United States
Department of
Agriculture

Forest
Service

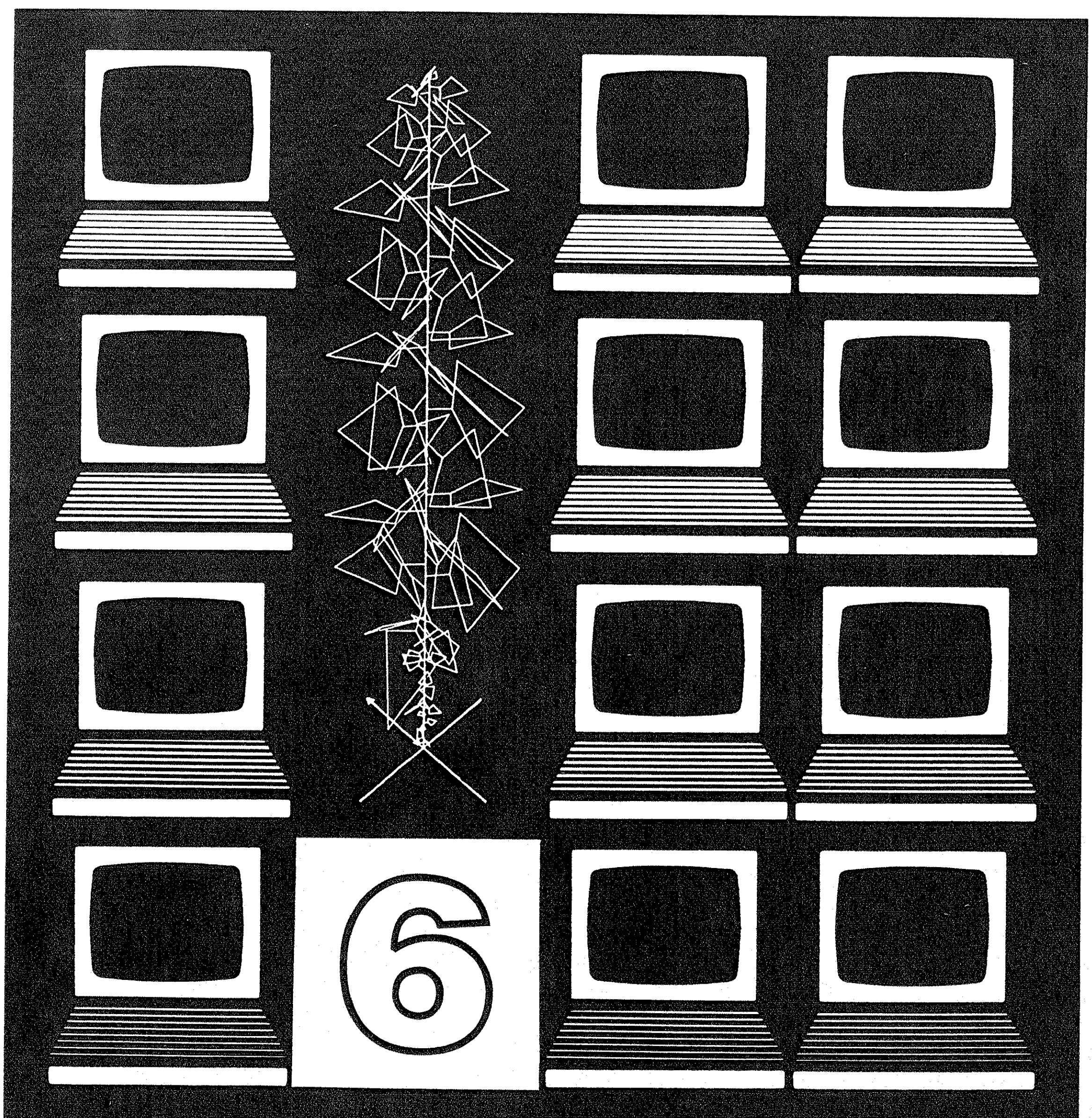
North Central
Forest Experiment
Station

General Technical
Report NC-141

The Microcomputer Scientific Software Series 6

The ECOPHYS User's Manual

George E. Host, H. Michael Rauscher, J.G. Isebrands, Donald I. Dickmann,
Richard E. Dickson, Thomas R. Crow, and D.A. Michael



ACKNOWLEDGMENT

This research was performed as part of an interagency agreement with the U.S. Department of Energy — Contract # DE-A105-800R20763.

North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
Manuscript approved for publication September 11, 1990
1990

ECOPHYS QUICK INSTALLATION

ECOPHYS may be installed by using an INSTALL program included on the disks, or by manually copying and expanding the compressed data files. These two installation methods are described below. Words in **boldface** are to be typed by the user. Words in brackets represent keys on the computer keyboard. For example, <Enter> indicates that the user should press the ENTER key (also called the RETURN key).

1. The INSTALL program

An INSTALL program is included with ECOPHYS to properly install all of the program and data files on a hard disk. This program will create a directory called ECOPHYS and copy all files in their proper format. The following instructions explain how to install ECOPHYS using the INSTALL program.

To install ECOPHYS:

(1) Insert Disk 1 into drive A
(2) Type **A:** <Enter> to make drive A the default drive
(3) Type **INSTALL** x: <Enter>

where x: is the drive designation for the hard disk. For example, if the hard disk is drive C, type:

INSTALL C: <Enter>

(4) The program will prompt you to insert the remaining disks at the appropriate times, and will indicate when the installation procedure has been completed.

2. Manual Installation

Many of the ECOPHYS data files are stored in a special compressed format using PKXARC, a public-domain file archiving utility. As a result, simply copying all files to the hard disk will result in a "FILE NOT FOUND" error when the program is run. To install ECOPHYS manually, copy all files on all three disks to the hard disk, and enter the following two commands:

PKXARC /e clonlib *.* <Enter>
PKXARC /e weather *.* <Enter>

This will extract the clonal library and weather data files from their respective file archives.

TABLE OF CONTENTS

The Microcomputer Scientific Software Series #6: The ECOPHYS User's Manual

George E. Host, H. Michael Rauscher, J. G. Isebrands, Donald I. Dickmann, Richard E. Dickson, Thomas R. Crow, and D. A. Michael

1. Introduction

The ECOPHYS User's Manual provides documentation on the structure and use of the ECOPHYS model. The manual is divided into five sections. The first section presents a brief overview of the model and describes the installation procedures. The second section describes how to run a simulation. The third section shows how to use the various editors to modify model inputs (*e.g.*, light, temperature, clonal parameters). The fourth section discusses the clonal library system and the structures of the various input files. The final section discusses applications and future plans for the model.

1.1 Model Overview

ECOPHYS is an explanatory ecophysiological whole-tree process model that simulates the growth of *Populus* during the establishment year. The model was developed as part of the North Central Forest Experiment Station's research program on Intensively Cultured Plantations for Fiber and Energy Production, funded cooperatively through the Department of Energy. A primary purpose of the ECOPHYS model is to identify physiologically based factors that influence the growth of *Populus*. Knowing how these factors affect poplar growth allows the identification of genetic selection criteria, which may be used for the selection and breeding of poplar clones. The model may also be used to evaluate and screen the growth potential of a large number of clones for intensive culture. ECOPHYS may be used to simulate the growth of poplars under varying environmental conditions, such as different light or temperature regimes—simulations that would be difficult or impossible to conduct as field experiments. Finally, the model may be used to illustrate basic concepts of plant physiology, such as the importance of light interception to photosynthate production, or the transport of photosynthates from source leaves to various growth centers within the plant.

ECOPHYS is based on experimental field studies of the morphology, physiology, and growth of *Populus euramericana* cv. 'Eugenei' (*Populus deltoides* Bartr. ex Marsh x *Populus nigra* L.) at the USDA Forest Service Forestry Sciences Laboratory in Rhinelander, Wisconsin, USA. The model simulates the growth of poplar cuttings grown in short-rotation intensive culture (SRIC) plantations, where moisture and nutrients are maintained at optimal levels. The simulation begins as an "initial tree" early in the growing season and ends at the bud set date. Morphology of the initial tree may be varied to simulate different leaf shapes, orientation patterns, and other variables. The tree is modeled as a single main stem; in *P. eugenei* branches generally are absent in the establishment year, although this may vary by climate and clone.

George E. Host, Research Associate, Natural Resources Research Institute, University of Minnesota, Duluth, MN; **H. Michael Rauscher**, Research Forester, North Central Forest Experiment Station, Grand Rapids, MN; **J. G. Isebrands**, Project Leader, North Central Forest Experiment Station, Rhinelander, WI; **Donald I. Dickmann**, Professor, Department of Forestry, Michigan State University, East Lansing, MI; **Richard E. Dickson**, Research Plant Physiologist, **Thomas R. Crow**, Project Leader, North Central Forest Experiment Station, Rhinelander, WI; and **D. A. Michael**, Software Innovations, Battle Creek, MI.

The principal biological unit of the model is the individual leaf: solar radiation received by the leaf is converted to photosynthate by a leaf-specific photosynthate production function, and photosynthates are transported to other locations within the plant based on leaf-specific transport coefficients. The primary time step of the model is the hour. The quantities of direct and diffuse solar radiation (expressed as photosynthetically active photon flux density or PPFD) received by a leaf during each hour are calculated based on solar altitude and azimuth and the leaf shading patterns for that hour. Leaf shading patterns are determined geometrically by projecting each leaf in a three-dimensional coordinate system and determining the area of each leaf shaded by other leaves. Dimensional growth and biomass production are calculated based on the quantity of photosynthate available for growth at each growth center after respiratory losses are subtracted. There are no limits to maximum or minimum growth specified by the model; all growth is strictly a function of photosynthate production and distribution.

A unique feature of ECOPHYS is the means by which photosynthates are transported throughout the plant. Each leaf on the plant has a unique carbon distribution or transport pattern, based on leaf plastochron index (Larson and Isebrands 1971). The photosynthate transport coefficients used by ECOPHYS were determined by ^{14}C tracer studies in controlled environments and in the field (Dickson 1986, Isebrands and Nelson 1983, Larson 1977). Photosynthate may be transported upward to other leaves or stem internodes, or downward to stem internodes, the cutting, and the roots. Newly emerged leaves (*i.e.*, LPI's 1-4) retain all of their photosynthate, leaves in the expanding leaf zone (*i.e.*, LPI's 5-9) transport most of their photosynthate upward to leaves and stem internodes, and mature leaves transport most of their photosynthate downward to stem internodes, cutting, and roots (table 1). Each destination (or sink) leaf or internode above a source leaf has its own transport coefficient, as shown in tables 2 and 3. The coefficients in table 2 illustrate the effect of the 2/5 phyllotaxy that is characteristic of *P. eugenei*. For example, source LPI's 5, 6, and 7 send relatively large amounts of photosynthate to LPI's 2, 3, and 4, respectively. Few, if any, whole-plant growth process models have incorporated such specific photosynthate transport coefficients.

Carbon allocation patterns vary among clones, within a clone over the course of a growing season, and as a response to various forms of environmental stress (Bazzaz *et al.* 1987, Chapin *et al.* 1987). For this reason we have included an option in ECOPHYS that allows editing of the transport coefficient matrices. With this option, the carbon allocation patterns of a clone may be altered, and new transport coefficient matrices for different clones may be created. Future versions of ECOPHYS will allow photosynthate transport coefficients to change over the course of the growing season, or as a response to stress. Allowing manipulation of the transport coefficients increases the applicability of the model, and allows the existing model to be extended to other portions of the growing season.

Although ECOPHYS incorporates much detail in modelling the early growth of poplar, the mathematical structures that drive the model are relatively simple; moreover, these structures have a biological basis, so that the model simulates growth *processes* rather than growth *relationships*. A complete description of the concepts and development of ECOPHYS can be found in Isebrands *et al.* (In press) and Rauscher *et al.* (In prep.).

1.2 Program Overview

ECOPHYS consists of three primary modules, which control the actual simulation; and several supporting modules, which allow physiological, environmental, and simulation parameters to be modified. The modules are linked together through the MAIN MENU, as shown in figure 1. In a typical run the user chooses the desired clonal and environmental conditions, specifies the starting date and ending dates for the simulation, and selects the screen and printer reports to be generated during the run. Once all initial conditions are specified, the user selects RUN SIMULATION from the MAIN MENU and program control is passed to the SIMULATE module. SIMULATE keeps track of the hours and days and passes control to the HOURSTEP or GROW modules, as appropriate (fig. 1). When the ending date is reached, summary reports are printed or written to disk files, and program control is passed back to the MAIN MENU. At this point, a graphic representation of the tree may be viewed on the screen or sent to a plotter for output (fig. 2).

Table 1.—*Summary of photosynthate transport coefficients*[1]

Destinations	Source LPI																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19-50
Upward to:																			
Leaves	0	0	0	0	0.73	0.67	0.54	0.47	0.36	0.27	0.17	0.12	0.13	0.1	0.1	0.06	0.03	0.02	0
Internodes	0	0	0	0	.25	.27	.28	.29	.22	.22	.22	.16	.1	.1	.05	.02	.02	.01	0
Downward to:																			
Internodes	0	0	0	0	.02	.03	.09	.11	.26	.33	.4	.4	.4	.4	.4	.4	.4	.4	.4
Cutting	0	0	0	0	0	.01	.02	.03	.04	.05	.07	.08	.09	.1	.11	.11	.11	.12	.15
Roots	0	0	0	0	0	.02	007	.1	.12	.13	.14	.24	.28	.3	.34	.41	.44	.45	.45
Total	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

[1]Values represent fraction of exported photosynthates transported to plant growth centers (leaves, internodes, cuttings, and roots).

Table 2.—*Transport coefficients for photosynthates transported into leaves above the source leaf*[1]

Destination LPI	Source LPI																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
0	0	0	0	0	0.25	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.03	0.01	0.01
1	0	0	0	0	0	.24	.02	.03	.1	.06	.01	.04	.01	.01	.03	.02	.01	.01
2	0	0	0	0	.29	.01	.24	.04	.1	.01	.05	.01	.05	.01	.02	.01	.01	0
3	0	0	0	0	.18	.28	.01	.21	.03	.04	.01	.02	.01	.03	0	0	0	0
4	0	0	0	0	.01	.08	.18	.01	.06	.03	.01	0	.01	0	0	0	0	0
5	0	0	0	0	0	0	.03	.12	0	.06	.01	0	0	0	0	0	0	0
6	0	0	0	0	0	0	.01	.01	.01	0	.03	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	.01	.01	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	.01	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0.73	0.67	0.54	0.47	0.36	0.27	0.17	0.12	0.13	0.1	0.1	0.06	0.03	0.02

[1] Values represent fraction of exported photosynthates.

Table 3.—*Transport coefficients for photosynthates transported into stem internodes above the source leaf*[1]

Destination internode	Source LPI																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
0	0	0	0	0	0.01	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.007	0.006	0.003	0.001	0.001	0.0005
1	0	0	0	0	.01	.02	.02	.02	.02	.02	.01	.01	.007	.006	.003	.001	.001	.0005
2	0	0	0	0	.01	.02	.02	.02	.02	.02	.01	.01	.007	.006	.003	.001	.001	.0005
3	0	0	0	0	.03	.03	.02	.03	.02	.02	.01	.01	.007	.006	.003	.001	.001	.0005
4	0	0	0	0	.05	.03	.03	.02	.02	.02	.01	.01	.007	.006	.003	.001	.001	.0005
5	0	0	0	0	.14	.04	.03	.05	.02	.02	.01	.01	.007	.006	.003	.001	.001	.0005
6	0	0	0	0	0	.1	.07	.03	.02	.02	.01	.01	.007	.006	.003	.001	.001	.0005
7	0	0	0	0	0	.1	.07	.03	.01	.02	.01	.01	.007	.006	.003	.001	.001	.0005
8	0	0	0	0	0	0	0	.06	.04	.02	.01	.01	.007	.006	.003	.001	.001	.0005
9	0	0	0	0	0	0	0	0	.03	.02	.01	.01	.007	.006	.003	.001	.001	.0005
10	0	0	0	0	0	0	0	0	0	.02	.01	.01	.007	.006	.003	.001	.001	.0005
11	0	0	0	0	0	0	0	0	0	0	.01	.01	.007	.006	.003	.001	.001	.0005
12	0	0	0	0	0	0	0	0	0	0	0	.01	.007	.006	.003	.001	.001	.0005
13	0	0	0	0	0	0	0	0	0	0	0	0	.007	.006	.003	.001	.001	.0005
14	0	0	0	0	0	0	0	0	0	0	0	0	0	.006	.003	.001	.001	.0005
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	.003	.001	.001	.0005
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	.001	.001	.0005
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	.001	.0005
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	.0005
Total	0	0	0	0	0.25	0.27	0.28	0.29	0.22	0.22	0.22	0.16	0.1	0.1	0.05	0.02	0.02	0.01

[1]Values represent fraction of exported photosynthates.

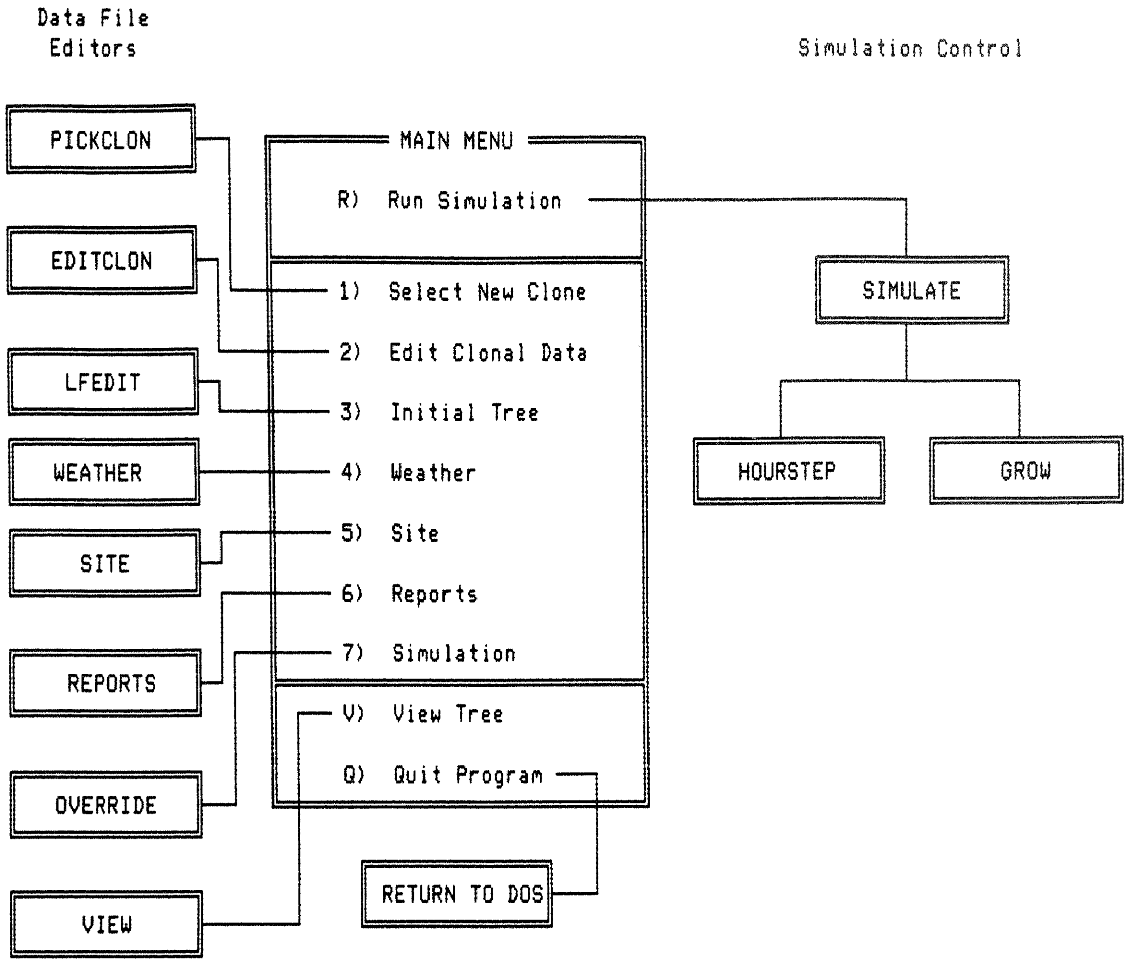


Figure 1.—*General ECOPHYS program structure, showing files called during editing and simulation.*

1.3 System Configuration and Hardware Requirements

ECOPHYS has been written and compiled using Microsoft QuickBASIC Versions 2-4 and runs under MS-DOS on IBM and IBM-compatible microcomputers. The program requires a Color Graphics Adapter (CGA) or Enhanced Graphics Adapter (EGA) card, but will run on both color and monochrome monitors. A hard disk or 1.2 MB floppy disk is required to store the program and associated data files; it is recommended that the ECOPHYS files be stored in a separate subdirectory. An Epson-compatible printer is required for generating printer reports. A Hewlett-Packard plotter (7475 series or compatible system) is needed to plot the graphic display of the tree. The program sends information to the plotter using serial port 1 (COM1:) at a 2400 baud rate.

