A physiological production model for cacao:

Model description and technical program manual of CASE2 version 2.2

Pieter A. Zuidema, Wouter Gerritsma, Liesje Mommer & Peter A. Leffelaar

January 2003
Address for ordering copies of this report
Secretariat Plant production systems group
Wageningen University
PO Box 430
6700 AK Wageningen
The Netherlands

Fax: +31 317 484892
E-mail: Office.PP@wur.nl

Authors addresses:
Plant production systems group
Wageningen University
PO Box 430
6700 AK Wageningen
The Netherlands

Fax: +31 317 484892
E-mail: Peter.Leffelaar@wur.nl

Copies of related reports on CASE2 (“A physiological production model for cacao: results of model simulations” and “A physiological production model for cacao: user’s manual of CASE2 version 2.2 under FSEWin”) are available from the secretariat of the Plant production systems group at the above address.

This report has been produced within the framework of the “Collaborative research for an agrotechnological growth and quality model of cocoa” of the Dutch Cocoa Association (NVC) and Wageningen University. Financial support for this study was obtained from the Dutch cocoa processing industry, the Dutch Ministry of Economic Affairs and Wageningen University.
A physiological production model for cacao:

Model description and technical program manual of CASE2 version 2.2

Pieter A. Zuidema, Wouter Gerritsma, Liesje Mommer & Peter A. Leffelaar

January 2003

Plant Production Systems group
Wageningen University
The Netherlands

Keywords: Theobroma cacao, cacao, cocoa, simulation model, growth and yield, reference manual.

© 2003 P.A. Zuidema, W. Gerritsma, L. Mommer & P.A. Leffelaar
Preface

This report contains a detailed description of the CASE2 (CAcao Simulation Engine for water-limited production) model and a technical manual of the CASE2 program, written in Fortran language. CASE2 is a physiological model for cacao growth and yield. This report is meant as a background document for advanced users of the CASE2 model or as reference for persons with interest in expanding this model, or building models for cacao or related species. For normal use of the CASE2 model, there exists a user's manual (Zuidema & Leffelaar 2002b). Basic background information on the procedures, model assumptions and limitations of CASE2 are included in another report (Zuidema & Leffelaar, 2002a). These reports and extra copies of this report and the CASE2 and FSEWin programs can be obtained from the Plant Production Systems group at Wageningen University (see author's addresses on previous page). Any queries or comments can also be directed to the authors.

This report is one of the results of a cocoa research and modelling programme of Wageningen University on behalf of the Dutch Cocoa Association (NCV)\(^1\). The current version of the model has been developed in the period April 2001-January 2002.

This report consists of three parts:
(1) a model description in which the principles behind the model are explained;
(2) a technical program manual containing extensive explanation on the Fortran model code; and
(3) a part containing the data input files used by the program, including a documentation of the sources for the parameter values.

Several people have contributed in the development of the CASE2 model. Wouter Gerritsma and Liesje Mommer developed previous versions of the model. Jan Goudriaan provided valuable input for model development. Wouter Gerritsma gave important reference to literature and commented on model development. Rudy Rabbinge provided overall guidance during this phase of the project. Daniel van Kraalingen developed the FSEWin program. Gon van Laar assisted in the FSEWin development and tested the program. Sander de Vries tested the CASE2 model. Weather data were kindly made available by various persons at the Department of Plant Sciences and Plant Research International (both at Wageningen University and Research Centre). Financial support was obtained from the Dutch Cocoa Association (NCV), the Dutch Ministry of Economic Affairs, and the Plant Production Systems group at Wageningen University. All contributions are gratefully acknowledged.

Parts of the text of this report are taken from or based on Gerritsma (1995) and Mommer (1999).

Wageningen, January 2003

---

\(^1\) “Collective research for an agro-technical growth and quality model of cocoa"
# Table of Contents

## Preface

**Table of Contents**

1. **Introduction**
   1.1 Purpose of this report
   1.2 Layout of this report
   1.3 Purpose of the CASE2 simulation model
   1.4 CASE2 under FSEWin and other Fortran compilers

**Part I Scientific description**

2. **Light interception**
   2.1 Basic principles
   2.2 Shade trees

3. **Rain interception, evapotranspiration and soil water balance**
   3.1 Rain interception
   3.2 Evapotranspiration
   3.3 Soil water balance

4. **Cacao tree growth and yield**
   4.1 Photosynthesis
   4.2 Maintenance respiration
   4.3 Replacement and growth of plant parts
      4.3.1 Age vs. size: allometric relations
      4.3.2 Replacement of lost biomass
      4.3.3 Net growth of plant parts
   4.4 Leaf dynamics
      4.4.1 Boxcar train
      4.4.2 Leaf production and loss
      4.4.3 Leaf area and Specific leaf area
   4.5 Root dynamics and water uptake
      4.5.1 Taproot length
      4.5.2 Lateral roots distribution
      4.5.3 Root surface and water uptake
   4.6 Pod growth, development and harvesting
      4.6.1 Pod ripening
      4.6.2 Pod growth and initialisation
      4.6.3 Pod harvesting
   4.7 Parameters derived from pod harvest
      4.7.1 Commercial bean yield
      4.7.2 Butter hardness
      4.7.3 Harvest indices
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.7.4</td>
<td>Nutrient loss through bean harvest</td>
<td>34</td>
</tr>
<tr>
<td>Part II</td>
<td>Technical program manual</td>
<td>35</td>
</tr>
<tr>
<td>5.</td>
<td>Program structure and execution</td>
<td>37</td>
</tr>
<tr>
<td>5.1</td>
<td>Program structure</td>
<td>37</td>
</tr>
<tr>
<td>5.2</td>
<td>Subroutines and data files</td>
<td>38</td>
</tr>
<tr>
<td>5.3</td>
<td>Order of program execution</td>
<td>39</td>
</tr>
<tr>
<td>6.</td>
<td>The FSE subroutine</td>
<td>41</td>
</tr>
<tr>
<td>6.1</td>
<td>Purpose</td>
<td>41</td>
</tr>
<tr>
<td>6.2</td>
<td>Declarations</td>
<td>41</td>
</tr>
<tr>
<td>6.3</td>
<td>Initialisation section</td>
<td>43</td>
</tr>
<tr>
<td>6.4</td>
<td>Rate calculation or dynamic section</td>
<td>47</td>
</tr>
<tr>
<td>6.5</td>
<td>Terminal section</td>
<td>49</td>
</tr>
<tr>
<td>7.</td>
<td>The MODELS subroutine</td>
<td>51</td>
</tr>
<tr>
<td>7.1</td>
<td>Purpose</td>
<td>51</td>
</tr>
<tr>
<td>7.2</td>
<td>Input and output</td>
<td>51</td>
</tr>
<tr>
<td>7.3</td>
<td>Declarations</td>
<td>52</td>
</tr>
<tr>
<td>7.4</td>
<td>Initialisation section</td>
<td>52</td>
</tr>
<tr>
<td>7.5</td>
<td>Rate calculation section</td>
<td>54</td>
</tr>
<tr>
<td>7.6</td>
<td>Integration section</td>
<td>55</td>
</tr>
<tr>
<td>7.7</td>
<td>Terminal section</td>
<td>56</td>
</tr>
<tr>
<td>8.</td>
<td>The INTERCEPT subroutine</td>
<td>57</td>
</tr>
<tr>
<td>8.1</td>
<td>Purpose</td>
<td>57</td>
</tr>
<tr>
<td>8.2</td>
<td>Input and output</td>
<td>57</td>
</tr>
<tr>
<td>8.3</td>
<td>Initialisation section</td>
<td>57</td>
</tr>
<tr>
<td>8.4</td>
<td>Rate calculation section</td>
<td>58</td>
</tr>
<tr>
<td>9.</td>
<td>The CASE2 subroutine</td>
<td>59</td>
</tr>
<tr>
<td>9.1</td>
<td>Purpose</td>
<td>59</td>
</tr>
<tr>
<td>9.2</td>
<td>Input and output</td>
<td>59</td>
</tr>
<tr>
<td>9.3</td>
<td>Declarations</td>
<td>60</td>
</tr>
<tr>
<td>9.4</td>
<td>Initialisation section</td>
<td>60</td>
</tr>
<tr>
<td>9.5</td>
<td>Rate calculation section</td>
<td>65</td>
</tr>
<tr>
<td>9.5.1</td>
<td>Photosynthesis</td>
<td>66</td>
</tr>
<tr>
<td>9.5.2</td>
<td>Maintenance respiration</td>
<td>67</td>
</tr>
<tr>
<td>9.5.3</td>
<td>Replacement of plant parts with turn over</td>
<td>67</td>
</tr>
<tr>
<td>9.5.4</td>
<td>Actual growth of plant parts</td>
<td>70</td>
</tr>
<tr>
<td>9.5.5</td>
<td>Total growth and death rates</td>
<td>73</td>
</tr>
<tr>
<td>9.5.6</td>
<td>Pod and bean yield</td>
<td>74</td>
</tr>
<tr>
<td>9.5.7</td>
<td>Ten-day and annual totals</td>
<td>74</td>
</tr>
<tr>
<td>9.5.8</td>
<td>Finish conditions</td>
<td>76</td>
</tr>
<tr>
<td>9.5.9</td>
<td>Output</td>
<td>76</td>
</tr>
<tr>
<td>9.6</td>
<td>Integration section</td>
<td>77</td>
</tr>
<tr>
<td>9.6.1</td>
<td>Carbon balance check</td>
<td>78</td>
</tr>
<tr>
<td>9.7</td>
<td>Terminal section</td>
<td>79</td>
</tr>
<tr>
<td>18.1.1</td>
<td>Purpose and usage</td>
<td>113</td>
</tr>
<tr>
<td>--------</td>
<td>-------------------</td>
<td>-----</td>
</tr>
<tr>
<td>18.1.2</td>
<td>File listing</td>
<td>113</td>
</tr>
<tr>
<td>18.2</td>
<td>Control.dat</td>
<td>116</td>
</tr>
<tr>
<td>18.2.1</td>
<td>Purpose and usage</td>
<td>116</td>
</tr>
<tr>
<td>18.2.2</td>
<td>File listing</td>
<td>116</td>
</tr>
<tr>
<td>18.3</td>
<td>Plant.dat</td>
<td>117</td>
</tr>
<tr>
<td>18.3.1</td>
<td>Purpose and usage</td>
<td>117</td>
</tr>
<tr>
<td>18.3.2</td>
<td>File listing</td>
<td>117</td>
</tr>
<tr>
<td>18.4</td>
<td>Reruns.dat</td>
<td>121</td>
</tr>
<tr>
<td>18.4.1</td>
<td>Purpose and usage</td>
<td>121</td>
</tr>
<tr>
<td>18.4.2</td>
<td>Explanation of parameters</td>
<td>121</td>
</tr>
<tr>
<td>18.5</td>
<td>Soil.dat</td>
<td>122</td>
</tr>
<tr>
<td>18.5.1</td>
<td>Purpose and usage</td>
<td>122</td>
</tr>
<tr>
<td>18.5.2</td>
<td>Explanation of parameters</td>
<td>122</td>
</tr>
<tr>
<td>18.6</td>
<td>Timer.dat</td>
<td>125</td>
</tr>
<tr>
<td>18.6.1</td>
<td>Purpose and usage</td>
<td>125</td>
</tr>
<tr>
<td>18.6.2</td>
<td>Explanation of parameters</td>
<td>126</td>
</tr>
</tbody>
</table>

19. Weather files

19.1 Purpose and usage

Literature used

Appendix: List of parameters I-1
1. Introduction

1.1 Purpose of this report

The purposes of this report are:
(1) to justify and document the processes modelled in CASE2;
(2) to document the parameter values used in CASE2; and
(3) to document the Fortran source code.

1.2 Layout of this report

This report consists of three parts:
Part I: This part contains a scientific description of the model, focusing on how the different processes are modelled.
Part II: This part contains a technical program manual in which the program lines in the Fortran source code are explained. Only those parts of the source code that are specific to the CASE2 program are discussed: subroutines that are generic and have been documented elsewhere are not treated in this report. In case such generic subroutines have been modified for the use within the CASE2 program, only the modifications will be discussed.
Part III: This part contains an explanation and documentation of the data input files used by the CASE2 program.

Note that the complete Fortran source code is not included in the report but can be found on the CD-ROM that is provided with this report or can be obtained from the authors.

1.3 Purpose of the CASE2 simulation model

CASE2 is the Cacao Simulation Engine for water-limited production. CASE2 is a physiological model that simulates cocoa growth and yield for different weather and soil conditions and cropping systems. The model serves the following purposes:
(1) To estimate cocoa yields in relation to weather and soil conditions and cropping systems;
(2) to obtain insight in factors determining production;
(3) to integrate existing knowledge on the physiology and morphology of cacao trees; and
(4) to identify gaps in knowledge on the physiological basis for estimating cocoa growth and yield.

A short non-technical description of the CASE2 model is included in a report on simulation results using CASE2 (Zuidema & Leffelaar 2002a).

1.4 CASE2 under FSEWin and other Fortran compilers

The CASE2 model can be run using regular Fortran compilers such as Digital Fortran, but also using the FSE Windows shell (FSEWin). FSEWin (Fortran Simulation Environment for Windows) is a user-friendly shell to be used for simulation models written in Fortran. It can be used to edit, compile
and run Fortran programs, and it produces output in charts and spreadsheets. The program has been developed by D.W.G. van Kraalingen, Wageningen Software Labs (W!SL), Alterra, the Netherlands. Version 1.04 of FSE Windows is provided on the CD-ROM that is with this report (or can be obtained from the authors).

The CASE2 program as included on the CD-ROM is adapted for use with the FSEWin. This implies that at several locations in the CASE2.FOR and FSE.FOR files, some lines have been added to specify charts in FSEWin. To run CASE2 without FSEWin (using a Fortran compiler such as Visual Fortran), these lines should be removed. See Chapter 6 (for FSE.FOR), Sections 9.3 and 9.5.9 (for CASE2.for).
Part I   Scientific description
2. **Light interception**

This chapter discusses the principles that form the basis for the SASTRO, SSKYC, ASSIMC, LEAFPAR subroutines in the TOTASC.FOR file.

### 2.1 Basic principles

Light interception in CASE2 is modelled as in the SUCROS models (Van Laar et al. 1997) which is based on principles explained in Goudriaan & Van Laar (1994). The basic idea is that the canopy of the crop is considered to consist of individual leaves with a soil underneath. Total light absorption and reflection of the canopy is based on these components. A distinction is made between direct and indirect light fluxes: part of the canopy receives direct light and part receives indirect light. The transmission of light in the crop canopy is described in detail, taking into account the vertical distribution of light intensity over the canopy. The orientation of leaves in the canopy is also taken into account. Leaves are assumed to be spherically orientated. The reflection and transmission of leaves and the reflection of soil is included in the calculations.

Input in these calculations is the daily short-wave radiation and the geographical position to calculate day length and solar track. The model takes into account that incoming radiation may be in the form of direct and diffuse radiation.

For more information, see Goudriaan & Van Laar (1994) and Van Laar et al. (1997).

### 2.2 Shade trees

Cocoa is often grown under shade of other tree crops. Cocoa and shade trees compete with each other for light, water and nutrients. Light interception by cocoa and its shade trees needs to be accounted for explicitly when a model for cocoa growth and production is developed, since this is one of the most important competition mechanisms for crop growth. In order to estimate the effects of shading, light interception by shade trees has been explicitly incorporated into the CASE2 model. The above-mentioned principles of light interception are applied for both the canopy of the shade tree and that of the cacao tree. This is done using the descriptions from the INTERCOM model (Kropff & Van Laar, 1993).

*Figure 2.1. Shading and transmission of light in shaded cacao plantations, as modelled in CASE2. Arrows denote photosynthetically active radiation.*
Photosynthetically active radiation (PAR) is intercepted by the shade and cacao trees (Figure 2.1). The amount of PAR decreases exponentially from above the canopy to the soil surface according to Beer's law. This decrease is a function of the cumulative leaf area and the extinction coefficients of shade and cacao trees (Figure 2.2). Light competition in CASE2 is based on the effective leaf area (the leaf area weighted by the extinction coefficient) of the species and the difference in canopy height. Light interception by the leaves of cacao and shade trees depends – among others – on the leaf density. This parameter is calculated using the vertical distribution of leaves within the canopy (this is assumed to be parabolic) and the total leaf area index (LAI, the number of leaf layers above a certain area of soil). Apart from the leaves, light is also intercepted by the trunks and branches of the cacao trees. This is explicitly accounted for in this model. Canopies of shade and cacao trees may overlap.

One important assumption of the light interception calculations in CASE2 is that the crowns of both cacao trees and shade trees are supposed to be homogeneous (no wholes in the crowns) and connected (no wholes between crowns). Thus, one continuous and homogeneous canopy is assumed for each of the species.

For more information, see Kropff & Van Laar (1993).
3. Rain interception, evapotranspiration and soil water balance

This chapter discusses the principles that form the basis for the INTERCEPT subroutine in the MODEL2.FOR file, the SETPMD subroutine in the SETPMD.FOR file, the DRSAHE subroutine in the DRSAHE.FOR file, and the DRPOT subroutine in the DROPT.FOR file.

3.1 Rain interception

Part of the daily rainfall is intercepted by the canopy of cacao trees before reaching the soil (Figure 3.1). Rain reaches the soil by through-fall through the canopy. It may also reach the soil by stem flow, but this is not considered in CASE2 at this stage, due to lack of information.

A linear relation between through-fall and daily rainfall is assumed, based on measurements in Cameroon (Boyer 1970). The part of the daily rainfall that is intercepted by the canopy evaporates and thus reduces the amount of water required for evapotranspiration (see Section 3.2); the rain reaching the soil surface is used as input in the soil water balance (see Section 3.3). Note that the amount of intercepted rain does not depend on the leaf area index (LAI, the number of leaf layers above a certain soil area) of the model trees. For high values of LAI, as in tree plantations, no increase in interception is expected with increasing LAI. The relation between through-fall and rainfall is shown in Figure 3.2.
3.2 Evapotranspiration

Water is lost from the cacao plantation system by evapotranspiration (see Figure 3.1). This is the sum of transpiration and evaporation; transpiration is the loss of water from plants, and evaporation the loss of water from the soil or from a free-water surface. In CASE2, two types of evapotranspiration rates are calculated: potential and actual evapotranspiration. The potential evapotranspiration rate is the amount of water loss that is required to balance energy input (from radiation) and output (heat loss and evapotranspiration) of the trees. The potential evapotranspiration can only reached when water availability is not limiting. The actual evapotranspiration rate is equal to the potential rate in case sufficient water can be extracted from the soil. If the soil can not supply enough water to the trees, actual evapotranspiration is lower than potential. A water availability factor ($\phi$) is calculated as $\phi = \frac{ET_a}{ET_p}$, with $ET_a$ as actual and $ET_p$ as potential evapotranspiration. Its value is 1 in case the potential evapotranspiration is attained (actual = potential), and below one if water limitation occurs.

