Digital simulation of potential reforestation problems in the Rung Sat Delta, Viet Nam.

Report to the National Research Council Committee on the use of Herbicides in Viet Nam. January, 1973.

Philip C. Miller
James R. Ehleringer
Barry Hynum
Wayne Stoner

Department of Biology
Center for Regional Environmental Problems
California State University, San Diego
San Diego, California 92115

Part A

A mechanistic model incorporating the processes of heat and vapor exchange within a canopy and the physiological-environmental relationships of photosynthesis and water relations was developed to look at the possibility that a modification of the microclimate in the Rung Sat Delta occurred and that this modification is inhibiting the redevelopment of the mangrove vegetation.

Simulation results indicate that redevelopment appears to be influenced by the rate of desiccation of the soil. Channelization and a modification of the soil through exposure may be amplifying this effect. Potential lethal leaf temperatures and plant water stress conditions may exist in the dry months (around February) and during the sunniest months (around May). Stress conditions may be reached during other months of the year, but most likely to a lesser extent.

The modeling project was supported by a subcontract from the University of Florida. Field work was carried out on A.E.C. contract AT(04-3)-807.

INTRODUCTION

Between 1962 and 1969 about 5 million acres of forest land and crop land in Viet Nam were sprayed with herbicides. Agent orange, containing 2, 4-D and 2, 4, 5-T, and agent white, containing 2, 4-D and picloram, were applied at rates of 11.7 pounds per acre and 5.6 lbs. per acre respectively in multiple applications (Golley, 1971; Tschirley, 1969). In much of the sprayed areas, reestablishment of the original forest has been negligible. (Golley, 1971). One such area, the Rung Sat Delta, south of Saigon, was chosen to study the possible causes of the lack of colonization. The area is thought to have been last sprayed in 1970. Mangroves which once covered about 80% of the area have been killed and the remaining dead wood harvested for fuel. Aerial photographs taken in 1971 indicate little or no seedling growth in this area.

Originally the area consisted of a gradient from predominantly red mangroves (Rhizophora sp.) on the seaward side to a mixture of red and black mangrove (Avicennia sp.) on the inland side. The seaward side is indundated daily with salinities ranging from 25 to 35 parts per thousand, while on the inland side inundation occurs only during the highest tides and salinities are less, ranging between 15 and 25 ppt. The Saigon River borders the area to the west. Mangroves still occur to the north, interspersed with farmland.

Climatic data for the region are scarce, but some data are available from Tan-Son-Nhut (Saigon). Rainfall is greatest in September and lowest in February (Table 1). Temperatures are warmest in May, but the mean monthly air temperatures vary less than four degrees annually.

Solar radiation remains at about 325-375 langleys day^{-1} most of the year because of the constant cloudiness. The sunniest months, February, March, and April are also the driest (Table 2), with the daily radiation total increasing to 400-450 langleys day^{-1}.

The reasons why the mangrove vegetation is recovering slowly or possibly not at all are not yet known. It is however possible to speculate as to what is currently happening. The purpose of this paper is to bring together existing knowledge of the area in terms of climatological, geological, and physiological characteristics in order to attempt to understand the processes and interactions influencing redevelopment in the Rung Sat area. The method we shall use is digital modeling. Without giving an extensive review of the history and validity of digital modeling, digital modeling as a technique in understanding relationships and interactions within a system, whether it be biological, chemical, or physical, has demonstrated itself in the past to be a useful tool.

A model is only beneficial if it helps to clarify our understanding of relationships within a system. A model is most useful if it utilizes relationships and parameters which can be measured. Also the model should yield insight into the processes of the system that 1) require further investigation and 2) are most crucial to the system. This is the philosophy used in this modeling exercise. The model is based on data recorded in the literature and from field research on mangroves carried out in south Florida on an A.E.C. contract.

Although the reasons why mangrove vegetation is not recovering or is recovering very slowly are not clear, several hypotheses that could be tested using digital simulations were constructed. These hypotheses are attempts to delineate the physical and biological processes acting to constrain the redevelopment of the mangrove forests. The hypotheses stem from the idea that upon removal of the vegetation, the microclimate is changed. The new microclimate will then influence all of the vegetation attempting to establish in that area. Four principal hypotheses were constructed to be tested by the digital simulations. These were:

1) Surface temperatures lethal to propagules and seedlings may be produced at certain times of the year.
2) High leaf temperatures may be reached in the exposed seedling canopies causing a decrease in net production, and if leaf temperatures are high enough, an increase in seedling mortality.
3) The substrate surface dries faster than the mangrove seedlings can grow roots, and the propagules die of desiccation at certain times of the year.
4) Low immigration and high mortalities result in slow propagule establishment and reforestation.

Predation by man and herbivorous animals were not considered, nor was competition between mangroves and other species, such as grasses, because the principal constraint on the mangrove redevelopment was thought to be due to environmental factors or to physiological responses.

Two modeling approaches were undertaken: a total ecosystem model which simulates the redevelopment of mangroves over a span of several years, and a detailed physical and physiological response model (CANOPY) of mangrove-environment interactions, which simulates a period of twenty-four hours.

Description of each model and a discussion of the data base, simulation results, and conclusions are presented separately in the following section.

DESCRIPTION OF THE DETAILED PHYSICAL AND PHYSIOLOGICAL RESPONSE MODEL

I. CANOPY

CANOPY is a canopy-microclimate-primary production model which estimates hourly values of net primary production and transpiration by strata throughout a canopy. CANOPY calculates the microclimate of the strata and then evaluates the effect of the microclimate on the vegetation. The model will be discussed in two parts: 1) a description of the processes influencing the micrometeorological profiles and 2) a description of the processes influencing leaf temperature and primary production.

To best understand how CANOPY works, we will briefly run through one cycle of the program (Figure 1). This description is given here in order to give the reader an idea of the processes and interactions involved in the model. Input data necessary for CANOPY include hourly microclimate values, canopy leaf area distributions, and physiological parameters for the species being modeled (Tables 3-5). Hourly calculations are then made on the processes within the canopy which influence primary production, transpiration, and energy exchange. Short wave radiation penetration through the canopy is calculated as described by Miller (1969, 1972b). Transpiration, internal leaf water status, and water uptake rates are then calculated. The profiles of microclimatic variables are determined by a modification of the model discussed by Waggoner and Reifsnyder (1968). Leaf temperatures are calculated by an iterative solution of the leaf energy budget. Finally, net photosynthesis is estimated. Hourly summaries are printed, after which the model proceeds to the next hour with the information needed from the previous hour. A flowchart of CANOPY appears as Figure 1a.

CANOPY incorporates several digital models which have been or are being described in the literature. These are: 1) a model to describe solar radiation penetration into the canopy from Miller (1969, 1972b); 2) a model to estimate net primary production, leaf temperatures, and physical processes within a canopy from Miller (1972a) and Miller and Tieszen (1972), 3) a model to describe water relations within plants from Miller and Ehleringer (1972), 4) a model to calculate microclimatic profiles from Waggoner and Reifsnyder (1968), and 5) a model to calculate soil temperatures, soil water content, and the movement of heat and water in saturated and nonsaturated soils from Ng and Miller (1972). No attempt will be made here to give a complete description of the models as more complete discussions can be found in each respective paper.

CANOPY is an updating of these models, incorporating equations which express a more detailed mechanistic understanding of processes affecting primary production than were discussed in the Miller (1972a) primary production model. These additional equations will be discussed later. CANOPY is further modified to simulate processes affecting primary production and revegetation of mangroves in the Rung Sat Delta, Viet Nam.

Specific features of CANOPY for the Rung Sat simulations include the hypothesized effects of herbicides on photosynthesis and the effect of salt water on the soil water potential and on transpiration.

II. MICROMETEOROLOGICAL PROFILES

Micrometeorological profiles are calculated by four submodels: WAR, RADMOD, SOILT, and INFRA. WAR is the submodel to calculate air temperature and vapor density profiles, modified from Waggoner and Reifsynder (1968). RADMOD is the Miller (1972b) submodel for calculating short wave radiation profiles within the canopy. The submodel for the calculation of values for soil variables is SOILT and is adapted from Ng and Miller (1972). INFRA is a submodel which calculates infrared radiation profiles.

As microclimatic input data to CANOPY, we need 24 hour values of total short wave radiation, diffuse short wave radiation, infrared radiation from the sky, air temperature, and the vapor density for a point just above the canopy. Given also the leaf area, leaf angle distribution, and the declination of the sun for the 24 hour period, the microclimatic profiles for air temperature, vapor density, and short and long wave radiation. Utilizing the canopy leaf area distributions, RADMOD calculates profiles of direct, diffuse, and reflected radiation.

The WAR submodel uses as input the solar radiation profiles, air temperature and vapor density above the canopy, the soil surface temperature, the vapor density just above the soil surface, and the profile of diffusive leaf resistances. The values for the profile of leaf resistances come from the transpiration stream calculations portion of CANOPY. Soil temperature and vapor density just above the soil surface are calculated by SOILT. SOILT calculates the surface temperature, soil water content (volume/volume), soil suction, and soil water potentials (bars) to a depth where daily fluctuations no longer occur.

The WAR submodel then proceeds to iteratively solve for the air temperature and vapor density profiles while leaf temperatures are being calculated. An intermediate infrared radiation submodel INFRA supplies calculated values of infrared radiation from leaves, ground, and sky to the leaf and air temperature calculations.

III. LEAF TEMPERATURES

Leaf temperature calculations are based on the heat transfer equation for a single leaf (Gates, 1962; Miller, 1967) which states that in an equilibrium state the energy absorbed by a leaf equals the energy lost. Moreover the absorbed energy from solar and infrared radiation and convection is lost by reradiation, convection, and transpiration. Thus

$$aS + \varepsilon IR = IR_{\ell} \pm C + LE \qquad (1)$$

where: a is the leaf absorptance to solar radiation; S is the solar radiation incident on the leaf; ε is the absorption of the leaf to infrared radiation; IR is the infrared radiation from the environment incident on the leaf; IR_{ℓ} is the infrared reradiation by the leaf; C is the convectional energy exchange; L is the latent heat of evaporation; and, E is the evaporation rate.

Each process by which energy is lost from the leaf depends on the leaf temperature. Thus if the leaf temperature is T_{ℓ} in °C,

$$IR_{\ell} = \varepsilon\sigma(T_{\ell} + 273.)^4 \qquad (2)$$

$$C = h_c(T_{\ell} - T_a) \qquad (3)$$

$$E = (\rho_{s,T_{\ell}} - \rho_a)(r_{\ell} + r_a)^{-1} \qquad (4)$$

where: σ is the Stefan Boltzmann constant; h_c is the convection coefficient; $\rho_{s,T_{\ell}}$ is the saturation vapor density at leaf tempeature; ρ_a is the vapor density of the air; r_{ℓ} is the leaf resistance to water loss; and, r_a is the laminar boundary layer resistance. Once the absorbed radiation is known, leaf temperature and transpiration can be calculated by solving the above equations simultaneously by iteration.

IV. PRIMARY PRODUCTION CALCULATIONS

The net photosynthetic rate is a good index of the rate of primary production. This being the case, we focus our model of primary production on determining the rates of net photosynthesis at the different strata within a canopy. The physiological leaf parameters determining the rate of photosynthesis become quite important. If a model is to accurately simulate photosynthesis, it must also accurately simulate those parameters which indirectly determine the rate of photosynthesis.

Net photosynthesis is related to the absorbed solar radiation, atmospheric carbon dioxide content, leaf resistance, boundary layer resistance, and mesophyll resistance by the equations:

$$P_N = \frac{[CO_2]_a - [CO_2]_{chl}}{r_a + 1.56r_\ell + r_{mes}} \quad \text{(modified after Gaastra, 1963)} \qquad (5)$$

$$P_N = (aS)\ (a_p aS + b_p)^{-1} \quad \text{(Monteith, 1965)} \qquad (6)$$

where: P_N is the unadjusted net photosynthetic rate; $[CO_2]_a$ and $[CO_2]_{chl}$ are the carbon dioxide concentrations in the air and at the chloroplasts; r_{mes} is the mesophyll resistance to carbon dioxide transport; and, a_p and b_p are parameters empirically derived from the photosynthesis light response curve. The leaf resistance to water transfer is modified for carbon dioxide diffusion by multiplying by the ratio of the diffusion coefficients of carbon dioxide and water.

Leaf temperature and herbicide influence net photosynthesis through the equations:

$$P_{NT} = (P_N)(T_\ell - T_o)/(T_{opt} - T_o) \qquad (7)$$

$$P_{NTH} = (P_{NT})(1 - H) \quad (8)$$

$$H = bhe^{-kt} \quad (9)$$

where: P_{NT} is the net photosynthetic rate after the effect of temperature is included; T_o is the leaf temperature at which net phototsynthesis equals zero; T_{opt} is the optimum leaf temperature for photosynthesis. There are two values for T_o, one on either side of T_{opt}. The one used depends on which side of the optimum leaf temperature the leaf temperature falls.

P_{NTH} is the net photosynthetic rate after the effects of the herbicide have been included; H is the relative effect of the herbicide on photosynthesis; b relates the herbicide concentration to its effect on the photosynthetic process; h is the initial herbicide concentration; k is the decay coefficient for the herbicide; and t is the elapsed time since the herbicide application.

Net photosynthesis is first calculated by equations (5) and (6), and the smaller of the two values is taken as the actual value. This allows photosynthesis to be limited by both light and by carbon dioxide diffusion. The calculated value of net photosynthesis is then corrected for the effects of leaf temperature and herbicides. Temperature and herbicide effects are assumed to be linear. Linear interpolation for the temperature effects on photosynthesis yields a fair approximation to the temperature response data of Moore et al. (1972).

Net photosynthesis for the canopy is calculated as

$$P_T = \sum_{i=o}^{n} ({}_iP_{NTH})(LAI_i) \quad (10)$$

where: P_T is the total net photosynthesis; ${}_iP_{NTH}$ is the net photosynthetic rate at the i-th level; LAI_i is the leaf area index at the i-th level; and, n is the number of levels in the canopy.

V. TRANSPIRATION STREAM CALCULATIONS

Water movement out of the leaves is related to the vapor density gradient and to the resistances to water diffusion by the equation as previously described in equation (4).

Internal leaf water status is dependent on the leaf water deficit. This is the relative saturation deficit (Barrs, 1968) from the fully turgid state. It is expressed as a percentage and is related to the transpiration and water uptake rates as

$$WD_t = WD_{t-1} + D_T^{-1} \int (E - W_{up})dt \qquad (11)$$

where: WD_t and WD_{t-1} are the leaf water deficits at time t and time t-1; D_T is the saturation leaf density, and W_{up} is the water uptake rate. The saturation leaf density is defined as the fully turgid leaf weight per square centimeter.

The leaf water potential is calculated as a second order regression from the data of Miller and Ehleringer (1972). The regression is

$$\psi_\ell = -0.78 - 0.46WD - 0.032WD^2 \qquad (12)$$

where ψ_ℓ is the leaf water potential.

The water uptake rate is calculated using the Ohm's Law analogy, where the potential driving force is the water potential gradient between the leaf and the soil. Resistance to water uptake is offered by the roots and the soil. The uptake rate is also moderated by the relative surface areas of the roots and leaves. Thus,

$$W_{up} = \alpha(\psi_s - \psi_\ell)/(r_r + r_s) \tag{13}$$

where: α is the ratio of root to shoot surface areas; ψ_s is the soil water potential; and, r_r and r_s are the resistances to water transfer of the roots and soil respectively. These resistances are assumed to be constant.

Soil water potential is related to the seawater and is herein assumed to contain only sodium chloride, so the equation for soil water potential simplifies to,

$$\psi_s = \beta S_s + \gamma S_{sc} \tag{14}$$

where: β is a conversion factor relating mean soil suction (S_s) to water potential; γ is a conversion factor relating molarity of sodium chloride to water potential; and S_{sc} is the salinity of the seawater.

Leaf resistance to water loss is related to the solar radiation absorbed by the leaf and the internal water status by the equation,

$$r_\ell = \frac{r_{cut} - aS(gWD + mWD^x)}{1 + aS(D)} \quad \text{(from Miller and Ehleringer, 1972)} \tag{15}$$

where: r_{cut} is the cuticular resistance, the resistance with the stomata completely closed; g and m are constants related to the water deficit at which the minimum resistance occurs; x is an exponent related to the steepness of the leaf resistance-water deficit curve at high water deficits; and, D is a parameter related to the stomatal opening with light.

Transpiration stream calculations commence with the calculation of the

the leaf water deficit, based on the transpiration rate and water uptake rate of the previous period. Calculation of the leaf water potential follows, afterwhich the leaf resistance can then be calculated. The soil water potential and uptake rates are calculated after the leaf resistance. Transpiration is solved for iteratively as the leaf temperature is being calculated. Total water loss by the canopy is calculated in a manner identical to the calculation of net photosynthesis in equation (10).

VI. CLIMATIC INPUT DATA

The CANOPY simulations used climate data for the months of February and May as input data. These two months were chosen as they represent extremes in climate conditions. February is the driest and one of the sunniest months of the year, whereas May is one of the warmest and cloudiest months (Tables 1, 2).

If the environment is too harsh for mangrove seedling survival, then through the simulation of the primary production processes on these extreme months insight into the potential reforestation problems may be gained. Our interest is in testing conditions which might be straining the system, not conditions underwhich the system will easily survive. Accordingly, four input days were used in CANOPY simulations. These were an average February day (450 ly), an extreme sunny February day (600 ly), the average May day (350 ly), and a sunny May day (500 ly) in which the maximum monthly temperature was reached.

The probabilities of having the sunny February day or having the sunny May day are not known, because we do not have daily temperature records for the area. By comparison though with climates of other areas we put forth the possibility that the chances of having these extreme days could be between 0.25 and 0.10.

RESULTS AND DISCUSSION

Canopy Simulation

A series of simulations were run using the four climate days previously described. Additionally, two different photosynthesis temperature response curves (Table 2) and three different substrate salinities were simulated. Two different photosynthesis temperature response curves were used as the temperature adaptations of the Viet Nam mangroves were not known. The temperature response curve for the lower optimum temperature has been measured on Rhizophora mangle in south Florida (Moore et al., 1972; Moore, unpublished data). The temperature response curve with the higher optimum temperature was used as it may be a more reasonable adaptation by mangroves to the warmer and more stable climate of Viet Nam. These results provide a complete matrix for comparative purposes to different locations along the salinity gradient of the Rung Sat Delta area.

The soil characteristics and properties used in the simulations were that of a clay soil. Zinke (1972) after visiting the Rung Sat area describes the soil as being a silty, clay soil. There is a small difference in the two soils, but because the physical properties relating to the clay soil were the only ones available at the time of the simulations, they were the ones used. In the current simulations, it was also assumed that the soil surface was saturated, but not inundated. In essence, this is saying that the soil water potential is equal to the solute water potential of the incoming tide.

The leaf area index for these simulations was 0.45 which roughly corresponds to a seedling density of 40 individuals per square meter. This assumes that each seedling has four leaves, and that each leaf is approximately 30 cm^2 in area (Table 4). This leaf area is used only for purposes of convenience in the simulations. In actuality, the appropriate leaf area would be less than 0.45. The main idea to remember is that in small sparse canopies, such as propagule canopies, the principle interactions are between the climate and the leaf, not between leaves. The use of a canopy with a leaf area index of 0.45 is small enough that interactions between leaves are still small.

The effect of herbicides in these simulations is assumed to be zero. This was done partly for simplification of the model, but mostly because residual concentrations, if any, and decomposition rates were not known.

The first simulation results are estimates of productivity, transpiration, and the internal physiological response to the four microclimate days. Comparing the February sunny day with the average February day (Figures 2-5), it appears that net photosynthesis on average days is three times higher than on sunny days (0.232 g O.M.$m^{-2}day^{-1}$ vs. 0.706 g O.M. $m^{-2}day^{-1}$ at a salinity of 12‰). From Figure 5 it can be seen that the reason for this drop in production is that the leaf temperatures on the sunny day are much higher. Transpiration is much higher on the sunny day as expected, but transpiration does not drop off as steeply when the salinity is increased on the sunny day as it does on the shady day. This suggests that on sunny days the role of solar radiation intensity is more important than that of substrate salinity. Mangroves on the sunny February day are under more water stress (Figure 4) and this in part is reflected in the higher leaf temperatures. Net photosynthesis appears to be almost constant with increasing salinity on both

February days. There is, however, a slight peak in production at a salinity of twenty parts per thousand.

A comparison of the sunny May day and the average May day shows similar trends. The discrepancy in production has increased so that on the average day the net production is five times greater than on the sunny day (0.098 g O.M. m^{-2} day^{-1} vs. 0.542 g O.M. m^{-2} day^{-1} at a salinity of 12‰). The difference is decreased when the hypothetical photosynthesis temperature response curve is used. By simply shifting the photosynthesis temperature response curve to the right three degrees C, we have lowered the difference down to a factor of two (0.679 g O.M. $m^{-2}day^{-1}$ vs. 1.065 g O.M. m^{-2} day^{-1} at 12 ‰). 0.5 g O.M. m^{-2} day^{-1} is gained by shifting the response curve because leaf temperatures are to the right of the optimum temperature and in a zone when production is sensitive to leaf temperature. Transpiration on the sunny May day compares well with transpiration of the sunny February day (Figure 2). However, transpiration on the average May day is much lower than any of the other days because the leaf temperatures were not abnormally high and the air vapor density was high, meaning that the vapor density gradient between leaf and air was low. Minimum leaf water potentials exhibit similar trends (Figure 4). The highest minimum leaf water potential and the lowest transpiration were on the average May day. This is because the vapor density gradient is lowest then.

Water stress can exist during either month. It can occur in February, because of the higher radiation loads and the drier air. It can occur in May because of the potential for high leaf temperatures.