The model is calculation-intensive; mutual leaf shading patterns and photosynthate production are calculated for each leaf each sunlit hour of the day. Execution time will be greatly reduced if the program is installed on a machine with a high-speed CPU, such as an 80286 or higher. Typical execution times for a seasonal run on an 80286-based computer range from 3 to 5 hours, depending on clock speed. Math coprocessors (8087, 80287, or 80387 chips) will be used if available. The program will automatically use software routines to emulate a math coprocessor if one is not present, but this reduces program execution speed. You can override software emulation and speed up the program by typing NO87 <Enter> at the DOS prompt before running the program.

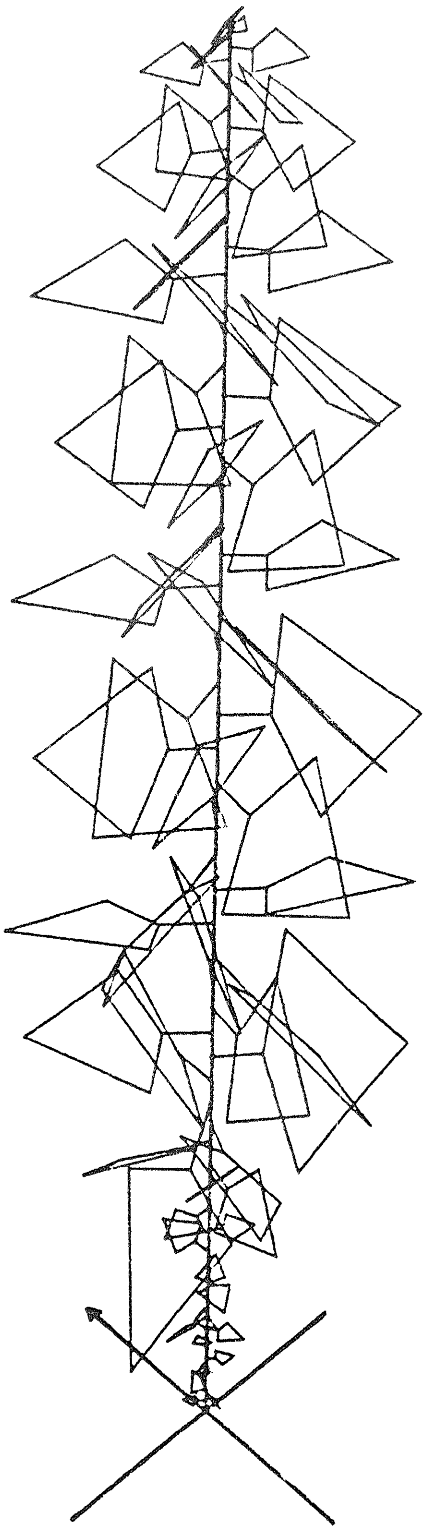


Figure 2.—*Plotter output for* P. eugenei *at the end of the simulation (Julian Day 256).*

1.4 Installation

ECOPHYS files must be installed on a hard disk or 1.2 Mb floppy disk; the files require approximately 1.0 Mb of disk space. The INSTALL.BAT file provided on Disk 1 creates a directory named /ECOPHYS and copies the required files to this directory. To execute this batch file, put Disk 1 in Drive A: and type INSTALL x: <Enter>, where x: is the drive designation for the hard disk. You will be prompted to insert the remaining diskettes at the appropriate times. Do not simply copy all files to your hard disk because several required files are stored in a special compressed format and must be restored.

Table 4 lists and describes all files included on the ECOPHYS disks.

2. Using the Model

The program is started by typing ECOPHYS <Enter> at the DOS prompt. The ECOPHYS batch file installs a screen management program, displays the opening screen, and transfers the user to the SELECT CLONE menu. The MAIN MENU is displayed after a clone has been selected. The MAIN MENU allows the user to edit various model parameters, select reports for screen or printer output, specify the starting and

```
ECOPHYS MAIN MENU

R)   RUN Simulation

1)   Select New Clone
2)   Edit Clonal Data
3)   Initial Tree
4)   Weather
5)   Site
6)   Reports
7)   Simulation

V)   VIEW Tree

Q)   QUIT Program
```

Figure 3.—*The MAIN MENU controls the selection of clones, the editing of clonal library files, and the management and execution of the simulation.*

Table 4.—*Program, data, and supporting files distributed with the ECOPHYS model*

Disk 1 - Executable and batch files

ECOPHYS	BAT	starts the program
INSTALL	BAT	installs ECOPHYS on the hard disk
ECOINST	BAT	supports install routine
KILL	BAT	clears memory resident program
NO87	BAT	turns off 80287 emulation, speeds up program
BRUN40	EXE	supporting routines for the BASIC compiler
CLONLIB	EXE	clonal library management
CUTTING	EXE	editor for cutting/root data
ECOMENU	EXE	Main Menu
EDITCLON	EXE	editors for clonal library data
GROW	EXE	distribute PSYN and grow tree
HOURSTEP	EXE	hourly light interception/PSYN production
LFEDIT	EXE	editor for initial tree matrix
OVERRIDE	EXE	reads data from previous run
PICKCLON	EXE	selects clone screen
PLOTTER	EXE	plots tree on screen

Disk 2 - Executable files, continued

HPPLOT	EXE	HP plotter driver
PSEDIT	EXE	editor for PSYN allocation coefficients
PTRANSED	EXE	editor for PSYN export coefficients
REPORTS	EXE	selects printer and screen reports
SIMULATE	EXE	controls program flow
SITE	EXE	edits site data
STEMDATA	EXE	edits cutting/root data
SUMMARY	EXE	produces summary reports
TCEDIT	EXE	edits photosynthate transport coefficients
TITLSCR	EXE	displays the opening screen
TREEVIEW	EXE	displays tree at end of run
VIEW	EXE	controls tree display
WEATHER	EXE	edits weather data

Table 4., continued

Disk 3 - Utilities, screen library, and data files

OVERRIDE	DAT	data from the previous run
REPORTS	DAT	desired run time reports
SUMMARY	DAT	desired summary reports
SITE	EL	site data for East Lansing MI
SITE	EHI	site data for Rhinelander WI
SITE	WAS	site data for Puyallup WA
PKXARC	COM	extraction utility for weather data
VIDPOP	COM	memory-resident screen manager
ECOPHYS	LIB	screen library
WEATHER	ARC	archive of weather data files

This archive contains the following files:

WEATHER	EL	East Lansing MI site
WEATHER	RHI	Rhinelander WI site
WEATHER	WA	Puyallup WA site

CLONLIB	ARC	archive of clonal library files

This archive contains the following files:

EUGENEI	CLF	clonal library data for *P. eugenei*
EUGENEI	DTC	downward PSYN transfer coefficients
EUGENEI	INT	initial tree data file for *P. eugenei*
EUGENEI	ITC	internode PSYN
EUGENEI	LTC	leaf PSYN TCs
EUGENEI	STM	initial stem data
GENERIC	CLF	generic tree file
GENERIC	DTC	generic tree file
GENERIC	INT	generic tree file
GENERIC	ITC	generic tree file
GENERIC	LTC	generic tree file
44-136	CLF	clonal library data for clone 44-136
44-136	INT	initial tree data for clone 44-136
ILL-5	INT	initial tree data for clone ILL-5
ILL-5	CLF	clonal library data for clone ILL-5
TRISTIS	CLF	clonal library file for *P. tristis*
TRISTIS	INT	initial tree data file for *P. tristis*

The MAIN MENU options are selected by moving the highlight bar with the arrow keys and pressing the <Enter> key, or by typing the first letter/number of the option. The MAIN MENU options are summarized below; the following sections describe each menu choice in detail.

2.1 Main Menu Options

R) Run Simulation
: Begins the simulation run, passing control to SIMULATE. This option is selected after the appropriate poplar clone, run parameters, and the report requests have been selected.

1) Select New Clone
: Allows the user to select a clone from the clonal library.

2) Edit Clonal Data
: Allows the user to change the morphological, physiological, and phenological parameters of a clone.

3) Initial Tree
: Allows editing of the initial tree data files, which contain size and orientation information for individual leaves and internodes, biomass values for the cutting and roots, and the starting Julian date.

4) Site
: Allows the user to change latitude and soil reflectance values.

5) Weather
: Allows editing of the weather data file, which contains the hourly temperatures and PPFD data for the growing season.

6) Reports
: Allows the user to choose the hourly, daily, or summary reports to be sent to the screen or printer. Also enables a graphic display of leaf projections at each hour.

7) Simulation
: Allows the user to set simulation management variables, such as the beginning/ending and printer report dates.

V) View
: Allows the user to view the tree from various distances, azimuths, and altitudes. Exiting VIEW with the Quit option writes the file PLOTDATA.DAT, which is the data file required to plot the tree on a graphics plotter.

Q) Quit
: Closes all files and returns the user to the operating system.

2.2 Running a Simulation

A simulation is run in five steps: (1) selecting a clone, (2) setting the simulation management variables, (3) changing the model inputs (optional), (4) selecting the screen or printer reports (optional), and (5) starting the simulation.

2.2.1 Selecting a poplar clone

Poplar clones differ in their overall morphological (leaf orientation), phenological (bud break, bud set dates), and physiological (photosynthesis, respiration rates) characteristics. ECOPHYS has been designed to allow the simulation of several clones. The SELECT CLONE menu, which is displayed immediately after the opening screen, prompts the user to select one of several clones (fig. 4). The user may also change clones from the MAIN MENU using the SELECT CLONE option.

The current version of ECOPHYS contains a full clonal data set for *P. eugenei* and partial data sets for *P. deltoides* Clone Ill-005 and *P. trichocarpa* x *P. deltoides* Clone 44-136. The latter two clones use experimentally derived coefficients for the photosynthate production functions, and empirical phenological and morphological measurements, but they use photosynthate transport coefficients developed for *P. eugenei.* Validation studies have shown, however, that the *P. eugenei* transport coefficients give acceptable results in predicting height growth of Ill-005 and 44-136 (Host *et al.* 1990a).

```
WELCOME TO ECOPHYS

Please begin by selecting a clone

Eugenei

Tristis

Illinois-5

44-136

Generic Clone
```

Figure 4.—*The Select Clone screen, showing clones available for simulation.*

2.2.2 Setting the simulation management variables

Simulation management variables are set using the SIMULATION option from the MAIN MENU. These variables consist of the starting and ending dates for the simulation, the printer report periods, and an option to use or replace a previous run. The upper portion of the SIMULATION MANAGEMENT screen is used to set the beginning and ending Julian dates (fig. 5). The starting date is usually the date specified in the Initial Tree Data File (Section 4.2), although it is possible to begin a run at a later date if data from a previous run have been stored on disk. The starting date for the simulation cannot be earlier than the date specified in the initial tree matrix; using an earlier date will produce an error message. The simulation should be terminated on or before the bud set date.

The center portion of the screen displays the title and beginning/ending dates from the previous run of ECOPHYS. The user has the option of beginning a new run <Y> or using data from a previous run <N>. A <Y> response will overwrite the existing data files with the current run. This approach is used when a new run is desired (*i.e.*, starting a new full season run, using a different clone, changing clonal parameters). A <N> response will allow a run to be started in mid-season; data from the previous run are used to quickly bring the model up to the starting date. It is often most efficient to run the complete season overnight without generating printed reports, and then to use the <N> option to generate the desired printed reports for specific days.

The lower portion of the SIMULATION MANAGEMENT screen allows the user to set up to five periods in the growing season (as a range of Julian days) when hourly or periodic reports will be sent to the printer. The specific reports to be printed are selected using the REPORTS option from the MAIN MENU.

2.2.3 Changing model inputs

ECOPHYS is a versatile model in that most of the model inputs may be changed. Inputs to the model include hourly temperature and light data (*i.e.*, PPFD); morphological, phenological, and physiological characteristics of the clone; leaf sizes and orientations for the initial tree; and photosynthate transport coefficients. One of the most powerful features of a process model is the ability to run a simulation under different initial and run-time conditions. This feature allows the user to experiment with different growing conditions or clonal attributes; such experiments would be difficult or impossible to conduct in field situations. For example, Rauscher *et al.* (1988) simulated the growth of *P. eugenei* under different light and temperature regimes, and found that the interaction of light and temperature

```
SIMULATION MANAGEMENT VARIABLES

                 Beginning Run Date (Julian) -->  204
                 Ending    Run Date (Julian) -->  256
          Simulated time increment (1,2,4 Hours) -->  1
------------------------------------------------------------------------
         The Title of the current Tree Morphology data file is:


         with Julian Dates [ 205  ]  to  [ 1   ]  represented.
         Replace it with this run (Y/N) ?  --> Y
------------------------------------------------------------------------
     Set up to 5 periods in the growing season when printer reports
     will be allowed:
                           Period      Julian Date ON     Julian Date OFF
                             1       -->     0              -->     0
                             2       -->     0              -->     0
                             3       -->     0              -->     0
                             4       -->     0              -->     0
  [ESC] TO QUIT              5       -->     0              -->     0
```

Figure 5.—*The Simulation Management screen is used to set the simulation length, overwrite status, and printer report periods.*

could increase or reduce yield by 50 percent over a "base" year. Crow *et al.* (1987) used the simulation to determine the effects of canopy architecture on light interception; the results of this type of experiment can provide criteria for the early selection of poplar genotypes.

Model inputs are changed through a series of editors accessed from the MAIN MENU. Documentation for using these editors is presented in Section 3, Changing the Model Inputs.

2.2.4 Selecting screen and printer reports

The REPORTS option is used to select screen and printer reports to be displayed or printed during run time (fig. 6). Individual reports may be turned ON or OFF by selecting <Y> or <N>, respectively. Five run-time screen reports are available; the content of these reports is shown in figures 7a-7e. The screen reports are updated as each leaf is processed. A report may be "fixed" on the screen (and run suspended) using the PAUSE key (or Ctrl-NumLock on older keyboards); striking any key resumes program execution. The LEAF OVERLAP PLOT report permits a graphic representation of the tree to be displayed each hour. The tree is shown from the "sun's perspective," that is, leaves are projected on a plane perpendicular to the solar vector (fig. 7c).

Printer reports may be produced for many aspects of the model, such as the clonal parameters, photosynthate production within a given hour, or daily records of height growth. Examples of all printer reports are presented in the Appendix. Reports may be printed at the beginning of the simulation, at hourly intervals or leaf initiation periods, or at the end of the simulation (table 5). Specific reporting periods may be selected through the SIMULATION option (Section 2.2.2).

Selecting <ESC> from the REPORTS screen transfers the user to the SUMMARY REPORTS screen. These reports present day-by-day summaries of the morphological and physiological states of the tree. The final choice on this menu, "VIEW TREE ON SCREEN," displays a graphic representation of the tree at the end of the simulation

A graphic representation of the initial tree may be obtained using the VIEW TREE option from the MAIN MENU. If the LEAF OVERLAP PLOT option has been selected from the previous screen, the tree will be plotted on the HP graphics plotter.

2.2.5 Starting the simulation

Once the clone, input parameters, and desired reports have been selected, the simulation is started by selecting the RUN SIMULATION option from the MAIN

Screen Reports

Leaf Orientation	Y	Leaf Overlap Plot	Y
Leaf Orientation Plot	Y	PPFD (light)	Y
Leaf Projection	Y	Photosynthesis	Y
Leaf Overlap	Y	Growth	Y

Printer Reports

Initial Tree Leaf Data	N	PPFD (light)	N
Initial Tree Stem Data	N	Photosynthesis	N
Weather Data - season	N	Leaf Respiration	N
Site Data	N	Leaf PSYN Transport	N
Clonal Library Data	N	Leaf Growth	N
Leaf Orientation	N	Internode Respiration	N
Leaf Orientation Plot	N	Internode Growth	N
Leaf Projection	N	Cutting and Root Growth	N
Leaf Overlap	N	Weather Data - hourly	N
Leaf Overlap Plot	N	Leaf Morphological Data	N

Figure 6.—*The Report Selection screen is used to select printer, plotter, and screen reports produced during and after the simulation.*

►SIMULATION STATUS   DAY: 204 HOUR: 14

Tree		Environmental		Physiological	
# Leaves:	22	Solar Alt:	55	Total PSYN:	808
Leaf Area:	829	Solar Azm:	235	Current PSYN:	147
Leaf Dry Wt:	5.049	Direct PPFD:	1531	Storage PSYN:	808
Stem Dry Wt:	2.3	Diffuse PPFD:	201		
Root Dry Wt:	12.3	Air Temp:	26.6		
Height:	49.9				
Diam:	0.60				

Leaf Orientation Calculations

Leaf # From Base	Leaf Vertex	Coordinates X	Y	Z
6	1	0	3	13
	2	2	4	11
	3	0	9	13
	4	-2	4	14

Figure 7.—*Run-time Screen Reports. The Simulation Status Screen presents run-time information on changes in morphological, environmental, and physiological parameters. Other selected screen reports present leaf-level information: a) Leaf Orientation; b) Leaf Projection; c) Graphic Display of Tree; d) Leaf Overlap; e) PPFD (light).*

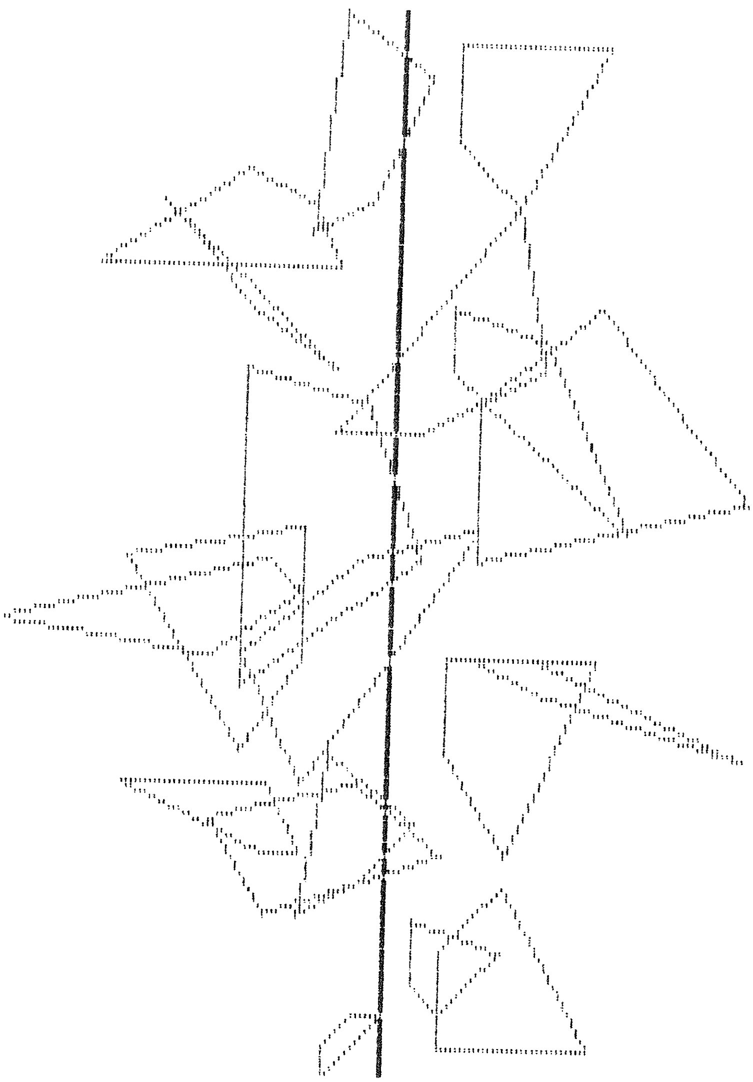
▸SIMULATION STATUS DAY: 204 HOUR: 8

Tree		Environmental		Physiological	
# Leaves:	22	Solar Alt:	35	Total PSYN:	35
Leaf Area:	829	Solar Azm:	96	Current PSYN:	35
Leaf Dry Wt:	5.049	Direct PPFD:	543	Storage PSYN:	35
Stem Dry Wt:	2.3	Diffuse PPFD:	37		
Root Dry Wt:	12.3	Air Temp:	21.6		
Height:	49.9				
Diam:	0.60				

Leaf Projection Calculations

Leaf # From Base	Leaf Vertex	Coordinates X	Y	Z
10	1	-3	21	14
	2	-5	19	10
	3	-13	11	18
	4	5	13	11

7b.—*Leaf Projection.*



7c.—*Graphic Display of Tree.*

```
                           ▸SIMULATION STATUS          DAY:  204 HOUR:   8
          Tree            Environmental          Physiological
 # Leaves:          22 | Solar Alt:       35 | Total PSYN:          35
 Leaf Area:          2 | Solar Azm:       96 | Current PSYN:        35
 Leaf Dry Wt:    5.049 | Direct PPFD:    543 | Storage PSYN:        35
 Stem Dry Wt:      2.3 | Diffuse PPFD:    37 |
 Root Dry Wt:     12.3 | Air Temp:      21.6 |
 Height:          49.9 |                     |
 Diam:            0.60 |                     |

                 PPFD Calculations

              Leaf #        Sun      Shade
            From Base       PPFD      PPFD

                10           98        18
```

7d).—*Leaf Overlap.*

```
>>>>

                           ▸SIMULATION STATUS          DAY:  204 HOUR:  12
          Tree            Environmental          Physiological
 # Leaves:          22 | Solar Alt:       65 | Total PSYN:         522
 Leaf Area:          4 | Solar Azm:      180 | Current PSYN:        12
 Leaf Dry Wt:    5.049 | Direct PPFD:   1482 | Storage PSYN:       510
 Stem Dry Wt:      2.3 | Diffuse PPFD:   275 |
 Root Dry Wt:     12.3 | Air Temp:      23.8 |
 Height:          49.9 |                     |
 Diam:            0.60 |                     |

                          PGA Calculations

   Leaf #    Sun   Shade    Sun     Shade   Sun   Shade   TOTAL
 From Base  Area    Area    PPFD     PPFD   Pga    Pga     PGA

     5       16      4      668      168     3      1       4
```

7e.—*PPFD (light).*

Table 5.—*Available printer reports*

Beginning of run	Hourly	Leaf initiation periods	Simulation summary reports
Initial Leaf Raw Data	Leaf Orientation	Leaf Respiration	Daily photosynthesis
Initial Stem Data	Leaf Projection	Leaf PSYN Transport	Daily dry weight
Weather Data - season	Leaf Overlap	Leaf Growth	Daily solar radiation
Site Data	PPFD (light)	Internode Respiration	
Clonal Data	Photosynthesis	Internode Growth	
	Weather Data - hr	Cutting and Root Growth	
	Leaf Raw Data		

MENU. The user is prompted to enter a title for the run. Control of the program passes to SIMULATE, a module that directs the temporal flow of the model (fig. 8). A simulation status screen displays the morphological, environmental, and physiological variables for each hour (fig. 7a); screen summary reports that have been selected from the REPORTS option are also displayed. Program execution may be suspended using the PAUSE (Ctrl-NumLock) key; this will allow individual reports to be examined.