As evaporation from the soil surface is negligible in multi-layer canopies in which little sunlight reaches the soil, the rate of evapotranspiration depends on the transpiration of the plantation canopy. In CASE2, potential evapotranspiration is calculated using the Penman-Monteith combination equation, an adaptation of the Penman algorithm as described in Van Kraalingen & Stol (1997). The Penman-Monteith equation was modified for the use in cacao, as described below (and in Mommer, 1999). Adaptations in the Fortran source code are discussed in Chapter 17.

The potential evapotranspiration ($ET$) is calculated as the sum of two terms: the radiation term and the drying power term (Wallace, 1996; Radersma & de Ridder, 1996; note difference with equation in Van Kraalingen & Stol 1997).

$$ET = \frac{\Delta R_n}{\lambda(\Delta + \gamma(1 + r_c / r_a))} + \frac{\rho c_p \delta}{r_a}$$

In this equation $ET$ is the daily potential evapotranspiration (in mm d$^{-1}$); $\Delta$ is the slope of the vapour pressure curve (kPa °C$^{-1}$); $R_n$ is the net radiation flux at canopy surface (kW m$^{-2}$); $\rho$ is the density of dry air (kg m$^{-3}$); $c_p$ is the specific heat capacity of dry air (= 1.013 kJ kg$^{-1}$ °C$^{-1}$); $d$ is the vapour pressure deficit (kPa); $\gamma$ is the psychrometer coefficient (kPa °C$^{-1}$); $\lambda$ is the latent heat of water (kJ kg$^{-1}$); $r_a$ is the aerodynamic resistance and $r_c$ the surface resistance of the canopy (both in s m$^{-1}$). Net radiation is calculated following the methods in Van Kraalingen & Stol (1997), using the Swinbank method to calculate incoming long-wave radiation.
The resistances in the equation are derived as follows: as no wind function has been defined for tree crops, the aerodynamic resistance \( r_a \) for cacao is taken from literature \((38 \text{ s m}^{-1}, \text{Radersma & de Ridder 1996})\). The surface resistance of the canopy \( r_c \) depends on resistance of transpiration by the canopy, soil water evaporation and on zero-resistance to evaporation of intercepted rainwater. Due to the lack of data, the simple approach of Kelliher et al. (1995) was used. This compares minimum resistances at leaf and canopy scale, for non-stressed crops at LAI of more than 3.5. According to Kelliher et al. (1995), the canopy resistance is three times lower than the minimum leaf resistance. Minimum leaf resistance for cacao was taken from literature (amounting to 150 \text{ s m}^{-1} \text{ for a situation without water stress}; \text{Radersma & de Ridder 1996}).

### 3.3 Soil water balance

The soil compartment in CASE2 consists of a number of layers, each described by a thickness and certain soil characteristics (see Figure 3.1). Rain that reaches the soil enters in the first soil layer. The temporal changes in water content of the different soil layers is described in a water balance model. Two types of water balances are used in CASE2: one for a potential (non water-limited) situation (DRPOT) and one for water-limited production (DRSAHE). In the first case, the water content in each of the soil layers is constantly kept at field capacity, thus at optimal water availability. In this case, periods of drought do not have an effect on water uptake and tree growth. In the second case a soil water balance is used in which the water content in each soil layer may vary between wilting point (the volumetric water content at which plants cannot take up water anymore; pF = 4.2) and field capacity (the optimal volumetric water content for plant growth; pF = 2.0). One-dimensional vertical movement of water in the soil is described according to the 'tipping bucket' principle (as in the ARID CROP model of Van Keulen 1975). The processes included in this water balance are transpiration, irrigation, runoff, infiltration, evaporation, vertical redistribution of water and drainage (Van Kraalingen 1994). The runoff and irrigation processes are not used in CASE2. The impact of water table and capillary rise is assumed to be negligible. In CASE2, only the cacao trees take up water for transpiration; the shade trees do not. Hence, the assumption is made that the water uptake by shade trees does not influence the water availability for the cacao trees. This assumption is met in case shade trees have deeper roots or take up a minor portion of the water in the rooting zone of the cacao trees.

The water balance model redistributes the water among the soil layers within one day. It therefore assumes a high conductivity of the soil and is best suited for use in environments where soils are not saturated throughout the year.

The rate and state equations and description of processes of DRSAHE originate from the water-limited version of SUCROS (Van Laar et al., 1992). The principles of this soil water balance (SAHEL or DRSAHE) are described in the documentation of the ARID CROP model (Van Keulen, 1975) and in Van Kraalingen (1994). Information on the composition of the different soil types in Table 3.1 is taken from Driessen (1986). The principles of water uptake are described in Section 4.5.3.
Table 3.1. Description and characteristics of soil types ("Driessen soils") as used in the CASE2 model. The code refers to the value of the TYL parameter in the soil.dat file. Gamma is a texture-specific constant describing the water-retention curve (Driessen 1986). Water content is the volumetric percentage of water in the soil at different soil water suctions. Source: Driessen 1986.

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
<th>Gamma</th>
<th>Volumetric water content (WC, mm H₂O mm⁻³ soil) at Saturated field capacity wilting point air dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Coarse sand</td>
<td>0.0853</td>
<td>0.395 0.065 0.000 0.000</td>
</tr>
<tr>
<td>2</td>
<td>Medium coarse sand</td>
<td>0.045</td>
<td>0.365 0.141 0.005 0.000</td>
</tr>
<tr>
<td>3</td>
<td>Medium fine sand</td>
<td>0.0366</td>
<td>0.350 0.161 0.011 0.000</td>
</tr>
<tr>
<td>4</td>
<td>Fine sand</td>
<td>0.0255</td>
<td>0.364 0.212 0.033 0.000</td>
</tr>
<tr>
<td>5</td>
<td>Humous loamy medium coarse sand</td>
<td>0.0135</td>
<td>0.470 0.353 0.133 0.014</td>
</tr>
<tr>
<td>6</td>
<td>Light loamy medium coarse sand</td>
<td>0.0153</td>
<td>0.394 0.285 0.094 0.007</td>
</tr>
<tr>
<td>7</td>
<td>Loamy medium coarse sand</td>
<td>0.0243</td>
<td>0.301 0.180 0.031 0.001</td>
</tr>
<tr>
<td>8</td>
<td>Loamy fine sand</td>
<td>0.0299</td>
<td>0.439 0.233 0.027 0.000</td>
</tr>
<tr>
<td>9</td>
<td>Sandy loam</td>
<td>0.0251</td>
<td>0.465 0.273 0.044 0.001</td>
</tr>
<tr>
<td>10</td>
<td>Loess loam</td>
<td>0.0156</td>
<td>0.465 0.334 0.108 0.008</td>
</tr>
<tr>
<td>11</td>
<td>Fine sandy loam</td>
<td>0.0186</td>
<td>0.504 0.340 0.088 0.004</td>
</tr>
<tr>
<td>12</td>
<td>Silt loam</td>
<td>0.0165</td>
<td>0.509 0.359 0.108 0.007</td>
</tr>
<tr>
<td>13</td>
<td>Loam</td>
<td>0.0164</td>
<td>0.503 0.355 0.108 0.007</td>
</tr>
<tr>
<td>14</td>
<td>Sandy clay loam</td>
<td>0.0101</td>
<td>0.432 0.349 0.168 0.031</td>
</tr>
<tr>
<td>15</td>
<td>Silty clay loam</td>
<td>0.0108</td>
<td>0.475 0.378 0.173 0.029</td>
</tr>
<tr>
<td>16</td>
<td>Clay loam</td>
<td>0.0051</td>
<td>0.445 0.399 0.276 0.118</td>
</tr>
<tr>
<td>17</td>
<td>Light clay</td>
<td>0.0085</td>
<td>0.453 0.378 0.204 0.050</td>
</tr>
<tr>
<td>18</td>
<td>Silty clay</td>
<td>0.0059</td>
<td>0.507 0.447 0.292 0.109</td>
</tr>
<tr>
<td>19</td>
<td>Heavy clay</td>
<td>0.0043</td>
<td>0.540 0.493 0.361 0.177</td>
</tr>
<tr>
<td>20</td>
<td>Peat</td>
<td>0.0108</td>
<td>0.863 0.686 0.314 0.052</td>
</tr>
</tbody>
</table>
4. Cacao tree growth and yield

This chapter discusses the principles that are the basis for the subroutines in the CASE2.FOR file (CASE2, LEAF, ROOT, WUPT, POD) and subroutines called by these subroutines.

4.1 Photosynthesis

The photosynthesis calculations used in CASE2, are based on SUCROS (for monostands) and INTERCOM (for several competing species). SUCROS is documented in Van Laar et al (1992 & 1997) and Goudriaan & van Laar (1994); INTERCOM in Kropff & van Laar (1993).

The maximum photosynthesis rate at light saturation ($A_{\text{max}}$) is calculated as the highest rate found in studies on cacao trees ($A_{\text{max}, \text{lit}}$, Figure 4.1) and multiplied with a temperature factor (accounting for lower photosynthesis at high and low temperatures, Figure 4.2), and a factor accounting for the reduced rate of photosynthesis in young leaves (see Figure 4.3). This factor is calculated as the gross photosynthesis that is attained when taking lower photosynthesis for young leaves into account, divided by the potential rates when disregarding the reduction (based on data in Figure 4.3). Although old leaves show lower photosynthesis as well (Figure 4.3), this reduction could not be taken into account in CASE2 as the model does not calculate photosynthesis for cohorts of

**Figure 4.1.** Maximum photosynthesis rates for cacao as obtained in 13 studies. Maximum photosynthesis rates were generally measured in high-light conditions. In case of multiple measurements, bars denote the range of observed rates and circles the average value. The studies are in chronological order. Sources: Murray 1940 (1); Lemee 1956 (2); Baker & Hardwick 1973 (3); Okali & Owusu 1975 (4); Hutcheon 1977 (5); Guers 1985 (6); Raja Harun & Hardwick 1986 (7); Machado & Hardwick 1988 (8); Deng et al 1990 (9); Joly & Hahn 1991 (10); Yapp & Hadley 1994 (11); Yapp 1992 (chap 4; 12); Miyaji et al. 1997 (13).

**Figure 4.2.** Relation between a temperature factor and average temperature, as used to account for the effect of temperature on maximum photosynthesis rate in CASE2 for low (Joly & Hahn, 1991) and high temperatures (temperatures above $33^\circ$C are assumed to reduce photosynthesis rates).
leaves, but for layers of leaves in the canopy.

The rate of photosynthesis for cacao leaves is calculated using the maximum photosynthesis rate at light saturation ($A_{\text{max}}$), the initial slope of the photosynthesis-light curve and the light absorbed by the leaves. Calculations of leaf photosynthesis at various times of the day and in various layers of the cacao tree canopy are integrated over time and over the canopy to obtain the canopy photosynthesis on a daily basis (Gaussian integration is used, see Goudriaan & Van Laar, 1994). The total daily production of carbohydrates by photosynthesis of the cacao canopy is multiplied by a water availability factor to account for the closure of stomata during periods of water stress. This factor is equal to the quotient of actual and potential evapotranspiration (see Section 3.2).

### 4.2 Maintenance respiration

The daily amount of carbohydrates produced by photosynthesis, is stored in a reserve pool. Carbohydrates in this pool are used to provide energy for maintaining the existing biomass. Maintenance respiration in CASE2 is calculated as in SUCROS (Van Laar et al. 1992, 1997). It is proportional to the tree biomass and depends on the protein and mineral content of the tissue. For each of the plant organs, a maintenance coefficient is calculated (Table 4.1). The maintenance respiration of the trunk and branches is calculated applying the maintenance coefficient to living sapwood only, the fraction of physiological inactive heartwood tissue is excluded from the calculation (Mohren, 1987).


<table>
<thead>
<tr>
<th>Plant organ</th>
<th>N [%]</th>
<th>Minerals [%]</th>
<th>Maintenance coefficient [$gCH_2O \ g^{-1} d^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>leaves</td>
<td>1.91</td>
<td>2.7</td>
<td>$6.9 \times 10^3$</td>
</tr>
<tr>
<td>sapwood</td>
<td>0.43</td>
<td>1.8</td>
<td>$2.4 \times 10^3$</td>
</tr>
<tr>
<td>roots</td>
<td>1.08</td>
<td>2.5</td>
<td>$4.7 \times 10^3$</td>
</tr>
<tr>
<td>fruits</td>
<td>3.62</td>
<td>8.7</td>
<td>$1.6 \times 10^2$</td>
</tr>
</tbody>
</table>

**Figure 4.3.** Relation between gross photosynthesis and leaf age for cacao leaves in high light conditions in a Brazilian plantation. The initial lower photosynthesis for new leaves is taken into account in CASE2, by a photosynthesis reduction factor. Source: Miyaji et al 1997. The data in the graph are based on the information on net photosynthesis and respiration as given in the source.
Higher temperatures accelerate the turnover rates in plant tissue and hence increase the cost of maintenance respiration. Above a certain reference temperature, maintenance respiration is doubled for every temperature increase of 10°C (Penning de Vries & Van Laar, 1982).

4.3 Replacement and growth of plant parts

After “costs” for maintenance respiration have been subtracted from the carbohydrates produced by photosynthesis, the remaining carbohydrates can be used to produce new tissue in the different plant parts. In this part of the model, a number of important changes have been made when compared to the original SUCROS models on which CASE2 is largely based. In SUCROS, the partitioning of carbohydrates was based on age (or physiological age), whereas in CASE2 it is based on size (biomass). As a result, the partitioning procedure is divided in two parts, as illustrated in Figure 4.4. To explain the logic behind the change from age-based to size-based partitioning, the next section compares the two approaches in the case of cacao.

4.3.1 Age vs. size: allometric relations

For annual crops, especially when grown during a short season, the course of the development from small vegetative to large generative plants is closely related to plant age. In this case, the distribution of plant biomass over different plant parts correlates well with the age of the plant. In contrast, for long-lived tree crops, such as cocoa, this relation is weak. Differences in biomass growth between trees of the same age (expressed in years) may result in large differences in total biomass. This is illustrated in Figures 4.5: the portion of biomass in the different plant organs of cacao trees is poorly related to tree age. Related to this, the relation of total biomass with age is also rather weak (Figure 4.6). For cacao, the large variety of shade treatments (unshaded, light shade, heavy shade) leads to very different growth rates. As a result, even-aged trees may largely vary in biomass.

Relations between the biomass of a plant organ and the biomass of the total tree - so called allometric relations - are much stronger than those with plant age. Figure 4.7 shows the five allometric relations that were obtained using the same data as in Figures 4.5 and 4.6. These
relations were used in CASE2 to partition carbohydrates to the different plant organs. Thus, the total biomass (dry weight) of the model cacao tree may be used to estimate the distribution of biomass to the plant parts.

**Figure 4.5.** Distribution of biomass of cacao trees over different plant part, in relation to their age. The data for this graph are derived from various field studies, in which cacao trees were completely (or partially) cut down, divided in different plant parts and weighted. The measured cacao trees had grown in different shading environments in 6 countries: Brazil, Congo, Costa Rica, Malaysia, Nigeria and Venezuela. n.a. indicates that data on root biomass were not available. Sources: Himme 1959; Thong & Ng 1980; Aranguren et al 1982; Alpizar et al 1986, Teoh et al; 1986, Beer et al 1990; Opakunle 1991; Subler 1994.

**Figure 4.6.** Relation between total dry weight and age of cacao trees from plantations in different countries. Circles denote individuals trees (or average value for several trees), as reported in the sources, the drawn line is a logarithmic regression line through the data points. The regression line explains 21% of the variation in total weight by plant age ($R^2 = 0.2097$). The equation is: $y = 8.46 \ln(x) + 9.40$. Sources: as in Figure 4.5, but without Alpizar et al. 1996 and Beer et al 1990.

The relations in Figure 4.7 are static relations: they provide information on how the total biomass is distributed over plant parts for plants of different sizes (biomass). For the simulation model, however, dynamic information on the partitioning of carbohydrates over different plant parts is required. The allometric relations do not provide this information. For instance, investment in leaves cannot be directly determined from the allometric relation in graph a of Figure 4.7. These relations only provide the basis for partitioning the carbohydrates, by indicating that a plant of a certain biomass, on average has a certain weight of leaves. The differences in the slope of the lines in the parts of Figure 4.7, however, is an indication of the increment in biomass for the five plant parts. The steep line for stem and branch biomass (graph b) implies that for every kg extra in total tree weight, a large share is invested in stems and branches.

The reason why the allometric relations cannot be used directly to partitioning biomass is the turnover of plant parts: leaves are shed, fine roots die off and ripe fruits fall off or are harvested.
This rate of turnover differs between plant organs. The partitioning of carbohydrates in CASE2 takes the turnover into account and is done in two phases (see Figure 4.4). For the partitioning of available carbohydrates, first the “costs” of replacing the lost leaves, wood, roots and fruits should be covered. This is done by calculating the daily amount of biomass lost due to turnover and using the available carbohydrates to replace this lost biomass (this is described further in Section 4.3.2). The remaining carbohydrates are then used for the net growth of plant parts. For this purpose, the slopes of the allometric relations are used (see Section 4.3.3).

### 4.3.2 Replacement of lost biomass

After taking care of maintenance respiration, the carbohydrates available in the reserve pool are first used for the replacement of lost biomass due to turnover. Plant organs with turnover are leaves, fine lateral roots (< 2 mm in diameter), coarse lateral roots (> 2 mm in diameter), wood and fruits.

For fine roots, the amount of lost biomass per day is calculated as: \( \frac{dW_{\text{lost}}}{dt} = R_{\text{turnover}} \cdot W \), in which \( \frac{dW_{\text{lost}}}{dt} \) is the daily loss rate of dry weight (kg d\(^{-1}\)), \( R_{\text{turnover}} \) is the relative turnover rate (d\(^{-1}\), Muñoz & de Beer 2001) and \( W \) is the fine root dry weight. For leaves and fruits \( \frac{dW_{\text{lost}}}{dt} \) is calculated as the average dry weight loss over the 10 preceding days in the simulation. For leaves, this rate depends on the leaf life time and on water stress (see Section 4.4.2). For fruits (pods), the
lost biomass is the weight of the harvested fruits which depends on investment in fruits during the preceding months. For wood and coarse lateral roots, the turnover rate is calculated as a fraction of the loss of leaves and fine lateral roots, respectively, as no estimates for relative turnover rates were available.