The possibility of high leaf temperatures is interesting for several reasons. First, high leaf temperatures place a stress on the physiological processes of photosynthesis and transpiration. Secondly, high leaf temperatures pose a threat when temperatures approach or exceed the lethal limit of the plant. Just exactly what the lethal limit is we do not know. One would suspect that the lethal temperature is close to the maximum temperature of positive net photosynthesis. Once this temperature is passed the respiration rate is very high and the breakdown of enzyme systems is occurring. Miller (1972c) has limited data showing that seedling mortality in Rhizophora mangle from south Florida starts when the temperature exceeds 36°C.

If high temperatures are not immediately lethal, then there still exists the possibility that some physiological functions in the developing propagule may have been impaired and that death may occur in later development. The immediate effects though of high leaf temperatures other than death are water stress through excessive transpiration and a decrease in the net photosynthetic rate. Following the daily course of leaf resistance, leaf water potential, leaf temperature, and the photosynthetic rate for each of the four days will permit us to observe how close to a stress condition the leaf is. Figures 6-9 show these physiological responses for the four climate days at a substrate salinity of thirty parts per thousand. The photosynthesis-temperature response curve used is the one measured by Moore, et al. (1972) for Rhizophora mangle. Across each graph a dashed line for a leaf temperature equal to thirty-six degrees is drawn. This corresponds to the potential lethal leaf temperature.

Potential lethal temperatures are reached for four hours on the May sunny climate and for one hour in the February sunny climate. No lethal temperatures appear to be reached on the average climate days. Excessive water stress reflected in stomatal closure hardly occurs on the May sunny day. The input parameters used may be underestimated here, and in reality, water stress may be more prevelant than the model would predict.

The model predicts about a 7-10 bar gradient between soil and leaf water potentials. As the soil continues to dry this gradient will increase, placing the propagule under additional water stress. The frequency of inundation will then play an important role in the mangrove propagule water relations. As the soil is a clay, infiltration will be slow and the soil will achieve a low water potential at volumetric contents as high as 20%.

Soil Moisture

These points suggest that perhaps the soil may be limiting the revegetation rate. It may be possible that the soil is drying out so fast that propagules are either unable to establish themselves or that the soil moisture evaporates before the propagules can utilize it, because of the radiation load on the soil surface. Simulations were performed to follow the water content change for the open soil surface for each of the four days. These simulations were done using three initial soil water contents (volume H_2O/volume soil). These were 30%, 20%, and 15%. These correspond to -4, -9, and -16 bars soil water potential respectively. The water content after a twenty-four hour period is noted and a percentage change is calculated (Table 6).

The results indicate that the water content drops off quickly from the saturated state. By the time the water content reaches 20%, the rate of water loss has become small. At a water content of 15%, water loss during a twenty-four hour period is neglible. This water content has a water potential of -16 bars. Additionally, we must add to this the solute water potential of the salt from sea water. This total would put the plant under in high water stress condition. By adding the solute water potential, the plant may become under stress at water contents between 30% and 20%. The time to go from saturation down to a water content of 20% has not been calculated as it is also dependent on the drainage patterns.

Soil Temperature

The temperature at the soil surface is also of interest. It will be hotter in the day than if there was a canopy there, and colder at night. Just how much hotter during the day may be important. Simulations of the ground surface temperatures for bare soil and for an immature canopy of LAI 1.5 were made for the four climate days. The immature canopy is to serve as a contrast to the bare soil. The bare soil temperature is indicative of the temperature of a propagule lying flat on the surface of the soil. It is assumed that the propagule would be at or at least very close to the temperature of the bare soil. The bare soil in the simulations is assumed to be saturated, but with no standing water.

Figures 10-13 show that the surface temperatures can vary by only as much as three degrees between bare and covered soil. The chances of the soil approaching a lethal temperature appear to be quite small. The highest temperature reached is 38.2 °C (1100, May sunny), but temperatures are usually closer to 30°C. Bare soil surface temperatures appear not to be a deterrent to propagule invasion and establishment.

Redevelopment appears to be influenced by the rate of desiccation of the soil. Channelization and a modification of the soil through exposure may be amplifying this effect. Potential lethal temperatures and water stress conditions in leaves may exist for several hours on a number of days of the month in February and in May. It is also possible that these same stress conditions may be reached in other months of the year, although possibly to a lesser extent.

The lack of physiological data from Viet Nam detracts from the reliability of the model predictions. Actual estimates of parameters are expected to be different from those used in the simulations, but by the use of parameters from members of the same genus, it is thought that the values used will be close to the actual ones.

The critical variable influencing the system appears to be the microclimate. The success of reestablishment hinges on the stress placed on the propagule by the radiation load, the leaf-air vapor density gradient, and the rate of soil desication.

Table 1. Maximum, minimum, and mean monthly air temperatures (°C) and mean precipitation (mm) for Saigon, Viet Nam (after Conway (1963) and Cuong (1964)).

Month	Maximum air temperature	Minimum air temperature	Mean air temperature	Precipitation
January	32	17	24	6
February	33	18	25	3
March	36	19	27	6
April	38	20	28	55
May	38	18	28	200
June	35	18	26	205
July	33	18	25	200
August	32	18	25	184
September	33	17	26	198
October	31	17	26	202
November	31	16	24	64
December	31	15	24	35

Table 2. Mean monthly values of total solar radiation for Saigon from the Dept. of Commerce (1968). Units are langleys day^{-1}.

Month	Mean Langleys
January	350
February	422
March	456
April	438
May	368
June	391
July	386
August	369
September	356
October	335
November	316
December	316

Table 3. Microclimate input data for CANOPY. All values are for a point just above the top of the canopy. Units for radiation are cal cm^{-2} min^{-1}, for air temperature degrees Celsius, for vapor density g m^{-3}, and wind velocity cm sec^{-1}.

February sunny

Hour	Total solar	Diffuse solar	Infrared from sky	Air temperature	Air vapor den.	Wind velocity
1	0	0	0.60	23.0	19.0	60.
2	0	0	0.60	22.0	19.0	60.
3	0	0	0.60	21.0	19.0	60.
4	0	0	0.60	20.0	19.0	60.
5	0	0	0.60	19.0	18.5	60.
6	0	0	0.60	20.0	19.0	80.
7	0.10	0.10	0.60	21.0	19.5	100.
8	0.50	0.10	0.60	24.0	20.0	125.
9	1.00	0.20	0.60	27.0	20.0	150.
10	1.15	0.25	0.60	29.0	20.0	175.
11	1.20	0.30	0.60	31.0	20.0	200.
12	1.30	0.30	0.60	32.0	20.5	225.
13	1.20	0.30	0.60	31.5	21.0	250.
14	1.15	0.30	0.60	30.5	20.5	200.
15	1.00	0.25	0.60	30.0	20.0	175.
16	0.80	0.25	0.60	30.0	20.0	150.
17	0.50	0.20	0.60	29.5	20.0	150.
18	0.10	0.10	0.60	29.0	19.5	80.
19	0	0	0.60	28.5	19.5	80.
20	0	0	0.60	28.0	19.5	60.
21	0	0	0.60	27.0	19.0	60.
22	0	0	0.60	26.0	19.0	60.
23	0	0	0.60	25.0	19.0	60.

Table 3. (continued).

February average

Hour	Total solar	Diffuse solar	Infrared from sky	Air temperature	Air vapor density	Wind velocity
1	0	0	0.60	22.0	19.0	60.
2	0	0	0.60	22.0	19.0	60.
3	0	0	0.60	22.0	19.0	60.
4	0	0	0.60	22.0	19.0	60.
5	0	0	0.60	23.0	19.0	60.
6	0	0	0.60	24.0	19.0	80.
7	0.10	0.05	0.60	25.0	19.0	100
8	0.40	0.20	0.60	26.0	19.0	125.
9	0.70	0.30	0.60	27.0	19.0	150.
10	0.80	0.30	0.60	27.0	19.0	175.
11	0.90	0.40	0.60	27.0	19.0	200.
12	1.10	0.50	0.60	28.0	19.0	225.
13	0.90	0.60	0.60	28.0	19.0	250.
14	0.80	0.60	0.60	28.0	19.0	225.
15	0.70	0.50	0.60	27.0	19.0	200.
16	0.60	0.40	0.60	27.0	19.0	150.
17	0.40	0.30	0.60	27.0	19.0	150.
18	0.10	0.10	0.60	26.0	19.0	100.
19	0	0	0.60	26.0	19.0	80.
20	0	0	0.60	25.0	19.0	60.
21	0	0	0.60	24.0	19.0	60.
22	0	0	0.60	23.0	19.0	60.
23	0	0	0.60	22.0	19.0	60.
24	0	0	0.60	22.0	19.0	60.

Table 3. (continued).

May sunny

Hour	Total solar	Diffuse solar	Infrared from sky	Air temperature	Air vapor den.	Wind velocity
1	0	0	0.60	25.5	24.0	60.
2	0	0	0.60	25.0	24.0	60.
3	0	0	0.60	24.5	24.0	60.
4	0	0	0.60	24.0	24.0	60.
5	0	0	0.60	24.0	24.0	60.
6	0.05	0.05	0.60	25.0	24.0	80.
7	0.35	0.10	0.60	28.0	24.0	100.
8	0.70	0.20	0.60	31.0	24.0	125.
9	1.10	0.50	0.60	33.0	24.0	150.
10	1.15	0.60	0.60	35.0	24.5	175.
11	1.00	0.70	0.60	35.0	24.5	200.
12	0.90	0.70	0.60	35.0	24.5	225.
13	0.80	0.80	0.60	33.0	24.5	250.
14	0.70	0.70	0.60	32.0	25.0	225.
15	0.65	0.65	0.60	31.0	25.0	200.
16	0.60	0.60	0.60	30.0	24.5	150.
17	0.50	0.50	0.60	29.5	24.4	150.
18	0.40	0.40	0.60	29.0	24.5	100.
19	0.10	0.10	0.60	28.5	24.5	80.
20	0	0	0.60	28.0	24.0	60.
21	0	0	0.60	27.5	24.0	60.
22	0	0	0.60	27.0	24.0	60.
23	0	0	0.60	26.5	24.0	60.
24	0	0	0.60	26.0	24.0	60.

Table 3. (continued).

May average

Hour	Total solar	Diffuse solar	Infrared from sky	Air temperature	Air vapor den.	Wind velocity
1	0	0	0.60	26.0	24.0	60.
2	0	0	0.60	26.0	24.0	60.
3	0	0	0.60	26.0	24.0	60.
4	0	0	0.60	26.0	24.0	60.
5	0	0	0.60	26.0	24.0	60.
6	0	0	0.60	26.0	24.0	80.
7	0.20	0.10	0.60	26.0	24.0	100.
8	0.50	0.30	0.60	28.0	24.0	125.
9	0.70	0.40	0.60	29.0	24.0	150.
10	0.80	0.40	0.60	30.0	24.0	175.
11	0.70	0.60	0.60	30.0	24.0	200.
12	0.70	0.70	0.60	30.0	24.0	225.
13	0.60	0.60	0.60	30.0	24.0	250.
14	0.60	0.60	0.60	30.0	24.0	225.
15	0.50	0.50	0.60	30.0	24.0	200.
16	0.40	0.40	0.60	30.0	24.0	175.
17	0.25	0.25	0.60	30.0	24.0	150.
18	0.15	0.15	0.60	29.0	24.0	100.
19	0.o0	0.10	0.60	28.0	24.0	80.
20	0	0	0.60	27.0	24.0	60.
21	0	0	0.60	27.0	24.0	60.
22	0	0	0.60	27.0	24.0	60.
23	0	0	0.60	27.0	24.0	60.
24	0	0	0.60	26.0	24.0	60.

Table 4. Stand structure used in the CANOPY simulations. The total LAI is approximately 0.45. Strata 1 is at the top of the canopy. The actual data is hypothetical, but canopies of similar structure are found in mangrove swamps.

Strata	Leaf Area Index	Leaf angle (°)
1	.002	60.
2	.050	54.
3	.075	48.
4	.100	42.
5	.100	36.
6	.075	30.
7	.050	24.
8	.003	18.

Table 5. Physiological input parameters to CANOPY and values used in the simulations. All data are for Rhizophora mangle.

Variable	Symbol	Value	Data Source
minimum leaf resistance	r_{min}	0.04 min cm^{-1}	Miller and Ehleringer (1972)
cuticular leaf resistance	r_{cut}	0.50 min cm^{-1}	Miller and Ehleringer (1972)
photosynthesis light parameter	ap	2.5 cm^2 $ly(gCO_2)^{-1}$	Miller (1972)
photosynthesis light parameter	bp	0.03 gCO_2lycm^2	Miller (1972)
absorptance	a	0.60	Miller (1972)
mesophyll resistance	r_{mes}	0.30 min cm^{-1}	Moore, et al. (1972)
root resistance	r_r	0.2 min $cm^{-1}bar^{-1}$	Miller and Ehleringer (1972)
stomatal light parameter	D	14. $ly^{-1}min$	Miller and Ehleringer (1972)
leaf resistance parameter	X	16.	Miller and Ehleringer (1972)
saturation leaf density	D_T	50 mg cm^{-2}	Miller (1972)
Photosynthesis System 1			
leaf temperature w/ 0.0 net photosynthesis	T_o	10 °C	Moore, et al. (1972)
leaf temperature w/ 0.0 net photosynthesis	T_o	37 °C	Moore, et al. (1972)
optimum leaf temperature for photosynthesis	T_{opt}	27 °C	Moore, et al. (1972)
Photosynthesis System 2			
	T_o	10 °C	Hypothesized
	T_o	40 °C	Hypothesized
	T_{opt}	30 °C	Hypothesized

Table 6. Estimates of the rate at which the soil surface is drying out under open sky conditions and at different water contents for the three test days. Water content is in volume/volume.

Climate type	Initial water content at the beginning of the day	water content after 24 hours	percent change in one day
February sunny	0.300	0.276	8.0%
	0.200	0.199	0.5%
	0.150	0.150	0.0%
May average	0.300	0.274	8.7%
	0.200	0.198	0.7%
	0.150	0.150	0.0%
May sunny	0.300	0.274	8.7%
	0.200	0.198	0.7%
	0.150	0.150	0.0%
February average	0.300	0.277	7.9%
	0.200	0.199	0.5%
	0.150	0.150	0.0%

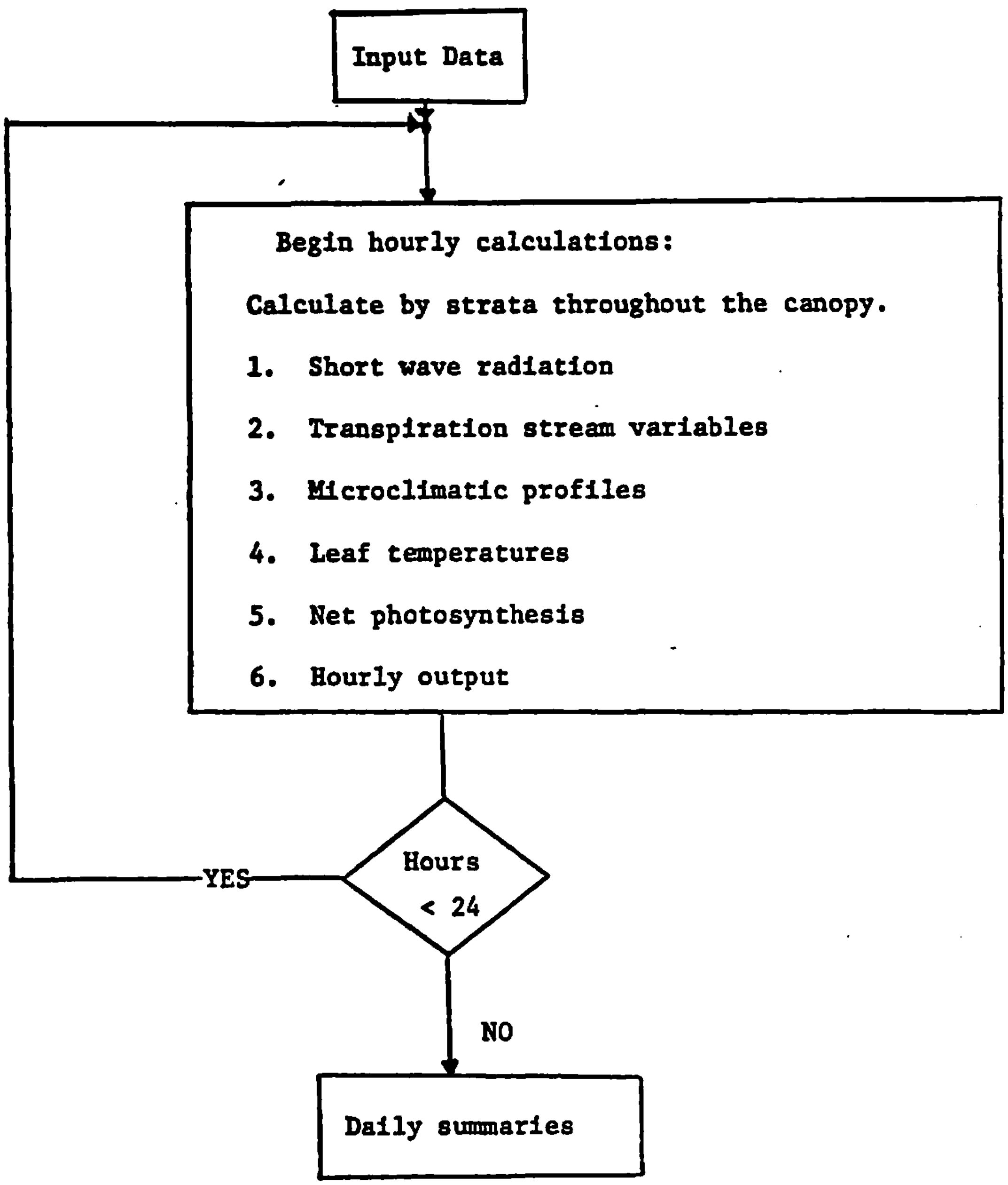

Figure 1. General flowchart of the program CANOPY.

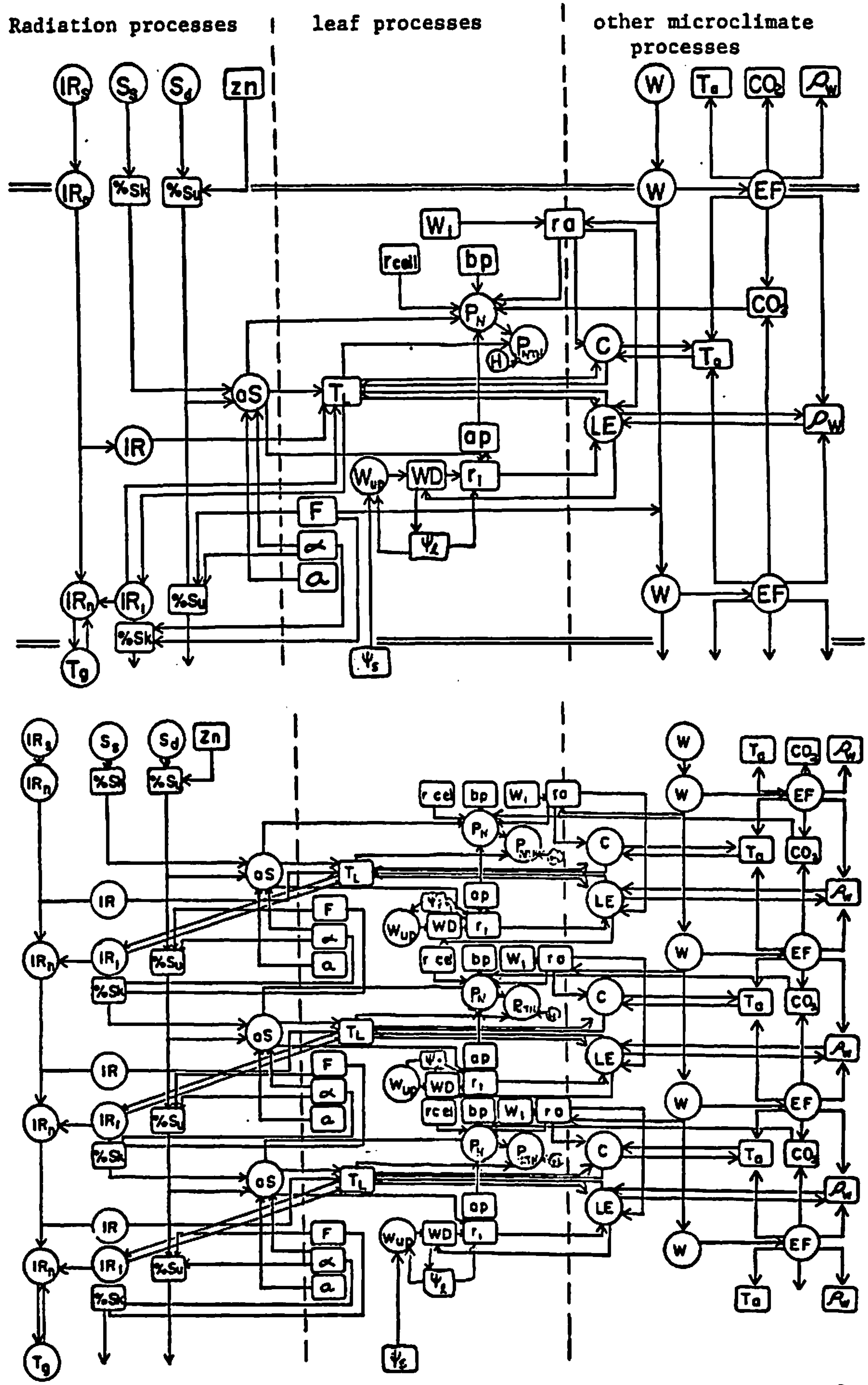

Fig. 1a Flow charts illustrating the interrelations between canopy variables and physical processes. Symbols are defined and explained in the text. The upper chart illustrates the interrelations for one level in the canopy; the lower chart, for a canopy divided into three levels. (after Miller, 1972)