SIMULATE directs program flow to HOURSTEP or GROW, depending on whether a new leaf has emerged in that hour (fig. 8). SIMULATE retains control of the program until the ending Julian date is reached. A growing season run may take several hours to complete, and is generally set up as an overnight run. For demonstration purposes, it is usually best to run the model for 2 or 3 Julian days. The Ctrl-Break key can be used to abort the run and return the user to the operating system. Disk files are continually updated during run time, so data will not be lost if the run is aborted.

2.3 Simulation Analysis

2.3.1 Graphic display

When the simulation ending date has been reached, a graphic representation of the tree will be displayed (fig. 2). The user may view the tree from different altitudes (0 to 90°), azimuths (0 to 360°), and distances (0 to 1000 cm). The ability to view the tree from many different perspectives allows the user to get a clear understanding of the leaf orientations, mutual leaf shading patterns, and overall tree morphology.

2.3.2 Simulation output files

In addition to the screen and printer outputs, simulation output is also stored on disk files. These files may be used to conduct statistical analyses, to produce customized reports, or to graph the model outputs, such as time-series graphs (*e.g.*, fig. 9). The output files are stored in space-delimited or comma-delimited ASCII format. Four output files are produced: DAILY.DAT, OUTPUT.DAT, RESP.DAT, and PLOTDATA.DAT. These files are described below:

DAILY.DAT summarizes daily environmental and morphological variables. Variables are stored in columns, days as rows. The columns in this file are as follows:

1 - Julian Date
2 - Number of Leaves
3 - Leaf Area (cm^2)
4 - Above-crown PPFD ($mol/m^2/d$)
5 - Average Daily Temperature (C)
6 - Average Daytime Temperature (C)
7 - Average Nighttime Temperature (C)

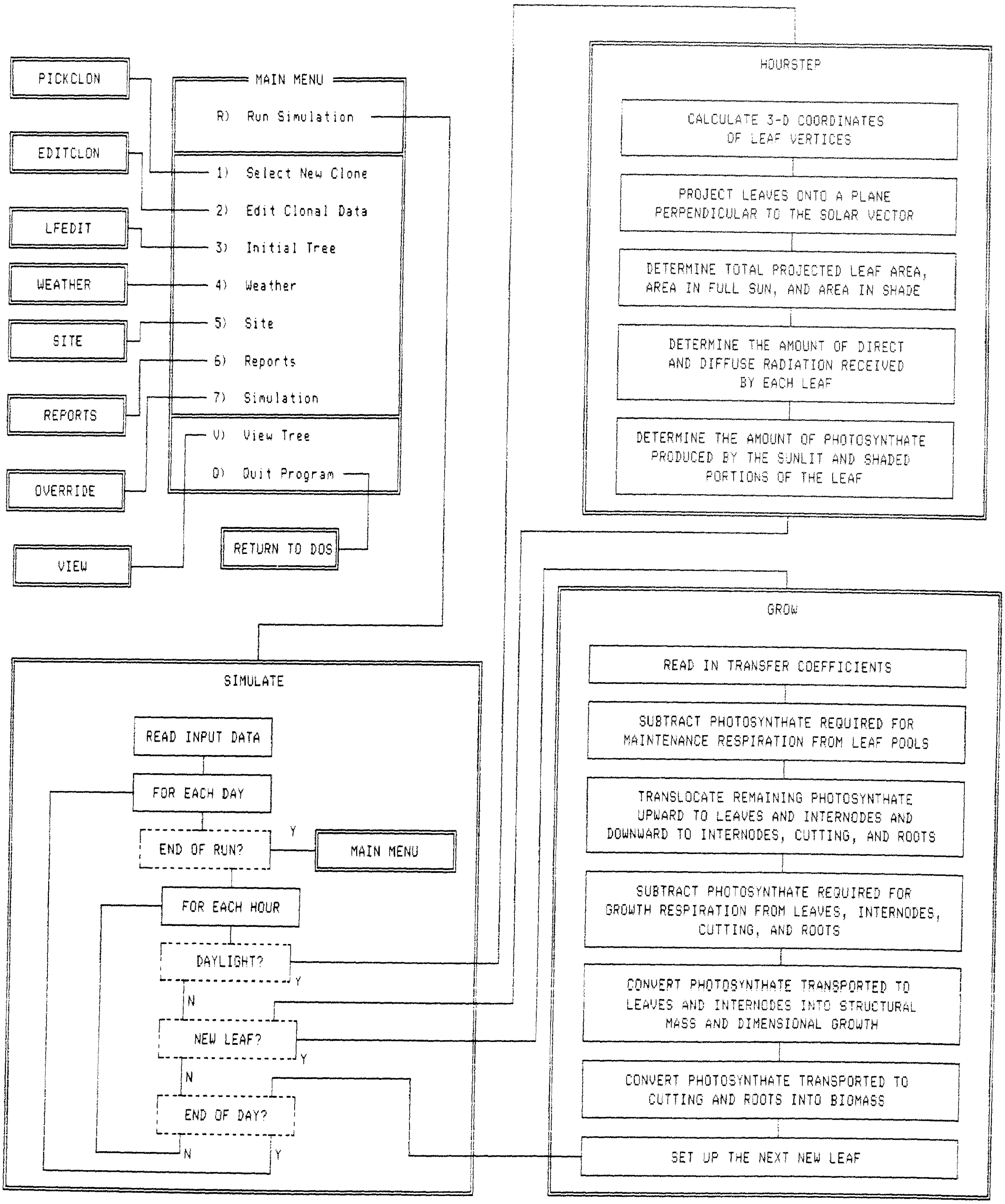


Figure 8.—*Generalized flowchart illustrating relationships and internal functions of SIMULATE, HOURSTEP, and GROW.*

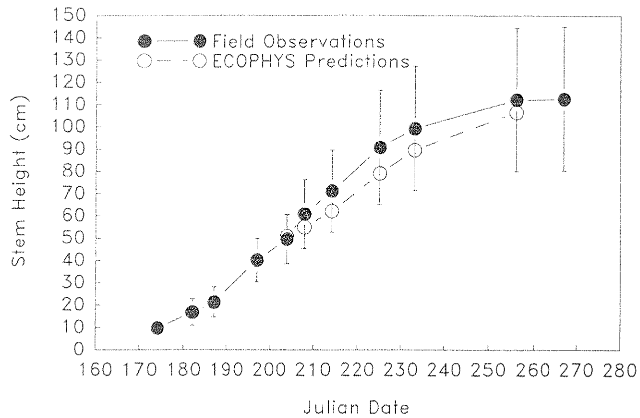


Figure 9.—*Height growth of* P. eugenei *compared with observed values from time-series data and destructive sampling over a growing season.*

8 - Daily Apparent Photosynthesis (mg CO_2/d)
9 - Height (cm)
10 - Diameter (cm)
11 - Leaf Dry Weight (g)
12 - Stem Dry Weight (g)
13 - Root and Cutting Dry Weight (g)
14 - Total Tree Dry Weight (g)
15 - Total Intercepted PPFD (mol/d)
16 - Intercepted PPFD (mol/m^2/d)
17 - Percent Light Intercepted (Intercepted PPFD/Above-crown PPFD)*100

An example DAILY.DAT file is presented in table 6.

OUTPUT.DAT summarizes daily leaf morphological data. The columns of OUTPUT.DAT are as follows:

1 - Julian Date
2 - Leaf Number from Base (LNFB)
3 - Leaf Age (d)
4 - Maturity Code
5 - Leaf Length (cm)
6 - Leaf Width (cm)
7 - Leaf Area (cm^2)
8 - Leaf Shape Code
9 - Petiole Length (cm)
10 - Petiole Angle (deg)
11 - Petiole Azimuth (deg)
12 - Petiole Insertion (height from base of tree-cm)
13 - Midrib Azimuth (deg)
14 - Midrib Angle (deg)
15 - Lamina Angle (deg)
16 - Date of Initiation (Julian date)
17 - Leaf Plastochron Index (LPI)
18 - Internode Length (cm)
19 - Internode Diameter (cm)
20 - Stored Leaf Photosynthates (mg CO_2)
21 - Shading Status
22 - Internode Dry Weight (g)
23 - Stored Internode Photosynthates (mg CO_2)
24 - Leaf Dry Weight (g)

An example OUTPUT.DAT file is presented in table 7.

RESP.DAT summarizes respiration data for various plant components. The columns of RESP.DAT are as follows:

1 - Julian Date
2 - Total PgA Accumulated (mg CO_2/d)
3 - Leaf Maintenance Respiration
4 - Leaf Growth Respiration
5 - Internode Maintenance Respiration
6 - Internode Growth Respiration
7 - Cutting Maintenance Respiration
8 - Cutting Growth Respiration
9 - Coarse Root Maintenance Respiration
10 - Coarse Root Growth Respiration
11 - Fine Root Maintenance Respiration
12 - Fine Root Growth Respiration

An example RESP.DAT file is presented in table 8.

PLOTDATA.DAT contains the spatial coordinate data used by the HP plotter to plot the tree at the end of the simulation. The tree may be plotted outside the ECOPHYS environment by typing HPLOT at the DOS prompt.

3. Changing the Model Inputs - ECOPHYS Editors

The primary advantages of this simulation model are the ability to change input parameters and to observe the effects of these changes on the model's output. Often these parameters are difficult or impossible to vary in field situations - *e.g.*, seasonal weather patterns. ECOPHYS has been designed to allow users to manipulate not only the state variables, such as the initial tree morphology, but also the rate constants (*e.g.*, photosynthesis and respiration rates) and transport coefficients (*e.g.*, photosynthate transport coefficients). A series of editors (WEATHER, SITE, CLONAL DATA, etc.) has been built into ECOPHYS to allow model inputs to be changed. The following sections describe the use of these editors.

3.1 Initial Tree - Editing Morphological Data

The Initial Tree option from the MAIN MENU allows editing of the initial tree data files. The Cutting/Root submenu allows editing of the weight and photosynthate storage of the cutting and root tissues at the start

Table 6.—*Example of the DAILY.DAT summary file*

204	22	829	49.95	21.9	23.6	14.0	1540	51	0.60	5.0	2.3	12.3	19.6	2.17	26.18	52
205	23	940	49.42	21.4	23.1	13.7	1582	54	0.63	5.6	2.7	12.4	20.7	2.29	24.32	49
206	23	940	40.00	17.9	19.5	13.6	1308	54	0.63	5.6	2.7	12.4	20.7	2.26	24.04	60
207	24	1026	26.12	16.8	19.7	11.4	1140	56	0.66	6.0	3.0	12.5	21.5	1.55	15.06	58
208	24	1026	26.84	17.2	18.5	13.3	1136	56	0.66	6.0	3.0	12.5	21.5	1.49	14.56	54
209	25	1132	52.80	16.7	20.0	6.8	2052	59	0.68	6.6	3.5	12.7	22.7	3.31	29.28	55
210	25	1132	47.28	18.4	21.1	8.3	2136	59	0.68	6.6	3.5	12.7	22.7	3.14	27.72	59
211	26	1275	26.49	18.8	19.7	12.5	1504	63	0.72	7.4	4.1	13.0	24.5	1.73	13.59	51
212	26	1275	21.68	16.0	17.2	10.3	1409	63	0.72	7.4	4.1	13.0	24.5	1.50	11.74	54
213	27	1390	51.92	16.5	19.7	8.7	2434	66	0.74	8.0	4.7	13.2	25.9	3.89	27.96	54
214	27	1390	45.15	17.6	20.6	9.5	2562	66	0.74	8.0	4.7	13.2	25.9	3.50	25.14	56
215	28	1578	50.13	19.8	22.5	11.4	3112	70	0.77	9.0	5.6	13.8	28.4	4.20	26.65	53
216	28	1578	38.21	21.5	24.1	12.7	2729	70	0.77	9.0	5.6	13.8	28.4	3.27	20.71	54
217	29	1776	43.55	18.2	20.4	10.8	3086	74	0.79	10.1	6.5	14.3	30.9	4.02	22.61	52
218	29	1776	36.79	18.4	19.7	11.8	2620	74	0.79	10.1	6.5	14.3	30.9	3.72	20.97	57
219	30	1968	39.28	23.7	25.3	18.5	3391	79	0.81	11.1	7.3	14.9	33.3	4.30	21.84	56
220	30	1968	45.15	19.0	21.0	11.5	3574	79	0.81	11.1	7.3	14.9	33.3	4.74	24.08	53
221	31	2197	11.37	15.0	15.6	10.0	1372	84	0.83	12.4	8.4	15.6	36.4	1.33	6.07	53
222	31	2197	41.06	15.4	16.2	12.3	2989	84	0.83	12.4	8.4	15.6	36.4	4.63	21.09	51
223	32	2350	38.92	13.1	17.0	5.4	3265	88	0.84	13.2	9.2	16.1	38.6	4.94	21.00	54
224	32	2350	24.35	12.9	15.4	8.4	2324	88	0.84	13.2	9.2	16.1	38.6	3.50	14.91	61
225	33	2528	49.95	15.2	17.1	9.0	3863	93	0.86	14.3	10.2	16.9	41.4	6.54	25.85	52
226	33	2528	49.42	9.6	11.0	5.5	2746	93	0.86	14.3	10.2	16.9	41.4	6.60	26.12	53
227	34	2717	45.69	10.3	14.8	2.9	3636	98	0.88	15.4	11.5	17.9	44.7	6.47	23.83	52
228	34	2717	29.69	9.7	12.7	5.1	2599	98	0.88	15.4	11.5	17.9	44.7	4.82	17.76	60
229	35	2881	11.01	13.6	14.4	8.9	1648	103	0.89	16.3	12.7	18.8	47.8	1.59	5.50	50
230	35	2881	34.66	18.6	20.0	14.4	4069	103	0.89	16.3	12.7	18.8	47.8	4.78	16.60	48
231	36	3014	37.68	17.2	19.3	12.5	4623	107	0.90	17.2	13.7	19.6	50.4	5.63	18.69	50
232	36	3014	36.44	18.3	19.5	11.8	4713	107	0.90	17.2	13.7	19.6	50.4	5.71	18.93	52
233	37	3211	45.33	17.6	19.9	10.3	5595	113	0.91	18.4	15.3	20.9	54.6	7.28	22.66	50
234	37	3211	8.16	16.0	16.7	10.8	1587	113	0.91	18.4	15.3	20.9	54.6	1.16	3.60	44
235	38	3356	17.05	16.7	17.9	10.6	3210	116	0.92	19.4	16.3	21.9	57.5	2.74	8.15	48
236	38	3356	24.35	13.2	13.6	9.0	3385	116	0.92	19.4	16.3	21.9	57.5	3.97	11.82	49
237	39	3500	41.41	15.4	17.8	10.7	4840	119	0.93	20.3	17.4	22.9	60.6	6.70	19.13	46
238	39	3500	23.10	15.0	16.9	8.9	3861	119	0.93	20.3	17.4	22.9	60.6	3.91	11.18	48
239	40	3682	27.19	15.0	16.2	11.5	4151	123	0.95	21.5	18.8	24.4	64.7	4.97	13.51	50
240	40	3682	12.43	15.3	15.8	14.9	2439	123	0.95	21.5	18.8	24.4	64.7	2.27	6.18	50
241	41	3808	36.97	19.3	20.7	14.9	5759	126	0.95	22.3	19.8	25.4	67.5	7.09	18.62	50
242	41	3808	42.66	16.8	17.9	13.1	5666	126	0.95	22.3	19.8	25.4	67.5	8.05	21.14	50
243	42	4006	25.06	19.4	19.9	15.8	5084	132	0.97	23.6	21.6	27.3	72.5	5.03	12.55	50
244	42	4006	30.04	20.9	22.3	16.2	6015	132	0.97	23.6	21.6	27.3	72.5	5.49	13.71	46
245	43	4168	18.12	16.7	18.2	12.6	4093	136	0.98	24.7	23.2	29.1	77.0	3.28	7.88	44
246	43	4168	19.19	13.2	14.4	12.0	3538	136	0.98	24.7	23.2	29.1	77.0	3.57	8.57	45
247	44	4275	28.98	16.8	18.6	18.1	5287	140	0.98	25.5	24.4	30.3	80.2	5.34	12.49	43
248	44	4275	33.24	21.7	23.5	16.5	7156	140	0.98	25.5	24.4	30.3	80.2	6.81	15.93	48
249	45	4450	25.95	13.7	14.7	12.7	4567	146	1.00	26.8	26.6	32.7	86.1	5.96	13.39	52
250	45	4450	31.46	7.7	9.6	4.6	3586	146	1.00	26.8	26.6	32.7	86.1	6.63	14.91	47
251	46	4572	36.45	10.1	11.6	4.7	5029	150	1.01	27.7	28.2	34.5	90.4	7.74	16.93	46
252	46	4572	26.13	16.5	18.6	17.3	5046	150	1.01	27.7	28.2	34.5	90.4	5.85	12.79	49
253	47	4712	36.45	13.8	13.7	11.8	5721	154	1.01	28.7	29.9	36.3	94.9	7.90	16.77	46
254	47	4712	10.12	11.9	12.3	11.4	2338	154	1.01	28.7	29.9	36.3	94.9	2.24	4.76	47
255	48	4818	15.64	12.8	14.1	16.6	3406	156	1.02	29.5	31.1	37.7	98.4	3.66	7.59	49