The required amount of carbohydrates necessary for replacing the lost biomass is calculated using a conversion factor \( G \) (assimilate requirement) for the assimilates needed to produce of one kg of tissue, which depends on its chemical composition. For pods, the growth respiration (or assimilate requirement) depends on the fat content of the beans. This is illustrated in Figure 4.8. For the remaining plant parts the conversion factors are fixed (Table 4.2).

![Fat content and growth requirements](image_url)

**Figure 4.8.** Relation between assimilation requirements for the production of pods and fat fraction in nibs (cotyledons of the cacao bean), as used in CASE2. The assimilation requirements are expressed in kg carbohydrates required for the production of 1 kg of pods. These values are calculated based on the chemical composition of pods, using conversion factors for different chemical composites (see Table 4.2). Source: Valle et al. 1990.

<table>
<thead>
<tr>
<th>Chemical components</th>
<th>Derived parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Carbohydrates</td>
</tr>
<tr>
<td>Leaves</td>
<td>0.53</td>
</tr>
<tr>
<td>Wood</td>
<td>0.49</td>
</tr>
<tr>
<td>Roots</td>
<td>0.57</td>
</tr>
<tr>
<td>Fruits</td>
<td>0.59</td>
</tr>
</tbody>
</table>

In case sufficient carbohydrates are available in the reserve pool to cover the required amount for replacement of lost biomass, all biomass is replaced during the same day. If this is not the case, the available reserves are distributed over the different plant parts proportional to the biomass lost. In case no reserves are available, no replacement takes place.

### 4.3.3 Net growth of plant parts

Carbohydrates present in the reserve pool after subtracting the needs for maintenance respiration and replacement of lost biomass, is used for net growth of plant parts. The distribution of
assimilates over the different organs depends on several factors: the actual proportions of biomass in the plant parts, the "ideal" proportion of biomass in the plant parts following the allometric relations (Figure 4.7), the slope of the allometric functions and the availability of water. The ideal proportion of biomass in each organ is calculated using the regression equations in Figure 4.7. That of leaves and fine lateral roots is modified by a water availability factor, the quotient of actual and potential evapotranspiration (see Section 3.2). For fine roots: \( p_{\text{ideal}} = p_{\text{allo}} \times \frac{E_{\text{act}}}{E_{\text{pot}}} \) and for leaves \( p_{\text{ideal}} = p_{\text{allo}} \times \left(2 - \frac{E_{\text{act}}}{E_{\text{pot}}}\right) \), in which \( p_{\text{ideal}} \) is the ideal proportion of biomass in roots or leaves, \( p_{\text{allo}} \) is the proportion of biomass in the allometric relations, \( E_{\text{act}} \) is the actual evapotranspiration and \( E_{\text{pot}} \) is the potential evapotranspiration. The relation between water availability and ideal proportions of leaves and roots is biologically logical, but it is not supported by empirical data for cacao trees.

For each organ, the ideal and actual proportions are compared. If the actual proportion is higher than or equal to the ideal proportion, the fraction of carbohydrates partitioned to this organ is zero. If it is lower, part of the available reserves is allocated to the organ. The partitioning is calculated as: \( f = \text{slope} \times \left(\frac{p_{\text{ideal}} - p_{\text{act}}}{p_{\text{act}}} \right) \), in which \( f \) is the fraction of carbohydrates partitioned to a certain organ (unitless, within a minimum value of zero) and slope is the slope of the allometric regression line (unitless, see Figure 4.7). This procedure is illustrated in Figure 4.9.

Using the calculated partitioning fractions and the assimilate requirements to produce each of the tissues (see Table 4.2), the total amount of assimilates to produce one kg of new tissue is calculated (as in SUCROS; Van Laar et al. 1992, 1997). The amount of assimilates in the reserve pool determines the total biomass growth of the trees.

### 4.4 Leaf dynamics

#### 4.4.1 Boxcar train

Leaf dynamics in CASE2 are modelled in a so called escalator boxcar train (Goudriaan & Van Roermund 1999). Leaves of a certain age (in days) are stored in a leaf age class with a width of one day. The number of age classes thus equals the maximum leaf life span in days. After each simulation day, all leaves are moved to the next class as they become one day older. New leaves
produced during a day are included in the first class (or boxcar). Leaves in the last class which have reached the maximum leaf age, are removed from the “train” and subtracted from the total amount of leaves.

4.4.2 Leaf production and loss

Leaf production in CASE2 takes place continuously, not in flushes as in real cacao trees. Leaf biomass is produced to replace shed leaves and to attain net increase in leaf biomass. The production of leaves thus depends on both the leaf loss and the allometric relation of leaf weight and total weight (Figure 4.7). In addition, it depends on the water availability: leaf production is reduced during periods of water stress (see Section 4.3.3).

Leaf shedding occurs when leaves have reached the maximum age (senescence) and due to drought. Leaves in the last age class are shed during the next day. Water shortage lowers the leaf life time: during periods of severe water stress, this is reduced to a certain minimum. The linear relation between leaf life time and a water availability factor (the quotient of actual and potential evapotranspiration (1=no water shortage; 0=actual evapotranspiration equals zero). The maximum leaf life span is the maximum age that leaves can reach in the model. This value is based on information on leaf life span under non-water limiting conditions (average for cacao leaves in different layers and flushes in a Brazilian plantation; Miyaji et al 1997). The minimum value is based on low leaf life span at extremely high temperature (Sale 1968).

Leaf loss due to age is not affected by water stress: it only depends on the average leave age in situations without water limitation. Each day during the simulation, leaves that have passed this age are shed. As the amount of leaves in each age class is not necessarily equal, the leaf loss rate due to ageing may vary in time. Leaf loss due to water stress depends on water availability, as leaf life span is adjusted with respect to water availability (see Figure 4.10 and text).
\(L_{\text{mas}}\) is the maximum leaf age. The relation of leaf loss and water availability is shown in Figure 4.11.

### 4.4.3 Leaf area and Specific leaf area

Leaf weights calculated in the model are converted into leaf area. This is necessary for the calculation of light interception. The conversion is: \(LA = SLA \times W_L\), in which \(LA\) is the leaf area (in \(m^2\)), \(W_L\) is the dry weight of leaves (kg) and \(SLA\) is the specific leaf area (the area of leaf surface per unit dry weight of leaves, \(m^2\) kg\(^{-1}\)). The value of \(SLA\) depends on plant size and light availability.

**Figure 4.12.** Empirical relations of the specific leaf area (SLA, the area of leaf per unit leaf weight) with total weight (left graph), and relative light availability (right graph). The relation in the left graph is based on measurements on cacao trees in a Malaysian plantation. The linear relation between SLA and plant weight is used to determine the SLA for new leaves and the SLA at the start of simulations. The linear regression line explains 58% of the variation in SLA. The closest symbol was not used in the regression, as trees of this size are not considered in CASE2. The relation in the right graph is for the relative value of the specific leaf area and the relative availability of light. A relative light availability of 1 is no shading, a value of 0.5 indicates 50% shading. The relative SLA equals 1 for full light. The logarithmic relation between SLA and light availability is used in CASE2 to correct the SLA value for the influence of shading. The original data for this relation were collected in a plantation in Cameroun. The regression line explains 96% of the variation in SLA. Sources: Thong & Ng 1980 (left), Guers 1971 (right).

SLA of cacao trees is related to tree size: small trees generally have a lower specific leaf area. In CASE2, the SLA of new leaves depends on the total tree biomass. The empirical relation used in CASE2 is shown in Figure 4.12a.

SLA values for cacao increase considerably with decreasing light availability. SLA values used in CASE2 are therefore modified for simulations with over 20% shading. An empirical relation between SLA and transmission is used to modify the age-dependent SLA value (Figure 4.12b). This calculation assumes that crowns of shade trees and cacao trees do not overlap. If they do, this would lead to a slight overestimation of SLA. The SLA calculation also does not take internal shading within the cacao crowns into account.
4.5 Root dynamics and water uptake

4.5.1 Taproot length

Cacao trees possess a taproot that may attain a depth of 2 m. Attached to this taproot are the lateral roots, of which part are responsible for water uptake. In CASE2, the taproot length determines in which soil layers these lateral roots are present. The taproot length is calculated based on the taproot weight and on the assumption that it has the shape of a cone. The basis for this calculation is the formula for the contents of a cone: \(1/3 \times \text{base} \times \text{height}\). The base is calculated as \(\pi r^2\) and the proportion of diameter (2r) and length (l) are taken to be 1 to 10. The base can then be calculated as: \(1/3 \times \pi \times l^3 \times 1/400\). The calculation of the taproot length then is: \(l_{\text{tap}} = [(W_{\text{tap}} \times 1200) / (sw \times \pi)]^{(1/3)}\), in which \(l_{\text{tap}}\) is the taproot length (m), \(W_{\text{tap}}\) is the weight of the taproot (kg) and \(sw\) is the specific weight of wood of the cacao tree which is used to convert the cone weight to a contents (kg m\(^{-3}\)).

4.5.2 Lateral roots distribution

In CASE2, lateral roots are distributed in all layers in which the taproot penetrates. Part of the lateral roots, the fine lateral roots (with a diameter of <2 mm), are able to take up water. These roots are distributed over the different soil layers for the calculation of water uptake. This distribution is an exponential decline of root weight over soil depth, which is based on empirical data from a cocoa plantation (Figure 4.13). For each simulation day, the fine root biomass is distributed over the available soil layers. Growth and turnover of fine roots is thus independent of their vertical position in the soil. For each soil layer, first an “ideal” weight of fine lateral roots is calculated as: \(W_{i,\text{ideal}} = b \times d_i^a \times \Delta d_i\), in which \(W_{i,\text{ideal}}\) is the ideal weight of fine lateral roots in soil layer \(i\) (kg), \(a\) (unitless) and \(b\) (kg m\(^{-2}\); negative) are constants based on the empirical relation in Figure 4.13, \(d_i\) is the depth of the centre of soil layer \(i\) (m) and \(\Delta d_i\) is the thickness of the soil layer (m). The real weight of fine roots in soil layer \(i\) is calculated as: \(W_{i,\text{real}} = W_{i,\text{ideal}} \times W_{\text{real}} / W_{\text{ideal}}\) in which \(W_{\text{ideal}}\) is the sum of ideal weights for all layers, \(W_{\text{real}}\) is the total weight of fine roots that may be distributed.

Figure 4.13. Empirical data on the vertical distribution of fine roots (< 2 mm diameter) of cacao trees in a plantation in Brazil. Shown is the amount of dry weight per unit soil volume at different depth in the soil. The exponential regression line, drawn through the data is used in CASE2 to distribute fine root biomass over soil layers. This regression line explains 84% of the variation in root biomass. Sources: Kummerrow et al 1981 and 1982.
4.5.3 Root surface and water uptake

Fine root weight per soil layer is converted to length and then to area, to obtain a measure for the water extraction capacity of these roots. Two categories of fine roots are distinguished: those with a diameter of <1 mm and those with a diameter of 1-2 mm. Each of these two categories contains half of the total weight of fine roots. The root length per category is calculated as half the fine root weight in a soil layer multiplied by the specific root length (unit length per unit weight) of that root category. The rooting surface \( A_i \) (m\(^2\)) is calculated from this as \( A_i = 2\pi * r * l_i \), in which \( r \) is the average radius of the roots (m) and \( l_i \) is the total root length (m).

The sum of the rooting surface in all soil layers \( A_{\text{tot}} \) (m\(^2\)) is used to determine the potential water extraction per unit root surface (in mm d\(^{-1}\) m\(^{-2}\)): \( WU_{\text{pot}} = \frac{ET}{A_{\text{tot}}} \), in which \( ET \) is the potential evapotranspiration (mm d\(^{-1}\), see Section 3.2).

A maximum water uptake per soil layer \( WU_{i, \text{max}, \text{mm d}^{-1}} \) is calculated based on the root surface and the potential water extraction: \( WU_{i, \text{max}} = A_i * f_{\text{drought}} * WU_{\text{pot}} \) in which \( A_i \) is the total root surface in soil layer \( i \) (m\(^2\)), and \( f_{\text{drought}} \) (unitless) is a water uptake reduction factor which is <1 in case of drought. The realised water uptake is equal to the maximum in case there is sufficient water available in the soil layer. If not, the available amount of water is extracted. The amount of available water in soil layer \( i \) (\( WC_{\text{avail}, i}, \text{mm} \)) is calculated as: \( WC_{\text{avail}, i} = (WC_{\text{field}, i} - WC_{\text{wilting}, i}) * \Delta d_i \), in which \( WC_{\text{field}, i} \) is the volumetric water content of the soil type of layer \( i \) at field capacity (unitless) and \( WC_{\text{wilting}, i} \) is that at wilting point (unitless, see Section 3.3), and \( \Delta d_i \) is the thickness of the soil layer (mm).

4.6 Pod growth, development and harvesting

The sequence of procedures in CASE2 to derive ripe beans from available reserves is illustrated in Figure 4.14. New pods are initiated and ripen during a certain period of time. When ripe, they are harvested, the biomass of beans in these pods is calculated and beans are dried and fermented.
4.6.1 Pod ripening

Similar to leaves, the growth and development of pods (fruits) is modelled in a so-called escalator boxcar train (see Section 4.4.1, Goudriaan & Van Roermund 1999). Pods are divided into age classes, each class containing pods of the same age (in days). After each simulation day, pods present in one class are moved to the next class, as they become one day older. The total number of classes equals the ripening period of pods. When pods are ripe, (when they have passed the last class) they are harvested. The rate of pod ripening depends on the average temperature.

For each of the pod classes, a value of the development stage is calculated, indicating the ripening status of the pods. The development stage is 0 for pollinated flowers and 1 for ripe pods, which can be harvested. At the start of the simulation, the development stage for all pod classes is calculated as the quotient of the age of the pods and the total ripening period. Each simulation day, when pods move from one class to the next, their development stage is increased by a certain development rate, which depends on the temperature during that day (Figure 4.15).

4.6.2 Pod growth and initialisation

The total biomass that is invested in pods is used for growth of existing pods and for the initialisation of new pods. New pods are included in the first age class (box car). The distribution of biomass over the age classes is done with a distribution parameter, the sink strength.

\[
\frac{dW_i}{dt} = s_i \cdot \frac{dW_{all}}{dt},
\]

in which \(dW_i/dt\) is the weighted growth rate of pods in class \(i\) (kg d\(^{-1}\)), \(s_i\) is the sink strength of class \(i\) (unitless), \(s_{sum}\) is the sum of sink strength of all categories (unitless), \(dW_{all}/dt\) is the increment in biomass of all pod classes (kg d\(^{-2}\)). Note that the distribution of new biomass over pod classes does not depend on the weight of pods in each class (biomass growth of pod classes is not weighted for the pod weight per class).

Sink strength of pod classes is related to the development stage. Both new and almost ripe pods have a low sink strength value, as illustrated in Figure 4.16. Sink strength values are based on measurements of the growth rate of pods in a cocoa plantation.

In contrast to real cacao trees, the model trees in CASE2, produce new pods each day. The weight of new pods, though, may vary periodically. This depends on the partitioning of carbohydrates to pods (see Sections 4.3.2 and 4.3.3 for description of partitioning). In periods of reduced production...
of carbohydrates (e.g. due to water stress), investment in pods and thus the weight of new pods is low.

4.6.3 Pod harvesting

Pods are ripe when the value of the development stage of a class exceeds 1. The pods in a class with a development stage >1 are harvested. The pod weight in that class is added to the daily harvest and the contents of the class (boxcar) is removed. The daily harvest is the outflux rate of the total pod weight.

4.7 Parameters derived from pod harvest

4.7.1 Commercial bean yield

To allow for a comparison of model simulation results with field data on commercial bean yield, the pod harvest values are converted into commercial bean yield. This is calculated as: $Y_b = f_b * f_{ferm} * (1 + c_{moist}) * Y_p$, in which $Y_b$ is the commercial bean yield (kg d$^{-1}$; slightly wet), $f_b$ is the weight fraction of beans in a pod (kg beans (kg pods)$^{-1}$), $f_{ferm}$ is the fraction of bean weight present after fermentation (unitless), $c_{moist}$ is the moisture content of dry beans (unitless), and $Y_p$ is the weight of harvested pods (kg d$^{-1}$; dry matter). The fermentation fraction $f_{ferm}$ is calculated as: $f_{ferm} = a * t_{ferm}$.
\[ + b, \text{ in which } a (d^{-1}) \text{ and } b \text{ (unitless) are regression coefficients and } t_{\text{term}} \text{ is the fermentation duration (days, see Figure 4.17).} \]

### 4.7.2 Butter hardness

\[ \text{Butter hardness is the ratio between saturated and unsaturated fatty acids (Wood \& Lass 1985) of harvested cocoa beans. It determines the melting point of cacao butter and is related to the ambient temperature at the onset of fruit ripening (high temperatures lead to high butter hardness values). Using information on average temperature and the relation in Figure 4.18, butter hardness of harvested beans is calculated in CASE2.} \]

**Figure 4.18.** Empirical relation between butter hardness of cacao beans and temperature at the onset of the fruiting. Butter hardness is calculated as the ratio of saturated and unsaturated fatty acids, and is related to the melting point of cocoa butter. The regression line in the graph is used in CASE2 to relate temperature at onset of fruiting with butter hardness of the ripe beans. This graph is based on measurements on weight growth of pods during ripening in a plantation in Cameroon. Source: Hutcheon 1977.

### 4.7.3 Harvest indices

Two harvest indices are calculated in CASE2. The “classical” harvest index (H.I.) is calculated as: 

\[ \text{HI} = \frac{W_{\text{harv}}}{W_{\text{above}}} \]

in which \( W_{\text{harv}} \) is the annual commercial bean yield (kg) and \( W_{\text{above}} \) is amount of aboveground biomass (kg). An index value specific for tree crops has been proposed by Cannell (1985). This harvest increment (H.Incr.) is defined as: 

\[ \text{Hincr} = \frac{dW_{\text{harv}}/dt}{dW_{\text{above}}/dt} \]

in which \( dW_{\text{harv}}/dt \) is the annual commercial bean yield (kg y\(^{-1}\)) and \( dW_{\text{above}}/dt \) is the annual biomass production aboveground (kg y\(^{-1}\)).