Legend to Figures 2,3,4,5

○	average February day
●	sunny February day
△	average May day
▲	sunny May day
L	literature photosynthesis temperature response curve
H	hypothetical photosynthesis temperature response curve

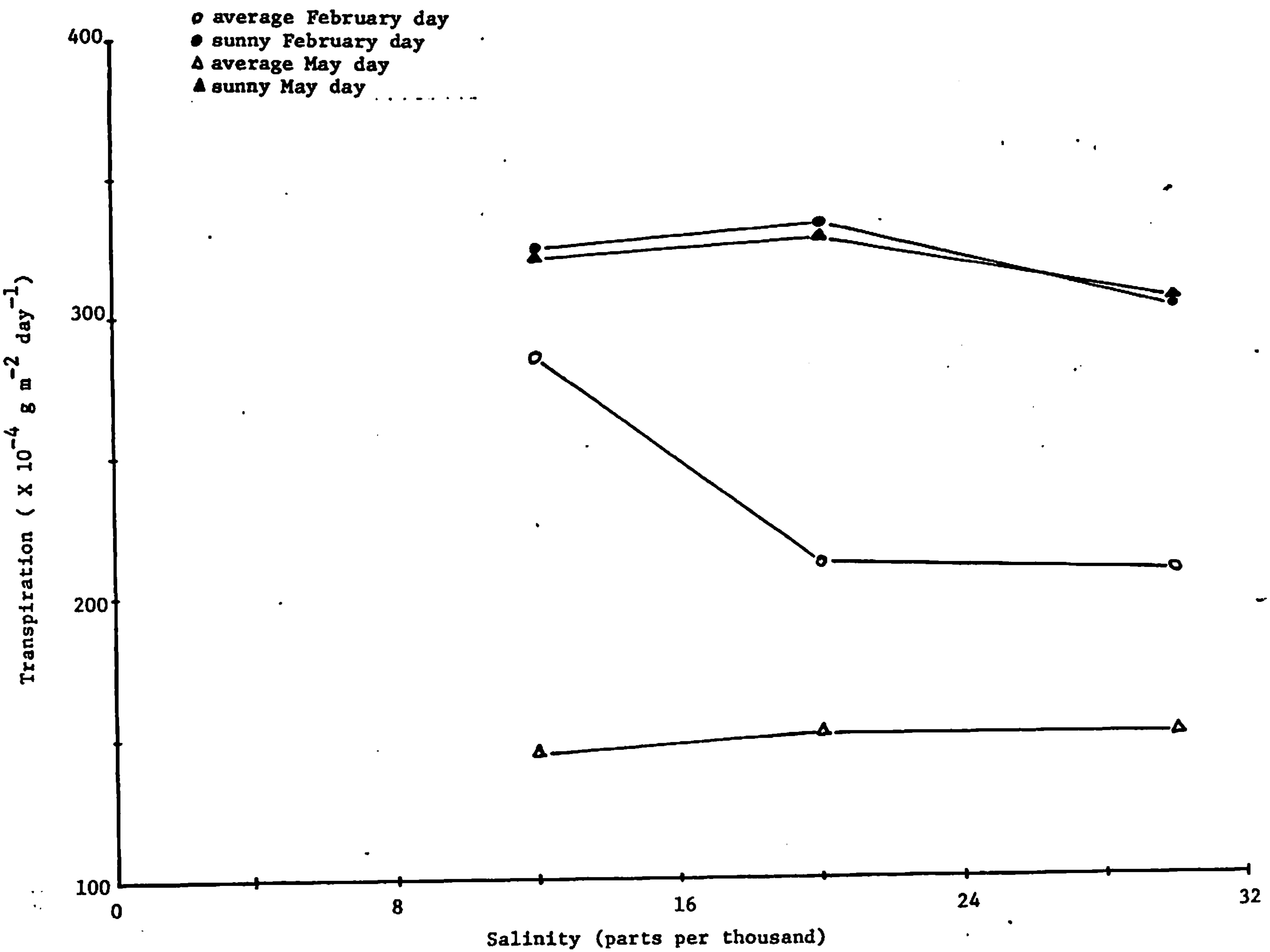

Figure 2. Daily transpiration totals for the microclimate days as a function of salinity.

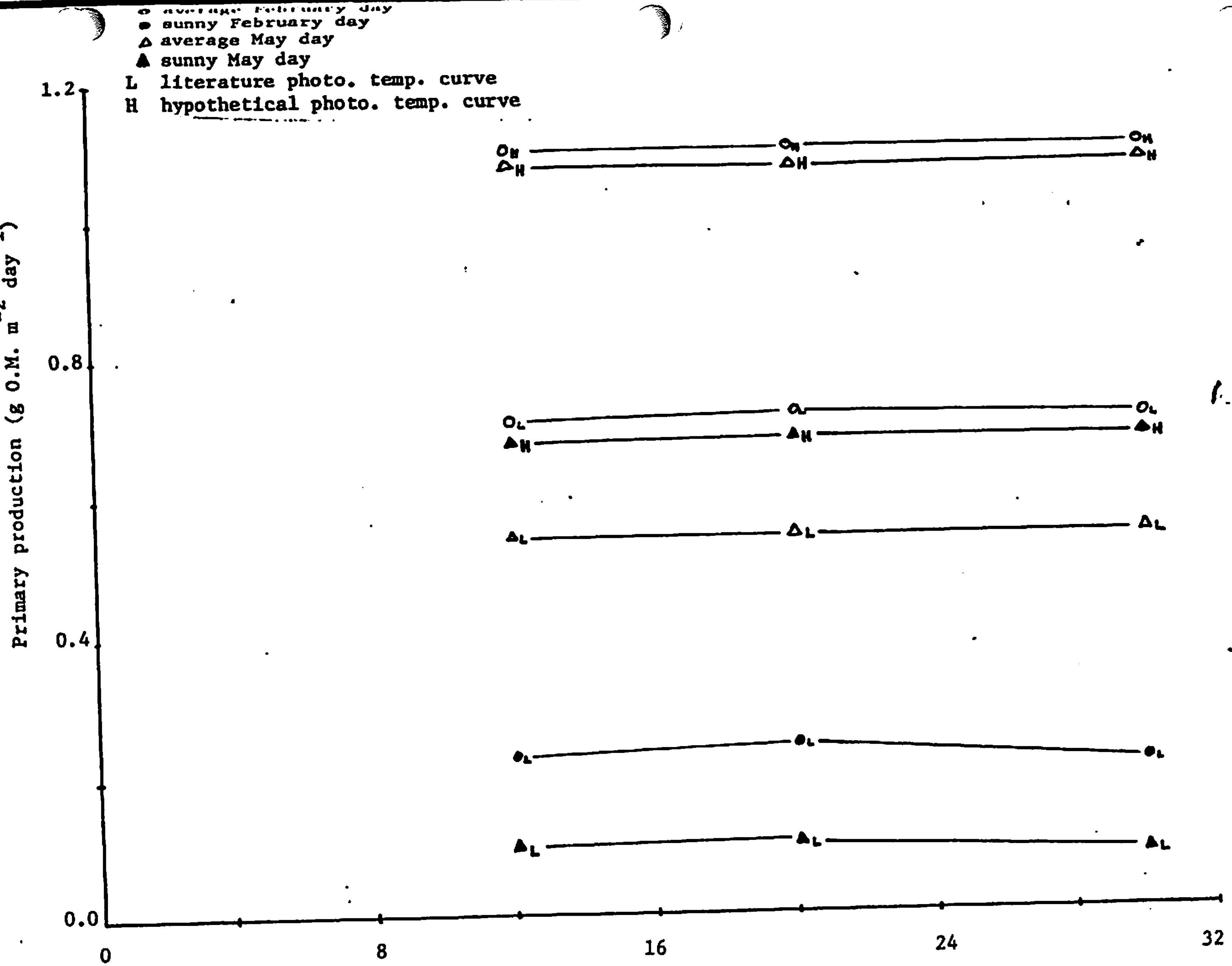

Figure 3. Daily production for the microclimate days as a function of salinity.

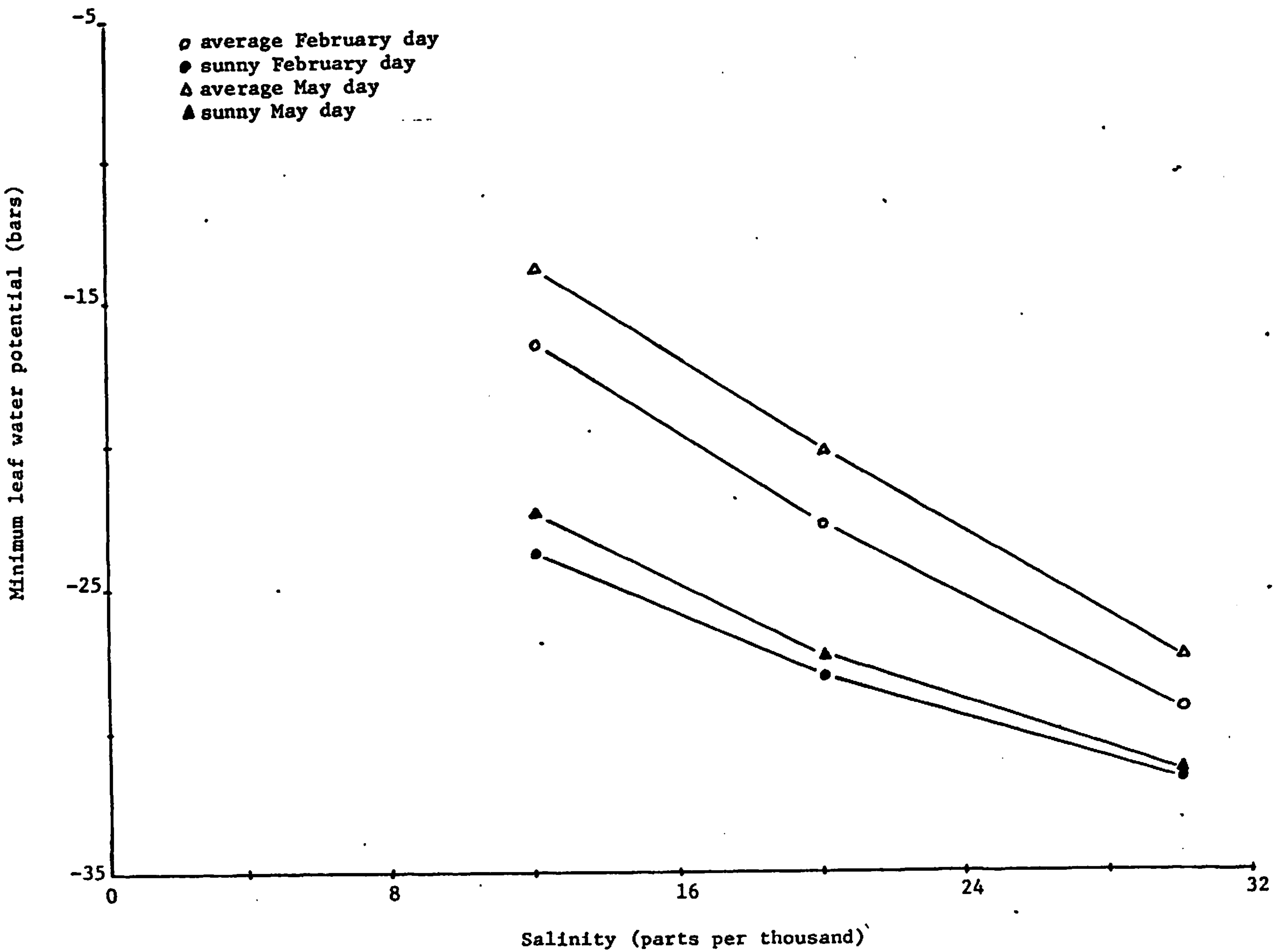

Figure 4. Minimum leaf water potential for the microclimate days as a function of salinity.

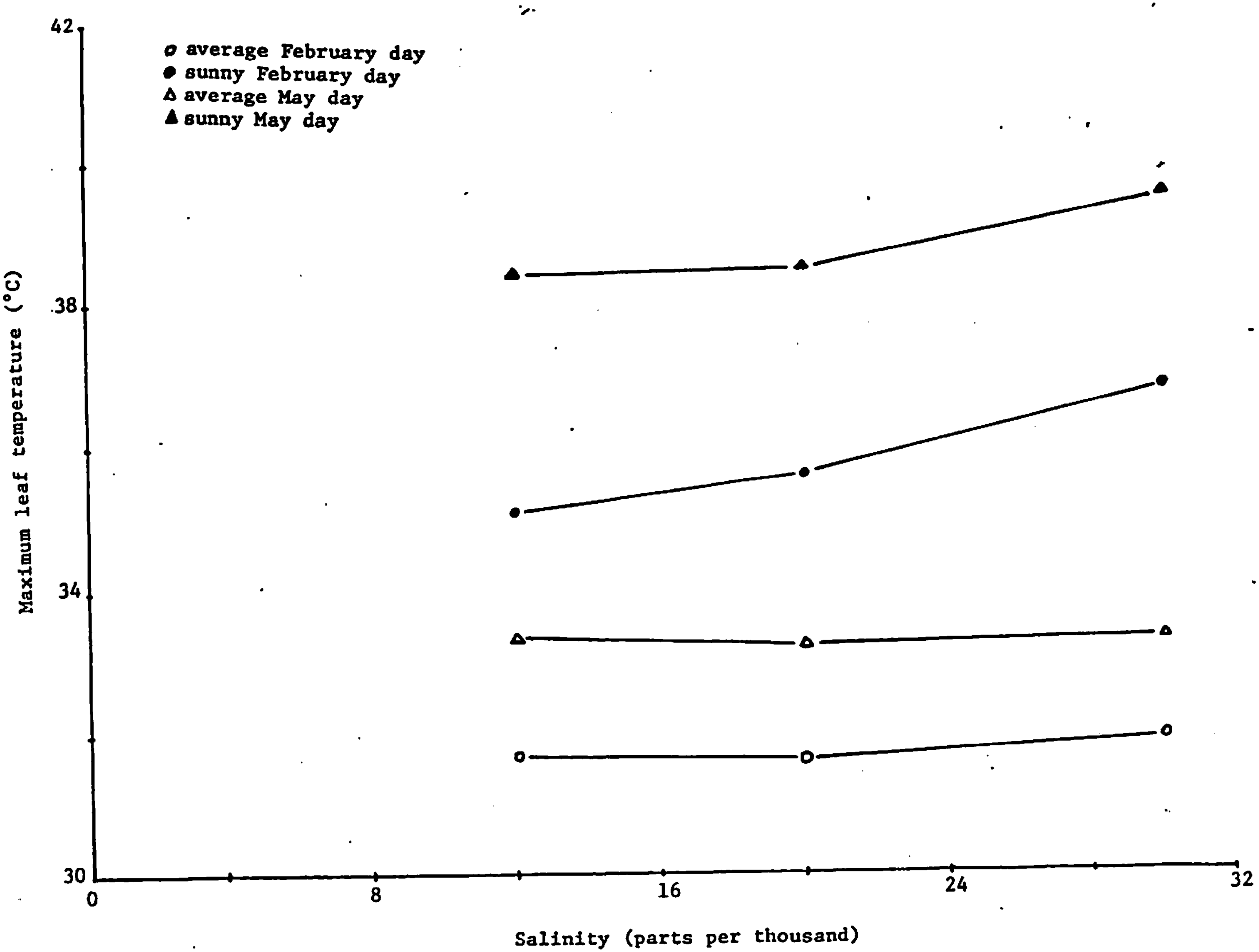

Figure 5. Maximum leaf temperature for the microclimate days as a function of salinity.

Legend to Figures 6,7,8,9

+	P	net photosynthesis	mg CO_2 dm^{-2} hr^{-1}
▲	T	leaf temperature	°C
■	W	leaf water potential	bars
●	R	leaf resistance	min cm^{-1}

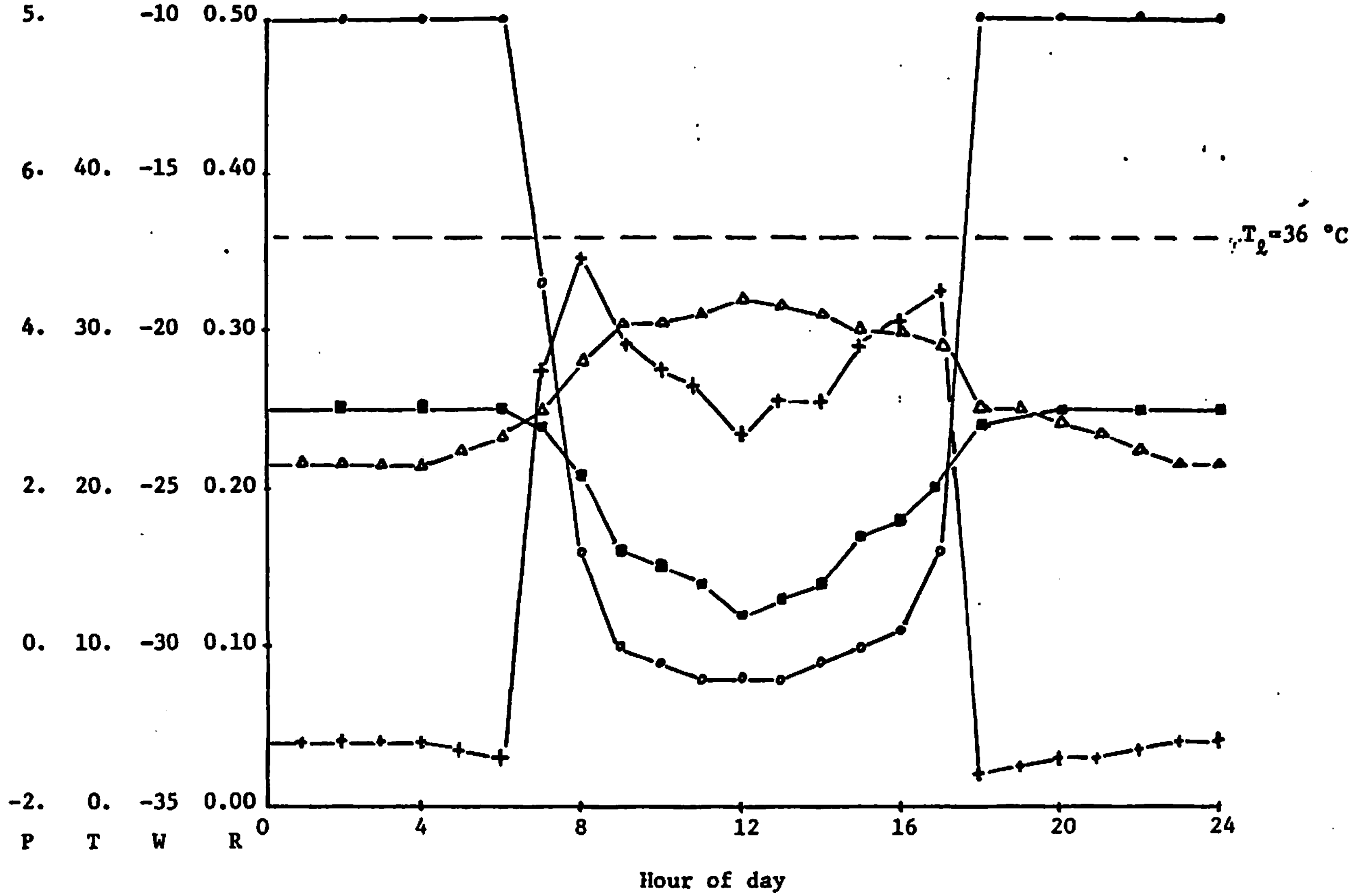

Figure 6. The daily course of physiological functions for the February average day.