Table 7.—*Example of the OUTPUT.DAT summary file*

205	1	43	4	3.5	3.5	10.0	0.20	1.8	65	0	1.52	0	97	40	162	22	1.52	0.63	0	1	0.16	0	0.092
205	2	41	4	3.6	3.6	10.2	0.20	2.0	60	144	3.04	144	77	35	164	21	1.52	0.59	0	1	0.16	0	0.101
205	3	39	4	5.7	5.7	17.0	0.20	2.3	49	288	4.56	288	90	140	166	20	1.52	0.56	0	1	0.16	0	0.172
205	4	37	4	6.0	6.0	15.8	0.18	2.4	90	72	7.46	72	90	30	168	19	2.90	0.52	0	1	0.21	0	0.166
205	5	35	3	6.8	6.8	20.2	0.19	2.7	85	224	10.36	224	85	20	170	18	2.90	0.51	0	1	0.20	0	0.214
205	6	33	3	6.5	6.5	23.8	0.18	2.6	94	0	13.26	0	94	45	172	17	2.90	0.50	0	1	0.19	0	0.251
205	7	31	3	8.7	8.7	39.8	0.27	3.3	65	148	16.16	148	65	75	174	16	2.90	0.48	0	1	0.17	0	0.348
205	8	29	3	7.5	7.5	33.4	0.16	2.9	95	244	19.06	244	95	140	176	15	2.90	0.47	0	1	0.16	0	0.314
205	9	27	2	9.4	9.4	53.8	0.17	3.5	100	48	23.06	48	100	155	178	14	4.00	0.46	0	1	0.15	0	0.419
205	10	25	2	9.8	9.8	53.9	0.19	3.6	80	202	25.96	202	80	20	180	13	2.90	0.45	0	1	0.14	0	0.389
205	11	23	2	9.6	9.6	66.9	0.16	3.5	95	322	28.86	322	95	130	182	12	2.90	0.44	0	1	0.12	0	0.395
205	12	21	2	12.0	12.0	72.5	0.18	4.3	80	137	31.76	137	80	45	184	11	2.90	0.43	0	1	0.12	0	0.352
205	13	19	1	13.0	13.0	84.4	0.18	4.6	90	260	34.66	260	90	30	186	10	2.90	0.42	0	0	0.11	0	0.312
205	14	17	1	13.3	13.3	88.6	0.18	4.7	110	44	37.56	44	110	30	188	9	2.90	0.43	0	0	0.11	0	0.392
205	15	15	1	13.5	13.5	91.0	0.18	4.8	100	148	40.69	148	100	145	190	8	3.13	0.40	0	0	0.10	0	0.434
205	16	13	1	11.3	11.3	64.0	0.18	4.1	100	294	43.51	294	100	145	192	7	2.82	0.40	0	0	0.09	0	0.289
205	17	11	1	11.0	11.0	61.0	0.17	4.0	110	84	46.00	84	110	140	194	6	2.49	0.40	0	0	0.07	0	0.295
205	18	9	1	9.1	9.1	41.6	0.18	3.4	115	214	48.11	214	115	10	196	5	2.11	0.40	0	0	0.06	0	0.203
205	19	7	1	7.3	7.3	26.9	0.18	2.8	90	4	49.86	4	90	70	198	4	1.75	0.40	0	0	0.05	0	0.138
205	20	5	1	7.3	7.3	26.5	0.20	2.8	100	118	51.19	118	100	60	200	3	1.34	0.40	0	0	0.04	0	0.133
205	21	3	1	5.1	5.1	12.8	0.20	2.1	100	260	52.24	265	100	60	202	2	1.05	0.40	0	0	0.03	0	0.066
205	22	1	1	5.0	5.0	12.4	0.20	2.1	100	42	53.00	42	100	60	204	1	0.76	0.40	0	0	0.02	0	0.065
205	23	0	1	2.0	2.0	2.0	0.20	1.1	100	190	53.50	190	100	150	205	0	0.50	0.40	0	0	0.03	0	0.010
207	1	45	4	3.5	3.5	10.0	0.20	1.8	65	0	1.52	0	97	40	162	23	1.52	0.65	0	1	0.18	0	0.093
207	2	43	4	3.6	3.6	10.2	0.20	2.0	60	144	3.04	144	77	35	164	22	1.52	0.61	0	1	0.18	0	0.102
207	3	41	4	5.7	5.7	17.0	0.20	2.3	49	288	4.56	288	90	140	166	21	1.52	0.58	0	1	0.18	0	0.174
207	4	39	4	6.0	6.0	15.8	0.18	2.4	90	72	7.46	72	90	30	168	20	2.90	0.54	0	1	0.23	0	0.168
207	5	37	4	6.8	6.8	20.2	0.19	2.7	85	224	10.36	224	85	20	170	19	2.90	0.53	0	1	0.22	0	0.216
207	6	35	3	6.5	6.5	23.8	0.18	2.6	94	0	13.26	0	94	45	172	18	2.90	0.52	0	1	0.21	0	0.255
207	7	33	3	8.7	8.7	39.8	0.27	3.3	65	148	16.16	148	65	75	174	17	2.90	0.50	0	1	0.19	0	0.352
207	8	31	3	7.5	7.5	33.4	0.16	2.9	95	244	19.06	244	95	140	176	16	2.90	0.49	0	1	0.17	0	0.319
207	9	29	3	9.4	9.4	53.8	0.17	3.5	100	48	23.06	48	100	155	178	15	4.00	0.47	0	1	0.16	0	0.424
207	10	27	2	9.8	9.8	53.9	0.19	3.6	80	202	25.96	202	80	20	180	14	2.90	0.47	0	1	0.15	0	0.396
207	11	25	2	9.6	9.6	66.9	0.16	3.5	95	322	28.86	322	95	130	182	13	2.90	0.45	0	1	0.13	0	0.402
207	12	23	2	12.0	12.0	72.5	0.18	4.3	80	137	31.76	137	80	45	184	12	2.90	0.44	0	1	0.13	0	0.359
207	13	21	2	13.1	13.1	85.6	0.18	4.7	90	260	34.66	260	90	30	186	11	2.90	0.43	0	1	0.11	0	0.317
207	14	19	1	13.7	13.7	93.2	0.18	4.8	110	44	37.56	44	110	30	188	10	2.90	0.43	0	0	0.12	0	0.412
207	15	17	1	14.0	14.0	98.7	0.18	5.0	100	148	40.69	148	100	145	190	9	3.13	0.41	0	0	0.11	0	0.468
207	16	15	1	11.7	11.7	68.5	0.18	4.2	100	294	43.65	294	100	145	192	8	2.96	0.40	0	0	0.10	0	0.309
207	17	13	1	11.6	11.6	67.7	0.17	4.2	110	84	46.32	84	110	140	194	7	2.67	0.40	0	0	0.08	0	0.325
207	18	11	1	10.0	10.0	50.2	0.18	3.7	115	214	48.64	214	115	10	196	6	2.32	0.40	0	0	0.07	0	0.242
207	19	9	1	8.4	8.4	34.9	0.18	3.1	90	4	50.56	4	90	70	198	5	1.92	0.40	0	0	0.06	0	0.174
207	20	7	1	8.5	8.5	36.4	0.20	3.2	100	118	52.08	118	100	60	200	4	1.51	0.40	0	0	0.05	0	0.177
207	21	5	1	6.3	6.3	20.1	0.20	2.5	100	260	53.29	265	100	60	202	3	1.21	0.40	0	0	0.04	0	0.099
207	22	3	1	6.3	6.3	19.9	0.20	2.5	100	42	54.23	42	100	60	204	2	0.94	0.40	0	0	0.03	0	0.099
207	23	2	1	4.1	4.1	8.3	0.20	1.8	100	190	54.91	190	100	150	205	1	0.68	0.40	0	0	0.04	0	0.039
207	24	0	1	2.0	2.0	2.0	0.20	1.1	100	337	55.41	337	100	30	207	0	0.50	0.40	0	0	0.03	0	0.010

Table 8.—*Example of the RESP.DAT summary file*

205	4746.943	180.6929	257.4513	82.3120	172.5223	115.7582	1.315972	85.89084	53.6738	57.2605	4.0651
207	3524.975	155.9478	142.3011	74.5698	95.69789	91.0481	0	70.27264	33.3093	45.1766	2.6215
209	4607.738	157.2212	162.8548	77.6611	134.1674	132.3812	0	68.55886	51.0454	42.7937	7.7601
211	6918.028	197.7939	271.9128	102.969	248.064	213.7637	0	84.31775	100.376	50.5687	18.389
213	5253.609	177.3053	165.1822	98.9217	146.1613	165.163	0	74.48843	61.1079	42.2747	10.893
215	8890.33	219.5206	323.8344	127.704	290.7971	240.2642	11.92051	91.30615	139.993	49.7795	29.227
217	9445.871	266.7653	378.2947	163.788	321.0575	264.3438	12.5258	111.0899	160.849	56.8687	33.382
219	9181.539	311.5678	379.6189	198.423	315.4002	281.2231	7.559394	129.6851	162.241	62.7686	33.006
221	10408.19	281.0627	351.5261	183.651	312.0411	234.1057	27.46882	116.9836	168.409	54.0328	36.975
223	6974.688	256.217	183.9091	172.736	167.2038	196.9701	8.216401	107.7522	88.9375	47.3087	18.719
225	8780.813	261.8531	208.6026	180.092	220.6429	191.2676	23.01979	110.7945	121.735	47.1610	27.182
227	9238.749	187.0644	141.1722	132.848	171.5043	129.8198	26.98082	80.73283	93.9499	33.1075	22.035
229	8798.764	200.5336	127.0278	148.472	164.9274	133.1645	26.1569	89.10849	90.5708	35.1968	21.178
231	8912.429	387.9119	213.1187	298.192	264.0465	248.6094	23.75278	177.2068	149.124	67.8279	32.381
233	13700.83	439.6921	358.792	346.403	467.6567	272.6069	71.83271	204.6957	285.895	76.4095	65.749
235	9508.714	400.2514	208.8638	326.919	246.8063	238.7105	33.35938	193.29	162.084	69.671	36.358
237	9065.125	341.0124	159.3676	283.468	194.9922	197.6792	33.33627	168.186	137.426	59.2958	31.599
239	12153.47	389.6309	227.5945	329.544	300.8508	220.6518	60.5154	196.9304	218.017	68.0086	51.197
241	9444.998	479.0222	186.7436	415.128	230.7288	264.9457	34.28962	250.9451	177.365	84.5346	39.824
243	15888.04	505.0841	317.1196	443.293	483.7003	274.0086	106.0788	270.2511	358.93	89.5637	85.060
245	14395.05	558.4448	277.8807	506.118	439.9945	297.6462	93.17818	312.8514	328.624	101.111	77.017
247	9673.39	423.9062	125.5769	394.257	210.1557	222.8949	43.32696	246.2234	155.549	78.0665	36.172
249	17620.31	543.5709	285.5221	514.926	546.97	283.4398	131.4853	323.3773	393.197	101.274	94.089
251	10319.95	223.6829	66.35691	219.970	134.8565	116.0398	35.98985	139.3578	99.2233	42.8114	24.155
253	13833.15	519.2601	190.4505	524.209	348.1718	269.4791	84.75481	334.2363	267.718	101.481	63.618
255	9642.633	378.1872	92.64616	390.250	165.3414	195.3821	41.2881	250.8895	131.652	75.2455	31.274

of the run. The file containing this data has the extension .STM (*e.g.*, EUGENEI.STM). The Leaf/Tree submenu contains morphological data for the starting tree, such as leaf lengths, widths, and orientations and internode diameters and heights. The Leaf/Tree editor (LFEDIT.EXE) reads the initial tree data file (*e.g.*, EUGENEI.INT) into a spreadsheet-style matrix (fig. 10). Because the matrix contains 23 columns, the columns are spread across two adjacent screens. The Ctrl-LEFT ARROW and Ctrl-RIGHT ARROW keys

EDIT LEAF DATA

			LAMINA				PETIOLE			
LFNB	AGE days	MAT. CODE	LENGTH cm	WIDTH cm	AREA sq cm	SHAPE	LENGTH cm	ANG. deg	AZM. deg	LOC. cm
1	42	4	3.5	3.5	10.0	0.20	1.8	65	0	1.52
2	40	4	3.6	3.6	10.2	0.20	2.0	60	144	3.04
3	38	4	5.7	5.7	17.0	0.20	2.3	49	288	4.56
4	36	4	6.0	6.0	15.8	0.18	2.4	90	72	7.44
5	34	4	6.8	6.8	20.2	0.19	2.7	85	224	10.34
6	32	4	6.5	6.5	23.8	0.18	2.6	94	0	13.24
7	30	3	8.7	8.7	39.8	0.27	3.3	65	148	16.14
8	28	3	7.5	7.5	33.4	0.16	2.9	95	244	19.04
9	26	3	9.4	9.4	53.8	0.17	3.5	100	48	21.94
10	24	2	9.8	9.8	53.9	0.19	3.6	80	202	24.84
11	22	2	9.6	9.6	66.9	0.16	3.5	95	322	27.74
12	20	2	10.2	10.2	70.0	0.18	3.7	80	137	30.64
13	18	1	8.2	8.2	80.0	0.18	3.1	90	260	33.54
14	16	1	9.6	9.6	80.0	0.18	3.5	110	44	36.44
15	14	1	10.0	10.0	78.4	0.18	3.7	100	148	39.34

<F1> to continue <ESC> for help

EDIT LEAF DATA - SCREEN 2

	MIDRIB					INTERNODE			
LFNB	AZM. deg	ANG. deg	LAM. ANG. deg	DAY OF INIT. julian	LPI	LENGTH cm	DIAM. cm	MASS g	LEAF MASS g
1	0	97	40	162	21	1.52	0.60	0.14	0.090
2	144	77	35	164	20	1.52	0.55	0.14	0.100
3	288	90	140	166	19	1.52	0.52	0.14	0.170
4	72	90	30	168	18	2.90	0.50	0.19	0.163
5	224	85	20	170	17	2.90	0.49	0.18	0.211
6	0	94	45	172	16	2.90	0.48	0.17	0.247
7	148	65	75	174	15	2.90	0.46	0.15	0.342
8	244	95	140	176	14	2.90	0.45	0.14	0.308
9	48	100	155	178	13	2.90	0.44	0.13	0.413
10	202	80	20	180	12	2.90	0.43	0.12	0.379
11	322	95	130	182	11	2.90	0.42	0.11	0.385
12	137	80	45	184	10	2.90	0.42	0.11	0.341
13	260	90	30	186	9	2.90	0.41	0.10	0.292
14	44	110	30	188	8	2.90	0.41	0.10	0.353
15	148	100	145	190	7	2.90	0.40	0.09	0.377

<F1> to continue <ESC> for help

Figure 10.—*The Initial Tree Data File Editor screen.*

allow the user to move from screen to screen; alternatively, the left and right arrow keys can be used to move from one screen to the other. Similarly, only 16 rows of the matrix may be displayed at one time; the PgUp and PgDn keys may be used to move up and down between screens. The arrow keys are used to move within a screen. The <ESC> key may be used to display a help screen.

A value is edited by selecting that value with the Enter key. A status line at the top of the screen will display the variable name and the current value of that variable; a new value may then be entered. Out-of-range values (*e.g.*, leaf azimuth >360) are not allowed. A complete description of each column in the initial tree matrix is presented in Section 4.2, The Initial Tree Data Files.

Once editing of the initial tree data file is complete, the <F1> key is used to display a file management menu. This menu allows the user to SAVE the file and return to the MAIN MENU, RETURN to the MAIN MENU without saving the file, CONTINUE editing, or ENTER a new starting date.

3.2 Edit Clonal Data - Editing Clonal Library Data

EDIT CLONAL DATA is used to edit morphological, physiological attributes (*i.e.*, variables) of a clone. The information required for each clone is stored in Clonal Library Files; the format of these files is explained in Section 4.1.

The EDIT CLONAL DATA option presents a menu of parameter categories (fig. 11). Selecting a category (by highlighting the category and pressing <Enter>) brings up the editing screen for that category. Instructions for specific screens are presented below.

3.2.1 Photosynthate production functions

There are four photosynthate production equations in ECOPHYS, corresponding to the four leaf maturity classes. Each equation is defined by three parameters: Fmax, Rd, and Pe. Fmax refers to the maximum rate of CO_2 assimilation at high light intensities, expressed as *u*mol $CO_2/m^2/s$. Rd is a negative value describing respiratory losses in the absence of light; Rd is also in units of *u*mol $CO_2/m^2/s$. Pe is a unitless measure defining the slope of the curve as it crosses the Y axis. Biologically, Pe represents the efficiency of photosynthesis at low light intensities. The production equation and parameters are described fully in Goudriaan (1982).

The PSYN Editor plots the four photosynthate production curves and prompts the user to select a leaf class to edit (fig. 12). The selected curve is displayed and the user may edit the parameters. The resulting curve is plotted on the screen; the original curve remains for

```
                    Modify  Clonal  Parameters

                      Select Variables to Edit

  1) Photosynthesis    -  CO2 Assimilation Rate / Photon Flux Density
  2) Respiration       -  Growth and Maintenance Respiration Rates
  3) Temperature       -  Correction Factors for Photosynthesis and Resp.
  4) Morphology        -  Leaf and Petiole Orientation / Specific Leaf Area
  5) Phenology         -  Bud-break, Bud-set, Leaf Initiation Rate
  6) Carbon Transport  -  Leaf to Leaf/Internode Transport Coefficients
  7) Main Menu         -  Return to Main Menu
```

Figure 11.—*The Select Clonal Parameter screen allows the uses to choose a set of clonal parameters to edit.*

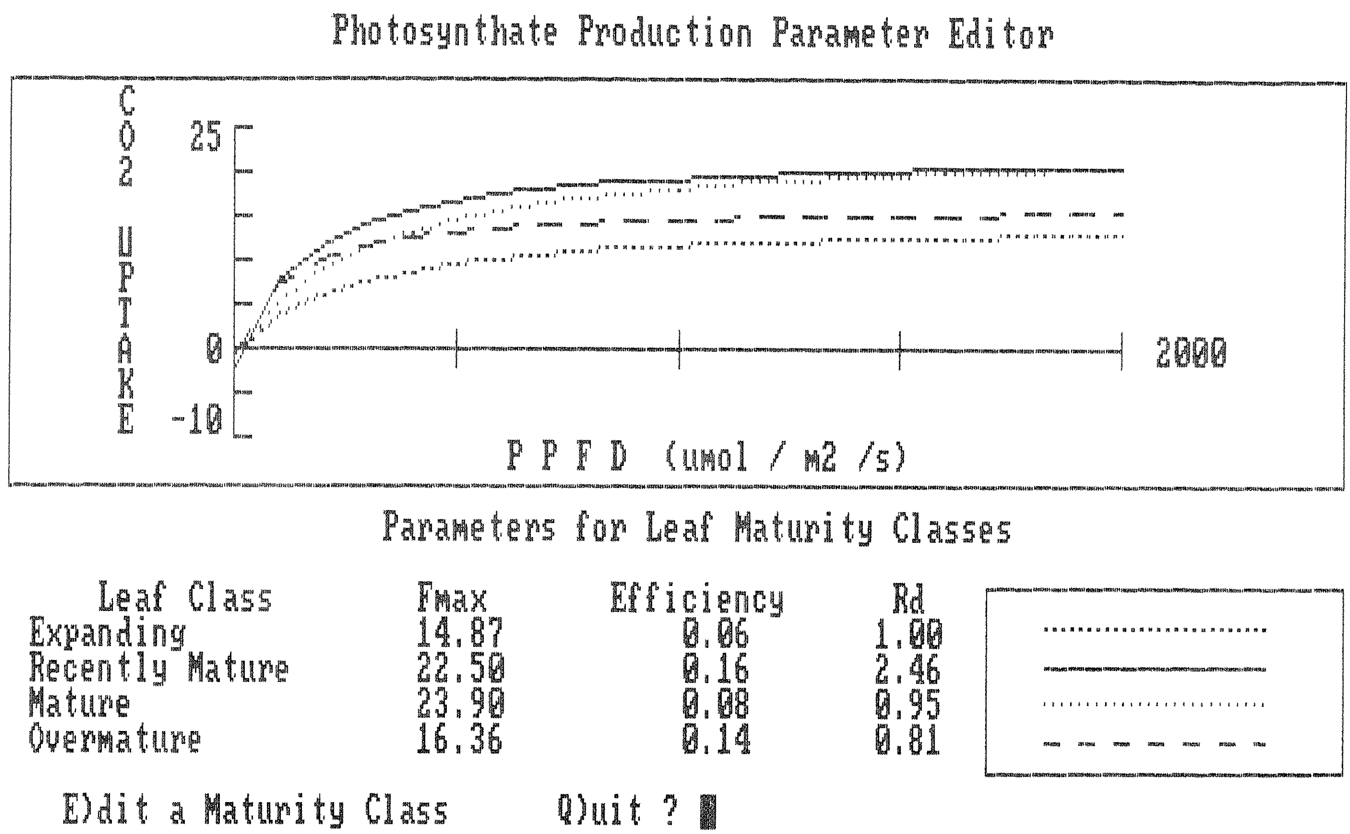


Figure 12.—*The Photosynthate Production Function Editor screen allows the production curve for a leaf maturity class to be changed by altering one of three parameters.*

comparison. Multiple curves may be plotted to test the effects of different parameters. When a desired curve is obtained, the user may write the new parameters to the clonal library file. Alternatively, the user may exit without saving the changes. The user may edit parameters for the other leaf maturity classes or return to the selection menu.

3.2.2 Respiration rates

This editor controls the rates of growth and maintenance respiration. The growth respiration rate is expressed as a ratio representing the proportion of photosynthate lost to respiration during growth of the leaves, stem, cutting, and roots. The maintenance respiration rate is expressed as the proportion of photosynthate consumed on a daily basis for maintenance respiration.

3.2.3 Temperature correction factors

This editor controls the temperature correction factors for photosynthesis and respiration. Leaf temperatures have been divided into eight classes; each temperature class has Temperature Correction Factors (TCF's) for photosynthesis and respiration. The amount of photosynthate produced or respired is multiplied by the appropriate TCF to adjust for temperature. Photosynthesis TCF's range from 0 to 1.00; respiration TCF's may exceed 1.00.

3.2.4 Morphological variables

The morphological variables describe the general orientation of new leaves produced during the simulation. (The orientations of leaves on the Initial Tree are edited using the INITIAL TREE option from the MAIN

MENU - see Section 3.1). The general orientation variables are the leaf midrib angle, leaf lamina angle, leaf shape code, and the petiole angle. Definitions of these variables are presented in section 4.2, The Initial Tree Data Files.

3.2.5 Phenological variables

Phenological variables are the bud break, bud set, and leaf senescence dates. Leaf senescence has not yet been built into the model; as a result, the simulation should end at the bud set date. The leaf initiation rate (expressed as number of hours between leaf initiations) is also edited in this screen. Photosynthates are distributed throughout the plant and converted to biomass and dimensional growth at each leaf initiation period. Biomass is converted to dimensional growth as functions of the Expanding Zone Specific Leaf Area, the Leaf Width/Length Ratio, and the Internode Specific Gravity, also included in this screen.