### 4.7.4 Nutrient loss through bean harvest

To evaluate the effect of bean removal from cocoa plantations on the nutrient cycles, the losses of N, P and K due to bean yield are estimated in CASE2. These estimates are based on the annual commercial bean yield and information on the nutrient content of the beans. Table 4.3 contains information on the N, P and K contents of dry beans.

**Table 4.3.** Nutrient content of dry cacao beans, for N, P and K, as used in CASE2 to calculate nutrient losses due to bean harvest. Source: Wood \& Lass 1985, average value for beans.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Nutrient weight per unit bean dry weight [g kg(^{-1})]</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>21.0</td>
</tr>
<tr>
<td>P</td>
<td>4.0</td>
</tr>
<tr>
<td>K</td>
<td>9.5</td>
</tr>
</tbody>
</table>
Part II   Technical program manual
5. Program structure and execution

5.1 Program structure

The general set up of the CASE2 model is depicted in Figure 5.1. This figure shows the different subroutines (programs), data files and library files that are used by the program. The CASE2 model uses the Fortran Simulation Environment (FSE) (Van Kraalingen, 1995). This modelling and simulation environment controls simulation runs, takes care of reading weather data and plant data, and generates output. This is done by the FSE driver that controls the program runs. It calls the MODELS subroutine, and in that subroutine the main programs related to rain interception (INTERCEPT), evapotranspiration (SETPMD), optimal moisture content (DRPOT), water balance (DRSAHE) and cacao tree growth (CASE2) are called. The plant module simulates light interception of the shade and cacao trees, canopy photosynthesis, cacao tree growth and production, water uptake and transpiration. The soil water balance module simulates the soil water content, its distribution, soil evaporation and drainage. The evapotranspiration module calculates potential evapotranspiration.

Three libraries are used in the CASE2 model: TTUTIL.LIB, CACAO.LIB and DRIVERS.LIB. The TTUTIL library (version 4) contains subroutines and functions used for reading input files, writing output, file handling and generating weather data (Van Kraalingen & Rappoldt 2000). The CACAO library contains a number of Fortran source code files used in the CASE2 model, which are usually not changed. The DRIVERS library is used by the FSEWin shell.

The CASE2 model uses 6 data files, some of which are used by different subroutines (see Section 5.2).
5.2 Subroutines and data files

A listing of the most important subroutines used in CASE2 is provided in Table 5.1. Table 5.2 contains a list of the 6 data files used by CASE2.

Table 5.1. List of Fortran subroutines used in the CASE 2 model. A description of the function of each subroutine is provided, as well as the Fortran source file in which the subroutine is included and the library in which it is included (if applicable). The documentation list includes references to original sources in case the subroutine has not been changed or slightly modified for use in CASE2. A complete program description is provided in this report for those subroutines that have been specifically written for CASE2 or have been significantly modified for use in CASE2. This table includes all subroutines shown in Figure 5.1, but does not include all subroutines used by the CASE2 model (a large number of subroutines is included in the three libraries: TTUTIL, DRIVERS and CACAO). All listed Fortran files (except for WEATHR.FOR) are included in subdirectories \program\ and \source within the c:\case2 directory.

<table>
<thead>
<tr>
<th>Subroutine</th>
<th>Calculates or conducts</th>
<th>Included in Fortran file</th>
<th>In library</th>
<th>Documented in</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASSIMC</td>
<td>Canopy assimilation</td>
<td>TOTASC.FOR</td>
<td>CACAO.LIB</td>
<td>Kropff &amp; van Laar 1993</td>
</tr>
<tr>
<td>CASE2</td>
<td>Cacao tree growth and production</td>
<td>CASE2.FOR</td>
<td>CACAO.LIB</td>
<td>Chapter 9</td>
</tr>
<tr>
<td>CLIMRD</td>
<td>Reading of monthly or long-term weather data</td>
<td>CLIMRD.FOR</td>
<td>CACAO.LIB</td>
<td>Hijmans et al. 1994</td>
</tr>
<tr>
<td>DRPOT</td>
<td>Water balance for potential production</td>
<td>DRPOT.FOR</td>
<td>CACAO.LIB</td>
<td>Chapter 15</td>
</tr>
<tr>
<td>DRSAHE</td>
<td>Water balance for water-limited production</td>
<td>DRSAHE.FOR</td>
<td>CACAO.LIB</td>
<td>Van Kraalingen 1994, Chapter 16</td>
</tr>
<tr>
<td>FSE</td>
<td>Control of program execution, input/output and time</td>
<td>FSE.FOR</td>
<td></td>
<td>Van Kraalingen 1995; Chapter 6</td>
</tr>
<tr>
<td>INTERCEPT</td>
<td>Rain interception</td>
<td>MODEL2.FOR</td>
<td></td>
<td>Chapter 8</td>
</tr>
<tr>
<td>LEAF</td>
<td>Leaf growth and senescence</td>
<td>CASE2.FOR</td>
<td></td>
<td>Chapter 10</td>
</tr>
<tr>
<td>LEAFPA</td>
<td>Parabolic leaf distribution</td>
<td>TOTASC.FOR</td>
<td></td>
<td>Kropff &amp; van Laar 1993</td>
</tr>
<tr>
<td>METEO</td>
<td>Control of weather data reading and generation</td>
<td>METEO.FOR</td>
<td>CACAO.LIB</td>
<td>Van Kraalingen et al. 1997</td>
</tr>
<tr>
<td>MODELS</td>
<td>Regulation of modules on crop growth, evapotranspiration and water balance</td>
<td>MODEL2.FOR</td>
<td></td>
<td>Chapter 7</td>
</tr>
<tr>
<td>POD</td>
<td>Pod growth</td>
<td>CASE2.FOR</td>
<td></td>
<td>Chapter 14</td>
</tr>
<tr>
<td>RNDIS</td>
<td>Rain distribution</td>
<td>RNDIS.FOR</td>
<td>CACAO.LIB</td>
<td>Hijmans et al. 1994</td>
</tr>
<tr>
<td>RGEN</td>
<td>Rain generation</td>
<td>RGEN.FOR</td>
<td>CACAO.LIB</td>
<td>Hijmans et al. 1994</td>
</tr>
<tr>
<td>ROOT</td>
<td>Root distribution</td>
<td>CASE2.FOR</td>
<td></td>
<td>Chapter 11</td>
</tr>
<tr>
<td>SASTRO</td>
<td>Basic astronomic data</td>
<td>SASTRO.FOR</td>
<td>CACAO.LIB</td>
<td>Kropff &amp; van Laar 1993</td>
</tr>
<tr>
<td>SETMPD</td>
<td>Evapotranspiration</td>
<td>SETMPD.FOR</td>
<td>CACAO.LIB</td>
<td>Van Kraalingen &amp; Stol 1997, Chapter 17</td>
</tr>
<tr>
<td>SSKYC</td>
<td>Fluxes of diffuse and direct radiation</td>
<td>TOTASC.FOR</td>
<td></td>
<td>Kropff &amp; van Laar 1993</td>
</tr>
<tr>
<td>SVSP1</td>
<td>Saturated vapour pressure</td>
<td>SVSP1.FOR</td>
<td>CACAO.LIB</td>
<td>Van Kraalingen &amp; Stol 1997</td>
</tr>
<tr>
<td>SWSE</td>
<td>Water uptake reduction due to drought</td>
<td>SWSE.FOR</td>
<td>CACAO.LIB</td>
<td>Chapter 13</td>
</tr>
<tr>
<td>TOTAL</td>
<td>Total daily canopy assimilation</td>
<td>TOTASC.FOR</td>
<td>CACAO.LIB</td>
<td>Kropff &amp; van Laar 1993</td>
</tr>
<tr>
<td>WEATHR</td>
<td>Reading of daily weather data</td>
<td>WEATHR.FOR</td>
<td>TTUTIL.LIB</td>
<td>Van Kraalingen et al. 1997</td>
</tr>
<tr>
<td>WUPT</td>
<td>Water uptake</td>
<td>CASE2.FOR</td>
<td></td>
<td>Chapter 12</td>
</tr>
</tbody>
</table>
Table 5.2. List of data input files used by the CASE2 model. A short description of their contents and a listing of subroutines that use each data file are provided, as well as a reference to the Section of this report where further explication can be found. The weather data files are not mentioned in this table. After installation, these are stored in sub-directories under c:\case2\weather.

<table>
<thead>
<tr>
<th>Data file</th>
<th>Contains</th>
<th>Read by subroutines</th>
<th>Documented Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>control.dat</td>
<td>File names of data files</td>
<td>FSE</td>
<td>18.2</td>
</tr>
<tr>
<td>reruns.dat</td>
<td>Information on variables to be changed in reruns</td>
<td>FSE</td>
<td>18.4</td>
</tr>
<tr>
<td>soil.dat</td>
<td>Soil characteristics per soil layer</td>
<td>DRSAHE, 18.5</td>
<td></td>
</tr>
<tr>
<td>timer.dat</td>
<td>Data on location of weather files, generation of output</td>
<td>FSE, MODELS 18.6</td>
<td></td>
</tr>
<tr>
<td>plant.dat</td>
<td>Data on physiology, resource partitioning, pod ripening and age-size relationships for cacao trees</td>
<td>INTERCEPT, CASE2, LEAF, ROOT, WUPT, POD 18.3</td>
<td></td>
</tr>
<tr>
<td>basic.dat</td>
<td>Basic data on locations, soil types, output frequency, cacao trees, cropping system and pod characteristics</td>
<td>FSE, MODELS, CASE2 18.1</td>
<td></td>
</tr>
</tbody>
</table>

5.3 Order of program execution

Simulations in CASE2 are carried out following a fixed sequence of calculations, which is directed by the FSE driver (FSE.FOR). The time step for the calculations is one day. This procedure is visualised in Figure 5.2.

![Figure 5.2.](image)

The simulation procedure starts with cacao trees of a certain size or age. Based on this information, other initial plant characteristics such as leaf area, root distribution and biomass of the different plant parts are determined. The initial tree characteristics (states) and the growing conditions (cropping system, weather conditions and soil characteristics) are then used to calculate rates of photosynthesis, respiration, water uptake, water loss, etc. These rates are used to determine the growth in biomass. Then, the values of these states are updated by adding their rates of change integrated over one day to obtain the values for the next day. During this next simulation day, the new states are used to calculate new rates, which then are used to obtain the state values for the following day, etc. This iterative procedure continues until the final simulation time, which is specified by the user.
6. The FSE subroutine

6.1 Purpose

This subroutine is included in the FSE.FOR file. It is a simulation environment (Fortran Simulation Environment) for simulation of biological processes in time, such as crop and vegetation growth. The principles of the FSE-system are described in Van Kraalingen (1995). A short introduction is given in Sections 5.1 and 5.3.

Version 2.1 of FSE.FOR (documented in Van Kraalingen 1995) was the basis for the adapted version used in the CASE2 model. The FSE.FOR file was adapted to allow for the use of monthly and long-term weather data (by Wouter Gerritsma), to read weather data in a simplified form (Pieter Zuidema) and to produce charts in the FSE Windows environment (Daniel van Kraalingen). Below, the complete Fortran code is printed for this subroutine, but comments are only provided for the adaptations done compared to the original version 2.1 as documented by Van Kraalingen (1995). Adaptations are printed in bold.

6.2 Declarations

The adaptations in relation to FSE 2.1 concern some added lines on the use of charts in FSEWin (second line and two lines at the end of the listing below). In case the CASE2 model is used outside FSEWin in another Fortran compiler (such as Visual Fortran), these lines have to be inactivated (by putting an * at the first position).

Some declarations related to reading of (monthly and long-term average) weather files and variables from the basic.dat file have been added.

```fortran
SUBROUTINE FSE

USE CHART

IMPLICIT NONE

*-----Standard declarations for simulation and output control
INTEGER   ITASK   , INSETS, ISET  , IPFORM, IL, LEN_TRIM
LOGICAL   OUTPUT  , TERMNL, RDINQR, STRUNF, ENDRNF
CHARACTER COPINF*1, DELTMP*1
INTEGER   INPRS   , STRUN , ENDRUN, I1
INTEGER   IMNPRS
PARAMETER (IMNPRS=100)
CHARACTER PRSEL(IMNPRS)*11

*-----Declarations for time control
INTEGER   IDOY, IYEAR
REAL      DELT, DOY, FINTIM, PRDEL, STTIME, TIME, YEAR

*-----Declarations for meteo system
INTEGER   IFLAG  , IUWE  , IWEATH , ISTN, IRNDAT
INTEGER   IYEARR  , IUAR  , NRYEARS
REAL      ANGA  , ANGB  , ELEV  , LAT  , LONG  , FRPAR
REAL      RDD   , TMMN  , TMMX  , VP  , WN    , RAIN
LOGICAL   WTRMES , WTRTER, RSETRG , RSETRD
CHARACTER WTRDIR*80, CLFILE*80, RAFILE*80
CHARACTER CNTR*7, WSTAT*6, DUMMY*1

*-----Declarations for soil type and production level
INTEGER   SOILTYPE, PRODLEV

END
```


*-----Declarations for output
  INTEGER OUTPUTFQ

*-----Declarations for location selection
  INTEGER LOCATION, STRTYR, ENDRYR
  * Declarations for higher IWEATH selections
  CHARACTER GEODIR*80, DRVDIR*80, DBRDIR*80, DBMDIR*80
  * Declarations for file names and units
  INTEGER IUNITR, IUNITD, IUNITO, IUNITL, IUNITC
  CHARACTER FILEON*80, FILEOL*80
  CHARACTER FILEIC*80, FILES*80, FILEI2*80, FILEI3*80, FILEI4*80, FILEI5*80
  CHARACTER STRNAM*80, RAFILE*80

*-----Declarations for file names and units
  INTEGER IUNITR, IUNITD, IUNITO, IUNITL, IUNITC
  CHARACTER FILEON*80, FILEOL*80
  CHARACTER FILEIC*80, FILEI1*80, FILEI2*80, FILEI3*80, FILEI4*80, FILEI5*80
  CHARACTER STRING*80

*-----Declarations for observation data facility
  INTEGER INOD, IOD
  INTEGER IMNOD
  PARAMETER (IMNOD=100)
  INTEGER IOBSD(IMNOD)

*-----For communication with OBSSYS routine
  COMMON /FSECM1/ YEAR,DOY,IUNITD,IUNITL,TERMNL
  SAVE

*-----File name for control file and empty strings for input
  * files 1-5. WTRMES flags any messages from the weather system
  DATA FILEIC /'CONTROL.DAT'/
  DATA FILEI1 /' '/, FILEI2 /' '/, FILEI3 /' '/
  DATA FILEI4 /' '/, FILEI5 /' '/
  DATA WTRMES /.FALSE./
  DATA STRUNF /.FALSE./, ENDRNF /.FALSE./

*-----Unit numbers for control file (C), data files (D),
  output file (O), log file (L) and rerun file (R).
  IUNITC = 10
  IUNITD = 20
  IUNITO = 30
  IUNITL = 40
  IUNITR = 50

*-----Unit number for WOFOST weather file
  IUWE  = 60

*-----Open control file and read names of normal output file, log file
  and rerun file (these files cannot be used in reruns)
  CALL RDINIT (IUNITC,0, FILEIC)
  CALL RDSCHA ('FILEOL', FILEON)
  CALL RDSCHA ('FILEOL', FILEOL)
  CALL RDSCHA ('FILEOL', FILEOL)

  * check if start run number was found, if there, read it
  IF (RDINQR('STRUN')) THEN
    CALL RDSINT ('STRUN', STRUN)
    STRUNF = .TRUE.
  END IF

  * check if end run number was found, if there, read it
  IF (RDINQR('ENDRUN')) THEN
    CALL RDSINT ('ENDRUN', ENDRUN)
    ENDRNF = .TRUE.
  END IF

  CLOSE (IUNITC)

*-----Open output file and possibly a log file
Chapter 6. The FSE subroutine

CALL FOPENS (IUNITO, FILEON, 'NEW', 'DEL')
IF (FILEOL.NE.FILEON) THEN
   CALL FOPENS (IUNITL, FILEOL, 'NEW', 'DEL')
ELSE
   IUNITL = IUNITO
END IF

c*     initialization of logfile for processing of end_of_run values
      CALL OPINIT

*-----See if rerun file is present, and if so read the number of rerun sets from rerun file
CALL RDSETS (IUNITR, IUNITL, FILEIR, INSETS)

*======================================================================*
*======================================================================*
*                                                                      *
*                   Main loop and reruns begin here                      *
*                                                                      *
*======================================================================*
*======================================================================*

IF (.NOT.ENDRNF) THEN
   no end run was found in control.dat file
   ENDRUN = INSETS
ELSE
   ENDRUN = MAX (ENDRUN, 0)
   ENDRUN = MIN (ENDRUN, INSETS)
END IF

IF (.NOT.STRUNF) THEN
   no start run was found in control.dat file
   STRUN = 0
ELSE
   STRUN = MAX (STRUN, 0)
   STRUN = MIN (STRUN, ENDRUN)
END IF

CALL ChartInit (IUNITO+2)
DO 10 ISET=STRUN,ENDRUN
   WRITE (*,'(A)') '   FSE 2.1m: Initialize model'
   *-----Select data set
      CALL RDFROM (ISET, .TRUE.)
      CALL ChartSetRunID (ISET)

6.3 Initialisation section

In the initialisation section, quite some changes have been made to organise the retrieval of information related to the location, soil type and output frequency. Especially the specification of weather data has been simplified. In the basic.dat file, a location number (LOCATION) is specified together with the desired start year (IYEAR) and period of the simulation (NRYEARS). Based on this information, the FSE.FOR subroutine, determines the weather data type, the location and name of the weather data file and the reading of the weather data. Similarly, the selection of output is also simplified: the user now chooses one of three output frequencies (OUTPUTFQ; annual, 10-daily or daily) and this determines the variables that are included in the output (both in table and chart format for FSEWin).
The following two variables reset the random number generator for the distribution of rainfall in case of monthly weather data (RSETD) or long-term average weather data (RSETG). See documentation on WOFOST model (Hijmans et al. 1994) for more information.

\[
\begin{align*}
\text{RSETG} & = \text{.TRUE.} \\
\text{RSETD} & = \text{.TRUE.}
\end{align*}
\]

*-----Read names of timer file and input files 1-5 from control file (these files can be used in reruns)Call RDINIT (IUNITC, IUNITL, FILEIC)
  CALL RDSCHA ('FILEIT', FILEIT)
  CALL RDSCHA ('FILEI1', FILEI1)
  CALL RDSCHA ('FILEI2', FILEI2)
  CALL RDSCHA ('FILEI3', FILEI3)
  CALL RDSCHA ('FILEI4', FILEI4)
  CALL RDSCHA ('FILEI5', FILEI5)
CLOSE (IUNITC)

The following lines organise the retrieval of basic information on the simulation from the basic.dat file. The basic.dat file in the first line and closed in the last.