- ✚ P net photosynthesis mg CO_2 dm^{-2} hr^{-1}
- ▲ T leaf temperature °C
- ■ W leaf water potential bars
- ● R leaf resistance min cm^{-1}

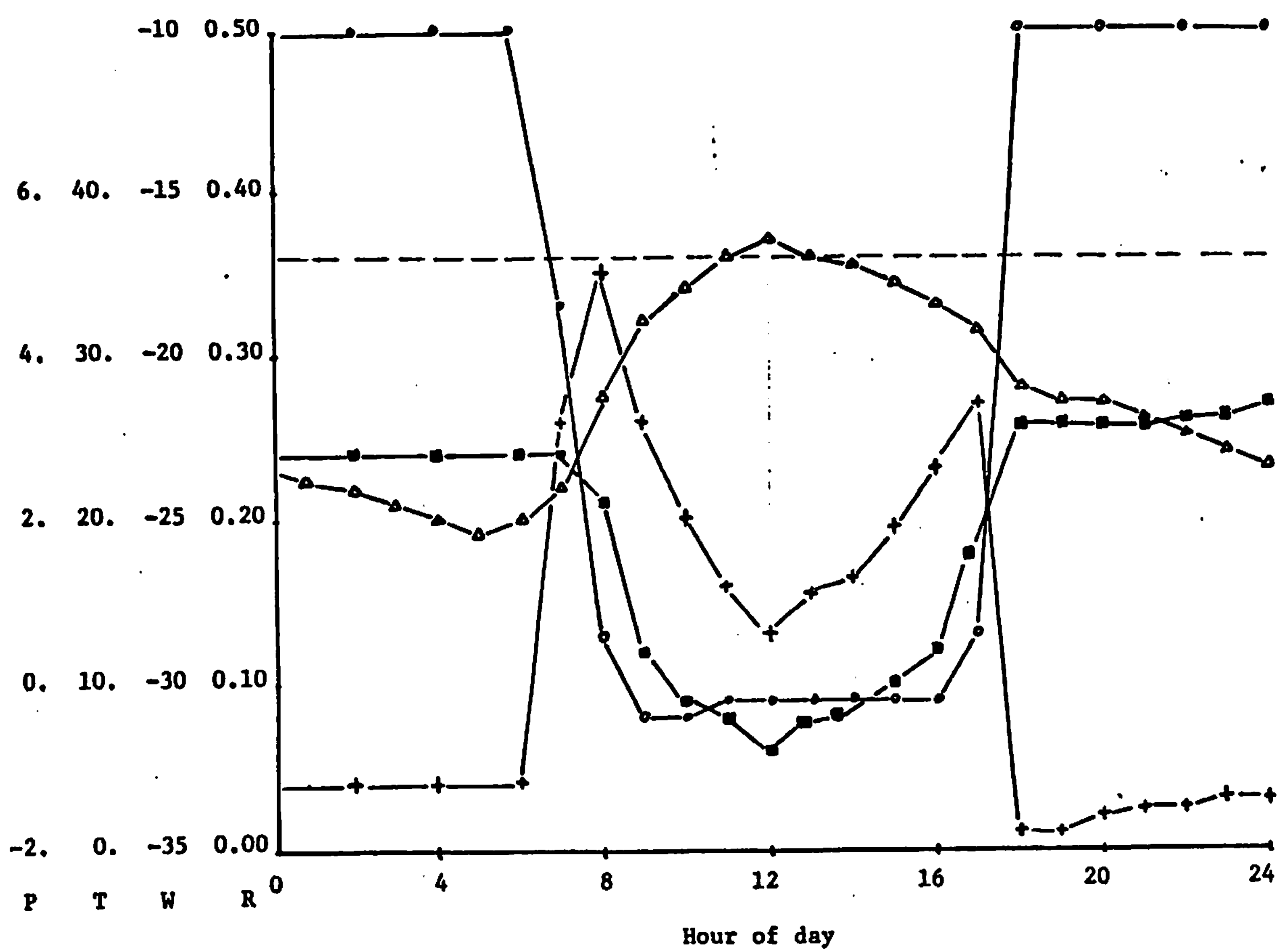

Figure 7. The daily course of physiological functions for the February sunny day.

+ P net photosynthesis mg CO_2 dm^{-2} hr^{-1}

△ T leaf temperature °C

■ W leaf water potential bars

○ R leaf resistance min cm^{-1}

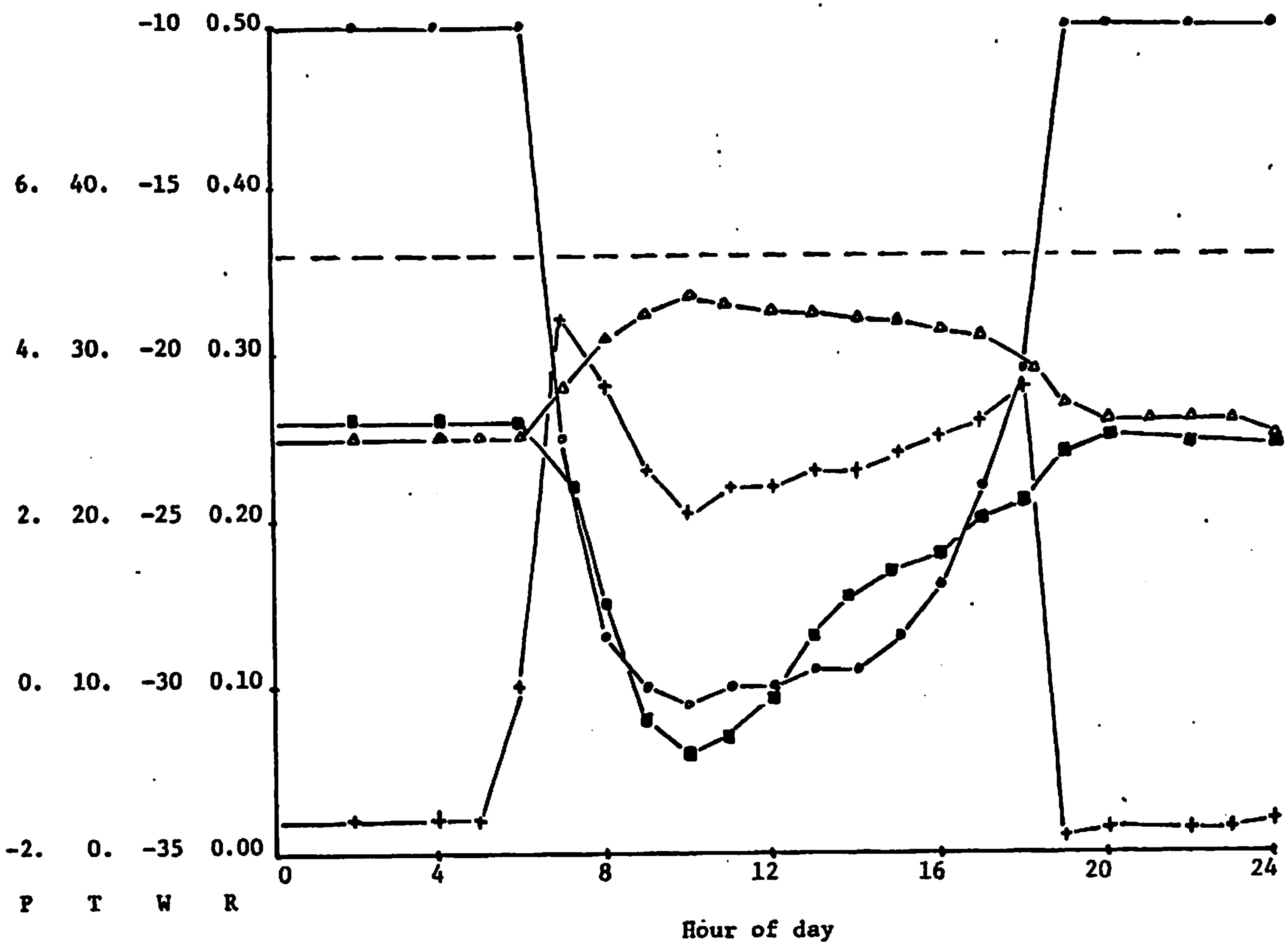

Figure 8. The daily course of physiological functions for the May average day.

+ P net photosynthesis mg CO_2 dm^{-2} hr^{-1}

▲ T leaf temperature °C

■ W leaf water potential bars

● R leaf resistance min cm^{-1}

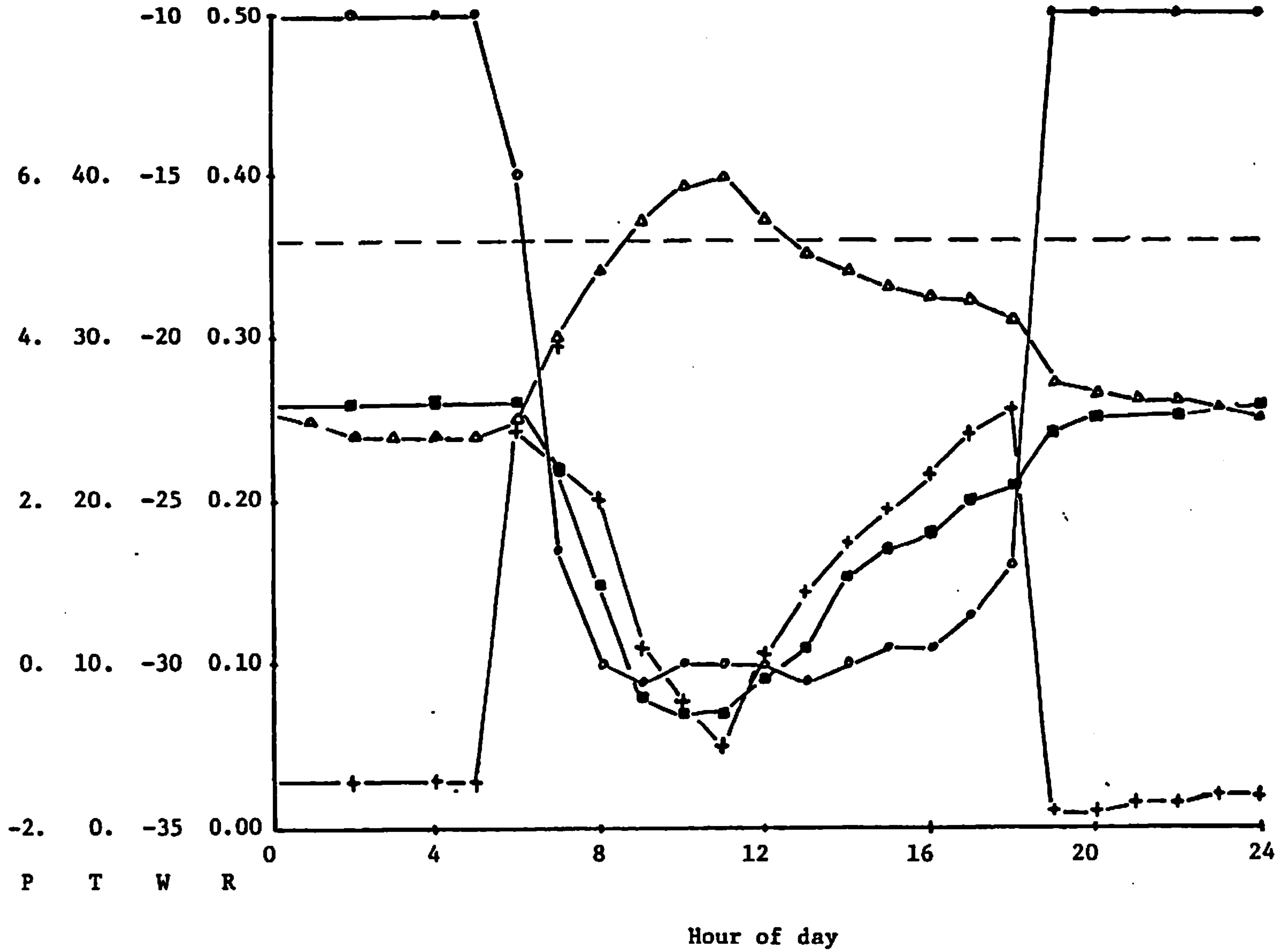

Figure 9. The daily course of physiological functions for the May sunny day.

- + P net photosynthesis mg CO_2 dm^{-2} hr^{-1}
- △ T leaf temperature °C
- ■ W leaf water potential bars
- ○ R leaf resistance min cm^{-1}

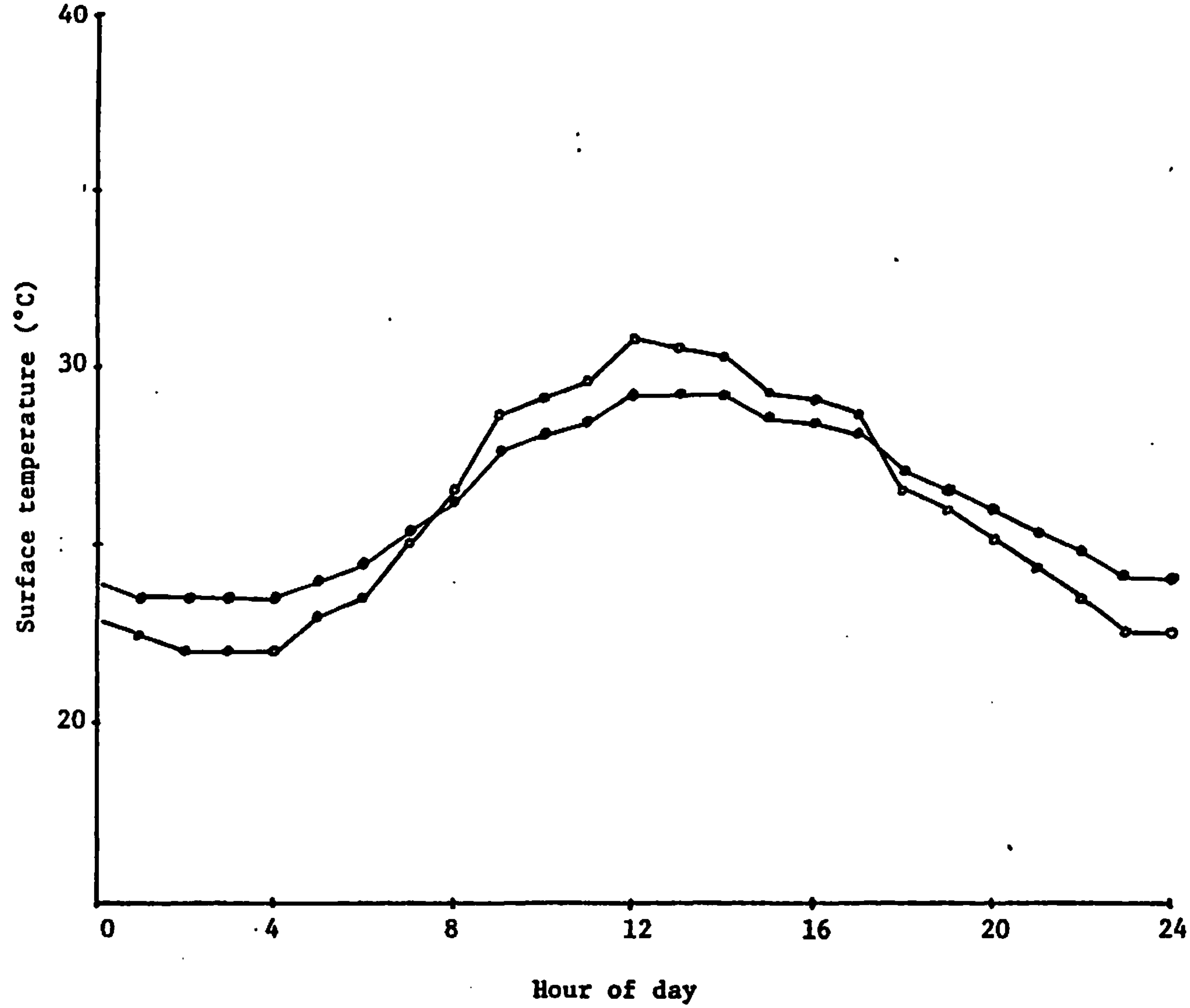

Figure 10. The daily course of ground surface temperatures on the February average day. (o no canopy; ● canopy of LAI=1.5 above)

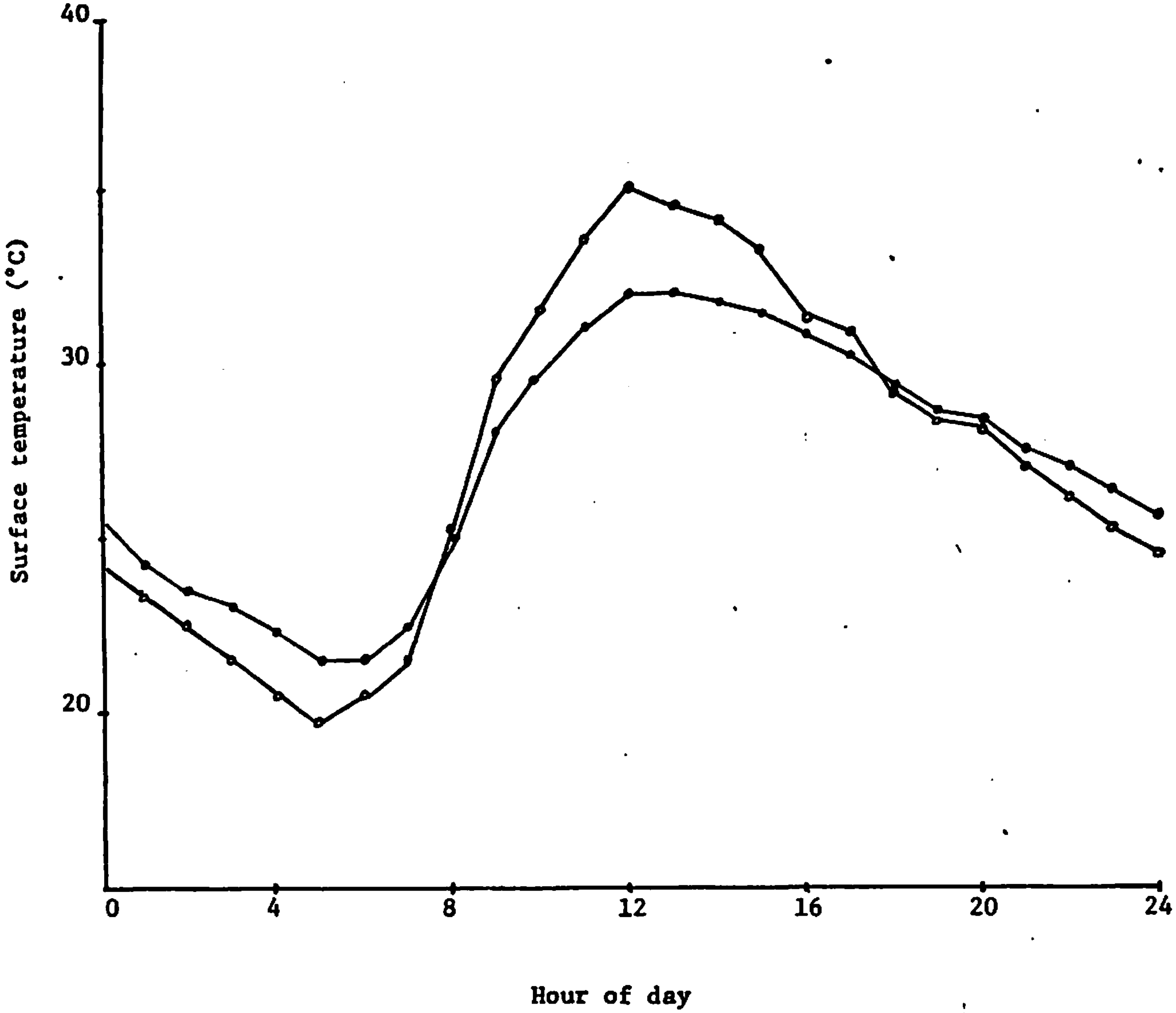

Figure 11. The daily course of ground surface temperatures on the February sunny day. (○ no canopy; ● canopy of LAI=1.5 above)

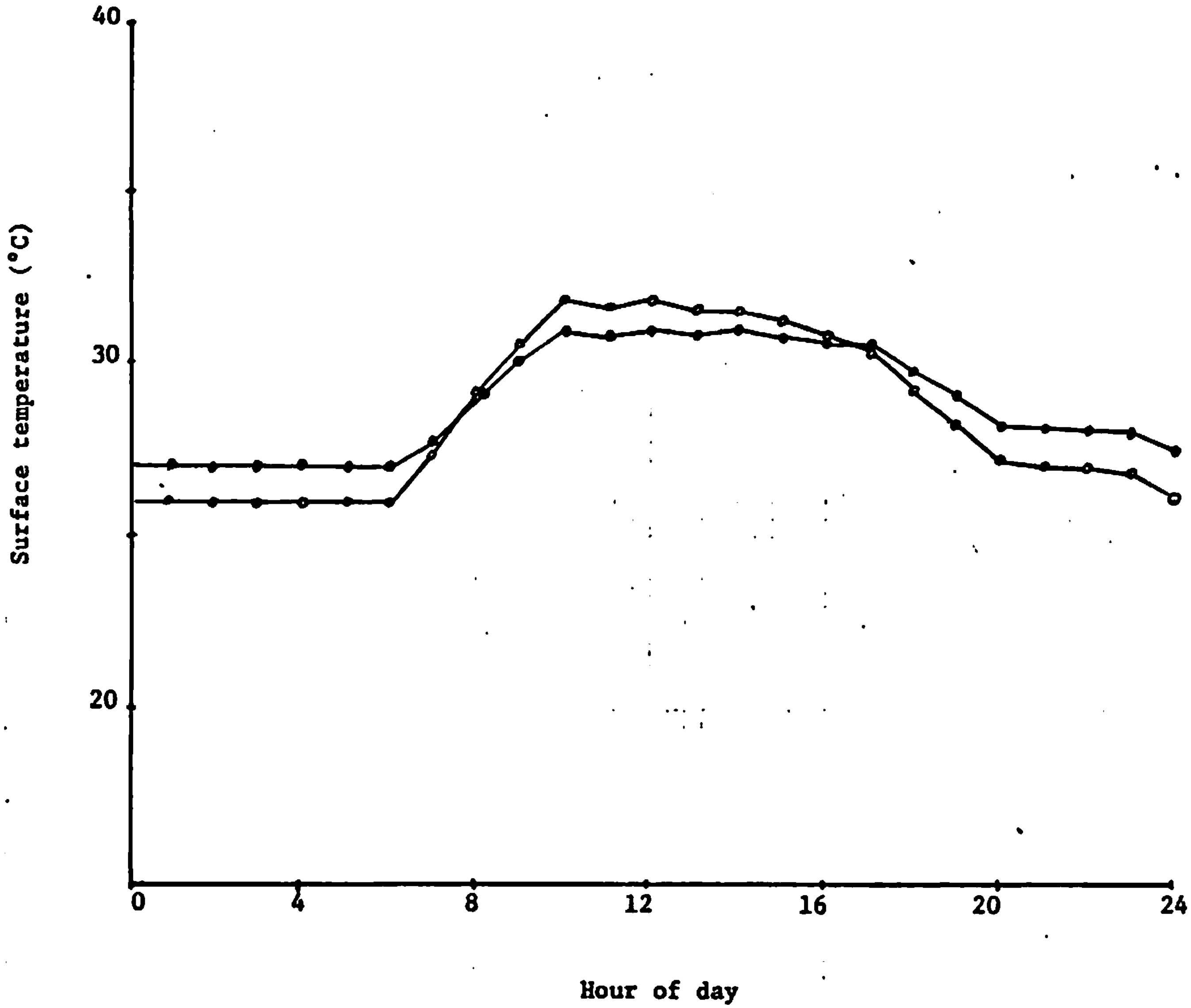

Figure 12. The daily course of ground surface temperatures on the May average day. (o no canopy; ● canopy of LAI=1.5 above)