3.2.6 Carbon transport coefficients

The carbon transport coefficients determine the total proportion of photosynthates exported from a leaf and the pattern of photosynthate allocation from the leaf to various growth centers within the plant. Three screens are used to edit the coefficients that determine allocation patterns. The screen for editing the downward transport coefficients (*i.e.*, lower stem internodes, cutting and roots) presents a summary table of both upward and downward transport coefficients (fig. 13). Two screens allow users to edit the upward transport coefficients (*i.e.*, transport upward to leaves and transport upward to internodes); these screens display the leaf-by-leaf SOURCE/DESTINATION matrices (figs. 14 and 15).

The transport coefficient editor has a spreadsheet-style format with help and error message screens. The cursor arrow and return keys are used to select the coefficient to edit; a status line at the top of the screen shows the SOURCE and DESTINATION LPI's and the current value of the cell. New coefficient values must lie between 0 and 1; the program will not accept out-of-range values. Coefficients that have been changed remain highlighted, and the TOTALS columns are adjusted accordingly. The <ESC> key returns the user to a file management menu.

The sum of the transport coefficients for each SOURCE LPI must, by definition, equal 1.0. The sum

Transport Coefficient Summary Screen

	Source LPI														
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19-50
Upward Transport															
Leaf	.73	.67	.49	.42	.31	.22	.17	.12	.13	.1	.1	.06	.03	0	0
Internode	.25	.27	.23	.24	.17	.17	.22	.16	.1	.1	.05	.02	.02	0	0
Downward Transport															
Internode	.02	.03	.09	.11	.26	.33	.3	.3	.3	.3	.3	.3	.3	.3	.35
Cutting	0	.01	.02	.03	.04	.05	.07	.08	.09	.1	.11	.11	.11	.15	.2
Root	0	.02	.17	.2	.22	.23	.24	.34	.38	.4	.44	.51	.54	.55	.45
Total=	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Figure 13.—*Summary screen for all photosynthate transport coefficients.*

Modify Transport Coefficients

	Source LPI 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
0					.25	.06	.04	.04	.04	.04	.05	.05	.05	.05	.05	.03	.01	.01
1						.24	.02	.03	.09	.04	.01	.04	.01	.01	.03	.02	.01	.01
D 2					.29	.01	.22	.04	.08	.01	.05	.01	.05	.01	.02	.01	.01	
e 3					.18	.28	.01	.18	.03	.03	.01	.02	.01	.03				
s 4					.01	.08	.16	.01	.05	.03	.01		.01					
t 5							.03	.11		.05	.01							
i 6							.01	.01	.01		.03							
n 7									.01	.01								
a 8										.01								
t 9																		
i 10																		
o 11																		
n 12																		
13																		
L 14																		
P 15																		
I 16																		
17																		
18																		
SUM=	0	0	0	0	.73	.67	.49	.42	.31	.22	.17	.12	.13	.1	.1	.06	.03	

Figure 14.—*The Upward Leaf Transport Coefficient Editor screen.*

Modify Transport Coefficients

	Source LPI 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
0					.01	.03	.02	.02	.02	.02	.01	.01	.00	.00	.00	.00	.00	.00
1					.01	.02	.02	.02	.02	.02	.01	.01	.00	.00	.00	.00	.00	.00
D 2					.01	.02	.02	.02	.02	.01	.01	.01	.00	.00	.00	.00	.00	.00
e 3					.03	.03	.02	.02	.02	.02	.01	.01	.00	.00	.00	.00	.00	.00
s 4					.05	.03	.02	.03	.01	.01	.01	.01	.00	.00	.00	.00	.00	.00
t 5					.14	.04	.03	.03	.01	.02	.01	.01	.00	.00	.00	.00	.00	.00
i 6						.1	.05	.03	.01	.01	.01	.01	.00	.00	.00	.00	.00	.00
n 7							.05	.03	.01	.02	.01	.01	.00	.00	.00	.00	.00	.00
a 8								.04	.03	.01	.01	.01	.00	.00	.00	.00	.00	.00
t 9									.02	.02	.01	.01	.00	.00	.00	.00	.00	.00
i 10										.01	.01	.01	.00	.00	.00	.00	.00	.00
o 11											.01	.01	.00	.00	.00	.00	.00	.00
n 12												.01	.00	.00	.00	.00	.00	.00
13													.00	.00	.00	.00	.00	.00
L 14														.00	.00	.00	.00	.00
P 15															.00	.00	.00	.00
I 16																.00	.00	.00
17																	.00	.00
18																		.00
SUM=	0	0	0	0	.25	.27	.23	.24	.17	.17	.22	.16	.1	.1	.05	.02	.02	

Figure 15.—*The Upward Internode Transport Coefficient Editor screen.*

of coefficients for each LPI is presented on the last line of the summary screen; if the coefficients do not sum to 1.0, the total for that column is highlighted in red and white.

**THE DATA FILES CANNOT BE SAVED UNLESS **

ALL TRANSPORT coefficients SUM TO 1.0.

This error trap prevents invalid coefficient matrices from being used by the model.

The transfer coefficients are stored in three ASCII files that have the following file extensions:

.LTC - upward transport to leaves
.ITC - upward transport to internodes
.DTC - downward transport to internodes, cutting, and roots

Tables 9 to 11 show the format of these files. The transport coefficient files are read by the program GROW, which is executed each time a new leaf is initiated (fig. 8). These files are associated with a given clone through the clonal library file (Section 4.1).

The SAVE AND EXIT or QUIT options return the user to the EDIT CLONAL DATA menu. The SAVE AND EXIT option replaces the three original files with the revised versions.

3.2.7 Main menu

This option ends the editing session and returns the user to the MAIN MENU. Changes made during editing will be used in the current simulation. The user has the option of writing these changes to the disk-based Clonal Library File for use in future simulations.

3.3 WEATHER - Editing Solar Radiation and Temperature Data

The weather editing screen displays the solar radiation and temperature data for a 24-hour period on a specified Julian date (fig. 16). Solar radiation is expressed as photosynthetically active photon flux

Table 9.—*Example of the EUGENEI.LTC file, containing the photosynthate transport coefficients that control transport upward to leaves*[1]

0	0	0	0	0.25	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.03	0.01	0.01
0	0	0	0	0	0.24	0.02	0.03	0.1	0.06	0.01	0.04	0.01	0.01	0.03	0.02	0.01	0.01
0	0	0	0	0.29	0.01	0.24	0.04	0.1	0.01	0.05	0.01	0.05	0.01	0.02	0.01	0.01	0
0	0	0	0	0.18	0.28	0.01	0.21	0.03	0.04	0.01	0.02	0.01	0.03	0	0	0	0
0	0	0	0	0.01	0.08	0.18	0.01	0.06	0.03	0.01	0	0.01	0	0	0	0	0
0	0	0	0	0	0	0.03	0.12	0	0.06	0.01	0	0	0	0	0	0	0
0	0	0	0	0	0	0.01	0.01	0.01	0	0.03	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0.01	0.01	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

[1]Values represent the fraction of total exported photosynthates sent upwards to leaves.

Table 10.—*Example of the EUGENEI.UTC file, containing the photosynthate transport coefficients that control transport upward to stem internodes*[1]

0	0	0	0	0.01.	0.03	0.02	0.02	0.02	0.02	0.018333	0.012307	0.007142	0.006666	0.003125	0.001176	0.001111	0.000526
0	0	0	0	0.01	0.02	0.02	0.02	0.02	0.02	0.018333	0.012307	0.007142	0.006666	0.003125	0.001176	0.001111	0.000526
0	0	0	0	0.01	0.02	0.02	0.02	0.02	0.02	0.018333	0.012307	0.007142	0.006666	0.003125	0.001176	0.001111	0.000526
0	0	0	0	0.03	0.03	0.02	0.03	0.02	0.02	0.018333	0.012307	0.007142	0.006666	0.003125	0.001176	0.001111	0.000526
0	0	0	0	0.05	0.03	0.03	0.03	0.02	0.02	0.018333	0.012307	0.007142	0.006666	0.003125	0.001176	0.001111	0.000526
0	0	0	0	0.14	0.04	0.03	0.05	0.02	0.02	0.018333	0.012307	0.007142	0.006666	0.003125	0.001176	0.001111	0.000526
0	0	0	0	0	0.1	0.07	0.03	0.02	0.02	0.018333	0.012307	0.007142	0.006666	0.003125	0.001176	0.001111	0.000526
0	0	0	0	0	0	0.07	0.03	0.01	0.02	0.018333	0.012307	0.007142	0.006666	0.003125	0.001176	0.001111	0.000526
0	0	0	0	0	0	0	0.06	0.04	0.02	0.018333	0.012307	0.007142	0.006666	0.003125	0.001176	0.001111	0.000526
0	0	0	0	0	0	0	0	0.03	0.02	0.018333	0.012307	0.007142	0.006666	0.003125	0.001176	0.001111	0.000526
0	0	0	0	0	0	0	0	0	0.02	0.018333	0.012307	0.007142	0.006666	0.003125	0.001176	0.001111	0.000526
0	0	0	0	0	0	0	0	0	0	0.018333	0.012307	0.007142	0.006666	0.003125	0.001176	0.001111	0.000526
0	0	0	0	0	0	0	0	0	0	0	0.012307	0.007142	0.006666	0.003125	0.001176	0.001111	0.000526
0	0	0	0	0	0	0	0	0	0	0	0	0.007142	0.006666	0.003125	0.001176	0.001111	0.000526
0	0	0	0	0	0	0	0	0	0	0	0	0	0.006666	0.003125	0.001176	0.001111	0.000526
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.003125	0.001176	0.001111	0.000526
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001176	0.001111	0.000526
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001111	0.000526
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.000526

[1] Values represent the fraction of total exported photosynthates sent upwards to stem internodes.

Table 11.—*Example of the EUGENEI.DTC file, containing the photosynthate transport coefficients that control transport downward to stem internodes, cutting and roots*[1]

.02	.03	.09	.11	.26	.33	.40	.40	.40	.40	.40	.40	.40	.40	.40
.00	.01	.02	.03	.04	.05	.07	.08	.09	.10	.11	.11	.11	.12	.15
.00	.02	.07	.10	.12	.13	.14	.24	.28	.30	.34	.41	.44	.45	.45

[1]Values represent the fraction of total exported photosynthates sent to sinks below the source leaf.

density (PPFD) in umol/m²/s; temperature is expressed in degrees C. Weather information may be taken from actual records or generated based on averages and/or desired conditions. The weather data are stored in the random access file WEATHER.EXT, where the file extension, .EXT, denotes the geographic location. WEATHER.RHI, for example, contains the weather data for Rhinelander, Wisconsin; WEATHER.WAS contains the weather data for Washington State. The name of the desired weather file is specified in the clonal library file (Sections 4.1, 4.3). Weather data can be edited on a day-by-day basis; the PgUp and PgDn keys allow the user to move between days. The <ESC> key saves the changes and returns the user to the MAIN MENU.

Currently, the weather files contain information for a single year in a specific location. Future versions of ECOPHYS will include a micro-climate simulator to create weather input files with user-designated characteristics.

3.4 SITE - Editing Site Information

SITE is used to change the geographic latitude and the soil reflectance values. Latitude is important in determining the appropriate solar altitudes and azimuths for a given hour. Light reflected from the soil surface may contribute to photosynthate production; the soil reflectance variable allows the user to vary this factor for different soil types. In future versions of ECOPHYS, other environmental variables, such as soil texture, drainage class, and nutrient status will be added to the SITE option. These environmental variables will allow the model to operate under suboptimal (*e.g.*, moisture stress or nutrient deficits) conditions. The <ESC> key saves the changes and returns the user to the MAIN MENU.

```
                         WEATHER DATA

          Julian Date:  204          Year:    1979

   Solar          Air                  Solar          Air
   Time    PPFD   Temp                 Time    PPFD   Temp
   -----   ----   ----                 -----   ----   ----
    01        0   18.8                  13     1580   25.5
    02        0   18.3                  14     1531   26.6
    03        0   17.7                  15     1482   25.5
    04        0   17.7                  16     1383   23.3
    05        0   17.2                  17     1136   23.8
    06        0   18.8                  18      592   23.8
    07      247   20.5                  19      296   23.3
    08      543   21.6                  20       49   22.7
    09      938   22.7                  21        0   22.7
    10     1185   23.3                  22        0   22.2
    11     1432   23.8                  23        0   21.6
    12     1482   23.8                  24        0   21.1
```

Figure 16.—*The Weather Data Editor allows the user to change the hourly light and temperature levels on selected Julian dates.*

4. The Clonal Library System

ECOPHYS was originally developed to model the growth of *P. eugenei*, but has since been expanded to accommodate other poplar clones. The Clonal Library System was developed to allow simulation of different poplar clones, with each clone defined by a set of morphological, physiological, and phenological parameters. These parameters are stored in CLONAL LIBRARY FILES. For a given clone, the CLONAL LIBRARY FILES comprise a main file (file extension .CLF), and several subordinate files, which contain the photosynthate transport coefficients, the initial tree data, and weather and site data (table 4). The following sections describe the structure of the CLONAL LIBRARY FILES and the information required to add a new clone to the ECOPHYS clonal library.

4.1 Clonal Library Files

The main clonal library file is named by clone plus file extension .CLF (*e.g.*, EUGENEI.CLF). The main library file consists of 21 lines, with the following information on each line:

The first eight lines contain the names of disk files enclosed in quotation marks. These files contain the weather and site data, initial tree data, and photosynthate transport coefficients. Having the file names stored in the clonal library allows the user a simple means of changing large blocks of information without editing the individual records. Files may have any legal DOS filename; it is best to name the files for their content and their clonal or geographic affiliation. For example, the files used by *P. eugenei* are:

"WEATHER.RHI" - weather data from Rhinelander, Wisconsin
"SITE.RHI" - latitude and soil reflectance for Wisconsin
"EUGENEI.INT" - the "initial leaf/tree" data matrix
"EUGENEI.STM" - the "initial cutting/root" data matrix
"EUGENEI.LTC" - upward leaf transport coefficients
"EUGENEI.ITC" - upward stem internode transport coefficients
"EUGENEI.DTC" - downward transport coefficients
"EUGENEI.PTC" - proportion of photosynthate exported

The ninth line contains the following phenological and morphological data:

- bud break date (Julian)
- bud set date (Julian)
- leaf senescence date (Julian)
- leaf initiation rate (number of days)
- leaf senescence rate (number of days)
- initial expanding leaf zone specific leaf area (cm^2/mg)
- budset expanding leaf zone specific leaf area (cm^2/mg)
- internode specific gravity (g/cm^3)
- ratio of leaf width to leaf length

The 10th line contains growth and maintenance respiration rates. The growth respiration rate is expressed as a ratio, and maintenance respiration is expressed on a per day basis.

The 11th and 12th lines each contain eight temperature correction factors for photosynthesis and respiration rates, respectively. The eight factors correspond to the following temperature ranges (degrees C):

- <= 7
- 8 - 12
- 13 - 17
- 18 - 22
- 23 - 27
- 28 - 32
- 33 - 37
- >= 38

The 13th through 17th lines contain leaf orientation data. There are six variables per line. The first two variables identify a range of leaf numbers (leaf numbers from base). The remaining four variables are the leaf midrib angle, leaf lamina angle, petiole angle, and the leaf shape code.

The 18th through 21st lines define the photosynthate production curves, *i.e.*, the amount of photosynthate produced per unit of light. Photosynthate production is calculated according to the hyperbolic model shown in fig. 17 (DeVries and van Laar 1982). The equations defining this relationship have the form:

$$CER = \frac{((Fmax + Rd) * Pe * PPFD)}{(Pe * PPFD) + Fmax + Rd} - Rd$$

where CER is the carbon dioxide exchange rate, PPFD is solar radiation, Fmax is the maximum rate of photosynthesis at light saturation, Rd is dark respiration (*i.e.*, Y intercept), and Pe is the efficiency of production at low light intensities (*i.e.*, the slope of the curve at the X axis) (Host *et al.* 1990b).

ECOPHYS divides the leaves on a tree into four maturity classes: expanding leaves (MC1), recently mature leaves (MC2), mature leaves in upper crown (MC3), and mature leaves in lower crown (MC4). Each maturity class has its own photosynthate production equation; for example, line 18 contains the Fmax, Pe, and Rd coefficients for Maturity Class 1, line 19 contains the coefficients for MC2.

The completed clonal library data for *P. eugenei*, which is named EUGENEI.CLF, are as follows:

```
"WEATHER.RHI"
"SITE.RHI"
"EUGENEI.CLF"
"EUGENEI.STM"
"EUGENEI.LTC"
"EUGENEI.ITC"
"EUGENEI.DTC"
"EUGENEI.PTC"
    128  252  268  37  0  .2222  .28  1.0
    .25  .015
    .22  .46  .65  .79  .95  1  .95  .79
    .17  .3  .67  1  1.1  1.3  1.83  2.5
    20  100  100  60  100  .2
    0  0  0  0  0  0
    0  0  0  0  0  0
    0  0  0  0  0  0
    0  0  0  0  0  0
   14.87  .06  1.00
   22.50  .16  2.46
   23.9   .08  0.95
   16.36  .14  0.81
```

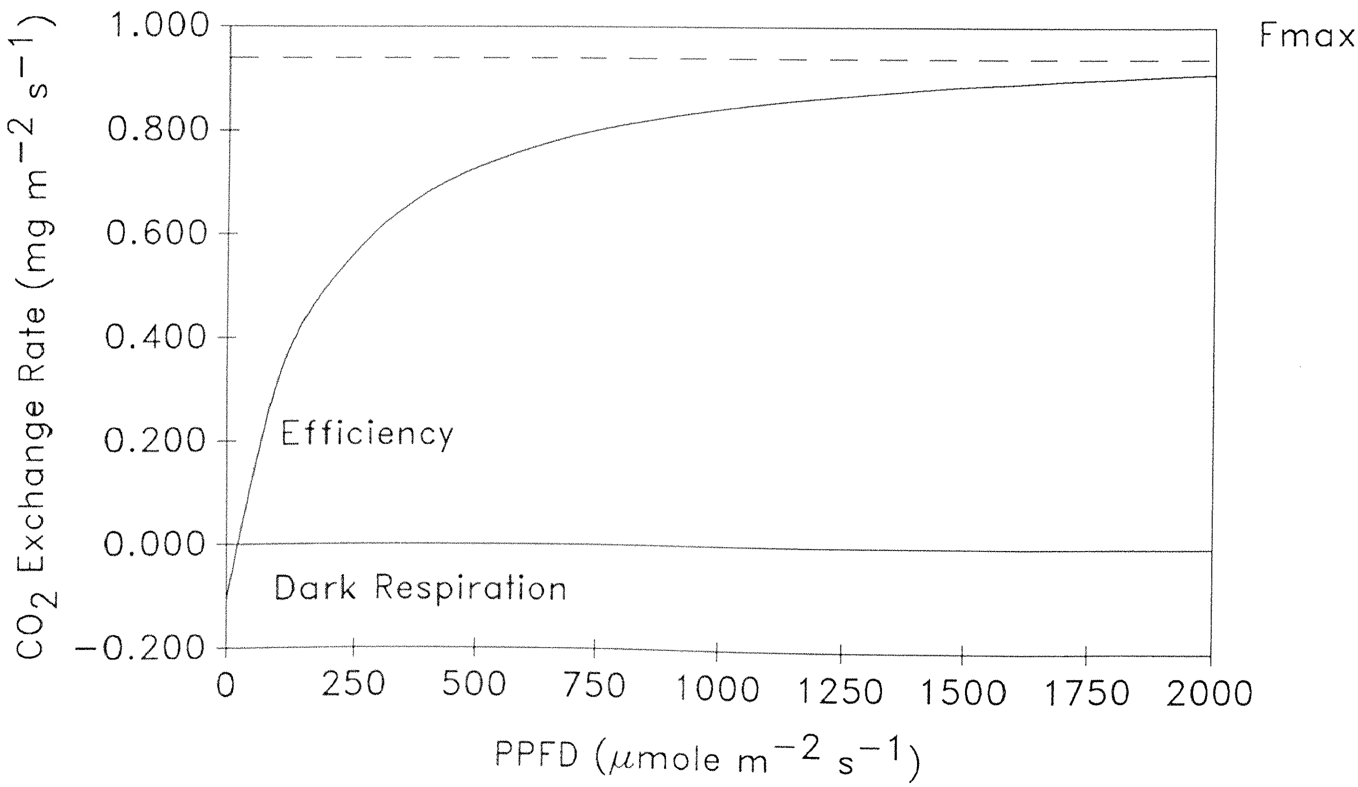


Figure 17.—*The relationship between photosynthate production and intercepted radiation, as modeled by a hyperbolic function (from DeVries and van Laar 1982).*

This set of data provides all the information required by ECOPHYS to define phenological, physiological, and morphological characteristics of *P. eugenei*, as well as the required environmental data. All data contained in this file may be edited using the previously described editors.

In addition to this information, data describing the initial tree on a specified Julian date must be provided; the following section describes the format of the initial tree data, which, for *P. eugenei*, are stored in the files EUGENEI.INT and EUGENEI.STM.