*-----Read information on location, simulation period and soil type
  CALL RDINIT (IUNITD, IUNITL, FILEI3)
  CALL RDSINT ('SOILTYPE', SOILTYPE)
  CALL RDSINT ('LOCATION', LOCATION)
  CALL RDSINT ('IYEAR', IYEAR)
  CALL RDSINT ('NRYEARS', NRYEARS)
  CALL RDSINT ('PRODLEVL', PRODLEVL)
CLOSE (IUNITD)

Several lines of the original FSE 2.1 code have been removed from the following listing.

*---Read time, control and miscellaneous weather variables from timer file
  CALL RDINIT (IUNITD, IUNITL, FILEIT)
  CALL RDSREA ('STTIME', STTIME)
  CALL RDSREA ('DELT', DELT)
  CALL RDSINT ('IPFORM', IPFORM)
  CALL RDSCHA ('COPINF', COPINF)
  CALL RDSINT ('IYEAR', IYEAR)
  CALL RDSINT ('PRODLEVL', PRODLEVL)
  IF (RDINQR('IFLAG')) CALL RDSINT ('IFLAG', IFLAG)

Next, the weather data variables are read from the timer.dat file, depending on the location (LOCATION) selected in the basic.dat file. Location numbers <51 are reserved for daily or monthly weather data; those >50 for long-term average weather data. The SIGLEN variable is used to store the significant length of the string, determined using the LEN_TRIM command; the TTUTIL function ADDINT is used to add the location number to the variable that is to be retrieved. For instance, if LOCATION = 12, the string “IWEATH” is changed to “IWEATH12” and this string is retrieved from the timer.dat file.

The next lines are for daily or monthly weather data. See the Appendix for information on the variable names. An error message is returned in case IWEATH equals zero, indicating that no information has been specified in the timer.dat file.

*---Read weather parameters depending on the location specified in BASIC.dat
  (Added PAZ 1-2002)
*  First for daily or monthly weather (LOCATION <51)
  IF (LOCATION.LT.51) THEN
*------read IWEATH
    STRING = 'IWEATH'
    SIGLEN = LEN_TRIM(STRING)
    CALL ADDINT(STRING, SIGLEN, LOCATION)
    IF (RDINQR(STRING)) CALL RDSINT (STRING, IWEATH)
    IF (IWEATH .EQ. 0) CALL FATALERR ('FSE',
& 'No information for this LOCATION in timer.dat')
*------read IRNDAT
    STRING = 'IRNDAT'
SIGLEN = LEN_TRIM(STRING)
CALL ADDINT(STRING,SIGLEN,LOCATION)
CALL RDSINT (STRING, IRNDAT)

*-------read WTRDIR
STRING = 'WTRDIR'
SIGLEN = LEN_TRIM(STRING)
CALL ADDINT(STRING,SIGLEN,LOCATION)
IF (RDINQR(STRING)) CALL RDSCHA (STRING, WTRDIR)

*-------read CLFILE
STRING = 'CLFILE'
SIGLEN = LEN_TRIM(STRING)
CALL ADDINT(STRING,SIGLEN,LOCATION)
IF (RDINQR(STRING)) CALL RDSCHA (STRING, CLFILE)

*-------read ISTN
STRING = 'ISTN'
SIGLEN = LEN_TRIM(STRING)
CALL ADDINT(STRING,SIGLEN,LOCATION)
IF (RDINQR(STRING)) CALL RDSINT (STRING, ISTN)

*-------read CNTR
STRING = 'CNTR'
SIGLEN = LEN_TRIM(STRING)
CALL ADDINT(STRING,SIGLEN,LOCATION)
IF (RDINQR(STRING)) CALL RDSCHA (STRING, CNTR)

*-------read IRNDAT
STRING = 'STRTYR'
SIGLEN = LEN_TRIM(STRING)
CALL ADDINT(STRING,SIGLEN,LOCATION)
CALL RDSINT (STRING, STRTYR)

*-------read ENDYR
STRING = 'ENDYR'
SIGLEN = LEN_TRIM(STRING)
CALL ADDINT(STRING,SIGLEN,LOCATION)
CALL RDSINT (STRING, ENDYR)

The same principle of adding the location number to a variable name is used for the variable that need to be retrieved from the timer.dat file for long-term average weather data. This variable (CLFILE) is the name of the weather data file. The remaining variables related to the weather data are the same for all files with long-term average weather data. An error message is returned in case no file name is specified in timer.dat for the given LOCATION number.

* Then for long-term weather (LOCATION > 50)
ELSE
STRING = 'CLFILE'
SIGLEN = LEN_TRIM(STRING)
CALL ADDINT(STRING,SIGLEN,LOCATION)
IF (RDINQR(STRING)) THEN
   CALL RDSCHA (STRING, CLFILE)
ELSE
   CALL FATALERR ('FSE',
&   'No information for this LOCATION in timer.dat')
ENDIF

WTRDIR = 'c:\case2\weather\longterm\'
IWEATH = 0
IRNDAT = 0
STRTYR = 1000
ENDYR  = 1000

CLOSE (IUNITD)

For daily and monthly weather data, the availability of weather data is checked for the period for which the user has indicated to perform the simulation. In case the desired start year (IYEAR) is outside the period for which weather data are available (from STRTYR to ENDYR), an error message is returned. In case the desired simulation period (NRYEARS) is longer than that for which weather data are available, an error message is returned as well. These error messages are not returned when long-term weather datasets are used, as in that case IYEAR equals 1000.

*-------Check whether simulation period as specified in BASIC.dat does not exceed period of available weather data
IF (IYEAR.LT.STRTYR.AND.IYEAR.NE.1000.) CALL FATALERR ('FSE',
&   'No weather data available for start year specified in BASIC.dat
&   choose later start year (IYEAR)')
IF (IYEAR.GT.ENDYR.AND.IYEAR.NE.1000.) CALL FATALERR ('FSE',
& 'No weather data available for start year specified in BASIC.dat
& choose earlier start year (IYEAR)')
IF ((IYEAR + NRYEARS - 1).GT.ENDYR.AND.IYEAR.NE.1000.)
& CALL FATALERR ('FSE',
& 'Simulation period exceeds period for which weather data are
& available: select an earlier start year (IYEAR)
& or a shorter period (NRYEARS) in BASIC.dat')
The finish time of the simulation is calculated in days, based on the NRYEARS specified in basic.dat and taking leap years into consideration.
*--Calculate FINTIM in days, based on NRYEARS and information on leap years
FINTIM = 0.
DO 11 I1 = IYEAR, (IYEAR + NRYEARS - 1)
   IF (I1.GT.1500.AND.MOD (I1,4).EQ.0) THEN
      FINTIM = FINTIM + 366.
   ELSE
      FINTIM = FINTIM + 365.
   END IF
11    CONTINUE
Next, the output frequency (OUTPUFQ) as specified in basic.dat is read:
*-----Read parameter on output frequency from basic.dat and set output
* parameters accordingly (added PAZ)
CALL RDINIT (IUNITD , IUNITL, FILEI3)
CALL RDSINT ('OUTPUTFQ' , OUTPUTFQ)
CLOSE (IUNITD)
and this is translated into values for the frequency of printing output (PRDEL). When OUTPUTFQ = 1 annual output is produced (at the last day of the year, either day 365 or 366); for 2 output is generated each 10 days; for 3 every day. Then the selection of variables for which output is to be generated is read from timer.dat (PRSEL1, PRSEL2 or PRSEL3 are translated into the general PRSEL).

CALL RDINIT (IUNITD , IUNITL, FILEIT)
IF (OUTPUFQ.EQ.1) THEN
   PRDEL = 0.
   CALL RDAINT ('IOBSD' , IOBSD, IMNOD, INOD)
   IF (IOBSD(1).EQ.0) INOD = 0
   ELSE IF (OUTPUFQ.EQ.2) THEN
      PRDEL = 10.
      CALL RDAINT ('PRSEL1',PRSEL,IMNPRS,INPRS)
   ELSE IF (OUTPUFQ.EQ.3) THEN
      PRDEL = 1.
      CALL RDAINT ('PRSEL2',PRSEL,IMNPRS,INPRS)
   ELSE
      CALL RDAINT ('PRSEL3',PRSEL,IMNPRS,INPRS)
   END IF
   CALL FATALERR
& ('FSE','Output frequency value (OUTPUTFQ) is invalid')
END IF
CLOSE (IUNITD)
The next lines are not used anymore (an * is put at the first position):
*-----See if observation data variable exists, if so read it
* INOD = 0
* IF (RDINQR('IOBSD')) THEN
* CALL RDAINT ('IOBSD' , IOBSD, IMNOD, INOD)
* IF (IOBSD(1).EQ.0) INOD = 0
* END IF
*-----See if variable with print selection exists, if so read it
* INPRS = 0
* IF (RDINQR('PRSEL')) CALL RDAINT ('PRSEL',PRSEL,IMNPRS,INPRS)
In the next listing, a chart command is added. The call to METEO for the opening and reading of weather files is added to allow the use of monthly or long-term average weather data. This call replaces calls to STINFO and WEATHR subroutines. The METEO subroutine further regulates the retrieval of weather data from the specified weather file(s). The call to MODELS is extended with some variables.
*-----Initialize TIMER and OUTDAT routines
CALL TIMER2 (ITASK, STTIME, DELT, PRDEL, FINTIM,
& IYEAR, TIME , DOY , IDOY , TERMNL, OUTPUT)
YEAR = REAL (IYEAR)
CALL OUTDAT (ITASK, IUNITO, 'TIME', TIME)

CALL ChartInitialGroup

*-----Open weather file and read station information and return
* weather data for start day of simulation.
CALL METEO (IYEAR, IDOY, IWEATH, WSTAT, 
& IFLAG, WTRDIR, CNTR, IUSTN, 
& CLFILE, IRNDAT, RSETRG, RSETRD, IUWE, 
& IURA, IYERR, RFILE, 
& ANGA, ANGB, LAT, LONG, ELEV, 
& RDD, TMMN, TMMX, RAIN, WN, VP)

6.4 Rate calculation or dynamic section

Only few adaptations have been done in this section compared to the original version 2.1. In the
following listing the call to the MODELS subroutine has been modified and there are new calls to
chart-related subroutines and to the METEO subroutine instead of those to STINFO and WEATHR.

WRITE (*,'(A)') 'FSE 2.1m: DYNAMIC loop'
20 IF (.NOT.TERMNL) THEN

*----------------------------------------------------------------------*
*                     Integration of rates section                     *
*----------------------------------------------------------------------*

IF (ITASK.EQ.2) THEN

*--------Carry out integration only when previous task was rate
* calculation
ITASK = 3

*--------Call routine that handles the different models
CALL MODELS (ITASK, IUNITD, IUNITO, IUNITL, 
& FILEIT, FILEI1, FILEI2, FILEI3, FILEI4, FILEI5, 
& OUTPUT, TERMNL, OUTPUTQ, SOILTYPE, 
& DOY, IDOY, YEAR, IYEAR, 
& TIME, STTIME, FINTIM, DELT, 
& ANGA, ANGB, FRPAR, 
& LAT, LONG, ELEV, WSTAT, WTRTER, 
& RDD, TMMN, TMMX, VP, WN, RAIN)

*--------Turn on output when TERMNL logical is set to .TRUE.
IF (TERMNL.AND.PRDEL.GT.0.) OUTPUT = .TRUE.

END IF
ITASK = 2

*-----Write time of output to screen and file
CALL OUTDAT (2, 0, 'TIME', TIME)

CALL ChartNewGroup
CALL ChartOutputRealScalar('TIME', TIME)

IF (OUTPUT) THEN
  IF (ISET.EQ.0) THEN
    WRITE (*, '(13X,A,I5,A,F7.2)')
    'Default set, Year:', IYEAR, ', Day:', DOY
  ELSE
    WRITE (*, '(13X,A,I3,A,I5,A,F7.2)')
    'Rerun set:', ISET, ', Year:', IYEAR, ', Day:', DOY
  END IF
END IF

*-----Get weather data for new day and flag messages
CALL METEO (IYEAR, IDOY, IWEATH, WSTAT,
& CLFILE, IRNDAT, RSETRG, RSETRD, IUWE,
& IURA, IYEARR, RAFILE,
& ANGA, ANGB, LAT, LONG, ELEV,
& RDD, TMMN, TMMX, RAIN, VP)

*------Calculation of rates and output section
*------

*------Call routine that handles the different models
CALL MODELS (ITASK, IUNITD, IUNITO, IUNITL,
& FILEIT, FILEI1, FILEI2, FILEI3, FILEI4, FILEI5,
& OUTPUT, TERMINL, OUTPUTFQ, SOILTYPE,
& DOY, IDOY, YEAR, IYEAR,
& TIME, STTIME, FINTIM, DELT,
& ANGA, ANGB, FRPAR,
& LAT, LONG, ELEV, WSTAT, WTRTER,
& RDD, TMMN, TMMX, VP, WN, RAIN)

IF (TERMNL.AND..NOT.OUTPUT.AND.PRDEL.GT.0.) THEN
  *--------Call model routine again if TERMNL is switched on while
  * OUTPUT was off (this call is necessary to get output to file
  * when a finish condition was reached and output generation
  * was off)
  IF (ISET.EQ.0) THEN
    WRITE (*, '(13X,A,I5,A,F7.2)')
    'Default set, Year:', IYEAR, ', Day:', DOY
  ELSE
    WRITE (*, '(13X,A,I3,A,I5,A,F7.2)')
    'Rerun set:', ISET, ', Year:', IYEAR, ', Day:', DOY
  END IF
ENDIF

*------Call model routine again if TERMINL is switched on while
* OUTPUT was off (this call is necessary to get output to file
* when a finish condition was reached and output generation
* was off)
IF (TERMNL.AND..NOT.OUTPUT.AND.PRDEL.GT.0.) THEN
  *--------Call model routine again if TERMNL is switched on while
  * OUTPUT was off (this call is necessary to get output to file
  * when a finish condition was reached and output generation
  * was off)
  IF (ISET.EQ.0) THEN
    WRITE (*, '(13X,A,I5,A,F7.2)')
    'Default set, Year:', IYEAR, ', Day:', DOY
  ELSE
    WRITE (*, '(13X,A,I3,A,I5,A,F7.2)')
    'Rerun set:', ISET, ', Year:', IYEAR, ', Day:', DOY
  END IF
ENDIF

* Time update
*
*------Check for FINTIM, OUTPUT and observation days
CALL TIMER2 (ITASK, STTIME, DELT, PRDEL, FINTIM,
& IYEAR, TIME, DOY, IDOY, TERMNL, OUTPUT)
YEAR = REAL (IYEAR)
DO 30 IOD=1,INOD,2
  IF (IYEAR.EQ.IOBSD(IOD).AND.IDOY.EQ.IOBSD(IOD+1))
&     OUTPUT = .TRUE.
30  CONTINUE
GOTO 20
END IF

6.5 Terminal section

In the terminal section, the only adaptations are the changes in the MODELS call and the added call to the ChartTerminalGroup subroutine. The remaining code has not changed and is not printed here.

*---------------------------------------------------------------------*
*                   Terminal section                                  *
*---------------------------------------------------------------------*
ITASK = 4
WRITE (*,'(A)') '   FSE 2.1m: Terminate model'
CALL ChartTerminalGroup

*------Call routine that handles the different models
CALL MODELS (ITASK, IUNITD, IUNITO, IUNITL,
&   FILEIT, FILEI1, FILEI2, FILEI3, FILEI4, FILEI5,
& OUTPUT, TERMNL, OUTPUTFQ, SOILTYPE,
& DOY, IDOY, YEAR, IYEAR,
& TIME, STIME, FINTIM, DELT,
& ANGA, ANGB, FRPAR,
& LAT, LONG, ELEV, WSTAT, WTRTER,
& RDD, TMMN, TMMX, VP, WN, RAIN)
7. The MODELS subroutine

7.1 Purpose

This subroutine is the interface routine between the FSE-driver (FSE.FOR) and the simulation models. This routine is called by the FSE-driver at each new task at each time step. It is used to specify calls to the different submodels that comprise the simulation model. In the CASE2 model, the subroutine is used to call the evapotranspiration modules, the water balance module and the crop module.

7.2 Input and output

This subroutine is included in the MODEL2.FOR file. The following input and output variables are used by this subroutine (see Table 8.1 for explanation):

```fortran
SUBROUTINE MODELS (ITASK, IUNITD, IUNITO, IUNITL,
                    FILEIT, FILEI1, FILEI2, FILEI3, FILEI4, FILEI5,
                    OUTPUT, TERMNL, OUTPUTFQ, SOILTYPE,
                    DOY, IDOY, YEAR, IYEAR,
                    TIME, STTIME, FINTIM, DELT,
                    ANGA, ANGB, FRPAR,
                    LAT, LONG, ELEV, WSTAT, WTRTER,
                    RDD, TMMN, TMMX, VP, WN, RAIN)
```

<table>
<thead>
<tr>
<th>Code</th>
<th>Type</th>
<th>Description</th>
<th>Unit</th>
<th>Input/output</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITASK</td>
<td>I4</td>
<td>Task that subroutine should perform</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>IUNITD</td>
<td>I4</td>
<td>Unit that can be used for input files</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>IUNITO</td>
<td>I4</td>
<td>Unit used for output file</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>IUNITL</td>
<td>I4</td>
<td>Unit used for log file</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>FILEIT</td>
<td>C*</td>
<td>Name of timer file</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>FILEI1</td>
<td>C*</td>
<td>Name of input file no. 1</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>FILEI2</td>
<td>C*</td>
<td>Name of input file no. 2</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>FILEI3</td>
<td>C*</td>
<td>Name of input file no. 3</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>FILEI4</td>
<td>C*</td>
<td>Name of input file no. 4</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>FILEI5</td>
<td>C*</td>
<td>Name of input file no. 5</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>OUTPUT</td>
<td>L4</td>
<td>Flag to indicate if output should be done</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>TERMNL</td>
<td>L4</td>
<td>Flag to indicate if simulation is to stop</td>
<td>-</td>
<td>I/O</td>
</tr>
<tr>
<td>OUTPUTFQ</td>
<td>I4</td>
<td>Code indicating the output frequency</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>SOILTYPE</td>
<td>I4</td>
<td>Code indicating the selected soil type</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>DOY</td>
<td>R4</td>
<td>Day number within year of simulation (REAL)</td>
<td>d</td>
<td>I</td>
</tr>
<tr>
<td>IDOY</td>
<td>I4</td>
<td>Day number within year of simulation (INTEGER)</td>
<td>d</td>
<td>I</td>
</tr>
<tr>
<td>YEAR</td>
<td>R4</td>
<td>Year of simulation (REAL)</td>
<td>y</td>
<td>I</td>
</tr>
<tr>
<td>IYEAR</td>
<td>I4</td>
<td>Year of simulation (INTEGER)</td>
<td>y</td>
<td>I</td>
</tr>
<tr>
<td>TIME</td>
<td>R4</td>
<td>Time of simulation</td>
<td>d</td>
<td>I</td>
</tr>
<tr>
<td>STTIME</td>
<td>R4</td>
<td>Start time of simulation</td>
<td>d</td>
<td>I</td>
</tr>
<tr>
<td>FINTIM</td>
<td>R4</td>
<td>Finish time of simulation</td>
<td>d</td>
<td>I</td>
</tr>
<tr>
<td>DELT</td>
<td>R4</td>
<td>Time step of integration</td>
<td>d</td>
<td>I</td>
</tr>
</tbody>
</table>
7.3 Declarations

In this first part of the subroutine, the input and output of the subroutine is defined and variables are declared (source code not shown).