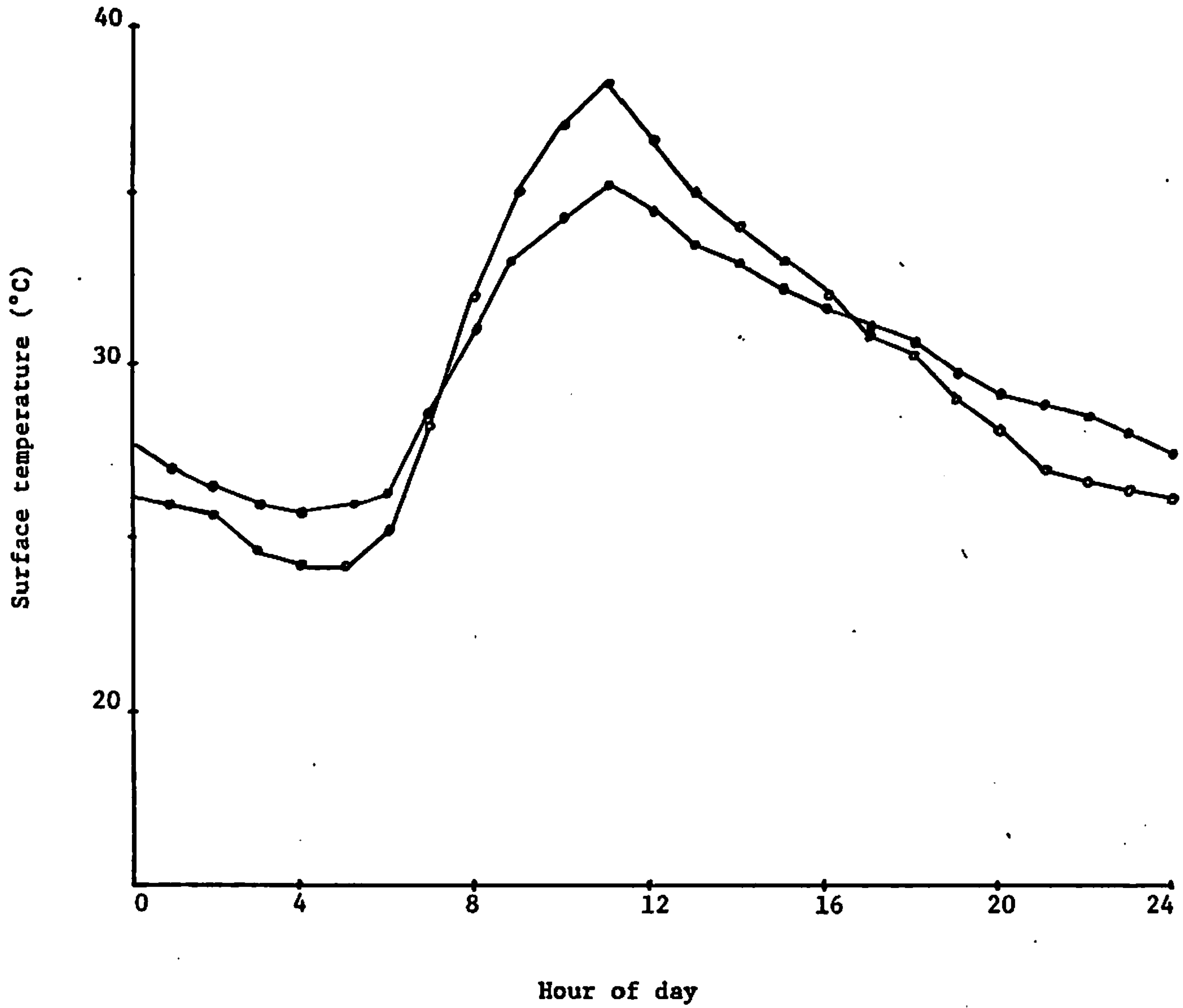

Figure 13. The daily course of ground surface temperatures on the May sunny day. (○ no canopy; ● canopy of LAI=1.5 above)

The long term simulation of red mangroves.

Currently in Viet Nam much of what used to be mangrove forests is now barren as a result of defoliation. Furthermore, reforestation appears to be impaired in some way. The following mathematical simulation is being used to determine possible long term causes. The two hypotheses being tested are: (1) the slow immigration of propagules retards reforestation and (2) the growth of propagules and seedlings is arrested as a result of increased temperature and salinity resulting from the initial defoliation. The red mangrove forest, *Rhizophora mangle L.*, of the Rung Sat Delta was being modeled. Figure 1 is a simplified flow chart of the model. The description of the model will follow the order of the state variables in the figure as numbered with the description of the driving variable preceding.

Model Description

I. Macroclimate

The driving variables in the model are solar radiation, temperature, precipitation and salinity. Mean monthly data were used to approximate mean daily values by means of a linear interpolation between two adjacent monthly means. A standard year is used throughout the simulation (see Table 1). Mean monthly temperature and total monthly precipitation were taken from Van Cuong (1964). Mean monthly total solar radiation was taken from summaries (Dept. of Commerce 1968) from the Saigon area. Mean monthly ambient salinities from a Florida brackish water mangrove swamp were used to approximate the daily values (Eric Heald, 1971). The salinity curve coincided with the solar radiation curve. Assuming a relationship between solar radiation and evaporation, the Florida salinities are used as an approximation to the Rung Sat Delta.

II. Propagules

The propagules are initiated through adult dropping and immigration from peripheral areas (Figure 2). The fruits ripen and fall from May to September. Ninety percent of the fruits produced stay next to the parent tree. Approximately ten percent of the indigenous propagules are assumed to be invading new areas. Propagule mortality is a function of varying temperature and salinity. The mathematical function describing mortality due to temperature is a linear decrease from sixty-seven percent mortality at 36°C to zero mortality at 30°C:

$$M_T = (30 - T_A)\ (0.67/5) \qquad (1)$$

where M_T is mortality due to T_A, the air temperature. The mortality due to salinity was approximated after Stern and Voigt (1959) where mortality increased from thirteen percent in sea water to forty-seven percent in tap water as follows:

$$M_S = (1 - S/45)\ (.5) \qquad (2)$$

where M_S is the mortality due to salinity S which is in parts per thousand. All the dead propagules are transfered directly to detritus.

Living propagules all germinate and grow leaves, stems, and roots with a rate or growth as follows:

$$dG/dt = kG(Gmax - G) \text{ (Salisbury and Ross, 1969)} \qquad (3)$$

where dG/dt is the rate of growth, k is a time constant relating to the length of time taken to reach Gmax which is the optimum biomass of the leaves, stems, or roots prior to the transfer to seedlings. G is the current biomass of the leaf, stem or root part in question. As a propagule only stored energy is used for growth. Optimum leaf, stem and root biomasses were calculated by taking the caloric values for propagules, leaves, stems, and roots (4.58, 4.18, 4.34, and 4.03 kcal per gram dry weight after Golley, 1969), converting to kilocalories per gram wet weight using a 0.4 dry to wet weight conversion factor, then dividing the propagule energy content by the weighted plant energy content assuming 0.22, 0.63, and 0.15 for leaf, stem, and root fractions respectively. This yields an estimate of propagule energy content after distribution according to seedling wet energy contents: ie. the propagule will grow to 2.4 times its dormant biomass before needing outside energy input. After taking 2.4 times the propagule wet weight and subtracting expected respiration losses, we can estimate the leaf, stem, and root biomasses as 22, 63 and 15 percent respectively of the remainder. Once the optimum leaf, stem and root biomasses are attained the propagules are transfered to the seedling catagory.

III. Seedlings and Adults

Once a propagule has attained the seedling leaf-stem-root ratio, the growth scheme given in Figure 3 is followed. The life pattern in seedlings is assumed to be exactly the same as that of an adult therefore the same flow chart and subroutine are used with different initiating parameters. First solar energy enters the canopy and fifty percent is absorbed by the leaf material. Net photosynthesis is calculated after Gaastra (1963) as follows:

$$Pn = ([CO_2]_a - [CO_2]_\ell / (1.56r_\ell + r_a + r_m) \qquad (4)$$

where Pn is the net photosynthesis for LAI equal to 1.0, $[CO_2]_a$ and $[CO_2]_\ell$ are the carbon dioxide concentrations of the air and leaves, r_ℓ is the leaf resistance to water loss, 1.56 is the ratio of the diffusion coefficients of carbon dioxide and water vapor, r_a is the laminar boundary layer resistance and r_m is the mesophyll resistance to carbon dioxide exchange. The leaf resistance to water loss is calculated using:

$$r_\ell = (0.5 - (0.0245)\ (WD \times SA) + (C \times WD \times SA)^{16})/(1. + (16 \times SA))$$

(Miller and Ehlringer, 1972) (5)

where WD is the water deficit, SA is solar absorbed, and C is a constant. The net photosynthesis is then multipiled times the leaf area index then stem and root respiration is subtracted. The Gaastra equation takes into account leaf respiration so only stem and root respirations are subtracted from the net photosynthesis. Respiration is calculated using the Q_{10} equation:

$$R = R_o Q_{10}^{\ 0.1(T - T_o)} \qquad (6)$$

where R_o and T_o are reference respiration rate and temperature, respectively. Daily respiration was estimated directly from equation (6) where as daily net photosynthesis was a linear approximation from the instantaneous solar noon rate.

The light entering the canopy was extinguished exponentially:

$$SA = SAe^{k_4 F} \qquad (7)$$

where F is the leaf area index, and k_4 is the extinction coefficient which is calculated as follows:

$$k_4 = \cos\ (I) \qquad \text{(Duncan, et al., 1967)} \qquad (8)$$

where I is the leaf inclination from horizontal. Dynamic strata were used to correct for reduced photosynthesis with the extinction of light through the canopy. It has been noted that the leaf angle used in equation (8) decreases from the top to the bottom in an adult canopy (Miller, 1972). Miller (1972) has also measured the leaf areas for various mangrove canopy strata and given a typical tree distribution for both leaf inclination and leaf area. Given the typical leaf area and leaf angle distribution for adult trees one can distribute a total leaf area index accordingly yielding a corresponding reduction of light for lower levels in the canopy. This process limits the size of the canopy in the following way. In the model if a stratum has a negative production, respiration exceeds photosynthesis for the stratum, then the stratum leaf biomass is reduced accordingly, also the stratum does not recieve new material for growth. The lower levels are then reduced as the leaf area index exceeds the value at which all strata sustain zero to positive production. This yields an optimum leaf area index and maximum tree size which maximizes production.

Once daily photosynthesis is calculated it is reduced according to the temperature function described in the accompanying paper. Zero efficiency occurs at 25°C with à linear decrease from 25°C to 15°C and 25°C to 35°C such that at 15°C or lower or 35°C or higher photosynthesis does not occur.

Assimilation is then the difference between respiration and net photosynthesis. If the daily assimilation is negative, leaf material is lost at a rate of twice the negative assimilation assuming fifty percent efficiency in the resorption. Fifty percent of the retracted leaf material goes to maintainence of the plant while fifty percent is transfered to detritus. If net photosynthesis is positive then it is allocated as follows:

$$F_i = 2(OF_i) - CF_i \tag{9}$$

where F_i is the fraction allocated to the i^{th} plant part, OF_i is the optimum fraction of the i^{th} plant part and CF_i is the current fraction of plant material residing in the i^{th} plant part. OF values for leaves, stems, and roots are 0.085, 0.610, and 0.310 for adults and 0.22, 0.63, and 0.15 for seedlings.

The seedling to adult transfer occurs at 7.2 grams of leaf material per plant. When this arbitrary leaf biomass is reached the seedling is then considered an adult. This weight standard corresponds to the weight of four mature leaves.

IV. Fruit Production

The fruit production scheme was designed from qualitative descriptions of red mangroves on the Rung Sat Delta. Fruiting begins in March with peak production from May to July with a steady decrease from July to August. Fruit production ceases in August. These observations were incorporated in the model as a discontinuous function as follows:

March to May $\quad F_f = (D/30) \times 0.5\ MX \qquad (10)$

May to July $\quad F_f = MX \qquad (11)$

July to August $\quad F_f = MX - D/30 \qquad (12)$

where F_f is the fraction of leaf material available for growth allocated to fruit production, D is the current day of the month and MX is the maximum fraction of net production allocated to fruit production. From January to March and from August to December F_f is set to zero. The MX value was arbitrarily set to fifty percent of leaf material available for growth.

V. Detritus, Nutrients, and Herbicide

All dead material is added to detritus which is undergoing a tidal exportation of 87.4 percent (Golley et al. 1962) and exponential decay:

$$D = de^{-k_1 t} \quad (13)$$

where D is the current weight in grams of detritus, d is the initial weight in grams of detritus, t is time lapse from initiation in days, and k_1 is 6.7×10^{-3} which is the decay constant associated with forty-five percent decomposition in two months (meetings on mangrove ecology, 1972).

A fraction of decomposed detritus is then allocated to nutrients and herbicide in solution. Thirty-five percent of decomposed detritus is assumed to be nutrients with 0.05 percent being assumed herbicide if the plant death is a result of herbicide introduction. Nutrients and herbicide in solution then undergo exponential decay as follows:

$$N = ne^{k_2 t} \quad (14)$$

$$H = he^{k_3 t} \quad (15)$$

where N is the current nutrient concentration, n is the initial nutrient concentration, k_2 is the decay constant relating decay exponentially to time, H is the current herbicide concentration, h is the initial herbicide concentration, and k_3 is the decay constant relating decay exponentially to time. It is assumed that 87.4 percent of the nutrients and herbicide in solution is exported with tidal inundation periodically.

If the herbicide concentration is above 10 lbs per acre or 11.2×10^3 gr. per hectare defoliation occurs and all the leaf material is transfered to detritus.(meetings on mangrove ecology, 1972).

Evaluation of Data Base and Estimation of Parameters

There are few data available regarding propagule and seedling growth. To determine an estimate of the leaf-stem-root fractions for seedlings two submodels were proposed using (1) the typical adult leaf-stem-root fraction indicated by Golley et al. (1962) and (2) a linear projection of the Golley data to approximate seedling leaf-stem-root fractions. If the plant part biomasses for leaves, stems, and roots are reduced to fraction of the total biomass and plotted versus the diameter at breast height clear trends are indicated for leaves and roots. Projecting these trends to zero diameter at breast height yields 0.22 and 0.15 for leaf and root fractions. This procedure was done by hand and the leaf and root fraction appear to be a curvilinear functions of diameter at breast height so the indicated values are crude estimates. With 0.22 for the leaf fraction and 0.15 for the root fraction we have 0.63 for the stem fraction. Submodel (1) resulted in a quick elimination of seedlings under a leaf area index of 1.0 and 3.0, and zero maturation to the adult catagories under a leaf area index of zero. Submodel (2) indicated four year survival under a leaf area index of 1.0 and maturation to the adult catagory in three years under a leaf area index of zero.

In determining the root fractions an approximation was used correcting the Puerto Rican data (Golley et al., 1962) for subsurface roots. Snedacker and Lugo (1972) indicated subsurface roots as thirty-six percent of the prop-root-subsurface root subtotal. All of the prop-root biomasses indicated by Golley were then divided by 0.63 to include an estimate of the addition due to subsurface roots.

Correcting the leaf-stem-root fractions indicated by Golley et al. (1962) at 2.8 cm. diameter at breast height we have adult fractions of 0.085, 0.610, and 0.305 for leaves, stems, and roots respectively. These values were used to characterize the typical adult plant in the model.

Two fruiting submodels were proposed: (1) a fraction of the assimilation allocated to leaf production was used for fruit production, and (2) a fraction of the total assimilation was used for fruit production. With submodel (2) fruits averaged ten percent at maturation of the total adult biomass. Submodel (1) indicated fruits between 1.5 and 3.1 percent at maturation of the total adult biomass. Snedacker and Lugo (1972) found between 0.0 and 4.1 percent residing fruits in their studies of red mangroves.

To determine seedling density for estimating the leaf biomass per plant the above ground dry weight at the end of five months growth was divided by 1.77 grams which is the above ground dry weight of five month old seedlings as indicated by Stern and Voight (1959). With an immigration of 3.0 grams of propagule a year this yields a first year density of 1.1 seedlings per meter squared. Typical assimilation data for this density are given in Table 2.

Results

The effects due to temperature are demonstrated in Figure 4. Three twenty year simulations were made with (1) normal temperatures, (2) half degree above normal temperatures and (3) a full degree above normal temperatures. Simulation (2) and (3) showed eighteen and forty-eight percent decreases in biomass below the biomass of simulation (1).

The effects due to salinity were less dramatic. Three twenty year simulations were made using (1) the normal salinities for brackish water, (2) one part per thousand above normal salinities for brackish water and (3) two parts per thousand above normal salinities for brackish water. There was less than one percent variation in total biomass between the three simulations.

Variations of reforestation due to varying immigration are shown in Figure 5. Three twenty year simulations were made using immigration rates of (1) 1.0 grams, (2) 2.0 grams and (3) 3.0 grams of propagule per meter squared per year. Simulations (1) and (2) showed twelve and nine percent decreases in biomass below the biomass of simulation (3).

Conclusion

The effects due to increased salinity appear to be relatively small. The effects of temperature play a major role in reforestation. The barren nature of the Rung Sat Delta due to defoliation and wood gathering has increased the likelihood of temperatures inhibitory to plant growth. Inhibitory temperatures and slow immigration are the major sources of inhibition in the model and in combination probably play the major role in reforestation problems on the Rung Sat Delta.

The most critical deficiency is the lack of data on the growth habits of propagules and seedlings. The nature of initial rooting and the role of solar radiation in activating propagules on the mud are unknown. Data are available on five month old seedlings and adults of unknown ages. There are data concerning adult photosynthesis, respiration, canopy structure and root structure but no intermediate points for seedlings and younger adults which would serve to improve and validate the model.

Table 1. Macroclimate Input

Month	1	2	3	4	5	6	7	8	9	10	11	12
Temperature (°C)	23.5	24.6	26.6	27.7	28.0	25.9	24.8	25.0	25.5	25.8	23.5	24.0
Precipitation (mm)	6.6	3.4	5.8	60.0	201.0	204.0	199.0	184.0	199.0	201.0	64.0	27.0
Total Solar Radiation ($cal/cm^2/min$)	350	422	456	438	367	391	386	369	355	334	316	316
Salinity (parts per thousand)	14.5	20.0	22.4	27.9	20.0	10.1	0.0	0.0	0.0	0.0	0.0	3.5

Table 2. Net photosynthesis, total respiration and plant assimilation in grams organic matter per meter squared per day are given for various growth stages with no overhead light extinction for seedlings of density 1.1 and adults of variable densities.

Months After Defoliation	Leaf Biomass	Photosynthesis	Respiration	Assimilation
5 months	1.2	0.021	0.004	0.017
17 months	3.6	0.066	0.012	0.054
29 months	10.3	0.187	0.034	0.152
Years After Defoliation				
5 years	19.1	0.334	0.104	0.230
7 years	39.6	0.675	0.315	0.359
9 years	51.3	0.856	0.554	0.301
11 years	78.8	1.220	0.790	0.430

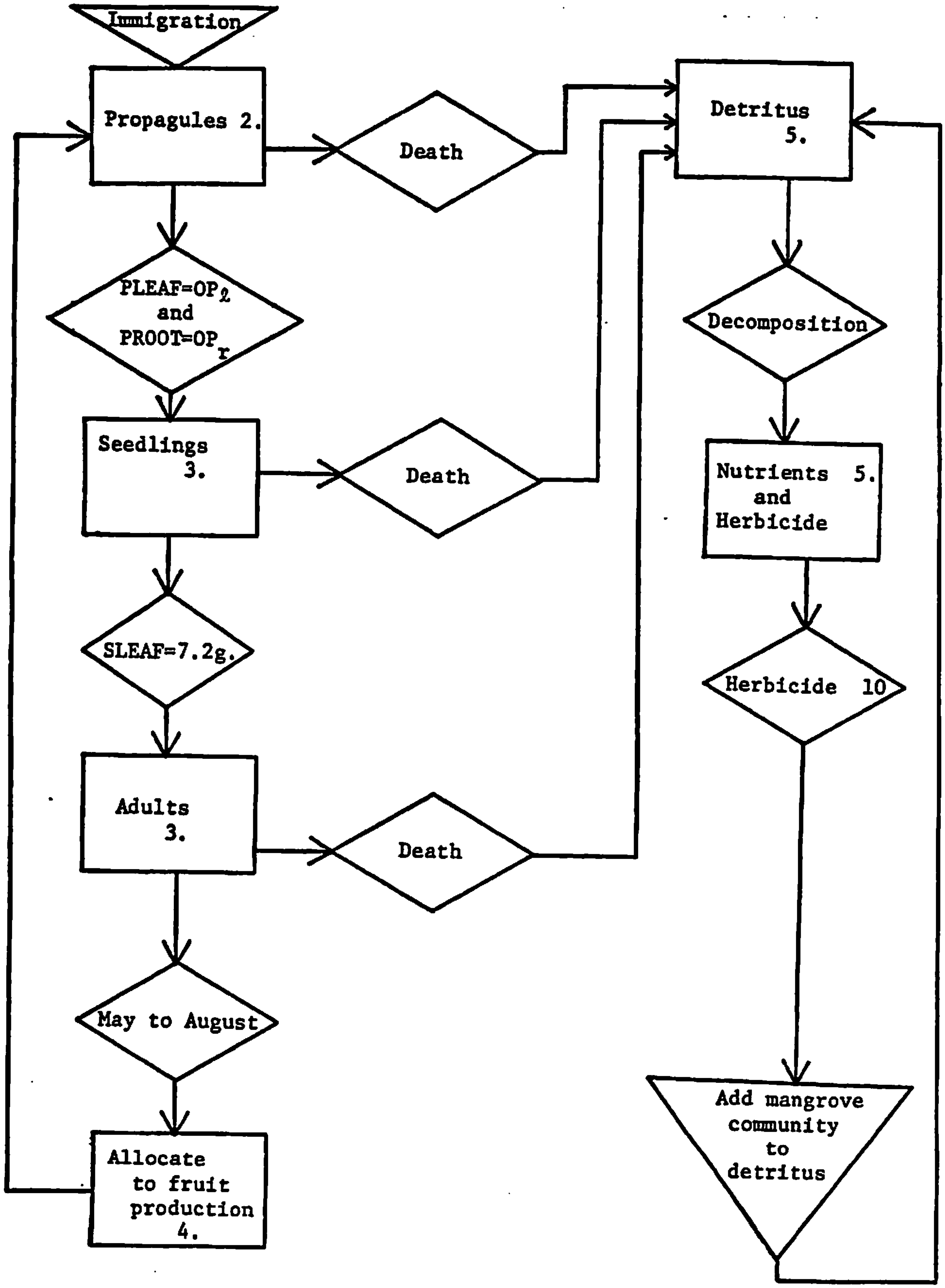

Figure 1. Model flow chart. Rectangles are state variables, diamonds are conditions for transers, and triangles are systems input-output.