4.2 The Initial Tree Data Files

ECOPHYS requires that an initial tree be supplied as a starting point for the simulation. Information describing the individual leaves and internodes of the initial tree is contained in the Initial Tree Data File (*e.g.*, EUGENEI.INT). This file contains a detailed record of the dimensions and orientation of the leaves and internodes of the initial tree on a starting Julian date. A related file (EUGENEI.STM) contains information on the cutting and root mass. The information contained in these files is accessed by the Clonal Library File (see previous section).

For most purposes, the initial tree should represent a "typical" tree for the clone; that is, the values for a given attribute should approximate the population mean for that attribute. Usually a set of empirical measurements is used to create the initial tree, but many of these attributes may also be calculated or estimated. Table 12 shows the Initial Tree Data File for *P. eugenei*. The first two values are the starting Julian date and number of leaves, respectively. Each row of the table presents the information for an individual leaf/internode combination, with leaves ordered from the base upward. Each column of the matrix describes an attribute of a leaf or stem internode. The following sections describe each of the initial tree attributes, and present methods of estimating these attributes.

<u>Column 1 - Leaf Number From Base (LNFB)</u>

Leaves are numbered consecutively from the base of the tree, with the lowermost leaf numbered as LNFB 1.

<u>Column 2 - Leaf Age (days)</u>

The number of days from when the leaf was initiated to the starting Julian date. The uppermost leaf will generally be 1 day old. The Leaf Initiation Rate (from the Clonal Library File) can be used to calculate the ages of the other leaves; for example, in *P. eugenei*, each leaf is 2 days older than the leaf above it.

<u>Column 3 - Leaf Maturity Code (1 to 4)</u>

The leaf maturity codes determine which photosynthate production parameters (Fmax, Pe, and Rd) are used to calculate photosynthate production from an individual leaf. The maturity codes are based on crown position, and are coded as follows:

Maturity code	**Leaf type**	**LPI (*P. eugenei*)**
1	Immature (expanding)	0-9
2	Recently mature	10-12
3	Mature	13-15
4	Overmature	16-21

<u>Column 4 - Leaf Blade Length (cm)</u>

Length of the leaf blade (*i.e.*, base of the leaf to the leaf apex along midrib) in cm.

<u>Column 5 - Leaf Blade Width (cm)</u>

Width of the blade (cm) at its widest point. The measurement is made perpendicular to the leaf midrib. It may be possible to estimate blade widths if the length:width ratio is known.

<u>Column 6 - Leaf Area (cm^2)</u>

The area of the leaf blade in cm^2. This value is most accurately obtained using a leaf area meter. If actual measurements of lengths, widths, and areas are available, a linear regression may be developed to predict area from length*width.

<u>Column 7 - Leaf Shape Code (0-1)</u>

The leaf shape code is a decimal value ranging from 0 to 1. This value determines the location of the widest part of the leaf blade along the leaf midrib. Low values produce a triangular or deltoid leaf shape, while values of .5 produce a more rhomboidal leaf. High values would produce a leaf that was wide at the apex and tapered toward the base. The shape code for *P. eugenei* ranges from 0.16 to 0.2.

Table 12.—*Example initial tree data for* P. eugenei

Initial date: **204**
# of leaves: **22**

		MAT.	BLADE				PETIOLE				MIDRIB		LAM.	DAY OF		INTERNODE						LEAF
LFNB	AGE	CODE	LENGTH	WIDTH	AREA	SHAPE	LENGTH	ANG.	AZM.	LOC.	AZM.	ANG.	ANG.	INIT.	LPI	LENGTH	DIAM.	LS	S	MASS	IS	MASS
	days		*cm*	*cm*	*sq cm*		*cm*	*deg*	*deg*	*cm*	*deg*	*deg*	*deg*	*Julian*		*cm*	*cm*	*mg/CO_2*		*g*	*mg/CO_2*	*g*
1	42	4	3.5	3.5	10.0	0.20	1.8	65	0.0	1.52	0	97	40	162	21	1.52	0.60	0	0	0.14	0	0.090
2	40	4	3.6	3.6	10.2	0.20	2.0	60	144.0	3.04	144	77	35	164	20	1.52	0.55	0	0	0.14	0	0.100
3	38	4	5.7	5.7	17.0	0.20	2.3	49	288.0	4.56	288	90	140	166	19	1.52	0.52	0	0	0.14	0	0.170
4	36	4	6.0	6.0	15.8	0.18	2.4	90	72	7.44	72	90	30	168	18	2.90	0.50	0	0	0.19	0	0.163
5	34	4	6.8	6.8	20.2	0.19	2.7	85	224	10.34	224	85	20	170	17	2.90	0.49	0	0	0.18	0	0.211
6	32	4	6.5	6.5	23.8	0.18	2.6	94	0	13.24	0	94	45	172	16	2.90	0.48	0	0	0.17	0	0.247
7	30	3	8.7	8.7	39.8	0.27	3.3	65	148	16.14	148	65	75	174	15	2.90	0.46	0	0	0.15	0	0.342
8	28	3	7.5	7.5	33.4	0.16	2.9	95	244	19.04	244	95	140	176	14	2.90	0.45	0	0	0.14	0	0.308
9	26	3	9.4	9.4	53.8	0.17	3.5	100	48	21.94	48	100	155	178	13	2.90	0.44	0	0	0.13	0	0.413
10	24	2	9.8	9.8	53.9	0.19	3.6	80	202	24.84	202	80	20	180	12	2.90	0.43	0	0	0.12	0	0.379
11	22	2	9.6	9.6	66.9	0.16	3.5	95	322	27.74	322	95	130	182	11	2.90	0.42	0	0	0.11	0	0.385
12	20	2	10.2	10.2	70.0	0.18	3.7	80	137	30.64	137	80	45	184	10	2.90	0.42	0	0	0.11	0	0.341
13	18	1	8.2	8.2	80.0	0.18	3.1	90	260	33.54	260	90	30	186	9	2.90	0.41	0	0	0.10	0	0.292
14	16	1	9.6	9.6	80.0	0.18	3.5	110	44	36.44	44	110	30	188	8	2.90	0.41	0	0	0.10	0	0.353
15	14	1	10.0	10.0	78.4	0.18	3.7	100	148	39.34	148	100	145	190	7	2.90	0.40	0	0	0.09	0	0.377
16	12	1	8.6	8.6	55.8	0.18	3.2	100	294	41.88	294	100	145	192	6	2.54	0.40	0	0	0.08	0	0.252
17	10	1	9.2	9.2	48.9	0.17	3.4	110	84	44.08	84	110	140	194	5	2.20	0.40	0	0	0.06	0	0.241
18	8	1	7.6	7.6	30.9	0.18	2.9	115	214	45.94	214	115	10	196	4	1.86	0.40	0	0	0.05	0	0.155
19	6	1	5.9	5.9	16.3	0.18	2.4	90	4	47.40	4	90	70	198	3	1.50	0.40	0	0	0.04	0	0.090
20	4	1	5.7	5.7	15.2	0.2	2.3	80	118	48.6	118	80	110	200	2	1.1	0.40	0	0	0.03	0	0.082
21	2	1	3.7	3.7	5.5	0.2	1.7	55	260	49.4	265	55	75	202	1	0.8	0.40	0	0	0.02	0	0.033
22	1	1	2	3.2	3.5	0.18	1.5	55	42	49.9	42	55	75	204	0	0.5	0.4	0	0	0.01	0	0.025

Column 8 - Petiole Length (cm)

Petiole length from the point of stem insertion to the leaf base. Petiole length may be estimated using the following equation (Pieters 1974):

Petiole length = .4836 + (.3178 * leaf blade length)

Column 9 - Petiole Angle (0 to 180 degrees)

Vertical angle of the petiole, measured by holding the 0° mark of a protractor toward the petiole base. If unavailable, set the petiole angle equal to the midrib angle (Column 13).

Column 10 - Petiole Azimuth (0 to 360 degrees)

The deviation of the midrib from magnetic north, based on a 360-degree coordinate system. If unavailable, set the petiole azimuth equal to the midrib azimuth (Column 12).

Column 11 - Petiole Location (cm)

Height of the petiole insertion above ground level. This value can also be calculated as the cumulative sum of stem internode lengths.

Column 12 - Midrib Azimuth (0 to 360 degrees)

The deviation of the midrib from magnetic north, based on a 360 degree coordinate system.

Column 13 - Midrib Angle (0 to 180 degrees)

Vertical angle of the midrib, measured by holding the 0° mark of a protractor toward the leaf's base and reading midrib angle where the plumb line intercepts the measurement scale (fig. 18a).

Column 14 - Lamina Angle (degrees)

Angle of the lamellar plane at its widest point and perpendicular to the midrib. This value is measured by

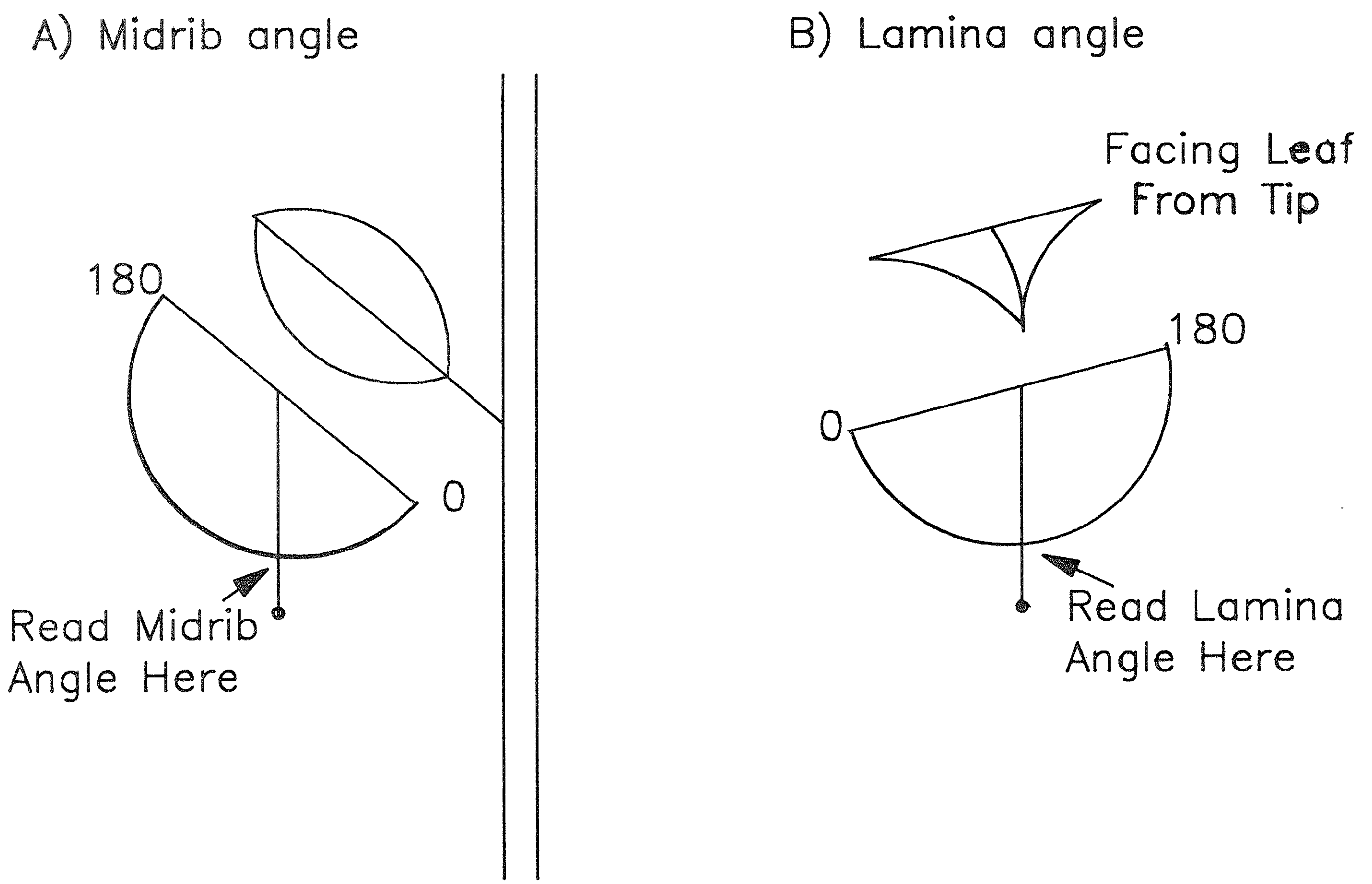


Figure 18.—*Methods used to measure leaf midrib and lamina angles. A) Leaf midrib angles are determined by holding the protractor parallel to the midrib and with the zero on the protractor scale toward the stem. Angle is read where the plumb line intercepts the protractor scale. B) Lamina angles are determined with the zero on the protractor scale held to the left, again using a plumb line.*

holding the 0° mark of a protractor on the left side of the leaf when facing the leaf tip (fig. 18b).

Column 15 - Day of Initiation (Julian Date)

The Julian date a leaf was initiated. The date of the youngest leaf will generally be one leaf initiation period less than the current Julian date. Initiation dates for other leaves may be determined by subtracting the leaf initiation period from each preceding date.

Column 16 - Leaf Plastochron Index (LPI)

LPI's are numbered consecutively from the top of the plant down, with the most recently emerged leaf (*i.e.*, 2 cm in length) defined as LPI 0 (Larson and Isebrands 1971). LPI's can be calculated by subtracting the LNFB (Column 1) from the total number of leaves.

Column 17 - Internode Length (cm)

The length of the internode between the petiole insertion of the current leaf and the petiole insertion of the next lower leaf.

Column 18 - Internode Diameter (cm)

Individual internodes are modeled as cylinders, so that diameter is constant for the length of an individual internode. Also, diameters of the internodes for LPI's 0 through 7 are constant; internode diameter growth does not begin until LPI 8. If basal diameter (*i.e.*, diameter 2.5 cm above the point of insertion of the main stem on the cutting) is known, the diameters of the intermediate internodes can be calculated by using a linear regression of diameter against LPI using the basal diameter, diameter at internode 7, and an intermediate interpolated value. Because of the geometric computations used to determine internode growth, *height growth of the model is very sensitive to the initial top internode diameter;* therefore, it is important that this value be accurately determined for each clone.

Column 19 - Leaf Photosynthate Storage (mg CO_2)

Photosynthate stored in leaves. In the initial tree matrix this value is 0 for all leaves.

Column 20 - Status (S)

A binary code indicating whether a leaf is shaded (1) or unshaded (0) during run-time. In the initial tree matrix this value is 0 for all leaves.

Column 21 - Internode Mass (g)

This value may be calculated by multiplying internode volume by internode specific gravity. Internode volume can be calculated by:

$$\text{pi} * (\text{diameter}/2)^2 * \text{height}$$

Internode specific gravity is a clonal characteristic; for example, this value was .0045 for *P. eugenei.*

Column 22 - Internode Storage of Photosynthate (mg CO_2)

Photosynthate storage in the stem internodes. In the initial tree matrix this value is 0 for all stem internodes.

Column 23 - Leaf Mass (g)

Leaf mass may be calculated by multiplying leaf area (Column 6) by the specific leaf area for a given day.

In the Initial Tree Data Files, the data matrix is preceded by two values: the starting Julian date and the total number of leaves on the "initial" tree. These values are used to set the starting date and read the initial tree data matrix file correctly. The complete initial tree data file for *P. eugenei* is shown in table 12.

The Initial Tree Data File may be edited by choosing the Leaf/Stem option after selecting the EDIT INITIAL TREE option from the MAIN MENU. The use of this editor has been described in Section 3.1.

The Initial Root/Cutting File (*e.g.*, EUGENEI.STM) describes the initial weight and photosynthate storage of the stem, cutting and roots. The file is structured as a 4 x 2 matrix; the two columns of the matrix represent the initial weight (in grams) and the initial photosynthate storage (in mg CO_2), and the four rows refer to the stem, cutting, coarse root, and fine root components of the plant. This data may be edited using the Root/Cutting option after selecting EDIT INITIAL TREE from the MAIN MENU.

4.3 The Weather Data File

The current version of ECOPHYS contains weather data files for three geographic areas: Rhinelander, Wisconsin USA (1979); Puyallup, Washington, USA (1985); and East Lansing, Michigan, USA (1987). These files are named WEATHER.RHI, WEATHER.WAS, and WEATHER.EL, respectively. The files are attached to a given clone using the

Clonal Library File (Section 4.1). The Rhinelander and East Lansing data represent a midwestern continental climate; the Puyallup data represent the longer, warmer growing season typical of the Pacific Northwest Coastal area of the U.S. Figure 19 shows a comparison of the cumulative heat and solar radiation sums for the three weather locations.

Due to file size and access time constraints, weather data are stored in random access format. Each record in the weather file comprises five variables or fields:

Julian date as a three-digit integer (1 to 365 or 366)
Year as a four-digit integer (*e.g.*, 1987)

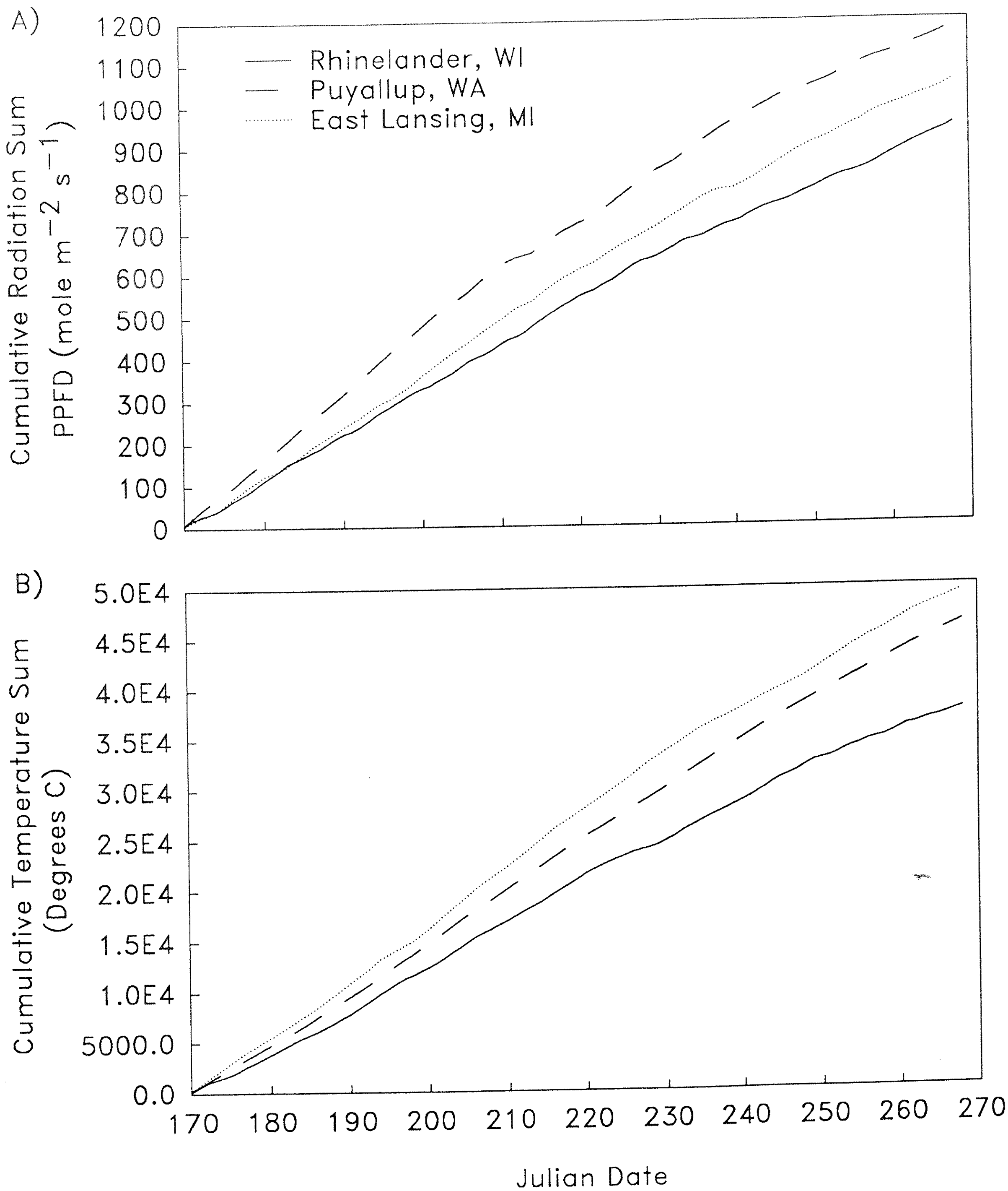


Figure 19.—*A) Comparison of cumulative heat sum between Rhinelander, WI and Puyallup, WA. B) Comparison of cumulative solar radiation between Rhinelander, WI and Puyallup, WA.*

Solar hour as a two-digit integer (1 to 24)
PPFD as a four-digit integer (0 to 9999)
Air temperature (C) as a three-digit real number (one decimal place, *e.g.*, 24.7)

All values are stored in IEEE format, a file format that provides efficient and accurate storage for floating-point decimals. A utility program (CONVERT.EXE) to convert ASCII flat files to IEEE format is distributed with ECOPHYS. It is necessary to store only the weather data for dates within the growing season. Because each record (the basic unit of a random access file) contains the information for one solar hour, the beginning record number for a given Julian date can be calculated as:

Record # =((Julian date - 1) * 24)

Once the weather file has been created, individual records may be edited using the WEATHER option from the MAIN MENU.