Next, the availability of rainfall data is checked. The variable WSTAT provides information on the availability of weather data, which is derived from the FSE-driver (FSE.FOR). The following lines change an unknown value for rainfall into a zero value and return a message to the weather log-file. The next do-loop checks the availability and use of the six weather variables and terminates the simulation run in case of a missing value for a used weather variable.

```
* Check weather data availability
IF (ITASK.EQ.1.OR.ITASK.EQ.2.OR.ITASK.EQ.4) THEN
  IF (WSTAT(6:6).EQ.'4') THEN
    RAIN       = 0.
    WSTAT(6:6) = '1'
    IF (.NOT.GIVEN) THEN
      WRITE (IUNITL,'(2A)') ' Rain not available,',
                      ' value set to zero, (patch DvK, Jan 1995)'
      GIVEN = .TRUE.
    END IF
  END IF
  DO I1=1,6
    IF (WUSED(I1:I1).EQ.'U' .AND.
        WSTAT(I1:I1).EQ.'4') THEN
      WTRTER = .TRUE.
      TERMNL = .TRUE.
      RETURN
    END IF
  END DO
END IF
```

7.4 Initialisation section

In the initialisation section (ITASK = 1), first the names of the plant module (PLTMOD) and evapotranspiration module (ETMOD) are read from timer.dat file. In spite of the fact that there are different modules available for the plant ('CACAO' or 'NO CROP') and the evapotranspiration module ('PENMAN', or 'PRIESTLEY/TAYLOR'; 'MAKKINK' is not used in CASE2, the relevant program lines are marked with an "**") the CACAO and the PENMAN (using the Penman-Monteith combination
Chapter 7. The MODELS subroutine

equation) modules are the standard used. (see Section 18.6 on the timer.dat file for more information).

IF (ITASK.EQ.1) THEN
  *  ----------------------
  *  Initialization section
  *  ----------------------
  *  Read modules to be used from timer.dat
  CALL RDSCHI (IUNITD, IUNITL, FILEIT)
  CALL UPPERC (PLTMOD)
  CALL RDSCHI ('ETMOD', ETMOD)
  CALL UPPERC (ETMOD)
  CLOSE (IUNITD)

Next, the production level (PRODLEVL) is read from the basic.dat file. PRODLEVL = 1 implies potential (non water-limited production; the water-balance subroutine DRPOT is used, not documented in this report) and 2 implies water-limited production (the water-balance DRSAHE is used, see Chapter 16).

  *  Read production level from basic.dat
  CALL RDSCHI (IUNITD, IUNITL, FILEI3)
  CALL RDSINT ('PRODLEVL', PRODLEVL)
  CLOSE (IUNITD)

The following lines write text on the start data and the modules used in the output file. Error messages are returned in case the module name is unknown. In the CASE2 model the Penman-Monteith evapotranspiration and cacao modules are chosen by default. The production level may be either potential or water-limited.

  *  Write line to mark start of new run
  WRITE (IUNITO,'(A,76A1)') '*','=',I1=1,76)

  *  Log messages to output file
  WRITE (IUNITO,'(A)'1)
  WRITE (IUNITO,'(A)'1)
  ** FSE driver info:
  WRITE (IUNITO,'(A,T7,A,I5,A,I4,A)').
  '*','Year:',IYEAR,', day:',IDOY,', System start'
  WRITE (IUNITO,'(A)'1)
  WRITE (IUNITO,'(A)'1)
  ** Modules used:

  *  Choose and check evapotranspiration modules
  IF (ETMOD.EQ.'PENMAN') THEN
   WRITE (IUNITO,'(A,T7,A)')
   '**','SETPMOD: Penman evapotranspiration'
   WUSED(1:5) = 'UUUUU'
  ELSE IF (ETMOD.EQ.'MAKKINK') THEN
   WRITE (IUNITO,'(A,T7,A)')
   '**','SETMKD: Makkink evapotranspiration'
   WUSED(1:3) = 'UUU'
  ELSE IF (ETMOD.EQ.'PRIESTLEY TAYLOR') THEN
   WRITE (IUNITO,'(A,T7,A)')
   '**','SETPTD: Priestley Taylor evapotranspiration'
   WUSED(1:3) = 'UUU'
  ELSE
   CALL FATALERR
  END IF

  *  Choose and check water balance modules
  IF (PRODLEVL.EQ.1) THEN
   WRITE (IUNITO,'(A,T7,A)')
   '**','DRPOT : Water balance for potential situations'
   WUSED(1:5) = 'UUUUU'
  ELSE IF (PRODLEVL.EQ.2) THEN
   WRITE (IUNITO,'(A,T7,A)')
   '**','DRSAHE: Tipping bucket water balance version 1.4'
   WUSED(6:6) = 'U'
  ELSE
   CALL FATALERR
  END IF
Choose and check crop modules

IF (PLTMOD.EQ.'CACAO'.AND.
PRODLEVL.EQ.1) THEN
WRITE (IUNITO,'(A,T7,A,/,A,T7,A)')
'CASE2: Cacao at potential production 2.2'
WUSED(1:3) = 'UUU'
ELSE IF (PLTMOD.EQ.'CACAO'.AND.
PRODLEVL.EQ.2) THEN
WRITE (IUNITO,'(A,T7,A,/,A,T7,A)')
'CASE2: Cacao at water limited production 2.2'
WUSED(1:3) = 'UUU'
ELSE IF (PLTMOD.EQ.'NO CROP') THEN
WRITE (IUNITO,'(A,T7,A)')
'NO CROP: no crop'
ELSE
CALL FATALERR
('MODELS','unknown module name for plant')
END IF

Avoid FORCHECK errors
WCLQT(1) = -99.
WCST(1) = -99.
END IF

7.5 Rate calculation section

In the rate calculation section (ITASK = 2), the evaporation, water balance and crop modules are called in this order. First some variables are calculated for use in the evaporation module: the reflection coefficient for the soil (based on the soil water content, see Van Laar et al. 1992), the reflection coefficient for the combination of soil and vegetation (based on the soil coefficient and the leaf area index of the shade and cacao trees together, GAI; see Van Laar et al. 1992), and the average day temperature (the average of minimum and maximum temperature).

ELSE IF (ITASK.EQ.2) THEN
* Rate calculation section
* ------------------------------------------------------
* Reflection of soil (see: van Laar et al 1992)
RFS = 0.25*(1.-0.5*WCLQT(1)/WCST(1))
* Total reflection (see: van Laar et al 1992)
RF = RFS*EXP(-0.5*GAI)+0.25*(1.-EXP(-0.5*GAI))
* Calculate average temperature
TMDA = (TMMX+TMMN)/2.

The evaporation subroutine is called (the value of ETMOD is specified in timer.dat). Note that the Makkink evaporation module cannot be used; using the Priestley-Taylor module is not recommended because this module is not adapted for tree crops, whereas the Penman module is.

IF (ETMOD.EQ.'PENMAN') THEN
Penman evapotranspiration
CALL SETPMD (IDOY,LAT,ISURF,RF,ANGA,ANGB,TMDI,
RDD, TMDA, WN,VP,
ETD, ETRD,ETAE, DT)
* Calculate potential soil evaporation taking into account
the standing crop
EVSC = EXP (-0.5*GAI)*(ETRD+ETAE)
ELSE IF (ETMOD.EQ.'MAKKINK') THEN
Makkink evapotranspiration
NOTE: This module is not used in CASE2
CALL SETMKD (RDD, TMDA, ETD)
* Estimate radiation driven and wind and humidity driven part
ETRD = 0.75*ETD
ETAE = ETD-ETRD
* Calculate potential soil evaporation taking into account
Chapter 7. The MODELS subroutine

* the standing crop
  EVSC = EXP (-0.5*GAI)*ETD
ELSE IF (ETMOD.EQ.'PRIESTLEY TAYLOR') THEN
  Priestley Taylor evapotranspiration
  CALL SETPTD (IDOY,LAT,RF,RDD,TMDA,ETD)
  * Estimate radiation driven and wind and humidity driven part
  ETRD = 0.75*ETD
  ETAE = ETD-ETRD
  * Calculate potential soil evaporation taking into account
  * the standing crop
  EVSC = EXP (-0.5*GAI)*ETD
END IF

* Make sure potential soil evaporation is always positive
* the amount of dew is unreliable anyhow
EVSC = MAX (EVSC, 0.)

The rain interception subroutine (INTERCEPT) is called for the calculation of rain that reaches the soil and the part that is intercepted by the canopy.

  Rain interception and throughfall
  CALL INTERCEPT (ITASK, IUNITD, IUNITL, FILEI1, & RAIN, RAINS, PINT)

The water balance subroutine is called: if PRODLEVL=2 (water-limited production, specified in basic.dat), the DRSAHE water balance is used (see Chapter 16), if PRODLEVL=1 (potential production) the DRPOT water balance is used (not described in this report: this subroutine keeps the water content in all layers at field capacity).

  Water balance module
  IF (PRODLEVL.EQ.2) THEN
    CALL DRSAHE (ITASK, IUNITD, IUNITO, FILEI2, SOILTYPE, & IDOY, IYEAR, DELT, OUTPUT, & NLXM, NL, EVSC, RAINS, TRWL, & TKL, ZRTMS, & WCAD, WCWP, WCFC, WCST, & EVSW, FLXQT, WCLQT, & DRAICU, EVSWCU, RAINCU, TRWCU, FLXCU)
  ELSE IF (PRODLEVL.EQ.1) THEN
    CALL DRPOT (ITASK, NLXM, NL, & TKL, ZRTMS, WCAD, WCWP, WCFC, WCST, & WCLQT)
  END IF

The crop subroutine is called: by default this is the CASE2 subroutine (PLTMOD = 'CACAO', specified in timer.dat). The NOCROP subroutine (PLTMOD = 'NO CROP') can be used if it is required to test the water balance output without a crop. This subroutine sets the water uptake and the leaf area index to zero.

  Crop module
  IF (PLTMOD.EQ.'CACAO') THEN
    CALL CASE2 (PLTMOD, ITASK, IUNITD, IUNITO, IUNITL, FILEI1, & FILEI3, OUTPUT, TERMINL, OUTPUTQ, & DOY, IDOY, IYEAR, DELT, TIME, STTIME, & LAT, FRPAR, RDD, TMMN, TMMX, & NLXM, NL, TRWL, TKL, & WCQ, WCWP, WCFC, WCST, & EVSC, ETRD, ETAE, PINT, & GAI, RAIN)
  ELSE IF (PLTMOD.EQ.'NO CROP') THEN
    CALL NOCROP (NLXM, TRWL, GAI)
  END IF

7.6 Integration section

In the integration section (ITASK = 3), the water balance and crop modules are called to perform integration of state variables. See comments on module used in the previous Section.

* ---------------------
* Integration section
* ---------------------

* Water balance module
IF (PRODLEVEL.EQ.2) THEN
   CALL DRSAHE (ITASK, IUNITD, IUNITO, FILEI2, SOILTYPE,
               IDOY, IYEAR, DELT, OUTPUT,
               NLXM, NL, EVSC, RAINS, TRWL,
               TKL, ZRTMS,
               WCAD, WCWP, WCFC, WCST,
               EVSW, FLXQT, WCLQT,
               DRAICU, EVSWCU, RAINCU, TRWCU, FLXCU)
ELSE IF (PRODLEVEL.EQ.1) THEN
   CALL DRPOT (ITASK, NLXM, NL,
               TKL, ZRTMS, WCAD, WCWP, WCFC, WCST,
               WCLQT)
END IF

* Crop module
IF (PLTMOD.EQ.'CACAO') THEN
   CALL CASE2 (PLTMOD, ITASK, IUNITD, IUNITO, IUNITL, FILEI1,
               FILEI3, OUTPUT, TERMNL, OUTPUTFQ,
               DOY, IDOY, IYEAR, DELT, TIME, STTIME,
               LAT, FRPAR, RDD, TMMN, TMMX,
               NLXM, NL, TRWL, TKL,
               WCLQT, WCWP, WCFC, WCST,
               EVSC, ETRD, ETAE, PINT,
               GAI, RAIN)
ELSE IF (PLTMOD.EQ.'NO CROP') THEN
   CALL NOCROP (NLXM, TRWL, GAI)
END IF

7.7 Terminal section

In the terminal section (ITASK = 4), the water balance and crop modules are called to perform any terminal operations on variables. Currently no tasks have been defined for the terminal section in the water balance and crop modules. This section starts with commands that print the final date of the simulation to the output:

ELSE IF (ITASK.EQ.4) THEN
   ----------------
   Terminal section
   ----------------
   WRITE (IUNITO, '(A)') '*'
   WRITE (IUNITO, '(A)') '* FSE driver info:'
   WRITE (IUNITO, '(A,T7,A,I5,A,I4,A)')
   '*','Year:',IYEAR,' day:',IDOY,' System end'

and then continues with calls to the water balance and crop modules as in the integration section (see previous Section for model code and explanation).
8. The INTERCEPT subroutine

8.1 Purpose

The purpose of the INTERCEPT subroutine is to calculate the rain intercepted by the canopy and the rain that reaching the soil. The intercepted rainfall (PINT) is used by the crop subroutine (CASE2) for the calculation of potential evapotranspiration, whereas the rain that falls through the canopy and reaches the soil surface (RAINS) is input in the soil water balance (DRSAHE).

8.2 Input and output

This subroutine is included in the MODEL2.FOR file. The following input and output variables are used by this subroutine (see Table 8.1 for explanation):

```fortran
SUBROUTINE INTERCEPT (ITASK, IUNITD, IUNITL, FILEP,
                        RAIN, RAINS, PINT)
```

<table>
<thead>
<tr>
<th>Code</th>
<th>Type</th>
<th>Description</th>
<th>Unit</th>
<th>Input/output</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITASK</td>
<td>I4</td>
<td>Task that subroutine should perform</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>IUNITD</td>
<td>I4</td>
<td>Unit that can be used for input files</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>IUNITL</td>
<td>I4</td>
<td>Unit used for log file</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>FILEP</td>
<td>C*</td>
<td>Name of file with plant data</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>RAINS</td>
<td>R4</td>
<td>Daily amount of rainfall</td>
<td>mm d-1</td>
<td>I</td>
</tr>
<tr>
<td>RAINS</td>
<td>R4</td>
<td>Daily amount of rain reaching the soil</td>
<td>mm d-1</td>
<td>O</td>
</tr>
<tr>
<td>PINT</td>
<td>R4</td>
<td>Daily amount of intercepted rain</td>
<td>mm d-1</td>
<td>O</td>
</tr>
</tbody>
</table>

8.3 Initialisation section

Necessary variable values are read from the plant.dat file. Note that the values for the stem flow regression coefficients (STFLA and STFLB) are zero, as stem flow is not considered in the current version of CASE2.

```fortran
IF (ITASK.EQ.1) THEN
  * ----------------------
  * Initialization section
  * ----------------------
  *
  Initialize input file
  CALL RDINIT (IUNITD, IUNITL, FILEP)
  *
  Stemflow and troughfall parameters
  CALL RDSREA ('TFALA' , TFALA )
  CALL RDSREA ('TFALB' , TFALB )
  CALL RDSREA ('STFLA' , STFLA )
  CALL RDSREA ('STFLB' , STFLB )

  CLOSE (IUNITD)
```
8.4 Rate calculation section

Part of the daily rainfall is intercepted by the canopy of the cacao trees. This amount (PINT) equals the total rainfall (RAIN) minus the troughfall (TFALL) and stemflow (STEMFL; which is equal to zero in the current version of CASE2). The throughfall is modelled as a linear function of actual rainfall (RAIN) with minimum of 0. and a maximum of the actual rainfall (RAIN). The amount of rainfall reaching the soil (RAINS) is the difference between rainfall and interception.

* Troughfall (TFALL), Stemflow (STEMFL) and Rainfall interception (PINT)
* TFALL = LIMIT (0., RAIN, TFALA*RAIN + TFALB) ! [mm d-1]
* STEMFL = LIMIT (0., RAIN, STFLA*RAIN + STFLB) ! [mm d-1]
* PINT = MAX(0.,RAIN - TFALL - STEMFL) ! [mm d-1]

* Rainfall reaching the soil (RAINS) = TFALL + STEMFL
* RAINS = RAIN - PINT ! [mm d-1]
9. The CASE2 subroutine

9.1 Purpose

The purpose of the CASE2 subroutine is to calculate growth and production of cacao trees depending on the availability of light and water. The CASE2 subroutine processes information on photosynthesis, leaf dynamics, root growth and distribution, water uptake and pod growth which is generated by other subroutines. The principles used are described in Sections 4.1, 4.2, 4.3 and 4.7.