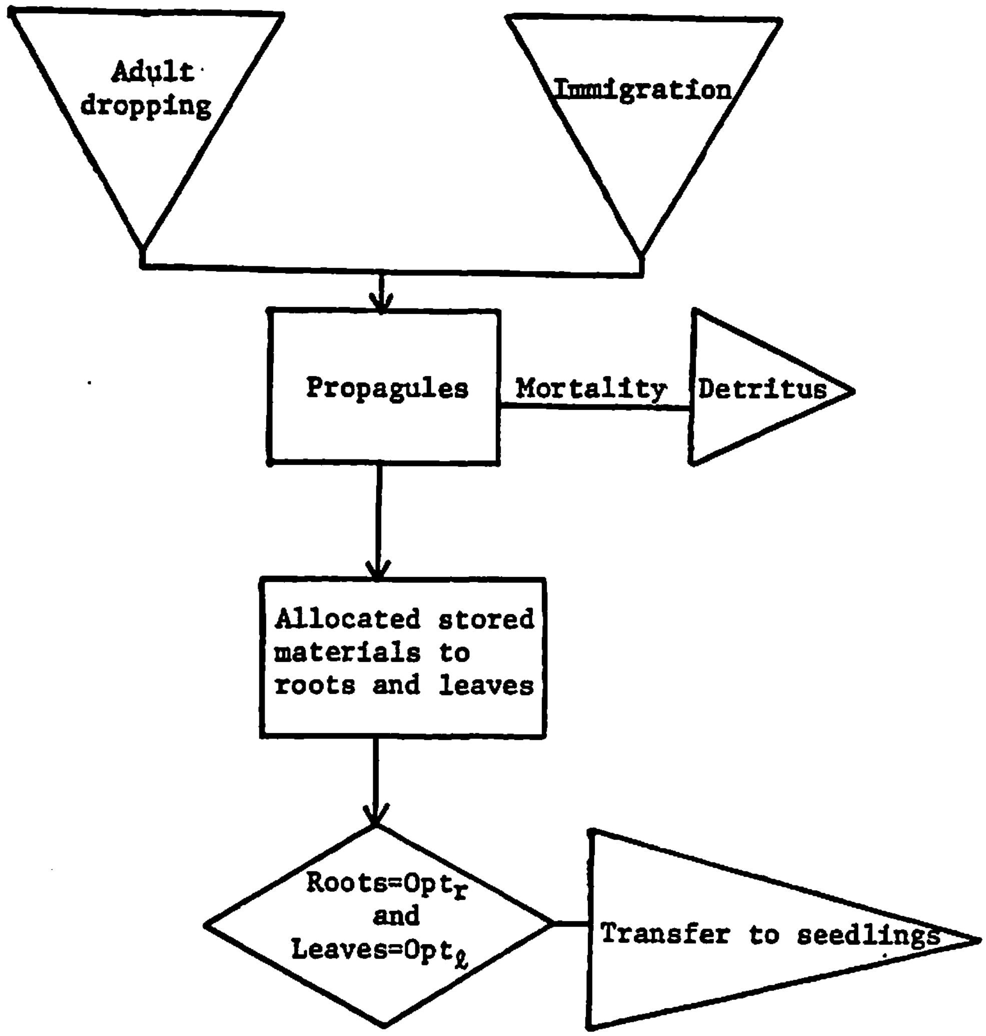

Figure 2. Propagules submodel flow chart.

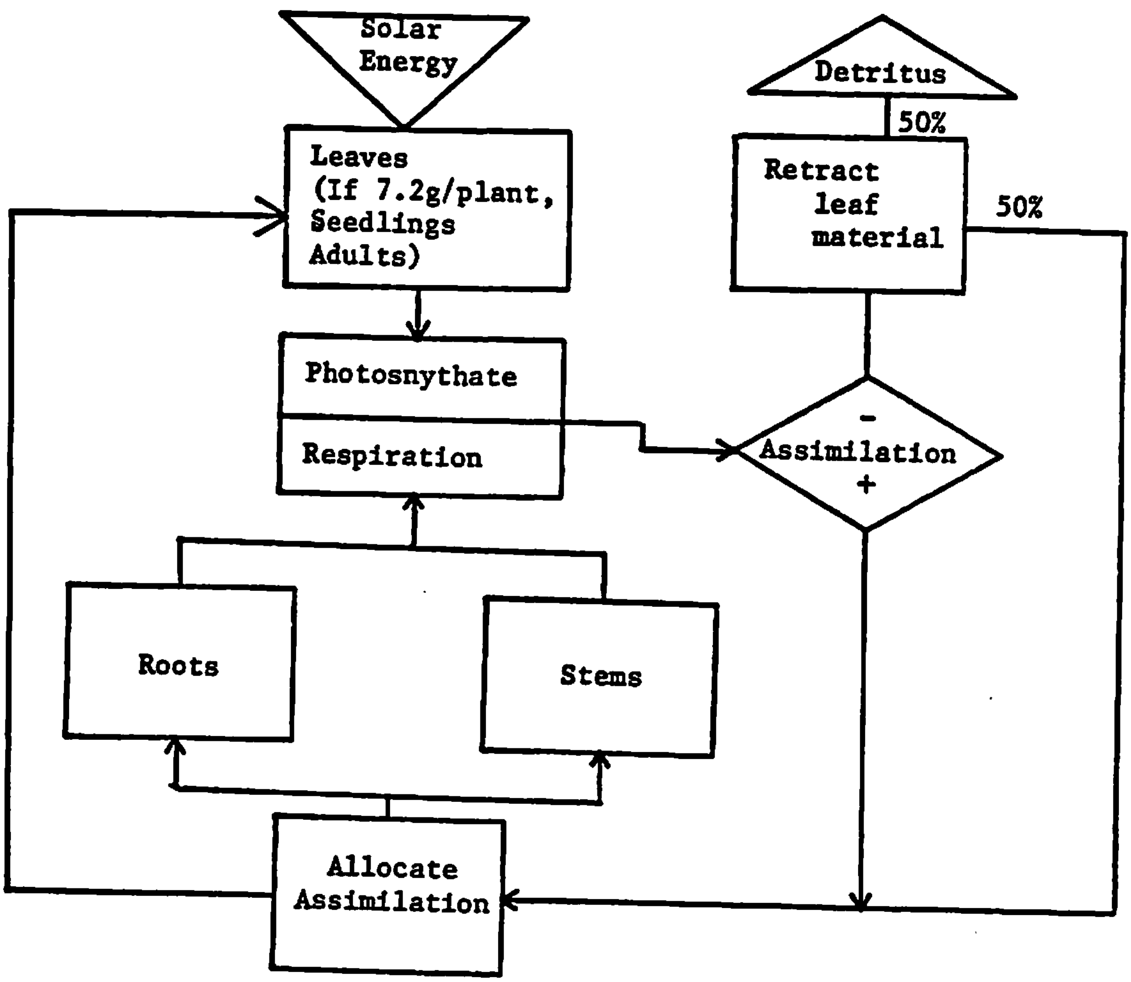

Figure 3. Seedling and adult submodel flow chart.

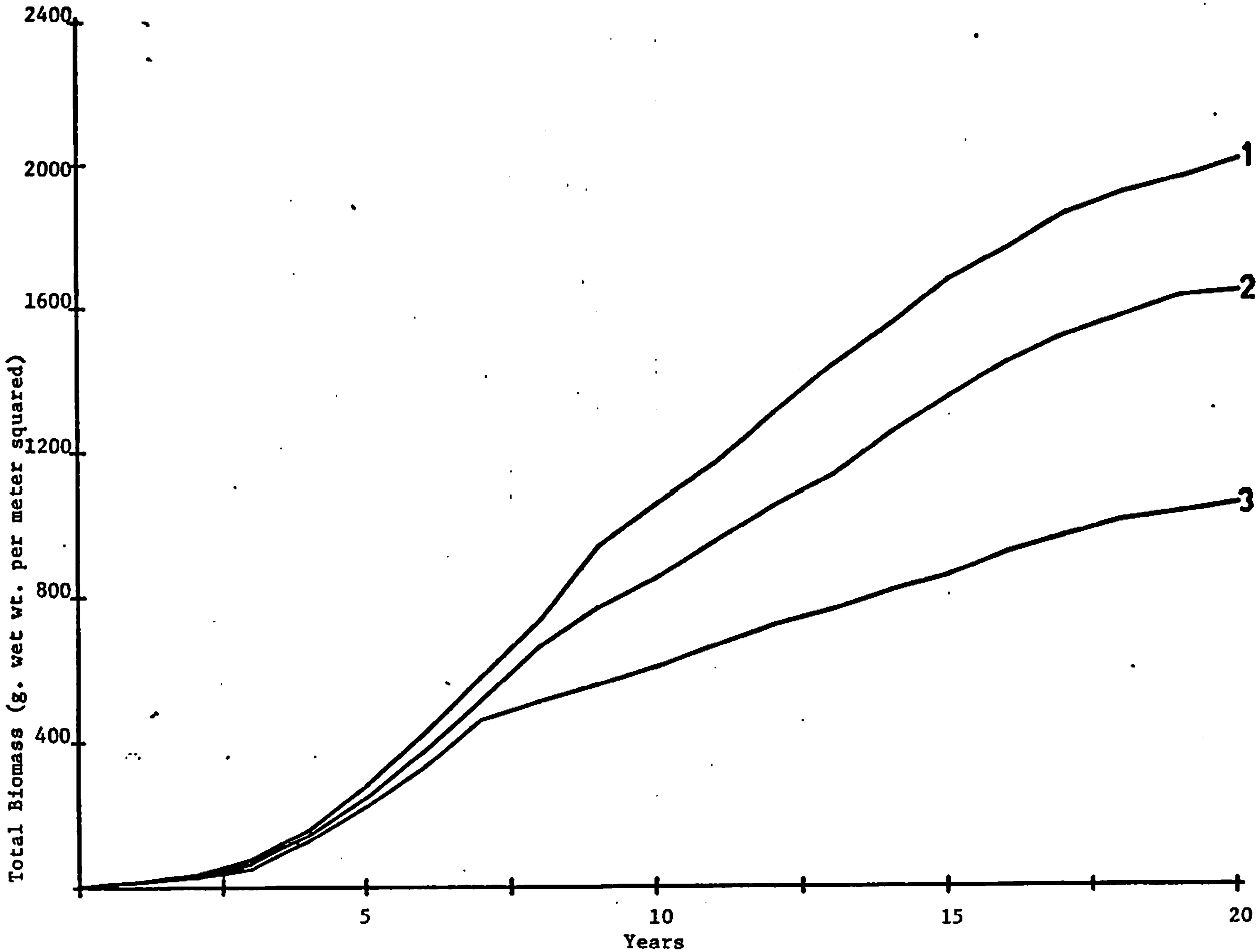

Figure 4. Total mangrove biomass with temperature variations.

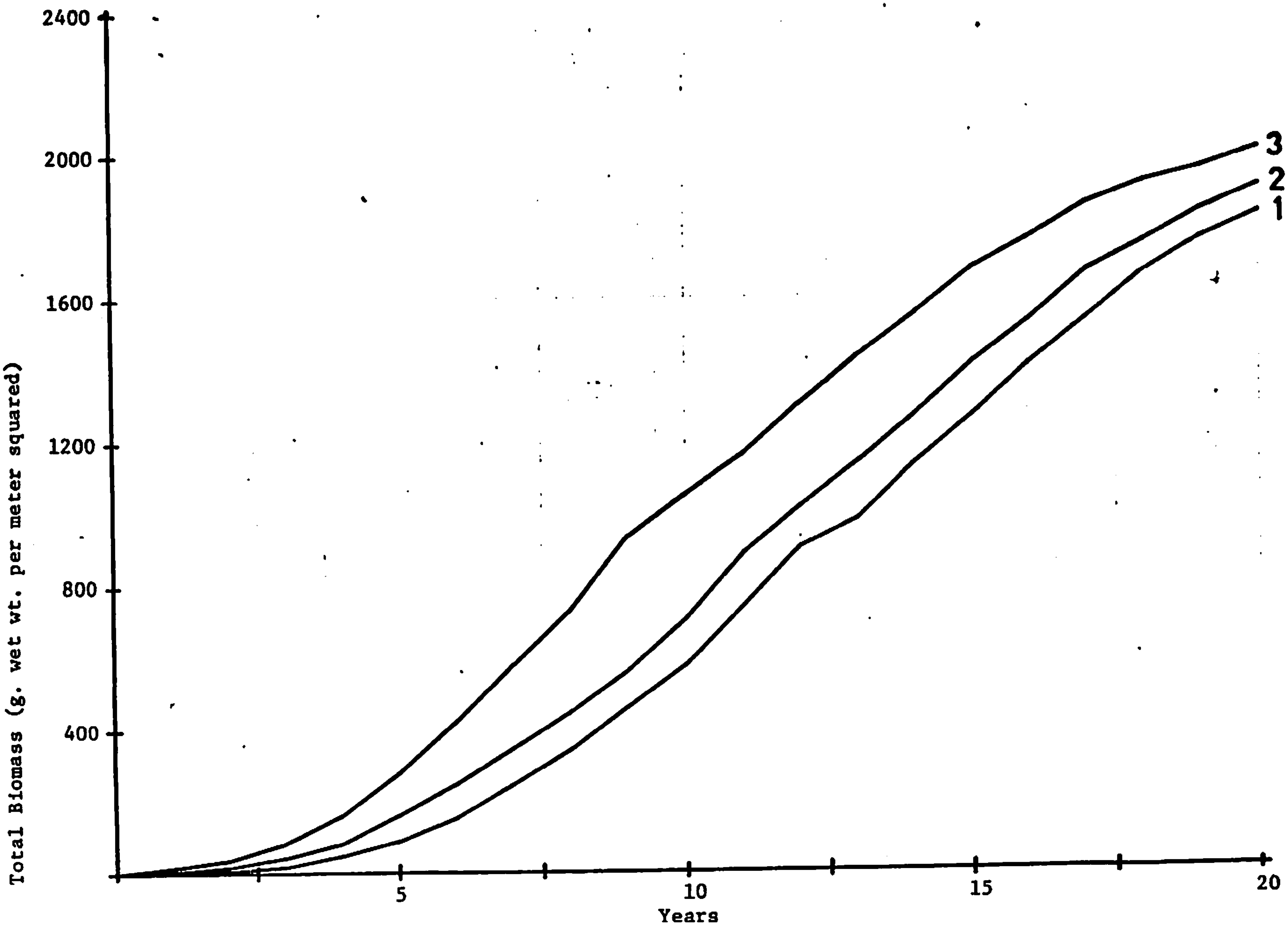

Figure 5. Total mangrove biomass with immigration variations.

LITERATURE CITED

Conway, H. 1963. The Weather Handbook. Conway Publications Inc., Atlanta. 255 pp.

Cuong, Humbert Vu Van. 1964. Flore et Vegetation de la mangrove. These de docteur, Universite de Paris.

Dept. of Commerce. 1968. Viet Nam solar radiation data for the period January, 1964 through October, 1967. Environmental Data Service, National Climate Center, Asheville, North Carolina.

Duncan, W. G., R. S. Loomis, W. A. Williams, and R. Hanau. 1967. A model for simulating photosynthesis in plant communities. Hilgardea 38.

Gaastra, P. 1963. Climatic control of photosynthesis and respiration. In L. T. Evans (ed.) Environmental Control of Plant Growth. Academic Press, New York.

Golley, F. B. 1969. Caloric values of wet tropical forest vegetation. Ecology 50 (3): 517-519.

Golley, F. B. 1971. Effect of Defoliation on Mangroves. Report to the National Res. Council Committee on the use of Herbicides in Viet Nam. 18 pp. Mimeo.

Golley, F., H. T. Odum, and R. F. Wilson. 1962. The structure and metabolism of a Puerto Rican mangrove forest in May. Ecology 43: 9-19.

Heald, E. 1971. The production of organic detritus in a south Florida estuary. Univ. of Miami, Coral Cables. Sea Grant Tech. Bull. 6.

Miller, P. C. 1972a. Bioclimate, leaf temperature, and primary production in red mangrove canopies in south florida. Ecology 53: 22-45.

Miller, P. C. 1972b. A test of radiation models in vegetation canopies. Submitted to J. Appl. Meteorol.

Miller, P. C. 1972c. Investigations of physical processes affecting leaf temperature profiles and primary production in the red mangrove ecosystem. Progress Report. AEC Contract AT (04-3)-807.

Miller, P. C. and J. Ehleringer. 1972. Comparison of leaf resistances to water loss and leaf water relations in three mangrove species in south Florida. Ecology (in review).

Miller, P. C. and L. Tieszen. 1972. A preliminary model of processes affecting primary production in the arctic tundra. Arctic and Alpine Res. 4: 1-18.

Monteith, J. L. 1965. Light distribution and photosynthesis in field crops. Ann. Bot. N.S. 19: 17-37.

Moore, R. T., P. C. Miller, D. Albright, and L. Tieszen. 1972. Comparative gas exchange characteristics of three mangrove species during the winter. Photosynthetica (in press).

Salisbury, F. B. and C. Ross. 1969. Growth and problems of morphogenesis. 407-438 pp. In Plant Physiology. Wadsworth Company, California.

Snedacker, S. C. and A. E. Lugo. Center for Aquatic Sciences. The role of mangrove ecosystems in the maintenance of environmental quality and a high productivity of desirable fisheries. Bureau of Sport Fisheries and Wildlife 14-16-008-606 Annual Report FY 71-72.

Stern, W. L. and G. K. Voight. 1959. The effects of salt concentration on growth of red mangroves in culture. Bot. Gazette 121(1): 36-39.

Tschirley, F. H. 1969. Defoliation in Viet Nam. Science 163: 779-786.

Waggoner, P. E. and W. E. Reifsnyder. 1968. Simulation of the temperature, humidity, and evaporation profiles in a leaf canopy. J. Appl. Meteor. 7: 400-409.

Zinke, P. 1972. Report on a reconnaissance of the soil fertility aspects of chemical defoliants in South Viet Nam. Report to the Committee on the use of Herbicides in Viet Nam.

