09/12/84	10/20/85	403	10
509	414	414	B	1	3	M	12/22/83	.	9
510	4141	414	B	2	2	12/22/83	06/14/84	175	5
511	41411	414	B	3	2	06/14/84	08/01/84	48	1
512	4142	414	B	2	2	12/22/83	M	.	3
513	41421	414	B	3	2	M	04/02/86	.	13
514	41422	414	B	3	2	M	08/15/84	.	2
515	4143	414	B	2	2	03/19/86	03/19/86	0	0
516	41432	414	B	3	2	M	06/12/85	.	7
517	415	415	M	1	2	M	02/23/84	.	9
518	4151	415	M	2	2	02/23/84	09/12/84	202	5
519	41511	415	M	3	2	09/12/84	02/20/85	161	4
520	4152	415	M	2	2	02/23/84	09/19/84	209	5
521	41521	415	M	3	2	09/19/84	11/21/85	428	7
522	41522	415	M	3	2	09/19/84	11/07/84	49	1
523	415222	415	M	4	2	11/07/84	06/12/85	217	2