9.2 Input and output

This subroutine is included in the CASE2.FOR file. The following input and output variables are used by this subroutine (see Table 9.1 for explanation):

```
SUBROUTINE CASE2 (PLTMOD, ITASK, IUNITD, IUNITO, IUNITL, FILEI1,
&                  FILEI3, OUTPUT, TERMNL, OUTPUTFQ,
&                  DOY, IDOY, IYEAR, DELT, TIME, STTIME,
&                  LAT, FRPAR, RDD, TMMN, TMMX,
&                  NLXM, NL, TRWL, TKL,
&                  WCLQT, WCPFX, WCFCX, WCSSX,
&                  EVSC, ETRD, ETAE, PINT,
&                  GAI, RAIN)
```

<table>
<thead>
<tr>
<th>Code</th>
<th>Type</th>
<th>Description</th>
<th>Unit</th>
<th>Input/output</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLTMOD</td>
<td>C*</td>
<td>Name of plant module used (cocoa or no crop)</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>ITASK</td>
<td>I4</td>
<td>Task that subroutine should perform</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>IUNITD</td>
<td>I4</td>
<td>Unit that can be used for input files</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>IUNITO</td>
<td>I4</td>
<td>Unit used for output file</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>IUNITL</td>
<td>I4</td>
<td>Unit used for log file</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>FILEI1</td>
<td>C*</td>
<td>Name of first file with plant data</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>FILEI3</td>
<td>C*</td>
<td>Name of second file with plant data</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>OUTPUT</td>
<td>L4</td>
<td>Flag to indicate if output should be done</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>TERMNL</td>
<td>L4</td>
<td>Flag to indicate if simulation is to stop</td>
<td>-</td>
<td>I/O</td>
</tr>
<tr>
<td>OUTPUTFQ</td>
<td>L4</td>
<td>Type of output requested (daily, 10-day, annual)</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>DOY</td>
<td>R4</td>
<td>Day number within year of simulation (REAL)</td>
<td>d</td>
<td>I</td>
</tr>
<tr>
<td>IDOY</td>
<td>I4</td>
<td>Day number within year of simulation (INTEGER)</td>
<td>d</td>
<td>I</td>
</tr>
<tr>
<td>IYEAR</td>
<td>I4</td>
<td>Year of simulation (INTEGER)</td>
<td>y</td>
<td>I</td>
</tr>
<tr>
<td>DELT</td>
<td>R4</td>
<td>Time step of integration</td>
<td>d</td>
<td>I</td>
</tr>
<tr>
<td>TIME</td>
<td>R4</td>
<td>Time of simulation</td>
<td>d</td>
<td>I</td>
</tr>
<tr>
<td>STTIME</td>
<td>R4</td>
<td>Start time of the simulation</td>
<td>d</td>
<td>I</td>
</tr>
<tr>
<td>LAT</td>
<td>R4</td>
<td>Latitude of site</td>
<td>dec. degr.</td>
<td>I</td>
</tr>
<tr>
<td>FRPAR</td>
<td>R4</td>
<td>Fraction PAR in shortwave radiation</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>RDD</td>
<td>R4</td>
<td>Daily shortwave radiation</td>
<td>J m2 d-1</td>
<td>I</td>
</tr>
<tr>
<td>TMMN</td>
<td>R4</td>
<td>Daily minimum temperature</td>
<td>°C</td>
<td>I</td>
</tr>
<tr>
<td>TMMX</td>
<td>R4</td>
<td>Daily maximum temperature</td>
<td>°C</td>
<td>I</td>
</tr>
<tr>
<td>NLXM</td>
<td>I4</td>
<td>no. of layers as declared in calling program</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>NL</td>
<td>I4</td>
<td>number of layers specified in input file</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>TRWL</td>
<td>R4</td>
<td>actual transpiration rate per layer</td>
<td>mm/d</td>
<td>I</td>
</tr>
<tr>
<td>Code</td>
<td>Type</td>
<td>Description</td>
<td>Unit</td>
<td>Input/output</td>
</tr>
<tr>
<td>--------</td>
<td>------</td>
<td>----------------------------------------------</td>
<td>------</td>
<td>--------------</td>
</tr>
<tr>
<td>TKL[]</td>
<td>R4</td>
<td>thickness of soil compartments</td>
<td>m</td>
<td>I</td>
</tr>
<tr>
<td>WCLQT[]</td>
<td>R4</td>
<td>volumetric soil water content per layer</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>WCWPX[]</td>
<td>R4</td>
<td>volumetric water content at wilting point</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>WCFCX[]</td>
<td>R4</td>
<td>volumetric water content at field capacity</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>WCSTX[]</td>
<td>R4</td>
<td>volumetric water content at saturation</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>EVSC</td>
<td>R4</td>
<td>actual (realized) evaporation rate</td>
<td>mm/d</td>
<td>O</td>
</tr>
<tr>
<td>ETRD</td>
<td>R4</td>
<td>Radiation driven part of ETPMD</td>
<td>mm/d</td>
<td>O</td>
</tr>
<tr>
<td>ETAE</td>
<td>R4</td>
<td>Dryness driven part of ETPMD</td>
<td>mm/d</td>
<td>O</td>
</tr>
<tr>
<td>PINT</td>
<td>R4</td>
<td>Daily amount of intercepted rain</td>
<td>mm/d</td>
<td>O</td>
</tr>
<tr>
<td>GAI</td>
<td>R4</td>
<td>Green area index of cocoa and shade crop</td>
<td>m2/m2</td>
<td>O</td>
</tr>
<tr>
<td>RAIN</td>
<td>R4</td>
<td>Daily amount of rainfall</td>
<td>mm/d</td>
<td>I</td>
</tr>
</tbody>
</table>

### 9.3 Declarations

Directly after the SUBROUTINE statement (the subroutine’s interface) and before the declaration, is the “Use chart” statement. This statement is used by FSE Windows (see Section 1.4) to indicate that charts should be used. In case the CASE2 model is used in a Fortran compiling program such as Visual Fortran, this line should be de-activated (by putting and * at the first position).

```fortran
USE CHART
```

After the declaration of variable names (the model code of this part is not shown), the value of DELT (the time step of the simulation) is checked. In case time step is less than one (day), an error message is generated and the program is halted.

```fortran
IF (DELT.LT.1.0) CALL FATALERR
   &   ('CASE2','FE1 - Time step (DELT) too small: <1 day')
```

### 9.4 Initialisation section

The initialisation section starts with defining titles for the output file and opens the plant.dat file:

```fortran
IF (ITASK.EQ.1) THEN
   *   ----------------------
   *   Initialization section
   *   ----------------------
   *
   *   Send title(s) to output file
   CALL OUTCOM (PLTMODE)
   CALL OUTCOM ('CASE2, Cacao Simulation Engine     Version 2.2')
   CALL OUTCOM ('       February 2002')
   *
   *   Read plant parameters from plant.dat with UNchangeable values
   CALL RDINIT (IUNITD  , IUNITL, FILEI1)
```

Then, a large number of parameters is read from the plant.dat file. The model code for these actions is not shown. The retrieved variables are: AGBIORA, AGBIORB, AMX, EFF, AMTMPT, AMINIT, MAXLAI, KDFL (changed into KDF(1)), KDFT (changed into KS(1)), MAINLRT, MAINTRT, MAINWD, MAINLV, MAINPD, Q10, TREF, MINCON, ASRQLRT, ASRQTRT, ASRQWD, ASRQLV, ASRQPDTB, CFLRT, CFTRT, CFWD, CFLV, CFPDTB, TAU, NCONTBN, PCONTBN, KONTBN, FMTA, FMTB, RTOWURT, WDLVDR, LRTWURTDR, FTRTRA, FLRTRA, FLVRA, FWDR, PDRA, FTRTRB, FLRTRB, FLVRB, FWDRB, FPDRB, AVGVLAGE, FWURT, HRTWDAGE, WTOTMIN. Variables are read using subroutines from the TTUTIL library (Van Kraalingen & Rappoldt 2000). For information on these variables, see Section 18.3 on the plant.dat file. After retrieval, the plant.dat file is closed.

```fortran
   *   Close plant file
```
CLOSE (IUNITD)

The total soil depth (TKLTOT) is calculated using information on the thickness of each of the layers, and a check is performed for total soil depth, which should be equal or > 1.5 m.

* Check total soil depth: should be > 1.5 m
  TKLTOT = 0.     ![m]
  DO II = 1,NLXM
    TKLTOT = TKLTOT + TKL(I1)      ![m]
  ENDDO
  IF (TKLTOT.LT.1.5) CALL FATALERR ('CASE2',
    & 'FE2 - Total thickness of soil layers too low: <1.5 m')

Subsequently, a second data input file (basic.dat) is opened:

* Read plant parameters from SECOND data file with changeable values
  CALL RDINIT (IUNITD , IUNITL, FILEI3)

and a number of variables are retrieved from that file (model code not shown): NPL, HGHL (changed into HGHL(1), HGHT (changed into HGHT(1)), SLAI (changed into LAI(2)), SKDFL (changed into KDF(2)), SHGHL (changed into HGHL(2)), SHGHT (changed into HGHT(2)), FMTDUR, MOISTC, FBEANS, PODVALUE, FATCONTENT.

Several checks are performed to ensure that the values of the input variables from basic.dat are within the range of possible values. If this is not the case, an error message is returned to the screen and the program is halted.

* Check planting density: should be between 700 and 2000 ha-1
  IF (NPL.LT.700.) CALL FATALERR ('CASE2',
    & 'FE3 - Planting density too low: < 700 ha-1')
  IF (NPL.GT.2500) CALL FATALERR ('CASE2',
    & 'FE4 - Planting density too high: > 2500 ha-1')

* Check extinction value for shade trees: should be between 0.4-0.8
  IF ((KDF(2).GT.0.8).OR.(KDF(2).LT.0.4)) CALL FATALERR ('CASE2',
    & 'FE5 - Extinction coefficient of shade trees too high or too low')

* Check value of LAI for shade trees: should not exceed 3 ha ha-1
  IF (LAI(2).GT.3.) CALL FATALERR ('CASE2',
    & 'FE6 - LAI of shade trees too high: >3. ha ha-1')

* Check value of shade tree height: should not exceed 40 m
  if upper height should be larger than lower height
  IF ((HGHT(2).GT.40.).OR.(HGHL(2).GT.40.)) CALL FATALERR
    ('CASE2','FE7 - Shade tree height too high: should be <40 m'
    & 'FE8 - Upper shade tree height <= lower height')

* Check value of cacao tree height: should not exceed 20 m
  if upper height should be larger than lower height
  IF ((HGHT(1).GT.20.).OR.(HGHL(1).GT.20.)) CALL FATALERR
    ('CASE2','FE9 - Cacao tree height too high: should be <20 m'
    & 'FE10 - Upper cacao tree height <= lower height')

Next, the initial weight or size of the cacao model trees is determined. Both size (biomass) and age (tree age) can be used as an input in the model. Which of the two is used, is determined by the value of switch variable SWINPUT (specified in basic.dat): 1 for age and 2 for weight. Depending on this value, the initial total dry weight (WTOTI) of the tree or the initial age of the tree (AGEIYR) is read from basic.dat. Checks are performed to verify whether tree age or biomass is not outside the range of possible values (18.5-70 kg dry weight or 3-39 year tree age), and whether SWINPUT does not have an illegal value (it should be either 1 or 2). If this is the case, an error message is returned to the screen and the program is halted.

If biomass is used, the age in days (AGEI) is calculated using an exponential regression equation, using two regression coefficients (AGBIOIRA and AGBIORB) derived from empirical data. If age is
Chapter 9. The CASE2 subroutine

The age in years (AGEIYR) is converted to days (AGEI) and used in a logarithmic regression to calculate initial biomass (WTOTI) using the same two regression coefficients (AGBIORA and AGBIORB). Finally, the basic.dat file is closed.

- Initial weight or size of cocoa trees
- First determine whether input is age or weight of the plants.
  CALL RDSINT ('SWINPUT', SWINPUT) ![-]
  IF (SWINPUT.EQ.2) THEN
    * Input is weight
    CALL RDSREA ('WTOTI', WTOTI) ![kg DW plant-1]
  ENDIF.
  ELSEIF (SWINPUT.EQ.1) THEN
    * Input is age
    CALL RDSREA ('AGEIYR', AGEIYR) ![d]
  ENDIF.
- Close plant file
  CLOSE (IUNITD)

The initial dry weight of the different plant parts (W..I)) is calculated using linear regression of the weight of the tree component vs. the total initial dry weight (WTOTI). A distinction is made between trees that have not attained the minimum reproductive size (WTOTMIN) and those that have. Note that in the current settings of WTOTMIN (set to 10 kg DW per tree) and the minimum allowable initial tree weight (WTOTI should be larger than 20 kg), initial model trees always start with a reproductive size. For each of the tree components (LV = leaves, WD = wood, TRT = taproot, LRT = lateral roots and PD = pods), a set of two regression coefficients is used. As the regression coefficients are based on the weight of individual trees, the result of the regression is multiplied by the planting density (NPL) to obtain the weight of the plant part per hectare. PRSCALE is a scaling factor used for the calculation of initial weights in case the reproductive size has not been reached.

- Initial weight of cocoa tree components (per ha basis)
  PRSCALE = 0.
  IF (WTOTI.LT.WTOTMIN) THEN
    PRSCALE = (FLVRA * WTOTI + FLVRB) + (FWDRA * WTOTI + FWDRB) +
               (FTRTRA * WTOTI + FTRTRB) + (FLRTRA * WTOTI + FLRTRB) +
               (FPDRA * WTOTI + FPDRB) ![kg DW ha-1]
    WLVI = (FLVRA * WTOTI + FLVRB) * PRSCALE / WTOTI * NPL ![kg DW ha-1]
    WWDI = (FWDRA * WTOTI + FWDRB) * PRSCALE / WTOTI * NPL ![kg DW ha-1]
    WTRTI = (FTRTRA * WTOTI + FTRTRB) * PRSCALE / WTOTI * NPL ![kg DW ha-1]
    WLRTI = (FLRTRA * WTOTI + FLRTRB) * PRSCALE / WTOTI * NPL ![kg DW ha-1]
    WPDI = 0. ![kg DW ha-1]
  ELSE
    WLVI = (FLVRA * WTOTI + FLVRB) * NPL ![kg DW ha-1]
    WWDI = (FWDRA * WTOTI + FWDRB) * NPL ![kg DW ha-1]
    WTRTI = (FTRTRA * WTOTI + FTRTRB) * NPL ![kg DW ha-1]
    WLRTI = (FLRTRA * WTOTI + FLRTRB) * NPL ![kg DW ha-1]
    WPDI = (FPDRA * WTOTI + FPDRB) * NPL ![kg DW ha-1]
  ENDIF
State variables related to tree weight are initialised. WRT (total root weight) and WTOT (total plant weight per hectare) and WTOTPP (total weight per plant) are introduced. Plant age is calculated in days and years.

* Initialise state variables

\[
\begin{align*}
WLV &= WLVI \quad ! [kg DW ha^{-1}] \\
WWD &= WWDI \quad ! [kg DW ha^{-1}] \\
WTRT &= WTRTI \quad ! [kg DW ha^{-1}] \\
WLRT &= WLRTI \quad ! [kg DW ha^{-1}] \\
WRT &= WTRT + WLRT \quad ! [kg DW ha^{-1}] \\
WPD &= WPDI \quad ! [kg DW ha^{-1}] \\
WTOT &= WLV + WWD + WPD + WRT \quad ! [kg DW ha^{-1}] \\
WTOTPP &= WTOT / NPL \quad ! [kg DW plant^{-1}] 
\end{align*}
\]

* Plant age in days and years

\[
\begin{align*}
AGE &= AGEI \quad ! [d] \\
AGEYR &= AGE / 365. \quad ! [yr]
\end{align*}
\]

The root and water uptake (WUPT) subroutines are initialised. In the root subroutine, the weight of water-uptaking roots and the length of the taproot are calculated, and the number of soil layers from which water can be extracted is determined based on the taproot length.

* Initialise subroutines

\[
\begin{align*}
\text{CALL ROOT (ITASK, IUNITD, IUNITL, FILEI1, DELT, NL, NLA, NLXM, NLBM,} \\
& \quad \text{I1, TKL, CUMTKL, WCLQT, WCWPX, AGE, NPL, FWURT,} \\
& \quad \text{WLRT, WTRT, LTRT, WWURT, WTWURT, LTWURT,} \\
& \quad \text{ATWURT, ANURT, WSERT)} \\
\text{CALL WUPT (ITASK, IUNITD, IUNITL, FILEI1, NLXM, NL, NLA, NLBM,} \\
& \quad \text{TKL , WCLQT , WCWPX , WCFCX , WCSTX , ATWURT ,} \\
& \quad \text{ANURT, ETRD , ETAE , EVSC , GAI ,} \\
& \quad \text{TRWL , PINT, PTRANS, ATRANS, PCEW ,} \\
& \quad \text{PENMAN, CROPF )}
\end{align*}
\]

The leaf subroutine is initialised to calculate the leaf life time (AVGLVAGE), specific leaf area and the leaf area index (LAI). Prior to this, an array of water availability values over a period of 10 days is initialised (PCEW10) and filled with the value 1 (no water shortage). Then, the average of the array is calculated (PCEWMN). During the simulation, the values of the water availability factor (PCEW) in the array are actualised, and the average value may change accordingly. The variable PCEWMN is used to determine the actual leaf life time in the LEAF subroutine, taking into account the effect of drought on leaf life time. Next, the fraction of transmitted light below the shade canopy (TRMIS) is calculated, using information on the leaf area index of the shade trees (LAI(2)) and their extinction coefficient (KDF(2)) and applying an exponential decline of transmitted light. This transmission value is later used to determine the specific leaf area of new leaves in the LEAF subroutine.

* Initialise array of PCEW values of the last 10 days, and fill with ten times the same value

\[
\begin{align*}
\text{DO I1 = 1,10} \\
PCEW10(I1) &= 1. \quad ! [-] \\
\text{ENDDO} \\
\text{PCEWMN} &= \text{SUM(PCEW10(1:10))} / 10. \quad ! [-]
\end{align*}
\]

* Calculate fraction light transmission through shade canopy, assuming that cocoa and shade crowns do not overlap.

\[
\begin{align*}
\text{TRMIS} &= \exp(-\text{KDF(2)} * \text{LAI(2)}) \\
\text{CALL LEAF (ITASK, IUNITD, IUNITL, FILEI1, TERMINL, DELT, AGE, NPL,} \\
& \quad \text{TRMIS,GLV,PCEWMN,WTOTPP,} \\
& \quad \text{WLV, DLV, DLV1, DLV2, LAI(1))}
\end{align*}
\]

The pod subroutine is initialised to determine the initial ripening period, distribution of pods in age classes and the butter hardness of the beans. The average day temperature of the first day (TMAV) is first calculated for use in the pod subroutine. It is the average of the daily minimum (TMMN) and maximum (TMMX) temperatures.