SE*U.FORFLO.S MAIN
FLOACHARTED BY FORFLO /X808/ ON 07 DEC 72 AT 21:40:07

```
      CSEDIT  6,66,2,2.
C
C
C
C   STAND PHOTOSYNTHESIS MODEL USED IN VIET NAM MANGROVE SIMULATIONS  MOD 2.0
C
C
C VARIABLES DEFINING THE ENVIRONMENT
      DIMENSION ZENIH(24), STOTO(24), SDIFO(24), TRSKY(24), EDDFO(24),
     1 WINDO(24), TAG(24), HUMO(24), TG(24), VAPDN(650), PSKY1(9)
      REAL*4 LFDEN
      DIMENSION LIMIT(10,2)
      DIMENSION SFUP(10), PRGND(10)
      DIMENSION TRUP(10,24)
C
C VARIABLES DEFINING THE STAND
      DIMENSION F(10), HT(11), ALADO(10), AP(10), DP(10)  ,
     1          RATUT(10),          WIDTH(10), LFDEN(10), ABSOP(10),
     2 AL(10), ALPHA(10), SF(10), TO(10), RSPO(10), Q10(10), NSTND(10)
C
C CALCULATED VARIABLES DEFINING THE STAND CLIMATE
      DIMENSION PRSUN(10,24), PRSHD(10,24), PRSKY(10), EXCOF(24),
     1 SDIR(10,24), SDIF(10,24), SREF(10,24), TR(11,24), TRDN(10,24),
     1 TAIRP(10),WIND(10),HUMP(10),SABSP(10)
     2 , VEL(10,24), TAIR(10,24), HUM(10,24), EDDIF(10,24)
      DIMENSION PSKY(10),PSUN(10,24)
C
C CALCULATED VARIABLES DEFINING LEAF PROCESSES
      DIMENSION SABS(10,2), TRANS(10), ENABS(10,2), TL(10,2),TRLF(10,2),
     1   CONLF(10,2), TRNLF(10,2), EVAPL(10,2), WD(10,2), WATDF(10,24),
     2          RLRAT(10,2), RL(10), HC(10), RSAIR(10), RSL(10,2),
     3 PHONT(10,2)
      DIMENSION PHETL(10,2)
      DIMENSION          RT(10),PSI(10,2)
      DIMENSION TSUN(24), TSHADE(24)
C
C CALCULATED STAND SUMMARIES
      DIMENSION NTITLE(40),NAME(10)
      DIMENSION DATLS(10,24),                 PSDNT(10,24),
     1 WST(10),            PSTNT(10),          WSH(24),
     2 PSHNT(24 )
      REAL IRNET1,IRNET2
C
C
C        PLOT STUFF ***
C
      DIMENSION G1(5,24),G2(5,24),G3(5,24)
      DIMENSION PLOT1(5,15),PLOT2(5,15),PLOT3(5,15)
```

```
      DIMENSION SCAL1(5),SCAL2(5),SCAL3(5)
      DIMENSION XMIN1(5),XMIN2(5),XMIN3(5)
      DIMENSION NUMBER(5)
C DEFINE CONSTANTS
C
C
      COMMON CMPRS(8)
C
C
      TAN(X) = SIN(X) / COS(X)
C
C
C   DEFINE LOGIC NUMBERS FOR INPUT AND OUTPUT
      NR=5
      N4=6
C
C
C
C
C   DEFINE CONSTANTS
C
      READ(NR,6158) (CMPRS(IX),IX=1,8)
 6158 FORMAT(8F10.4)
      PI = 3.1416
      SIGMA = 8.13E-11
      SIGEP=.95*SIGMA
      XKDIF=1.
      CLUST=.7
      CALL VD(VAPLN)
      READ (NR,4) (PSKY (I), I = 1,9)
    4 FORMAT (9F5.3)
C   READ NAME OF SIMULATION
      READ(NR,561) NTITLE
  561 FORMAT(40A2)
C        READ PLOT ONE
      NUMBER(1)=5
      DO 2560 J=1,5
      READ(NR,1099) (PLOT1(J,I),I=1,15),XMIN1(J),SCAL1(J)
 2560 CONTINUE
C        READ PLOT TWO
      NUMBER(2)=5
 1099 FORMAT(15A2,2F10.0)
      DO 2561 J=1,5
      READ(NR,1099) (PLOT2(J,I),I=1,15),XMIN2(J),SCAL2(J)
 2561 CONTINUE
C        READ PLOT THREE
      NUMBER(3)=5
      DO 2562 J=1,5
      READ(NR,1099) (PLOT3(J,I),I=1,15),XMIN3(J),SCAL3(J)
 2562 CONTINUE
C
C     DEFINE ENVIRONMENT
C
      RHOAR  = 1.2E-3
```

```
      CP = 0.245
      VHC = CP*RHOAR
      DO 1095 J=1,10
      RT(J)=0.25
 1095 CONTINUE
      CONCL=75.0
      CONCA=325.0*1.997E-9
      AKCHO    =  1.0
      CONST = 5.85E-3
 9000 CONTINUE
C
C   DEFINE PLANT CANOPY STRUCTURE AND PARAMETERS
C
C   READ VERSION NUMBER AND NUMBER OF LEVELS IN THE CANOPY
       READ(NR,101,END=99) NAME ,NLEV
  101 FORMAT(10A2,I3)
       READ(NR,102) (HT(L+1),HT(L) , F(L), LFDEN(L), WIDTH(L), AL(L),
     1 ALBDO(L), ABSOP(L),                       AP(L), BP(L), GIO(L),
     2 TO(L), RSPG(L), L=1,NLEV)
  102 FORMAT (2F4.2, F5.3, F5.1, F4.1, F4.0, 2F4.2, 10X  ,  F5.2,F4.3,
     1 F4.1, F5.1, F6.3)
       READ(NR,563) RCUT,RMIN,XPR,D,WM,RROOT,PSOIL,WDINIT
       READ(NR,563) TOPTM,POH,POL,PHOPTM,RCELL
       READ(NR,549) RSR
  563 FORMAT(10F8.0)
       WRITE(NW,562) NTITLE
  562 FORMAT(1H1//35X,'STANDPHOT -- MANGROVE PHOTOSYNTHESIS SIMULATION'/
     2///40X,40A2//)
       WRITE(NW,500) NAME
  500 FORMAT(//30X,10A2)
       WRITE(NW,520) NLEV
  520 FORMAT(1X,6HLEVELS=    ,I3,//20X,26HCANOPY PARAMETERS BY LEVEL  )
       WRITE(NW,521)(HT(L+1),HT(L),  F(L), LFDEN(L), WIDTH(L), AL(L),
     1 ALBDO(L), ABSOP(L),                       AP(L,, BP(L), GIO(L),
     2 TO(L), RSPG(L), L=1,NLEV)
  521 FORMAT(1X,2F6.2,F7.3,F7.0,F6.1,F6.0,2F6.2,      F8.2,F9.3,
     1  F6.2, F7.1, F8.3)
       WRITE(NW,566)
  566 FORMAT(//25X,29HPHYSIOLOGICAL PARAMETERS  )
       WRITE(NW,564) RCUT,RMIN,XPR,D,WM,WDINIT,WDMIN,RROOT
  549 FORMAT(//10X,4HRCUT,10X,4HRMIN,10X,3HXPR,10X,1HD,10X,2HWM,10X,
     26HWDINIT, 8X,5HWDMIN,8X ,5HRROOT/5X,9(F10.4,3X)/1H )
       WRITE(NW,565) RCELL,TOPTM,POH,POL,PHOPTM
  565 FORMAT(//10X,5HRCELL, 8X,5HTOPTM, 8X,3HPOH,10X,3HPOL,10X,6HPHOPTM/
     25X,5(F10.4,3X)/)
       WRITE(NW,567) RSR
  567 FORMAT(//10X,20HROOT TO SHOOT RATIO    ,F3.1)
C
C
C   READ IN HOURLY MICROCLIMATE VALUES
C
C
C   READ DECLINATION, MODEL VERSION NUMBER, AND WAR PRINT(1) OR NO PRINT(2)
       READ(NR,101) DEC,NSTND,NPRT
```

```
   10 FORMAT(F5.0,4X,10A2,T35,I1)
      CALL ZEN(DEC,ZENIH)
      READ(NR,569) SALNTY
      READ(NR,569) HERB
  569 FORMAT(8F10.4)
      SSAP=-(44./58.5)*SALNTY
 9001 READ(NR,11)(STOTO(LHOUR), LHOUR = 1,24)
      READ (NR,11)(SDIFO(LHOUR), LHOUR = 1,24)
   11 FORMAT ( 12F4.2)
      READ (NR,12) (TRSKY(LHOUR), LHOUR = 1,24)
   12 FORMAT ( 12F4.2)
      READ(NR,13) (WINDO(LHOUR) , LHOUR = 1,24)
   13 FORMAT (12F4.0)
      READ(NR,17) (EDDFO(LHOUR), LHOUR = 1,24)
   17 FORMAT (12F5.0)
      READ(NR,14) (TAO (LHOUR), LHOUR = 1,24)
   14 FORMAT (12F4.1)
      READ (NR,15) (HUMO  (LHOUR) , LHOUR = 1,24)
   15 FORMAT (12F4.1)
      READ(NR,16) (TG   (LHOUR), LHOUR = 1,24)
      READ(NR,16) EXTCD,RESGRD
   16 FORMAT(12F4.1)
      WRITE(NW,1098) NSTND
 1098 FORMAT(1H1,19X,10A2//)
      WRITE (NW,501)  (ZENIH(LHOUR), LHOUR = 1,12)
      WRITE (NW,502)  (STOTO(LHOUR), LHOUR = 1,12)
      WRITE (NW,503)  (SDIFO(LHOUR), LHOUR = 1,12)
      WRITE (NW,504)  (TRSKY(LHOUR), LHOUR = 1,12)
      WRITE (NW,505)  (WINDO(LHOUR), LHOUR = 1,12)
      WRITE (NW,506)  (EDDFO(LHOUR), LHOUR = 1,12)
      WRITE (NW,507)  (TAO  (LHOUR), LHOUR = 1,12)
      WRITE (NW,508)  (HUMO (LHOUR), LHOUR = 1,12)
      WRITE (NW,509)  (TG   (LHOUR), LHOUR = 1,12)
      WRITE (NW,501)  (ZENIH(LHOUR), LHOUR = 13,24)
      WRITE (NW,502)  (STOTO(LHOUR), LHOUR = 13,24)
      WRITE (NW,503)  (SDIFO(LHOUR), LHOUR = 13,24)
      WRITE (NW,504)  (TRSKY(LHOUR), LHOUR = 13,24)
      WRITE (NW,505)  (WINDO(LHOUR), LHOUR = 13,24)
      WRITE (NW,506)  (EDDFO(LHOUR), LHOUR = 13,24)
      WRITE (NW,507)  (TAO  (LHOUR), LHOUR = 13,24)
      WRITE (NW,508)  (HUMO (LHOUR), LHOUR = 13,24)
      WRITE (NW,509)  (TG   (LHOUR), LHOUR = 13,24)
  501 FORMAT (1X, 5HZENIH  ,  12F6.0)
  502 FORMAT (1X, 5HSTOTO ,1X,12F6.2)
  503 FORMAT (1X, 5HSDIFO ,1X,12F6.2)
  504 FORMAT (1X, 5HTRSKY ,1X,12F6.2)
  505 FORMAT (1X, 5HWINDO  ,  12F6.0)
  506 FORMAT (1X, 5HEDDFO  ,  12F6.0)
  507 FORMAT (1X, 5HTAO   ,1X,12F6.1)
  508 FORMAT (1X, 5HHUMO  ,1X,12F6.1)
  509 FORMAT (1X, 5HTG    ,1X,12F6.1,/)
      DO 9002 LH = 1, 24
 9002 HUMO(LH)=HUMO(LH)*0.01
      DO 9006 LH= 1,24
```

```
      DO 9006 L=1,NLEV
      TAIR(L,LH)=TAO(LH)
 9006 HUM(L,LH)=HUMO(LH)
C
C     CALCULATE WD EQUAL TO PSOIL
C
      DO 9005 J=1,50
      WDD=J
      PSIO=-0.78-0.46*WDD-0.032*WDD**2.
      IF ( PSIO .LT. PSOIL) GO TO 9007
 9005 CONTINUE
 9007 WDMIN=WDD
C
C
C   CALCULATE VARIOUS LAI DISTRIBUTION VARIABLES
C
      SF(1) = F(1)
      SFUP(NLEV)=F(NLEV)
      DO116 L = 2,NLEV
  116 SF(L) = SF(L-1) + F(L)
      DO 117 L=2,NLEV
      K=NLEV-L+1
  117 SFUP(K)=SFUP(K+1)+F(K)
      TLAI=0.0
      DO 103 L = 1, NLEV
      TLAI=TLAI+F(L)
      ALPHA(L) = AL(L) * 0.0174
      DO 63 LSUN=1,2
   63 EVAPL(L,LSUN)=0.
  103 WATUT(L) = .70
C
C   ACCUMULATORS = 0
C
C   DAILY TOTALS
      TOTPG = 0
      TOTPN = 0
      TOTPR = 0
      TOTA  = 0
C   DAILY TOTALS FOR EACH LEVEL
      DO 190 L = 1,NLEV
      PSTNT(L) = 0
      WST(L)   = 0
C   ACCUMULATED AMOUNT BY LEVEL AND HOUR
      DO 190 LHOUR = 1,24
      PSDNT(L,LHOUR) = 0
      WATDF(L,LHOUR)=0
  190 WATLS(L,LHOUR) = 0
C   HOURLY TOTALS
      DO 191 LHOUR = 1,24
      PSHNT(LHOUR) = 0
  191 WSH  (LHOUR) = 0
C
C
C CALCULATE PRSKY
```

```
C
      ALP=0.0
      DO 195 L = 1,NLEV
      ALP = ALP + ALPHA(L)
      PRGND(L)=0.
  195 PRSKY(L) = 0
      XL = NLEV
      ALP = ALP/XL
      DO 199 L=1,NLEV
      BETA = - 0.0870
      DO 199 I = 1,9
      BETA = BETA + 0.174
       IF (ALP - BETA)  196, 196, 197
  196 S = COS(ALP)
      GO TO 193
  197 THETA=ACOS((1.0/TAN(ALP))*TAN(BETA))
      S=(2./PI*SIN(ALP)*COS(BETA)*SIN(THETA)+(1.0-THETA/90.0)*COS(ALP)
     1*SIN(BETA))/SIN(BETA)
  193 S=S*CLUST
      PRSKY(L)=PRSKY(L)+PSKYI(I)*EXP(-S*SF(L))
      PSKY(L)=PSKY(L)+PSKYI(I)*EXP(-S*F(L))
      PRGND(L)=PRGND(L)+PSKYI(I)*EXP(-S*SFUP(L))
      IF (PRSKY(L) .LT. 0.0) PRSKY(L)=0.0
      IF (PSKY(L) .LT. 0.0) PSKY(L)=0.0
      IF (PRGND(L) .LT. 0.0) PRGND(L)=0.0
  199 CONTINUE
C
C BEGIN HOURLY CALCULATIONS
C
      DO 60 LHOUR=1,24
C
      SDIRO=STOTO(LHOUR)-SDIFD(LHOUR)
      WLOSS=0.
      IF (LHOUR-1) 202,202,203
  202 DO 201 L=1,NLEV
  201 WATOF(L,1)=WDINIT
      GO TO 204
  203 DO 205 L=1,NLEV
  205 WATOF(L,LHOUR)=WATOF(L,LHOUR-1)
  204 DO 220 L=1,NLEV
      EDDIF(L,LHOUR)=EDDFD (LHOUR) * EXP(-XKDIF*SF(L))
      VEL(L,LHOUR) = WINDO(LHOUR) * EXP(-XKWND *SF(L))
      WIND(L)=VEL(L,LHOUR)
      HC(L) = CONST*SQRT(VEL(L,LHOUR)/WIDTH(L))
      RSAIR(L) = VHC/HC(L)
  220 CONTINUE
      IF (ZENITH(LHOUR)-90.0) 900,999,999
  999 DO 998 L=1,NLEV
      PRSUN(L,LHOUR)=0.0
      PRSHD(L,LHOUR)=1.0
      DO 997 LSUN=1,2
      SABS(L,LSUN)=0.0
  997 CONTINUE
  998 CONTINUE
```

```
      LONE=2
      GO TO 414
C
C
C     CALCULATE RADIATION PROFILE  ** NEW MODEL **
C
  900 CALL RADMOD(ZENIH(LHOUR),PSKY,PSUN,PRSUN,PRSHD,NLEV,HT,ALP,F,SF,
     2EXCOF(LHOUR),SDIRO,SDIFO(LHOUR),SDIR,SDIF,SREF,LHOUR)
      LONE=1
      DO 801 L=1,NLEV
      SABS(L,1)=0.5D*ABSOP(L)*(SDIR(L,LHOUR)+SDIF(L,LHOUR)+SREF(L,LHOUR)
     1)
      SABS(L,2)=0.5D*ABSOP(L)*(SDIF(L,LHOUR)+SREF(L,LHOUR))
  801 CONTINUE
C
C   DO FIVE MINUTE CALCULATIONS
C
  414 DO 61 MINUT=1,12
C
C   CALCULATE LEAF RESISTANCE AND LEAF WATER POTENTIAL
C
      DO 803 L = 1,NLEV
      DO 878 LSUN=1,2
      IF ( EVAPL(L,LSUN) .LT. 0.0 ) EVAPL(L,LSUN)=0.0
C   CALCULATE WATER DEFICIT
      WD(L,LSUN)=WATDF(L,LHOUR)+0.5*((EVAPL(L,LSUN)-WATUT(L))/LFDEN(L))*
     2100.0
      IF (WD(L,LSUN) .LT. WDMIN) WD(L,LSUN)=WDMIN
C   CALCULATE LEAF WATER POTENTIAL
  808 PSI(L,LSUN)=-0./8-0.46*WD(L,LSUN)+0.032*WD(L,LSUN)**2.
C   CALCULATE LEAF RESISTANCE
      C=(RCUT-RMIN)/((XPR-1.0)*WM**XPR)
      B=XPR*C*WM**(XPR-1.0)
      RLWAT(L,LSUN)=(RCUT-B*(SABS(L,LSUN)*WD(L,LSUN))+C*SABS(L,LSUN)*WD(
     2L,LSUN)**XPR)/(1.C+D*SABS(L,LSUN))
  878 CONTINUE
      WATDF(L,LHOUR)=PRSUN(L,LHOUR)*WD(L,1)+PRSHD(L,LHOUR)*WD(L,2)
      PLEAF= PRSUN(L,LHOUR)*PSI(L,1)+PRSHD(L,LHOUR)*PSI(L,2)
      PSOIL=SSAP
      RSOIL=RROOT
C   CALCULATE WATER UPTAKE RATE
      WATUT(L)=-(PLEAF-PSOIL)/(RROOT+RSOIL)
      IF (WATUT(L) .LT. 0.0) WATUT(L)=0.0
      RLWN=PRSUN(L,LHOUR)*RLWAT(L,1)+PRSHD(L,LHOUR)*RLWAT(L,2)
      RL(L)=RLWN
  803 CONTINUE
C
C
C CALCULATE LEAF TEMPERATURE PROFILE
C
  400 IF(MINUT .NE. 1) GO TO 417
      DO 415 I=1,NLEV
      TAIR(I,LHOUR)=TAG(LHOUR)
  415 CONTINUE
```

```
  417 CONTINUE
      TR(1,LHOUR) = TRSKY(LHOUR)
      DO 401 L=2,NLEV
  401 TR(L,LHOUR) = SIGEP * (TAIR(L,LHOUR) + 273.)**4
      TR(NLEV+1,LHOUR)= SIGEP*(TG(LHOUR)+273.)**4.*.6+.4*SIGEP*(TAIR(NLE
     1V,LHOUR)+273.)**4.
      CALL INFRA(PSKY,TR,TG(LHOUR),TRSKY(LHOUR),NLEV,TRDN,TRUP,LHOUR)
      DO 402 L=1,NLEV
      TRABS(L)=0.97*(TRDN(L,LHOUR)+TRUP(L,LHOUR))*0.5
  402 CONTINUE
      IF(MINUT .NE. 1) GO TO 416
      LRUN=0
      LRUN=LRUN+1
      GO TO (601,602),LONE
  601 IRNET1=TRSKY(LHOUR)*0.95-SIGEP*(TAD(LHOUR)+273.0)**4
      IRNET2=TRABS(1)-TR(1,LHOUR)
      SABSP(1)=((1.0-PRSUN(1,LHOUR))
                                   *SDIR(1,LHOUR)*ABSOP(1)+(1.0-PRSKY(1)
     *
     *)*SDIFO(LHOUR)*ABSOP(1)+(1.0-PRSKY(1)))*(IRNET1-IRNET2))/60.0
      DO 600 L=2,NLEV
      IRNET1=TRABS(L-1)-TR(L-1,LHOUR)
      IRNET2=TRABS(L)-TR(L,LHOUR)
      SABSP(L)=((PRSUN(L-1,LHOUR)-PRSUN(L,LHOUR))*SDIR(L,LHOUR)*ABSOP(L)
     *+(PRSKY(L-1)-PRSKY(L))*SDIFO(LHOUR)*ABSOP(L)+(PRSKY(L-1)-PRSKY(L))
     **(IRNET1-IRNET2))/60.0
  600 CONTINUE
      GO TO 605
  602 IRNET1=TRSKY(LHOUR)*0.95-SIGEP*(TAD(LHOUR)+273.0)**4
      IRNET2=TRABS(1)-TR(1,LHOUR)
      SABSP(1)=((1.0-PRSKY(1))*(IRNET1-IRNET2))/60.0
      DO 603 L=2,NLEV
      IRNET1=TRABS(L-1)-TR(L-1,LHOUR)
      IRNET2=TRABS(L)-TR(L,LHOUR)
      SABSP(L)=((PRSKY(L-1)-PRSKY(L))*(IRNET1-IRNET2))/60.0
  603 CONTINUE
  605 CONTINUE
C
C
C
       CALL WAR (NLEV,RL,WIDTH(3),WIND,HT,F,SABSP,TAD(LHOUR),HUMO(LHOUR),
      1TG(LHOUR),EDDFO(LHOUR),HUMP,TAIRP,EXCOF(LHOUR),EXTCD,RESGRD,LHOUR,
      2NSTND,NPRT)
C
C
C
C
C     STILL CONTINUING WITH LEAF TEMPERATURE CALCULATIONS
C
       DO 1007 L=1,NLEV
       TAIR(L,LHOUR)=TAIRP(L)
 1007  HUM(L,LHOUR)=HUMP(L)
  916  CONTINUE
       DO 499 I = 1,5
       CALL INFRA(PSKY,TR,TG(LHOUR),TRSKY(LHOUR),NLEV,TRDN,TRUP,LHOUR)
```

```
      DO 499 L = 1, NLEV
  410 LTAR=TAIR(L,LHOUR)*10.+50.
      TRABS(L) = 0.97*(TRDN(L,LHOUR) + TR(L+1,LHOUR))*0.5
      RADA = SIGEP * (TAIR(L,LHOUR) + 273.)**4
  407 DO 404 LSUN = 1,2
      IF (I-1) 405,405,406
  405 LTA = TAIR(L,LHOUR)*10. + 50.
      GO TO 418
  406 LTA=(0.5*(TAIR(L,LHOUR)+TL(L,LSUN)))*10.+50.
      IF(LTA .GT. 650) WRITE(NR,1983) LTA
 1983 FORMAT(2X,'LTA OUT OF RANGE',I5)
  418  CONTINUE
      RSL(L,LSUN) = RL(L) + RSAIR(L)
      XLRL = .0505/RSL(L,LSUN)
      TERM2 = XLRL * (VAPDN(LTAR)- HUM(L,LHOUR))
      ENABS(L,LSUN) = TRABS(L) + SABS(L,LSUN)
      XNUM =ENABS(L,LSUN) - RADA - TERM2
      DEN1 = 4. * SIGEP * (TAIR(L,LHOUR) + 273.)**3
      DEN2 = XLRL*(VAPDN(LTA+20)-VAPDN(LTA-20))/4.
      DENOM = DEN1 + HC(L) + DEN2
      TL(L,LSUN) = TAIR(L,LHOUR) + XNUM/DENOM
      TRLF(L,LSUN) = SIGEP * (TL(L,LSUN) + 273.)**4
      LTL = TL(L,LSUN)*10. + 50.
      IF(LTL .GT. 650) WRITE(NR,1984) LTL
 1984 FORMAT(2X,'LTL OUT OF RANGE',I5)
      EVAPL(L,LSUN) = (VAPDN(LTL) - HUM(L,LHOUR))/RSL(L,LSUN)
      TRNLF(L,LSUN) = 0.6585 * EVAPL(L,LSUN)
      CONLF(L,LSUN) = HC(L) * (TL(L,LSUN) - TAIR(L,LHOUR))
  404 CONTINUE
  499 TRIL,LHOUR)=PRSUN(L,LHOUR)*TRLF(L,1)+PRSHD(L,LHOUR)*TRLF(L,2)
C
C CALCULATE NET PHOTOSYNTHESIS BY LEAF AND LEVEL
C
 390  CONTINUE
      CONC=CONCL*1.997E-9
      DO 300 L=1,NLEV
      IF(ZENITH(LHOUR) .GT. 90.0) GO TO 306
      DO 301 LSUN=1,2
C   CALCULATE PHOTOSYNTHESIS LIMITED BY LIGHT
      PNETL(L,LSUN)=SABS(L,LSUN)/(AP(L)+SABS(L,LSUN)*BP(L))
C   CALCULATE PHOTOSYNTHESIS LIMITED BY CO2 DIFFUSION
      PHONT(L,LSUN)=((CONCA-CONC)/(1.5A*RL(L)+RSAIR(L)+RCELL))*60.0E+4
      IF(PNETL(L,LSUN) .LT. PHONT(L,LSUN)) PHONT(L,LSUN)=PNETL(L,LSUN)
C   CALCULATE TEMPERATURE EFFECT ON PHOTOSYNTHESIS
      PHSLP=PHOPTH/(TOPTH-POH)
      IF (TL(L,LSUN) .LT. TOPTH) PHSLP=PHOPTM/(TOPTM-POL)
      TPHOTO=1.0+(TL(L,LSUN)-TOPTM)*PHSLP/PHOPTH
      IF(TPHOTO .GT. 1.0) TPHOTO=1.0
      PHONT(L,LSUN)=PHONT(L,LSUN)*TPHOTO
C   EFFECT OF HERBICIDES ON PHOTOSYNTHESIS
      PHONT(L,LSUN)=PHONT(L,LSUN)*HERB
  301 CONTINUE
      GO TO 300
  306 DO 307 LSUN=1,2
```

```
C   DARK RESPIRATION AT NIGHT
       PHONT(L,LSUN)=-(RSPO(L)*Q10(L)**((TL(L,LSUN)-TO(L))*0.10))
  307 CONTINUE
  308 CONTINUE
C
C   CALCULATE WATER LOSS
C
        WLOSS        = (PRSUN(L,LHOUR)*EVAPL(L,1) + PRSHD(L,LHOUR)*
     1  EVAPL(L,2))* 5. *F(L)
C
      PSDNT(L,LHOUR) = (PRSUN(L,LHOUR)*PHONT(L,1) + PRSHD(L,LHOUR)*
     1  PHONT(L,2))*F(L)
      WATLS(L,LHOUR)=WLOSS+WATLS(L,LHOUR)
      WST  (L) = WST  (L) + WLOSS
      PSTNT(L) = PSTNT(L) + PSDNT(L,LHOUR) /12.
      WSH  (LHOUR) = WSH  (LHOUR) + WLOSS
      PSHNT(LHOUR) = PSHNT(LHOUR) + PSDNT(L,LHOUR) /12.
  300 CONTINUE
   61 CONTINUE
C
C   HOURLY OUTPUT
C
      WRITE (NW,514) LHOUR,PSOIL
  514 FORMAT (1X,//,6H HOUR= , I3,5X,'POTENTIAL OF SOIL = ',F5.1)
      WRITE(NW,552)
  552 FORMAT(1H0,15X,3HSUN,27X,5HSHADE/1X,33(1H-),1X,35(1H-))
      WRITE(NW,553)
  553 FORMAT(1H ,3X,2HTL,4X,4HSABS,3X,5HTRNLF,3X,2HCC,2X,4HWPOT,5X,2HTL,
     24X,4HSABS,3X,5HTRNLF,3X,2HCC,2X,4HWPOT,
     3   6X,5HWLOSS,3X,5HWATDF,2X,2HRL,2X,4HRAIR,2X,4HWIND,2X,5HEDDIF,2X
     4,5HPRSUN,3X,5HWATUP)
      WRITE(NW,511) ((TL(L,LSUN),SABS(L,LSUN),TRNLF(L,LSUN),CONCL,
     2  PSI(L,LSUN),LSUN=1,2),WATLS(L,LHOUR),WATDF(L,LHOUR),RL(L),RSAIR(
     3L),VEL(L,LHOUR),EDDIF(L,LHOUR),PRSUN(L,LHOUR),WATUT(L),L=1,NLEV)
  511 FORMAT(2(3F7.2,F6.1,F6.1,1X),4X,F5.2,   F8.1,1X,2F5.2,1X,F6.1,F7.1
     2,1X,F5.2,1X,F10.3)
      WRITE(NW,1005) LRUN
 1005 FORMAT(/' REQUIRED',I5,' ITERATIONS')
      WRITE(NW,1009) (RL(IND),IND=1,NLEV), (WIND(IND),IND=1,NLEV),
     1(SABSP(IND),IND=1,NLEV),TAO(LHOUR),HUMO(LHOUR),TG(LHOUR)
 1009 FORMAT(' LEAF RESISTANCE',T18,8E12.3/' WIND',T18,8E12.3/' NET RADI
     1ATION',T18,8E12.3/'   TAO',E12.3,'   HUMO',E12.3,'   TG',E12.3)
      WRITE(NW,1008) (HUMP(I),I=1,NLEV),(TAIRP(I),I=1,NLEV)
 1008 FORMAT(' HUMIDITY PROFILE',T19,8E12.3/' TEMP PROFILE',T19,8E12.3)
C
C   SETUP INPUT TO GRAPHS
C
C         GRAPH ONE
      G1(1,LHOUR)=(PSHNT(LHOUR)/0.0681)/TLAI
      G1(2,LHOUR)=PSHNT(LHOUR)
      G1(3,LHOUR)=PSI(1,1)
      G1(4,LHOUR)=RL(1)
      G1(5,LHOUR)=PSOIL
C         GRAPH TWO
```

```
      G2(1,LHOUR)=TAIR(1,LHOUR)
      G2(2,LHOUR)=TL(1,1)
      G2(3,LHOUR)=TG(LHOUR)
      G2(4,LHOUR)=WINDO(LHOUR)
      G2(5,LHOUR)=STOTO(LHOUR)
C        GRAPH THREE
      G3(1,LHOUR)=TL(1,1)
      G3(2,LHOUR)=RL(1)
      G3(3,LHOUR)=WSH(LHOUR)/TLAI
      G3(4,LHOUR)=STOTO(LHOUR)
      G3(5,LHOUR)=WINDC(LHOUR)
      TSUN(LHOUR)=TL(1,1)
      TSHADE(LHOUR)=TL(1,2)
C
   60 CONTINUE
C
C TOTALS
C
      DO 302 L=1,NLEV
      TOTPN = TOTPN + PSTNT(L)
  302 TOTR  = TOTR  + WST  (L)
C
C   PRINT SUMMARY TABLES
C
      WRITE (NW,515)
  515 FORMAT (1H1, 19HSTAND SUMMARY      )
      WRITE (NW,516)
  516 FORMAT (//,1X, 33HTRANSPIRATION IN 10E-4 GM/CM2,HR        ,/)
      WRITE(NW,524)(LHOUR,(WATLS(L,LHOUR),L=1,10  ),WSH(LHOUR),LHOUR=1,2
     14)
      WRITE (NW,513) (WST(L),L=1,10  ), TOTR
      WRITE (NW,515)
      WRITE (NW,519)
  519 FORMAT (//,1X,40HNET PHOTOSYNTHESIS IN GM D.M./CM2,HR        ,/)
      WRITE(NW,524) (LHOUR,(PSDNT(L,LHOUR),L=1,10),PSHNT(LHOUR),LHOUR=1,
     224)
      WRITE (NW,513) (PSTNT(L),L=1,10  ), TOTPN
  524 FORMAT(1X,I4,11F9.3)
  513 FORMAT(' ',5X,11F9.3)
  531 FORMAT (1X,I4, 8F15.3)
      DO 2637 LHOUR=1,24
      DO 2637 L=1,NLEV
      PSDNT(L,LHOUR)=(PSDNT(L,LHOUR)/0.0681)/F(L)
 2637 CONTINUE
      WRITE(NW,515)
      WRITE(NW,518)
  518 FORMAT(//1X,*NET PHOTOSYNTHESIS IN MG/DM2/HOUR*/)
      WRITE(NW,517) (LHOUR,(PSDNT(L,LHOUR),L=1,10),LHOUR=1,24)
  517 FORMAT(1X,I4,10F9.3)
      WRITE(NW,570)
  570 FORMAT(1H1)
      WRITE(NW,571) (G1(3,L),L=1,12)
  571 FORMAT(///,1X,10HPS1 LEAF  ,12F7.1)
      WRITE(NW,572) (G1(5,L),L=1,12)
```

```
  572 FORMAT(1X,10HPSI SOIL  ,12F7.1)
      WRITE(NW,573) (TSUN(L),L=1,12)
  573 FORMAT(1X, 10HSUN LEAF  ,12F7.1)
      WRITE(NW,574) (TSHADE(L),L=1,12)
  574 FORMAT(1X,10HSHADE LEAF,12F7.1)
      WRITE(NW,575) (G1(1,L),L=1,12)
  575 FORMAT(1X,10HPHOTO RATE,12F7.2)
      WRITE(NW,571) (G1(3,L),L=13,24)
      WRITE(NW,572) (G1(5,L),L=13,24)
      WRITE(NW,573) (TSUN(L),L=13,24)
      WRITE(NW,574) (TSHADE(L),L=13,24)
      WRITE(NW,575) (G1(1,L),L=13,24)
      WRITE(NW,576) NSTND
  576 FORMAT(///,1X,9HCLIMATE..,10A2)
      WRITE(NW,577) TLAI
  577 FORMAT(1X,10HTOTAL LAI ,F5.3)
      WRITE(NW,578) SALNTY
  578 FORMAT(1X,14HSOIL SALINITY ,F4.0,19H PARTS PER THOUSAND )
      WRITE(NW,579) HERB
  579 FORMAT(1X,36HEFFECT OF HERBICIDE ON PHOTOSYNTHESIS ,F3.1)
C
C        PRODUCE GRAPH ONE
      CALL GRAPH(61,NUMBER(1),PLOT1,SCAL1,XMIN1)
C        PRODUCE GRAPH TWO
      CALL GRAPH(62,NUMBER(2),PLOT2,SCAL2,XMIN2)
C        PRODUCE GRAPH THREE
      CALL GRAPH(63,NUMBER(3),PLOT3,SCAL3,XMIN3)
C
      GO TO 9000
C
   99 CALL EXIT
      END
```