5. Summary

5.1 Model Applications

The ECOPHYS growth process model provides a means of simulating the growth of poplar clones under different environmental conditions, or with different morphological and/or physiological characteristics. As such, the model has several important applications for the intensive culture of poplar. The model may be used to evaluate and screen the growth potential of a large number of poplar clones for intensive culture, a process that is costly and time consuming when conducted through field trials. It may also aid the poplar geneticist in identifying "ideotypes" of poplar and developing morphological and physiological criteria for genetic selection. Because the growth form of an "ideotype" poplar will likely differ by climatic region, the model may be used to identify optimal growth forms for particular climatic regions (Host and Rauscher 1990). At the plantation level, silvicultural practices may be tailored to particular poplar clones or clonal mixtures based on an understanding of the predominant light interception strategies for those trees.

ECOPHYS may also be used for heuristic purposes, *i.e.*, to identify areas for future research. For example, we know that carbon allocation patterns vary as a response to stress, but do not clearly understand this stress response mechanism. To build the stress response into the model requires development of a theoretical basis for a control mechanism (*i.e.*, hormonal regulation of photosynthate distribution), translation of the theory into computer algorithms, and the physical experimentation required to test the theory (Isebrands *et al.* 1990). The use of the model to identify research needs may be one of the most powerful attributes of the simulation modeling approach.

Finally, ECOPHYS can be used to illustrate some of the basic processes of tree physiology; for example, the temperature-mediated production of photosynthates at varying quantities of sunlight, the distribution of photosynthates throughout the plant system, and the conversion of photosynthate to plant tissues and subsequent dimensional growth. The computer-simulated illustration of these fundamental processes of tree growth can be used to augment the laboratory exercises used in tree physiology or basic plant biology courses. Moreover, it can show the value of using a simulation modeling approach to solve biological problems.

5.2 Model Validation

The three clones currently accessed by the program have undergone extensive validation tests; *i.e.*, the comparison of the model predictions with empirical data. ECOPHYS effectively simulates the dimensional growth and biomass production of *P. eugenei* (Host and Rauscher 1990a). The model also predicts height growth patterns for clones Ill-5 and 44-136 within one standard deviation of the sample means (Host *et al.* 1990a). Model predictions of diameter growth and biomass production were lower than the observed data, primarily because the transfer coefficients for these clones were unavailable, and the *P. eugenei* coefficients were used in their place. Use of the empirical transfer coefficients, when available, is expected to improve the predictive ability of the model for these clones.

5.3 Future Developments

The future development of ECOPHYS will proceed along four lines: 1) the addition of an early growth phase to allow the simulation to begin with a poplar cutting, 2) the development of a root/soil system to allow simulation under suboptimal or stressed conditions, 3) the development of an "expert system" control module that emulates the hormonal regulatory system of the plant, and 4) the development of a micro-climatic weather simulator.

The growth of poplar from a cutting involves a transition from a heterotrophic state in which leaf development is controlled by the amount of carbohydrates stored in the cutting to an autotrophic state in which the leaves supply the carbohydrates used for growth. Simulating the early growth will therefore involve estimating the amount of carbohydrates stored in the cutting and distributing the carbohydrates to the newly developing leaves.

The present version of ECOPHYS assumes that moisture and nutrients are maintained at optimal levels throughout the growing season. Because SRIC plantations are often irrigated and fertilized, these assumptions are broadly met. There is a need, however, to accommodate suboptimal moisture and nutrient regimes so the ECOPHYS model is applicable to a wider range of growing conditions. There is also a need to be able to assess belowground competition for space and for available water and nutrients in poplar plantations. To accommodate these conditions, a root and soil simulation component must be added to the model. The primary biotic factors that must be considered are: 1) the three-dimensional architecture of roots within the soil volume, 2) the distribution of photosynthates from the shoot to the various root size-classes, 3) root respiration, 4) root/shoot feedback mechanisms, and 5) the uptake and translocation from the soil system through the root system and into aboveground portions of the plant. The primary abiotic factors that must be simulated are: 1) the soil moisture content and water transport within the soil system, 2) the release and availability of nutrients, and 3) the soil temperature dynamics. The development of the root/soil system will allow simulation of growth under conditions of moisture or nutrient stress.

Plants' responses to environmental stress or insect damage include alteration of carbon transport patterns, leaf senescence, and reduced growth rates. It is difficult to model some of these qualitative responses to stress with the traditional procedural languages of simulation modeling. We believe that logic-based programming languages will provide a more effective means of simulating plant response to stress. Artificial intelligence or expert systems languages such as PROLOG are well suited for simulating "control"-oriented aspects of the model. The future development of ECOPHYS will include an expert system that emulates the tree's hormonal regulatory system (Rauscher and Isebrands 1990). With continued experimental research, model development, and validation, the model should be able to predict the effects of competition, drought, air pollutants, or insect pests and pathogens on poplar growth, development, and mortality.

ECOPHYS provides the research scientist or science educator with a highly detailed, theoretically based growth process model of poplar. The model was developed by integrating many years of field and laboratory research with conceptual models of plant growth and designing the appropriate computer algorithms to embody these concepts. We believe the model will be valuable both as a specific tool for poplar research and as a general model of juvenile tree development.

5.4 Availability

For information on obtaining the ECOPHYS program files, contact the authors at:

ECOPHYS Simulation Software
USDA Forest Service
Forestry Sciences Laboratory
1831 Highway 169 East
Grand Rapids, Minnesota 55744

A list of registered users will be maintained, and users will be notified of program upgrades. Comments and suggestions for this program are welcome and should be sent to the above address.

The computer program is available on request with the understanding that the U.S. Department of Agriculture cannot assure the accuracy, completeness, reliability, or suitability for any other purpose than that reported. The recipient may not assert any proprietary rights thereto nor represent it to anyone as other than a Government-produced computer program.

The use of trade, firm, or corporation names in this paper is for the information and convenience of the reader. Such use does not constitute official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

6. Literature Cited

Bazzaz, F.A.; Chiariello, N.R.; Coley, P.D.; Pitelka, L.F. 1987. **Allocating resources to reproduction and defense**. BioScience. 37: 58-67

Chapin, F.S.; Bloom, A.J.; Field, C.B.; Waring, R.H. 1987. **Plant responses to multiple environmental factors**. BioScience. 37: 49-56

Crow, T. R.; Isebrands, J.G.; Rauscher, H.M.; Dickson, R.E.; Dickmann, D.I.; Michael, D.A. 1987. 1987. **Effects of canopy architecture on photosynthetic production in *Populus* seedlings: a simulation study**. Bulletin of the Ecological Society of America. 68: 286.

DeVries, F.W.; van Laar, H.H. 1982. **Simulation of growth processes and the model BACROS**. In: DeVries, F.W.; van Laar, H.H., eds. Simulation of plant growth and crop production. Wageningen, Netherlands: Centre for Agricultural Publishing and Documentation. 309 p.

Dickson, R.E. 1986. **Carbon fixation and distribution in young *Populus* trees**. In: Fujimori, T.; Whitehead, D., eds. Proceedings, Crown and canopy structure in relation to productivity. Ibaraki, Japan: Forestry and Forest Products Research Institute: 409-426.

Goudriaan, J. 1982. **Potential production processes**. In: Penning, F.W.T.; van Laar, H.H., eds. Simulation of plant growth and crop production. Wageningen, Netherlands: Centre for Agricultural Publishing and Documentation. 309 p.

Host, G.E.; Rauscher, H.M. 1990. **Validating the regional applicability of a whole-plant growth process model of juvenile poplar**. IUFRO Forest Simulation Systems Conference; 1988 November 2-5. Berkeley, CA: 97-106.

Host, G.E.; Rauscher, H.M.; Isebrands, J.G.; Dickmann, D.I. 1990a. **Validation and verification of the ECOPHYS model using three *Populus* clones**. In preparation.

Host, G.E.; Rauscher, H.M.; Isebrands, J.G.; Michael, D.A. 1990b. **Validation of photosynthate production in ECOPHYS, an ecophysiological growth process model of *Populus***. Tree Physiology. In press.

Isebrands, J.G.; Nelson, N.D. 1983. **Distribution of [14C]-labeled photosynthates within intensively cultured *Populus* clones during the establishment year**. Physiologia Plantarum. 59: 9-18.

Isebrands, J.G.; Rauscher, H.M.; Crow, T.R.; Dickmann, D.I. 1990. **Whole-tree growth process models based on structure-functional relationships**. In: Dixon, R.; Meldahl, R.; Ruark, G.; Warren, W., eds. Forest growth process modeling of responses to environmental stress. Timber Press: 96-112.

Larson, P.R. 1977. **Phyllotactic transitions in the vascular system of *Populus deltoides* Bartr. as determined by ^{14}C labeling**. Planta. 134: 241-249.

Larson, P.R.; Isebrands, J.G. 1971. **The plastochron index as applied to developmental studies of cottonwood**. Canadian Journal of Forest Research. 1: 1-11.

Pieters, G.A. 1974. **The growth of sun and shade leaves of *Populus euramericana* 'robusta' in relation to age, light intensity and temperature.** Meded. Landbouwhogesch. Wageningen. 74: 1-106.

Rauscher, H.M; Isebrands, J.G. 1990. **Using expert systems to model tree development**. IUFRO Forest Simulation Systems Conference, 1988 November 2-5; Berkeley, CA: 129-138.

Rauscher, H.M.; Isebrands, J.G.; Crow, T.R.; Dickson, R.E.; Dickmann, D.I.; Michael, D.A. 1988. **Simulating the influence of temperature and light on the growth of juvenile poplars in their establishment year**. In: Ek, A.R.; Shifley, S.R.; Burk, T., eds. Forest growth modeling and prediction. Gen. Tech. Rep. NC-120. St. Paul, MN: U. S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 331-339.

Rauscher, H.M.; Isebrands, J.G.; Host, G.E.; Dickson, R.E.; Dickmann, D.I.; Crow, T.R.; Michael, D.A. 1990. **ECOPHYS: an ecophysiological growth process model of poplar**. Forest Science. In preparation.

7. APPENDIX - EXAMPLE PRINTER REPORTS

Initial Tree Leaf Data Report
Initial Tree Stem Data Report
Site Data Report
Clonal Library Data Report
Leaf Orientation Report
Leaf Projection Report
Leaf Overlap Report
PPFD Hourly Report
Hourly Photosynthesis Report
Leaf PSYN/Respiration Report
Internode PSYN/Respiration Report
Cutting and Root PSYN/Respiration Report
Photosynthate Distribution and Dimensional
Growth Reports
Leaf Growth Report
Internode Growth Report
Cutting and Root Growth Report

E C O P H Y S   VERSION 2.0   NOVEMBER 1987

THE STARTING DATE IS: 01-03-1989
THE STARTING TIME IS: 09:05:51

RUN TITLE IS: Example Initial Tree Leaf Data Report

INITIAL TREE MORPHOLOGICAL DATA

		Leaf							Petiole			Internode		
LPI	LNFB	Age	Mat. Code	Length (cm)	Width (cm)	Area (cm2)	Dry Wt. (g)	Midrib Azimuth	Length (cm)	Insert. (cm)	Azimuth	Length (cm)	Diam. (cm)	Dry Wt. (g)
0	22	1	1	2.0	3.2	4	0.0250	42	2	49.9	42	0.5	0.400	0.0100
1	21	2	1	3.7	3.7	6	0.0330	265	2	49.4	260	0.8	0.400	0.0200
2	20	4	1	5.7	5.7	15	0.0820	118	2	48.6	118	1.1	0.400	0.0300
3	19	6	1	5.9	5.9	16	0.0900	4	2	47.4	4	1.5	0.400	0.0400
4	18	8	1	7.6	7.6	31	0.1550	214	3	45.9	214	1.9	0.400	0.0500
5	17	10	1	9.2	9.2	49	0.2410	84	3	44.1	84	2.2	0.400	0.0600
6	16	12	1	8.6	8.6	56	0.2520	294	3	41.9	294	2.5	0.400	0.0800
7	15	14	1	10.0	10.0	78	0.3770	148	4	39.3	148	2.9	0.400	0.0900
8	14	16	1	9.6	9.6	80	0.3530	44	4	36.4	44	2.9	0.410	0.1000
9	13	18	1	8.2	8.2	80	0.2920	260	3	33.5	260	2.9	0.410	0.1000
10	12	20	2	10.2	10.2	70	0.3410	137	4	30.6	137	2.9	0.420	0.1100
11	11	22	2	9.6	9.6	67	0.3850	322	4	27.7	322	2.9	0.420	0.1100
12	10	24	2	9.8	9.8	54	0.3790	202	4	24.8	202	2.9	0.430	0.1200
13	9	26	3	9.4	9.4	54	0.4130	48	4	21.9	48	2.9	0.440	0.1300
14	8	28	3	7.5	7.5	33	0.3080	244	3	19.0	244	2.9	0.450	0.1400
15	7	30	3	8.7	8.7	40	0.3420	148	3	16.1	148	2.9	0.460	0.1500
16	6	32	4	6.5	6.5	24	0.2470	0	3	13.2	0	2.9	0.480	0.1700
17	5	34	4	6.8	6.8	20	0.2110	224	3	10.3	224	2.9	0.490	0.1800
18	4	36	4	6.0	6.0	16	0.1630	72	2	7.4	72	2.9	0.500	0.1900
19	3	38	4	5.7	5.7	17	0.1700	288	2	4.6	288	1.5	0.520	0.1400
20	2	40	4	3.6	3.6	10	0.1000	144	2	3.0	144	1.5	0.550	0.1400
21	1	42	4	3.5	3.5	10	0.0900	0	2	1.5	0	1.5	0.600	0.1400

E C O P H Y S   VERSION 2.0   NOVEMBER 1987

THE STARTING DATE IS: 01-03-1989
THE STARTING TIME IS: 09:07:43

RUN TITLE IS: Example Initial Tree Stem Data Report

INITIAL STEM DATA REPORT

	MASS (g)	PSYN (mg CO2)
STEM	0.5000	0.2000
CUTTING	8.2500	5.0000
COARSE ROOTS	2.4000	1.0000
FINE ROOTS	1.6000	0.5000

E C O P H Y S   VERSION 2.0   NOVEMBER 1987

THE STARTING DATE IS: 01-03-1989
THE STARTING TIME IS: 09:14:17

RUN TITLE IS: Example Site Data Report

SITE DATA REPORT

SOIL REFLECT.	LATITUDE (deg)
0.000	45

E C O P H Y S   VERSION 2.0   NOVEMBER 1987

THE STARTING DATE IS: 01-03-1989
THE STARTING TIME IS: 09:15:44

RUN TITLE IS: Example Clonal Library Data Report

CLONAL LIBRARY DATA REPORT

Clonal Library File: EUGENEI.CLF

Bud Break Date: 128   Bud Set Date: 252
Leaf Senescence Date: 268   Leaf Initiation Rate: 37

Specific Leaf Area: 0.220   Internode Specific Gravity: 0.280

Growth Respiration Rate: 0.250   Maintenance Respiration Rate: 0.000

PgA Equation Coefficients

	Maturity Class			
	MC1	MC2	MC3	MC4
Pmax	14.870	22.500	23.900	16.360
EFFIC	0.060	0.160	0.080	0.140
Rd	1.000	2.460	0.946	0.806

E C O P H Y S VERSION 2.0 NOVEMBER 1987

THE STARTING DATE IS: 03-23-1988
THE STARTING TIME IS: 09:35:06

RUN TITLE IS: Printout of LEAF ORIENTATION REPORT

LEAF ORIENTATION REPORT
VERTEX COORDINATES - TREE COORDINATE SYSTEM
(4 POINTS DEFINE THE LEAF)

DAY: 204 - July 23
HOUR: 7

		VERTEX COORDINATES												LEAF CENTER POINT			LEAF NORMAL		
		1			2			3			4								
LPI	LNFB	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
		cm																	
0	22	1	1	50	2	1	49	3	3	49	0	3	50	1	2	49.53	2	2	50.07
1	21	-2	-0	49	-2	1	48	-5	-1	48	-2	-2	50	-2	-0	48.98	-2	-0	49.98
2	20	2	-1	48	2	-4	47	7	-4	47	4	0	49	3	-2	48.00	3	-2	48.50
3	19	0	2	47	3	3	46	1	8	47	-3	4	48	0	3	47.40	1	4	48.27
4	18	-1	-2	45	-2	-2	41	-5	-8	42	-3	-5	48	-2	-3	44.14	-2	-3	44.96
5	17	3	0	43	6	-2	46	12	1	40	3	3	39	5	0	42.38	5	1	42.16
6	16	-3	1	41	-4	4	45	-11	5	40	-5	-1	38	-4	2	41.06	-4	2	42.02
7	15	2	-3	39	1	-7	42	7	-11	37	5	-2	34	3	-5	38.38	4	-5	38.30
8	14	2	2	35	4	1	31	9	9	32	3	6	39	3	4	34.65	4	4	34.25
9	13	-3	-1	34	-5	1	30	-11	-2	34	-4	-3	37	-5	-1	33.54	-4	-1	34.53
10	12	2	-3	31	2	-7	28	9	-10	33	6	-1	35	4	-4	31.60	3	-4	31.72
11	11	-2	3	27	-0	6	30	-8	10	27	-6	1	24	-3	4	27.30	-3	3	28.15
12	10	-1	-3	25	-4	-5	21	-5	-12	27	-0	-5	30	-2	-5	25.79	-2	-4	26.13
13	9	3	2	21	6	2	25	9	9	20	2	4	17	4	3	21.05	3	3	20.68
14	8	-3	-1	19	-5	0	22	-9	-5	18	-2	-4	16	-4	-2	18.68	-4	-2	19.61
15	7	2	-3	18	-1	-7	18	6	-9	21	6	-2	20	3	-4	18.53	2	-4	19.17
16	6	0	3	13	2	4	11	0	9	13	-2	4	15	0	4	12.98	0	5	13.46
17	5	-2	-2	11	-4	-2	8	-7	-7	11	-2	-3	14	-3	-3	10.69	-2	-2	11.38
18	4	2	1	7	4	-0	5	8	3	7	3	3	10	3	1	7.44	4	0	6.98
19	3	-2	1	6	-2	3	8	-7	2	6	-3	-1	4	-3	1	6.07	-3	1	7.04
20	2	1	-1	4	1	-3	3	3	-4	5	2	-1	6	1	-2	4.20	0	-2	4.06
21	1	0	2	2	1	2	1	0	5	2	-1	2	4	0	2	2.20	0	3	2.57

E C O P H Y S   VERSION 2.0   NOVEMBER 1987

THE STARTING DATE IS: 03-23-1988
THE STARTING TIME IS: 09:46:46

RUN TITLE IS: Printout of the LEAF PROJECTION REPORT

VERTEX COORDINATES - SUN PROJECTION PLANE

DAY: 204 - July 23
HOUR: 7
ABOVE CROWN PPFD (uE/sqm/s): 247
AIR TEMP (C): 20.5
SOLAR ALT (deg): 24
SOLAR AZM (deg): 86

		VERTEX COORDINATES												LEAF CENTER POINT			LEAF NORMAL		
		1			2			3			4								
LPI	LNFB	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
		cm																	
0	22	1	45	979	0	43	979	3	43	978	3	46	980	1	44	979.10	1	45	978.12
1	21	0	45	982	1	45	983	0	46	986	-2	46	983	0	46	982.95	0	46	982.56
2	20	-1	43	979	-4	42	980	-4	40	975	0	43	976	-2	43	978.44	-3	43	978.69
3	19	2	43	981	3	41	979	8	43	980	4	45	983	3	43	980.85	4	44	980.16
4	18	-2	41	984	-1	38	986	-7	40	989	-5	44	984	-3	41	984.77	-3	42	984.20
5	17	0	38	980	-3	39	976	0	31	973	3	34	981	0	37	978.88	1	36	978.92
6	16	2	39	986	5	42	986	6	40	994	0	36	989	2	39	987.51	2	40	986.96
7	15	-3	35	983	-7	38	983	-12	31	980	-3	29	982	-5	34	982.41	-5	33	981.59
8	14	2	31	984	1	26	984	8	25	979	6	34	982	3	30	982.76	3	29	982.07
9	13	0	32	989	2	29	992	-1	35	997	-2	36	989	0	32	990.78	0	33	990.26
10	12	-3	28	985	-7	25	988	-11	27	979	-2	30	981	-4	27	984.20	-4	28	985.08
11	11	3	26	991	6	28	988	11	27	996	2	24	995	4	26	991.56	4	27	991.16
12	10	-3	24	991	-5	21	995	-12	27	995	-5	28	988	-5	24	991.81	-4	25	991.44
13	9	2	18	989	2	21	984	8	14	983	4	14	991	3	18	987.82	3	18	988.80
14	8	-1	18	995	1	22	996	-4	20	1001	-4	16	996	-2	19	995.89	-2	20	995.83
15	7	-3	15	992	-7	16	994	-10	17	987	-2	15	987	-5	16	990.31	-4	17	990.38
16	6	3	12	994	3	9	993	9	11	994	4	15	996	4	12	994.43	4	12	993.77
17	5	-2	10	998	-2	8	1001	-6	13	1002	-3	13	996	-3	11	998.34	-2	11	997.63
18	4	1	6	995	-1	3	995	2	3	989	2	8	993	1	5	993.85	0	5	993.62
19	3	1	6	999	3	8	998	3	8	1004	-1	5	1001	1	7	999.93	1	7	999.34
20	2	-1	3	998	-3	2	998	-4	3	996	-1	4	996	-2	3	997.11	-2	4	998.04
21	1	2	2	999	2	0	998	5	2	999	3	4	999	2	2	998.93	3	2	998.32