Total transpiration $\times 10^{-4}$ g m^{-2} day^{-1}

	12	20	30
Feb ave	285.	212.	209.
Feb sunny	324	332	302
May ave	146	151	151
May sunny	319	328	303

Pnet g O.M. m^{-2} day^{-1}

	12		20		30	
Feb ave.	0.706	1.086	0.713	1.091	0.710	1.088
Feb sunny	0.232	-	0.241	-	0.213	-
May ave.	0.542	1.065	0.546	1.070	0.549	1.071
May sunny	0.098	0.679	0.107	0.685	0.081	0.684

lowest leaf water potential (bars)

	12	20	30
Feb ave.	-16.5	-22.8	-29.2
Feb sunny	-23.8	-28.1	-31.7
May ave.	-13.9	-20.2	-27.5
May sunny	-22.4	-27.4	-31.6

hottest leaf temperature °C

	12	20	30
Feb. ave	31.7	31.6	31.9
Feb. sunny	35.1	35.6	36.8
May ave	33.3	33.2	33.3
May sunny	38.4	38.5	39.5

Salinity = 30‰

low photopm

		FEB ~~MAY~~	AVE		FEB ~~MAY~~	SUNNY		
HOUR	RL	ψ	TL	φ	RL	ψ	TL	φ
1	.50	22.6	21.6	-1.2	.50	22.7	22.4	-1.3
2	.50	22.6	21.6	-1.2	.50	22.7	21.6	-1.2
3	.50	22.6	21.6	-1.2	.50	22.7	20.8	-1.2
4	.50	22.6	21.6	-1.2	.50	22.7	20.0	-1.1
5	.50	22.6	22.4	-1.3	.50	22.7	19.2	-1.1
6	.50	22.6	23.3	-1.4	.50	22.7	20.0	-1.1
7	.33	23.	25.1	3.3	.33	22.7	21.8	3.1
8	.16	24.5	28.0	4.9	.13	24.3	27.3	5.0
9	.10	26.9	30.3	3.8	.08	28.9	32.0	3.2
10	.09	27.6	30.6	3.5	.08	30.4	34.1	2.0
11	.08	28.2	30.9	3.3	.09	31.2	35.6	1.2
12	.08	29.2	31.9	2.7	.09	31.7	36.8	0.6
13	.08	28.5	31.3	3.1	.09	31.1	35.7	1.1
14	.09	27.9	31.0	3.1	.09	30.8	35.2	1.3
15	.10	26.7	30.0	3.8	.09	30.0	34.2	1.9
16	.11	26.1	29.6	4.0	.09	28.7	33.0	2.6
17	.16	24.8	28.7	4.5	.13	26.1	31.3	3.4
18	.50	22.9	25.1	-1.6	.50	23.1	27.6	-1.8
19	.50	22.9	25.0	-1.5	.50	23.0	27.0	-1.8
20	.50	22.8	24.0	-1.4	.50	23.0	26.5	-1.6
21	.50	22.7	23.2	-1.4	.50	22.9	25.6	-1.5
22	.50	22.6	22.4	-1.3	.50	22.9	24.8	-1.5
23	.50	22.6	21.6	-1.2	.50	22.8	24.0	-1.4
24	.50	22.6	21.6	-1.2	.50	22.7	23.2	-1.4

Salinity is 30‰
low phytpm

	MAY AVE				MAY SUNNY			
HOUR	RL	ψ	TK	φ	RL	ψ	TL	φ
1	.50	22.6	25.1	-1.6	.50	22.6	24.7	-1.5
2	.50	22.6	25.1	-1.6	.50	22.6	24.3	-1.5
3	.50	22.6	25.1	-1.6	.50	22.6	23.9	-1.5
4	.50	22.6	25.1	-1.6	.50	22.6	23.5	-1.4
5	.50	22.6	25.1	-1.6	.50	22.6	23.5	-1.4
6	.50	22.6	25.2	0.1	.40	22.6	24.9	3.0
7	.25	23.0	27.8	4.4	.17	23.9	29.8	4.0
8	.13	24.6	30.6	3.6	.10	27.4	33.9	2.0
9	.10	26.3	32.3	2.6	.09	30.9	37.3	0.2
10	.09	27.5	33.3	2.1	.10	31.6	38.9	-.6
11	.10	26.6	32.7	2.4	.10	31.5	39.5	-1.0
12	.10	26.6	32.5	2.4	.10	30.2	37.3	0.
13	.11	25.8	32.0	2.6	.09	28.6	35.2	.9
14	.11	25.8	32.1	2.6	.10	27.2	34.1	1.5
15	.13	25.2	31.7	2.8	.11	26.4	33.3	1.9
16	.16	24.6	31.3	3.0	.11	25.7	32.4	2.3
17	.22	23.8	30.5	3.3	.13	24.9	31.6	2.8
18	.29	23.2	29.0	3.7	.16	24.3	30.9	3.1
19	.50	22.7	26.8	-1.8	.50	22.9	27.2	-1.8
20	.50	22.6	25.9	-1.7	.50	22.6	26.6	-1.8
21	.50	22.6	25.9	-1.7	.50	22.6	26.2	-1.7
22	.50	22.6	25.9	-1.7	.50	22.6	25.9	-1.7
23	.50	22.6	25.8	-1.7	.50	22.6	25.5	-1.6
24	.50	22.6	25.1	-1.6	.50	22.6	25.1	-1.6

Table 4.

Mud surface and propogule temperature under open sky during the three test days. ~~An assumption is~~ that the mud surface and the propogule lying flat on the mud are at the same temperature.

Hour	Feb. sunny	May ave.	May sunny	Hour	Feb sunny	May ave.	May sunny
1	23.3	26.2	25.8	13	34.5	31.5	35.0
2	22.4	26.0	25.3	14	34.0	31.5	33.9
3	21.5	26.0	24.8	15	33.2	31.2	32.9
4	20.6	25.9	24.3	16	32.2	30.9	32.0
5	19.8	25.9	24.3	17	30.9	30.4	30.8
6	20.4	25.9	25.1	18	29.1	29.3	30.4
7	21.4	27.3	28.3	19	28.2	28.3	29.0
8	25.1	29.1	31.9	20	27.8	27.2	28.1
9	29.3	30.6	35.0	21	26.9	27.0	27.6
10	31.7	31.9	37.0	22	26.1	27.0	27.2
11	33.6	31.7	38.2	23	25.2	26.9	26.7
12	34.9	31.8	36.7	24	24.4	26.1	26.2

SYSTEMS, SCIENCE AND SOFTWARE

PROGRAMMER ______ EXT. ______ BOX NO. ______

DATE ______ COMPANY ______

SPECIAL INSTRUCTIONS:

w/ LAI = 0., 1.5

HR	FEB sunny 0.0	FEB sunny 1.5	MAY SUNNY 0.0	MAY SUNNY 1.5
1	23.28	24.20	25.24	26.94
2	22.38	23.60	25.27	26.59
3	21.51	22.97	24.80	26.23
4	20.64	22.30	24.34	25.88
5	19.75	21.62	24.25	25.78
6	20.36	22.00	25.10	26.31
7	21.44	22.67	28.32	28.42
8	25.09	25.13	31.93	30.79
9	29.30	27.95	35.03	32.84
10	31.69	29.63	36.98	34.27
11	33.62	31.09	38.21	35.32
12	34.94	32.12	36.70	34.49

HR	FEB sunny 0.0	FEB sunny 1.5	MAY SUNNY 0.0	MAY SUNNY 1.5
13	34.47	31.97	34.98	33.50
14	34.03	31.83	33.88	32.88
15	33.23	31.44	32.93	32.30
16	32.23	30.89	31.97	31.67
17	30.85	30.11	30.84	30.[illegible]
18	29.10	29.07	30.39	30.68
19	28.24	28.53	28.98	29.80
20	27.75	28.18	28.14	29.23
21	26.93	27.58	27.63	28.84
22	26.08	26.96	27.16	28.46
23	25.22	26.33	26.70	28.09
24	24.36	25.67	26.24	27.71

MAY AVE

HR	0.	1.5	HR	0.	1.5
1	26.2	27.2	13	31.5	30.9
2	26.0	27.1	14	31.5	31.0
3	26.0	27.1	15	31.2	30.8
4	25.9	27.0	16	30.9	30.7
5	25.9	27.0	17	30.4	30.4
6	25.9	27.0	18	29.3	29.8
7	27.3	27.8	19	28.3	29.1
8	29.1	28.0	20	27.2	28.3
9	30.6	30.0	21	27.0	28.2
10	31.9	30.9	22	27.0	28.1
11	31.7	30.8	23	26.9	28.0
12	31.8	31.0	24	26.1	27.5

SYSTEMS, SCIENCE AND SOFTWARE

PROGRAMMER ______ EXT. ______ BOX NO. ______

DATE ______ COMPANY ______

FEB AVE.

NOTES:

GENERAL PURPOSE FORM

FIELD IDENTIFICATION

HR	.15 0.0	.15 1.5	.20 0.0	.20 1.5	.30 0.0	.30 1.5	HR	.15 0.0	.15 1.5	.20 0.0	.20 1.5	.30 0.0	.30 1.5
1	22.5	23.7		23.7			13	30.5			29.3		
2	22.3	23.6		23.6			14	30.3			29.2		
3	22.2	23.5		23.5			15	29.2			28.6		
4	22.2	23.4		23.4			16	28.7			28.4		
5	22.9	23.9		23.9			17	28.2			28.1		
6	23.7	24.4		24.4			18	26.4			27.0		
7	24.8	25.2		25.2			19	25.7			26.6		
8	26.7	26.4		26.4			20	25.1			26.0		
9	28.6	21.7		27.7			21	24.3			25.4		
10	29.1	28.1		28.1			22	23.4			24.8		
11	29.6	28.5		28.5			23	22.5			24.1		
12	30.7	29.3		29.3			24	22.4			23.9		

BEGIN .150 (-16.0) .200 (-9.3) .300 (-9.8)

END .150 .150 .199 .198 .277

(721.9) (723) (319.1)

FEB AVE