E C O P H Y S   VERSION 2.0   NOVEMBER 1987

THE STARTING DATE IS: 03-23-1988
THE STARTING TIME IS: 09:50:51

RUN TITLE IS: Printout of the LEAF OVERLAP REPORT

LEAF OVERLAP REPORT

DAY: 204 - July 23
HOUR: 7
SOLAR ALT (deg): 24
SOLAR AZM (deg): 86

		TOTAL	---- PROJECTED -------			------ ON LEAF ------	
		LEAF	LEAF	SUN	SHADE	TOTAL	TOTAL
LPI	LNFB	AREA	AREA	AREA	AREA	SUN AREA	SHADE AREA
		sq cm					
0	22	3.5	7.5	7.5	0.0	3.5	0.0
1	21	5.5	3.0	2.0	1.0	3.7	1.8
2	20	15.2	5.5	5.5	0.0	15.2	0.0
3	19	16.3	13.0	11.5	1.5	14.4	1.9
4	18	30.9	17.0	13.5	3.5	24.5	6.4
5	17	48.9	22.0	22.0	0.0	48.9	0.0
6	16	55.8	12.0	10.5	1.5	48.8	7.0
7	15	78.4	49.0	49.0	0.0	78.4	0.0
8	14	80.0	40.0	40.0	0.0	80.0	0.0
9	13	80.0	5.5	1.0	4.5	14.5	65.5
10	12	70.0	19.0	18.5	0.5	68.2	1.8
11	11	66.9	14.0	5.5	8.5	26.3	40.6
12	10	53.9	33.0	21.0	12.0	34.3	19.6
13	9	53.8	18.5	18.5	0.0	53.8	0.0
14	8	33.4	16.0	16.0	0.0	33.4	0.0
15	7	39.8	2.5	2.5	0.0	39.8	0.0
16	6	23.8	20.0	18.5	1.5	22.0	1.8
17	5	20.2	10.5	10.5	0.0	20.2	0.0
18	4	15.8	9.0	9.0	0.0	15.8	0.0
19	3	17.0	2.5	1.5	1.0	10.2	6.8
20	2	10.2	4.0	4.0	0.0	10.2	0.0
21	1	10.0	7.0	7.0	0.0	10.0	0.0

E C O P H Y S VERSION 2.0 NOVEMBER 1987

THE STARTING DATE IS: 03-23-1988
THE STARTING TIME IS: 09:53:44

RUN TITLE IS: Printout of the PPFD HOURLY REPORT

PPFD HOURLY REPORT

DAY: 204 - July 23
HOUR: 7
AIR TEMP (C): 20.5
SOLAR ALTITUDE (deg): 24
SOLAR AZIMUTH (deg): 86
ABOVE CROWN DIRECT PPFD (uE/sqm/s): 247
ABOVE CROWN DIFFUSE PPFD (uE/sqm/s): 11

LPI	LNFB	PPFD-SUN PORTION	PPFD-SHADE PORTION	ADX SUN	ADX SHADE	ABX SUN	ABX SHADE	SOIL DIF
		--- uE/sqm/s ---		------------- uE/s ------------				uE/sqm/s
0	22	235	2	234	1	110	2	0
1	21	129	2	128	1	110	2	0
2	20	139	2	138	1	110	2	0
3	19	230	2	230	1	110	2	0
4	18	57	2	145	2	110	2	0
5	17	146	3	145	2	82	6	0
6	16	33	3	32	2	82	6	0
7	15	234	4	233	3	82	6	0
8	14	214	5	213	3	82	6	0
9	13	77	6	75	4	82	6	0
10	12	33	7	31	5	82	6	0
11	11	55	8	52	5	82	6	0
12	10	47	9	168	8	82	6	0
13	9	16	11	168	8	17	7	0
14	8	172	12	168	8	52	10	0
15	7	106	13	101	9	52	10	0
16	6	247	14	256	9	52	10	0
17	5	36	11	141	10	52	10	0
18	4	146	15	141	10	31	11	0
19	3	90	16	84	11	31	11	0
20	2	26	11	256	11	31	11	0
21	1	247	17	256	11	0	0	0

E C O P H Y S VERSION 2.0 NOVEMBER 1987

THE STARTING DATE IS: 03-23-1988
THE STARTING TIME IS: 09:56:54

RUN TITLE IS: Printout of the HOURLY PHOTOSYNTHESIS REPORT

HOURLY PHOTOSYNTHESIS REPORT

DAY: 204 - July 23
HOUR: 7
HOURS REPRESENTED: 1
ABOVE CROWN PPFD (uE/sqm/s): 247
AIR TEMP (C): 20.5
SOLAR ALT (deg): 24.5
SOLAR AZM (deg): 85.6

LPI	LNFB	TOTAL AREA	SUN AREA	SHADE AREA	SUN PPFD	SHADE PPFD	SUN PGA	SHADE PGA	TOTAL PGA
		-------	sq cm	-----	- uE/msq/s --		--- mgCO2/s/leaf ---		
0	22	3.5	3.5	0.0	235	2	0.3	0.0	0.3
1	21	5.5	3.7	1.8	129	2	0.2	-0.0	0.2
2	20	15.2	15.2	0.0	139	2	0.9	0.0	0.9
3	19	16.3	14.4	1.9	230	2	1.2	-0.0	1.1
4	18	30.9	24.5	6.4	57	2	0.6	-0.1	0.5
5	17	48.9	48.9	0.0	146	3	2.8	0.0	2.8
6	16	55.8	48.8	7.0	33	3	0.5	-0.1	0.4
7	15	78.4	78.4	0.0	234	4	6.3	0.0	6.3
8	14	80.0	80.0	0.0	214	5	6.1	0.0	6.1
9	13	80.0	14.5	65.5	77	6	0.5	-0.5	-0.1
10	12	70.0	68.2	1.8	33	7	1.7	-0.0	1.6
11	11	66.9	26.3	40.6	55	8	1.3	-0.6	0.7
12	10	53.9	34.3	19.6	47	9	1.4	-0.3	1.2
13	9	53.8	53.8	0.0	16	11	0.2	0.0	0.2
14	8	33.4	33.4	0.0	172	12	3.3	0.0	3.3
15	7	39.8	39.8	0.0	106	13	2.7	0.0	2.7
16	6	23.8	22.0	1.8	247	14	2.9	0.0	3.0
17	5	20.2	20.2	0.0	36	11	0.8	0.0	0.8
18	4	15.8	15.8	0.0	146	15	1.7	0.0	1.7
19	3	17.0	10.2	6.8	90	16	0.8	0.1	0.9
20	2	10.2	10.2	0.0	26	11	0.3	0.0	0.3
21	1	10.0	10.0	0.0	247	17	1.3	0.0	1.3

TOTAL FOR THIS HOUR (mg CO2) = 36.2
CUMULATIVE TOTAL (mg CO2) = 36.2
Photosynthesis rates shown here represent rates extrapolated over 1 hour(s).

LEAF PSYN/RESPIRATION REPORT

LPI	LFNB	GROSS-PSYN	TRANSPORT OUT	TRANSPORT IN	RESPIRATION MAINT.	RESPIRATION GROWTH	NET-PSYN	LEAF WEIGHT	LEAF EQUIV.
		mg CO2	mg CO2	mg CO2	mg CO2	mg CO2	mg CO2	g	mg CO2
0	22	10.42	0.00	69.76	0.89	20.87	58.41	0.03	37
1	21	13.18	0.00	52.91	1.18	17.08	47.82	0.03	49
2	20	38.69	0.00	65.47	2.93	26.64	74.59	0.08	121
3	19	42.13	0.00	56.39	3.22	25.08	70.22	0.09	132
4	18	65.76	0.00	35.78	5.55	25.27	70.73	0.16	228
5	17	99.74	13.67	30.29	8.62	28.36	79.38	0.24	354
6	16	102.27	27.98	8.70	9.02	19.47	54.51	0.25	370
7	15	213.14	89.84	3.21	13.49	29.74	83.27	0.38	554
8	14	200.01	112.43	2.04	12.63	20.26	56.73	0.35	519
9	13	165.43	116.23	-0.00	10.45	10.20	28.55	0.29	429
10	12	239.25	204.34	-0.00	12.20	5.98	16.73	0.34	501
11	11	218.05	183.84	0.00	13.78	5.38	15.05	0.38	566
12	10	210.00	176.80	-0.00	13.56	5.17	14.47	0.38	557
13	9	144.94	117.14	0.00	14.78	3.43	9.59	0.41	607
14	8	136.25	112.71	-0.00	11.02	3.30	9.23	0.31	453
15	7	140.64	115.56	0.00	12.24	3.38	9.46	0.34	503
16	6	92.39	75.19	-0.00	8.84	2.20	6.16	0.25	363
17	5	62.61	49.56	0.00	7.55	1.45	4.06	0.21	310
18	4	57.56	46.56	0.00	5.83	1.36	3.81	0.16	240
19	3	56.51	45.39	0.00	6.08	1.33	3.72	0.17	250
20	2	30.75	24.46	0.00	3.58	0.72	2.00	0.10	147
21	1	33.73	27.46	-0.00	3.22	0.80	2.25	0.09	132

THE RESPIRATION-TEMPERATURE FACTOR IS: 1.052777

INTERNODE PSYN/RESPIRATION REPORT

LPI	LFNB	GROSS-PSYN	RESPIRATION MAINT.	GROWTH	NET-PSYN	INTERNODE WEIGHT	EQUIV.
		---------------- mg CO2			-------------	g	mg CO2
0	22	19.10	0.36	4.93	13.806	0.010	15
1	21	18.82	0.72	4.76	13.337	0.020	29
2	20	18.82	1.07	4.67	13.073	0.030	44
3	19	20.49	1.43	5.02	14.045	0.040	59
4	18	21.67	1.79	5.23	14.645	0.050	74
5	17	25.42	2.15	6.13	17.150	0.060	88
6	16	26.59	2.86	6.24	17.481	0.080	118
7	15	22.79	3.22	5.15	14.419	0.090	132
8	14	24.94	3.58	5.62	15.741	0.100	147
9	13	19.26	3.58	4.13	11.552	0.100	147
10	12	21.08	3.94	4.51	12.632	0.110	162
11	11	28.90	3.94	6.57	18.391	0.110	162
12	10	36.71	4.29	8.53	23.882	0.120	176
13	9	42.87	4.65	10.06	28.159	0.130	191
14	8	44.67	5.01	10.44	29.224	0.140	206
15	7	47.01	5.37	10.96	30.685	0.150	221
16	6	50.99	6.08	11.82	33.090	0.170	250
17	5	51.72	6.44	11.92	33.361	0.180	265
18	4	49.81	6.80	11.32	31.690	0.190	279
19	3	48.75	5.01	11.51	32.229	0.140	206
20	2	49.17	5.01	11.62	32.538	0.140	206
21	1	48.23	5.01	11.37	31.842	0.140	206

CUTTING AND ROOT PSYN/RESPIRATION REPORT

	GROSS PSYN	RESPIRATION MAINT.	GROWTH	NET PSYN
	----------------	mg CO2		----------------
CUTTING	120.76	115.76	1.32	3.68
COARSE ROOTS	289.82	85.89	53.67	150.26
FINE ROOTS	72.71	57.26	4.07	11.38

E C O P H Y S VERSION 2.0 NOVEMBER 1987

THE STARTING DATE IS: 03-23-1988
THE STARTING TIME IS: 11:02:34

RUN TITLE IS: Printout of PHOTOSYNTHATE DISTRIBUTION and DIMENSIONAL GROWTH reports

DAY: 205 - July 24
HOUR: 14
HOURS SINCE LAST LEAF: 37

REAL TIME IS NOW: 11:08:45

PSYN DISTRIBUTION REPORT (units= mg CO2)

LPI	LFNB	STARTING PSYN	TOTAL TRANSPORT	UPWARD LEAVES	UPWARD INTERNODES	DOWNWARD INTERNODES	CUTTING	LARGE ROOTS	SMALL ROOTS
5	17	91.12	13.67	9.98	3.42	0.27	0.00	0.00	0.00
6	16	93.25	27.98	18.74	7.55	0.84	0.28	0.45	0.11
7	15	199.65	89.84	48.51	25.16	8.09	1.80	5.03	1.26
8	14	187.38	112.43	52.84	32.60	12.37	3.37	8.99	2.25
9	13	154.98	116.23	41.84	25.57	30.22	4.65	11.16	2.79
10	12	227.05	204.34	55.17	44.96	67.43	10.22	21.25	5.31
11	11	204.27	183.84	31.25	40.45	73.54	12.87	20.59	5.15
12	10	196.44	176.80	21.22	28.29	70.72	14.14	33.94	8.49
13	9	130.16	117.14	15.23	11.71	46.86	10.54	26.24	6.56
14	8	125.23	112.71	11.27	11.27	45.08	11.27	27.05	6.76
15	7	128.40	115.56	11.56	5.78	46.22	12.71	31.43	7.86
16	6	83.55	75.19	4.51	1.50	30.08	8.27	24.66	6.17
17	5	55.06	49.56	1.49	0.99	19.82	5.45	17.44	4.36
18	4	51.73	46.56	0.93	0.47	18.62	5.59	16.76	4.19
19	3	50.43	45.39	0.00	0.00	18.15	6.81	16.34	4.08
20	2	27.17	24.46	0.00	0.00	9.78	3.67	8.80	2.20
21	1	30.51	27.46	0.00	0.00	0.00	4.12	18.67	4.67

E C O P H Y S   VERSION 2.0   NOVEMBER 1987

THE STARTING DATE IS: 03-23-1988
THE STARTING TIME IS: 11:20:09

RUN TITLE IS: Printout of LEAF, INTERNODE, and CUTTING GROWTH reports

DAY: 205 - July 24
HOUR: 14

LEAF GROWTH REPORT

LPI	LFNB	PREVIOUS LEAF LENGTH cm	PREVIOUS LEAF WIDTH cm	PREVIOUS LEAF AREA cm^2	PREVIOUS LEAF WEIGHT g	PETIOLE LENGTH cm	NEW LEAF LENGTH cm	NEW LEAF WIDTH cm	NEW LEAF AREA cm^2	NEW LEAF WEIGHT g	PETIOLE LENGTH cm	MATURITY CODE	LEAF AGE days
0	22	3.20	3.20	3.50	0.03	1.50	5.0	5.0	12.35	0.06	2.07	1	1
1	21	3.70	3.70	5.50	0.03	1.70	5.0	5.0	12.75	0.07	2.09	1	2
2	20	5.70	5.70	15.20	0.08	2.30	7.3	7.3	26.50	0.13	2.80	1	4
3	19	5.90	5.90	16.30	0.09	2.40	7.3	7.3	26.94	0.14	2.82	1	6
4	18	7.60	7.60	30.90	0.16	2.90	9.1	9.1	41.62	0.20	3.39	1	8
5	17	9.20	9.20	48.90	0.24	3.40	11.0	11.0	60.93	0.30	4.00	1	10
6	16	8.60	8.60	55.80	0.25	3.20	11.3	11.3	64.06	0.29	4.09	1	12
7	15	10.00	10.00	78.40	0.38	3.70	13.5	13.5	91.01	0.43	4.78	1	14
8	14	9.60	9.60	80.00	0.35	3.50	13.3	13.3	88.59	0.39	4.73	1	16
9	13	8.20	8.20	80.00	0.29	3.10	13.0	13.0	84.32	0.31	4.62	1	18
10	12	10.20	10.20	70.00	0.34	3.70	12.0	12.0	72.53	0.35	4.32	2	20
11	11	9.60	9.60	66.90	0.38	3.50	9.6	9.6	66.90	0.40	3.50	2	22
12	10	9.80	9.80	53.90	0.38	3.60	9.8	9.8	53.90	0.39	3.60	2	24
13	9	9.40	9.40	53.80	0.41	3.50	9.4	9.4	53.80	0.42	3.50	3	26
14	8	7.50	7.50	33.40	0.31	2.90	7.5	7.5	33.40	0.31	2.90	3	28
15	7	8.70	8.70	39.80	0.34	3.30	8.7	8.7	39.80	0.35	3.30	3	30
16	6	6.50	6.50	23.80	0.25	2.60	6.5	6.5	23.80	0.25	2.60	4	32
17	5	6.80	6.80	20.20	0.21	2.70	6.8	6.8	20.20	0.21	2.70	4	34
18	4	6.00	6.00	15.80	0.16	2.40	6.0	6.0	15.80	0.17	2.40	4	36
19	3	5.70	5.70	17.00	0.17	2.30	5.7	5.7	17.00	0.17	2.30	4	38
20	2	3.60	3.60	10.20	0.10	2.00	3.6	3.6	10.20	0.10	2.00	4	40
21	1	3.50	3.50	10.00	0.09	1.80	3.5	3.5	10.00	0.09	1.80	4	42

INTERNODE GROWTH REPORT

LPI	LFNB	------ PREVIOUS INTERNODE ------ PSYN mg CO2	LENGTH cm	DIAM cm	WEIGHT g	PETIOLE LOCATION cm	-------- NEW INTERNODE -------- PSYN mg CO2	LENGTH cm	DIAM cm	WEIGHT g	PETIOLE LOCATION cm
0	22	13.81	0.50	0.400	0.0100	49.90	13.81	0.76	0.400	0.0193	53.00
1	21	13.34	0.80	0.400	0.0200	49.40	13.34	1.05	0.400	0.0289	52.24
2	20	13.07	1.10	0.400	0.0300	48.60	13.07	1.34	0.400	0.0388	51.19
3	19	14.05	1.50	0.400	0.0400	47.40	14.05	1.75	0.400	0.0494	49.86
4	18	14.64	1.86	0.400	0.0500	45.94	14.64	2.11	0.400	0.0598	48.11
5	17	17.15	2.20	0.400	0.0600	44.08	17.15	2.49	0.400	0.0715	46.00
6	16	17.48	2.54	0.400	0.0800	41.88	17.48	2.82	0.400	0.0917	43.51
7	15	14.42	2.90	0.400	0.0900	39.34	14.42	3.13	0.400	0.0997	40.69
8	14	15.74	2.90	0.410	0.1000	36.44	15.74	2.90	0.426	0.1105	37.56
9	13	11.55	2.90	0.410	0.1000	33.54	11.55	2.90	0.422	0.1077	34.66
10	12	12.63	2.90	0.420	0.1100	30.64	12.63	2.90	0.432	0.1185	31.76
11	11	18.39	2.90	0.420	0.1100	27.74	18.39	2.90	0.437	0.1223	28.86
12	10	23.88	2.90	0.430	0.1200	24.84	23.88	2.90	0.451	0.1360	25.96
13	9	28.16	4.00	0.440	0.1300	21.94	28.16	4.00	0.457	0.1489	23.06
14	8	29.22	2.90	0.450	0.1400	19.04	29.22	2.90	0.474	0.1596	19.06
15	7	30.69	2.90	0.460	0.1500	16.14	30.69	2.90	0.484	0.1706	16.16
16	6	33.09	2.90	0.480	0.1700	13.24	33.09	2.90	0.504	0.1922	13.26
17	5	33.36	2.90	0.490	0.1800	10.34	33.36	2.90	0.514	0.2024	10.36
18	4	31.69	2.90	0.500	0.1900	7.44	31.69	2.90	0.522	0.2112	7.46
19	3	32.23	1.52	0.520	0.1400	4.56	32.23	1.52	0.559	0.1616	4.56
20	2	32.54	1.52	0.550	0.1400	3.04	32.54	1.52	0.587	0.1618	3.04
21	1	31.84	1.52	0.600	0.1400	1.52	31.84	1.52	0.632	0.1613	1.52

CUTTING AND ROOT GROWTH REPORT

---------- PREVIOUS ------------ CUTTING	COARSE ROOTS	FINE ROOTS	------------ NEW ---------- CUTTING	COARSE ROOTS	FINE ROOTS
8.2500	2.4000	1.6000	8.2525	2.5007	1.6076

☆ U.S. GOVERNMENT PRINTING OFFICE: 1990-757-734/20048

Host, George E.; Rauscher, H. Michael; Isebrands, J.G.; Dickmann, Donald I.; Dickson, Richard E.; Crow, Thomas R.; Michael, D.A.
1990. **The microcomputer scientific software series #6: the ECOPHYS user's manual**. Gen. Tech. Rep. NC-141. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 50 p.

ECOPHYS is an ecophysiological whole-tree growth process model designed to simulate the growth of poplar in the establishment year. This microcomputer-based model may be used to test the influence of genetically determined physiological or morphological attributes on plant growth. This manual describes the installation, file structures, and operational procedures for using the model.

KEY WORDS: *Populus*, whole-tree process model, short-rotation intensive culture, photosynthesis, carbon allocation.