* Determine average temperature (TMAV)
\[ TMAV = 0.5 \times (TMMX + TMMN) \quad \text{[degr C]} \]

\[
\text{CALL POD (ITASK, IUNITD, IUNITL, FILEI1, TERMNL, DELT, TMAV, &}
\text{GPD, WPD, YLDPD, IPOD, BHYLD)}
\]

Initial values for the leaf and pod turnover (TOLV and TOPD) are calculated for use in the rate calculation section. Leaf turnover (the weight of leaves that is lost per day) is calculated as the total leaf weight (WLV) divided by the maximum leaf life time (AVGLVAGE). Pod turnover is calculated in a similar way as the total pod weight divided by the average ripening period. In both cases, an array is filled with ten times the turnover value (DLV10 and DPD10) and the average of these values is calculated (TOLV and TOPD). This value is used in the rate calculation section for the distribution of assimilates in the plant.

Determine initial value for leaf turnover (TOLV), using given maximum leaf age (MAXLAG) and leaf weight (WLV).

\[
\text{DO } I1 = 1,10 \\
\text{DLV10} \,(I1) = \, \text{WLV} / \text{AVGLVAGE} \quad \text{[kg DW ha}^{-1} \text{d}^{-1}] \\
\text{ENDDO} \\
\text{TOLV} = \text{SUM(DLV10}(1:10)) / 10. \quad \text{[kg DW ha}^{-1} \text{d}^{-1}] \\
\]

Determine initial value for pod turnover (TOPD), using pod weight per pod category.

\[
\text{DO } I1 = 1,10 \\
\text{TOPD10} \,(I1) = \, \text{WPD} / \text{REAL(IPOD)} \quad \text{[kg DW ha}^{-1} \text{d}^{-1}] \\
\text{ENDDO} \\
\text{TOPD} = \, \text{SUM(TOPD10}(1:10)) / 10. \quad \text{[kg DW ha}^{-1} \text{d}^{-1}] \\
\]

A large number of rate and state variables and summary variables (integrals of state variables over 10 days or one year) are set to zero. This is important for reruns. The code is not shown; the following variables are set to zero: GLV, DLV, GPD, YLDPD, YLDBN, HARPODS, GTRT, GLRT, DLRT, GWD, DWD, WLV, WLRDT, WWDD, YRDD, YRAIN, YTRANS, YLDPD, YLDDBN, YPHOT, YGTOT, YLDV, YWDD, YHARPD, YREFF, YRNEFF, YHI, YHINCR, BHSUM, YMNBH, YNLOSS, YPLOSS, YKLOSS, LAISUM, YMLAI, IPODSUM, YMNIPOD, D10GTOT, D10YHARPD, D10YLDPP, D10YLDDBN, D10YRAIN, D10YRDD, D10YHARPD, D10YCOUNT, WTOTCM, WPDCUM, WBNCLASS, TNASS, CHKDF, CHKIN, CHKLD, CHKVD, CHKTRT, CHKPD.

The sum of leaf area indices of the cacao trees and shade trees (GAI) is calculated. This variable is used in the water-uptake subroutine (WUPT) to calculate potential evapotranspiration.

\[
\text{DO } I1=1,\text{INS} \\
\text{GAI} \, = \, \text{GAI} \, + \, \text{LAI}(I1) \quad \text{[m}^2 \text{ green leaf m}^{-2} \text{ soil]} \\
\text{ENDDO}
\]

Reserve weight (WRES) is initialised using the minimum concentration of reserves (MINCON) and the total weight (WTOT). The minimum amount of reserves is set to the initial amount of reserves. This variable is later used for the distribution of assimilates.

\[
\text{DO } I1=1,\text{INS} \\
\text{GAI} \, = \, \text{GAI} \, + \, \text{LAI}(I1) \quad \text{[m}^2 \text{ green leaf m}^{-2} \text{ soil]} \\
\text{ENDDO}
\]

Reserve weight (WRES) is initialised using the minimum concentration of reserves (MINCON) and the total weight (WTOT). The minimum amount of reserves is set to the initial amount of reserves. This variable is later used for the distribution of assimilates.

\[
\text{DO } I1=1,\text{INS} \\
\text{GAI} \, = \, \text{GAI} \, + \, \text{LAI}(I1) \quad \text{[m}^2 \text{ green leaf m}^{-2} \text{ soil]} \\
\text{ENDDO}
\]

The assimilate requirements for pod growth (ASRQPDR) and the carbon content of pods (CFPD) depend on the fat content of the nibs (cotyledons). The values of these variables are obtained from values in two tables (ASRQPDPDTB and CFPDPTB in the plant.dat file), using the linear interpolation function (LINT) from the TTUTIL library.

\[
\text{DO } I1=1,\text{INS} \\
\text{GAI} \, = \, \text{GAI} \, + \, \text{LAI}(I1) \quad \text{[m}^2 \text{ green leaf m}^{-2} \text{ soil]} \\
\text{ENDDO}
\]

Reserve weight (WRES) is initialised using the minimum concentration of reserves (MINCON) and the total weight (WTOT). The minimum amount of reserves is set to the initial amount of reserves. This variable is later used for the distribution of assimilates.

\[
\text{DO } I1=1,\text{INS} \\
\text{GAI} \, = \, \text{GAI} \, + \, \text{LAI}(I1) \quad \text{[m}^2 \text{ green leaf m}^{-2} \text{ soil]} \\
\text{ENDDO}
\]

The assimilate requirements for pod growth (ASRQPDR) and the carbon content of pods (CFPD) depend on the fat content of the nibs (cotyledons). The values of these variables are obtained from values in two tables (ASRQPDPDTB and CFPDPTB in the plant.dat file), using the linear interpolation function (LINT) from the TTUTIL library.

\[
\text{DO } I1=1,\text{INS} \\
\text{GAI} \, = \, \text{GAI} \, + \, \text{LAI}(I1) \quad \text{[m}^2 \text{ green leaf m}^{-2} \text{ soil]} \\
\text{ENDDO}
\]
Next, the CO₂ production factors for each of the plant parts is calculated. Growth respiration involves losses of C in the form of CO₂. This loss, or CO₂ production factors (CO₂p) is calculated from the tissue assimilate requirements (ASRQ..) and the fraction of carbon in each tissue (C..). The numbers indicate the ratios of the molecular weight of carbon (12), CO₂ (44) and CH₂O (30).

The CO₂ production factors are used in the carbon balance check in the integration section.

* CO₂ production factors
  CO₂LRT = 44./12. * (ASRQLRT*12./30. - CFLRT)  ![kg CO₂ kg⁻¹ DW]
  CO₂TRT = 44./12. * (ASRQTRT*12./30. - CFTRT)  ![kg CO₂ kg⁻¹ DW]
  CO₂WD = 44./12. * (ASRQWD*12./30. - CFWD)  ![kg CO₂ kg⁻¹ DW]
  CO₂LV = 44./12. * (ASRQLV*12./30. - CFLV)  ![kg CO₂ kg⁻¹ DW]
  CO₂PD = 44./12. * (ASRQPD*12./30. - CFPD)  ![kg CO₂ kg⁻¹ DW]

Finally, a secondary time variable (IDOYO) is initialised to be used to calculate annual totals in the rate calculation section.

IDOYO = IDOY  ![d]

9.5 Rate calculation section

The rate calculation section starts with an update of the plant age (AGE), using the age (in days) at the start of simulation (AGEI), the starting time of the simulation (STTIME, usual day one of the year) and the actual time of the simulation (TIME, in days). The corresponding age in years (AGEYR) is calculated.

* ------------------------
  Rate calculation section
* ------------------------
AGE = AGEI + TIME - STTIME              ![d]
AGEYR = AGE / 365.                      ![yr]

Some secondary weather variables are derived: the average temperature (TMAV) is calculated as the average of the daily minimum (TMMN) and maximum (TMMX) temperatures; the daytime average temperature (TMAVD) is approximated as daily maximum temperature minus 25% of the daily temperature difference. Two checks are performed to verify whether temperatures are within the range of possible values (10-40 °C). If not, an error message is returned to the screen and the program is halted.

* Weather data
* Average temperature (TMAV) and day time average (TMAVD)
  TMAV = 0.5 * (TMMX + TMMN)             ![deg C]
  TMAVD = TMMX - 0.25 * (TMMX-TMMN)       ![deg C]
  IF (TMAV.GT.40.) CALL FATALERR
&   ('CASE2','FE16 - Av. Temp greater than 40 C.')</br>  IF (TMMN.LT.10.) CALL FATALERR
&   ('CASE2','FE17 - Minimum temperature below 10 C.')</br

The root and water-uptake subroutines are called to return information on the area of fine lateral roots (those that take up water) in the soil and the actual water uptake by these roots (based on information on the potential evaportranspiration from the SETPMD subroutine, and the water content in each of the soil layers from the DRSAHE or DRPOT subroutines). Potential transpiration PTRANS and actual transpiration ATRANS of the cocoa crop are calculated in the subroutine WUPT. Water is taken up from the soil to meet the potential transpiration, resulting in the actual transpiration. The water uptake is extracted from the different soil layers in the subroutine SWSE, which is activated, by the WUPT subroutine. The ratio between the two transpiration rates is the assimilation-reducing factor PCEW. The average PCEW value over 10 days (PCEWMN) is updated with the newly calculated value.

* Transpiration and water uptake
  CALL ROOT (ITASK,IUNITD,IUNITL,FILEI1,DELT,NL,NLA, NLBM, I1,TKL, CUMTKL, WCLQT, WCWPX, AGE, NPL, FWURT, WLRT, WTRT, LTRT,
Chapter 9. The CASE2 subroutine

\[ \text{CALL WUPT (ITASK, IUNITD, IUNITL, FILEI1, NLXM, NL, NLA, NLBM,} \]
\[ \text{TKL, WCLQT, WCWPX, WCFCX, WCSTX, ATWURT,} \]
\[ \text{AWURT, ETRED, ETAE, EVSC, GAI,} \]
\[ \text{TRWL, PINT, PTRANS, ATRANS, PCEW,} \]
\[ \text{PENMAN, CROPF) } \]

* Calculate mean PCEW value over the last 10 days
\[
\text{DO } I1 = 9,1,-1
\]
\[
PCEW10(I1+1) = PCEW10(I1) \quad ![-]
\]
\[
\text{ENDDO}
\]
\[
PCEW10(1) = PCEW \quad ![-]
\]
\[
PCEWMN = \text{SUM(PCEW10(1:10)) / 10.} \quad ![-]
\]

9.5.1 Photosynthesis

The maximum rate of photosynthesis is calculated \((\text{AMAX}(1))\) taking into account the average daytime temperature \((\text{TMAVD})\) and the low photosynthetic rates of young leaves \((\text{AMINIT})\). The reduction factor for temperature \((\text{AMTMP})\) is obtained by linear interpolation of values in the \(\text{AMTMPT}\) table (specified in the plant.dat file). The literature value of the maximum rate of photosynthesis \((\text{AMX})\) is corrected for temperature (in case of extreme values) and an initial low photosynthesis.

* Carbohydrate production and respiration
  * Leaf CO2 assimilation
  * Interpolate the temperature correction for the maximum rate
  * of photosynthesis \((\text{AMAX}(1))\) from table \((\text{AMPTP})\)
  \[
  \text{AMTMP} = \text{LINT(AMTMPT, IAMTMN, TMAVD)} \quad ![-]
  \]
  \[
  \text{AMAX}(1) = \text{AMX} \times \text{AMTMP} \times \text{AMINIT} \quad ![\text{kgCO2 ha}^{-1} \text{ h}^{-1}]
  \]

The leaf area index \((\text{LAI})\) of the cocoa trees as used for the calculation of photosynthesis, is limited to a maximum value \((\text{MAXLAI}, \text{specified in the plant.dat file})\). When \(\text{LAI}\) is larger than \(\text{MAXLAI}\), the Gaussian integration in the TOTASC subroutine (that calculates the daily amount of photosynthesis) does not work properly (see Goudriaan & Van Laar 1994 for information on Gaussian integration).

In that case, the estimated photosynthesis will be unrealistically low as light availability in a large part of the canopy is low.

* \(\text{LAI}\) of the cocoa trees is set to the maximum of \(\text{MAXLAI}. \quad \text{At high}
  * \(\text{values of LAI the Gaussian integrations in TOTASC does}
  * \(\text{not work properly yielding low estimates for photosynthesis}
  * \(\text{(as light availability in large part of the canopy is low)}
  \]
  \[
  \text{LAIF}(1) = \text{MIN(\text{LAI}(1), MAXLAI)} \quad ![\text{ha leaf ha}^{-1} \text{ ground}]
  \]
  \[
  \text{LAIF}(2) = \text{LAI}(2) \quad ![\text{ha leaf ha}^{-1} \text{ ground}]
  \]

Next, the TOTASC subroutine is called to calculate the daily total gross CO2 assimilation \((\text{DTGA})\) and the fraction of light absorbed by the cacao trees \((\text{FRABS})\).

\[
\text{CALL TOTASC (IDOY, INS, LAT, RDD, FRPAR, KDF, KS,} \]
\[ \text{AMAX, EFF, LAIF, SAI, HGHT, HGHL,} \]
\[ \text{FRABS, DTGA) } \]

Now, the daily production of carbohydrates \((\text{GPHOT})\) can be calculated. To do so, the assimilated CO2 is converted to carbohydrates \(\text{CH}_2\text{O}\): for every kg of CO2 taken up 30/44 kg of \(\text{CH}_2\text{O}\) is formed (the numbers represent the molecular weight of \(\text{CH}_2\text{O}\) (30) and CO2 (44), respectively). The reduction of photosynthesis by water stress \((\text{PCEW})\) is also taken into account in GPHOT. The PCEW value indicates the relative water availability and is calculated as the ratio between the actual and potential transpiration (see above).

* Carbohydrate production
  \[
  \text{GPHOT} = \text{DTGA}(1) \times 30./44. \times \text{PCEW} \quad ![\text{kgCH2O ha}^{-1} \text{ d}^{-1}]
  \]
9.5.2 Maintenance respiration

For the calculation of maintenance costs, first the fraction of wood that is heartwood is calculated. This is of importance as heartwood does not have maintenance costs. The heartwood fraction depends on the tree age and the age at which softwood transforms into heartwood (HRTWDAGE, specified in plant.dat). Only trees older than this heartwood age contain heartwood. With increasing tree age, a larger share of the wood is transformed into heartwood.

```
*        Fraction of wood that is heartwood
IF (AGE.GT.HRTWDAGE) THEN
    FHRTWD = (AGE - HRTWDAGE)/AGE         ![-]
ELSE
    FHRTWD = 0.                           ![-]
END IF
```

Maintenance respiration is proportional to the biomass of the plant parts. First the total maintenance costs (MAINTS) without the influence of temperature is calculated using the weights of the plant parts and the plant part-specific maintenance coefficients. Note that the share of heartwood (FHRTWD) is subtracted from the weight of wood (WWD) and taproot (WTRT), as wood of the taproot is assumed to transform into heartwood. Then, the temperature-dependent increase in maintenance costs (TEFF) is calculated, assuming an non-linear increase of the maintenance respiration at every 10 °C increase in average temperature relative to a reference temperature (TREF). The Q10 variable (specified in plant.dat) determines the type of relation between temperature and extra maintenance costs. The first value for total maintenance costs (MAINTS) is multiplied by TEFF to obtain a second value that takes into account the influence of temperature (MAINT). Assimilated carbohydrates (GPHOT) in excess of the maintenance costs (MAINT) are used for the growth of the reserve pool (GRES).

```
*        Maintenance respiration
        MAINTS = MAINLRT*WLRT + MAINTRT*WTRT*(1-FHRTWD) +
                   MAINWD*WWD*(1-FHRTWD) + MAINLV*WLV + MAINPD*WPD
        ![kgCH2O ha-1 d-1]
        TEFF   = Q10**((TMAV - TREF)/10.)       ![-]
        MAINT  = MAINTS * TEFF                  ![kgCH2O ha-1 d-1]
        GRES   = GPHOT - MAINT                  ![kgCH2O ha-1 d-1]
```

9.5.3 Replacement of plant parts with turn over

The growth of plant parts is calculated in two steps: (1) the replacement of organs with a certain turnover to maintain the present biomass and (2) the actual growth of all organs. The replacement is discussed in this Section, the actual growth in Section 9.5.4. The principles of this way of modelling are explained in Section 4.3.2.

```
*        Growth consists of two parts:
*        1. Replacement of organs with a certain turnover to maintain
          biomass levels. This is done for leaves, lateral roots, wood and fruits. Turnover rates are used.
*        2. Actual growth of all organs. This is based on fraction partitioning depending on plant biomass.
```

First, the turnover rate is determined for the plant organs of which parts are lost in the course of time and should be replaced. These are: lateral roots (water-uptaking and coarse lateral roots), leaves, wood (branches) and pods. For water-uptaking roots, the loss of dry weight due to turnover (TOWURT) is calculated as the relative turnover (RTOWURT in d\(^{-1}\)) rate multiplied by the present weight of water-uptaking roots (WTWURT).

```
*        1. Replacement
*        1a. Of water-uptaking roots (< 2 mm diameter)
*        Death rate depends on relative death rate and weight of roots.
```
TOWURT = RTOWURT * WTWURT

For coarse lateral roots, no relative turnover rate was available in the literature on cacao trees. Therefore, the turnover rate (TOLRT) is based on that of water-uptaking roots (TOWURT), assuming a fixed relation (ratio) between the loss of fine root and that of coarse lateral roots (LRTWURTDR).

* 1b. Of coarse lateral roots
* Calculated as a percentage of loss rate of water-uptaking roots
TOLRT = LRTWURTDR * TOWURT

For leaves, the turnover rate (TOLV) is the average of simulated leaf death rates over a 10-day period. First, the array with leaf death rates (DLV10) is updated with the latest value. The turnover rate varies with leaf life time (which depends on the water availability) and leaf weight.

* 1c. Of leaves
* First calculate mean leaf loss over the last 10 days
DO I1 = 9,1,-1
  DLV10(I1+1) = DLV10(I1)
ENDDO

* then calculate leaf turnover rate as the mean of leaf loss
TOLV = SUM(DLV10(1:10)) / 10.

For wood, no information is available on turnover; instead, information on branch loss relative to leaf loss is used (the ratio between branch and leaf loss, WDLVDR). The wood turnover rate (TOWD) is calculated by multiplying this ratio with the turnover rate of leaves (TOLV).

* 1d. Of wood
* This is calculated as a percentage of the leaf loss rate
TOWD = WDLVDR * TOLV

For fruits, the turnover rate (TOPD) is the average of simulated pod harvest over a 10-day period. First, the array with the weights of harvested pods (TOPD10) is updated with the latest yield value (YLDPD). The turnover rate varies with pod production (which depends on water availability and temperature) and pod weight.

* 1e. Of fruits
* Turnover rate of fruits is in fact equal to the yield
* First calculate mean yield over the last 10 days
DO I1 = 9,1,-1
  TOPD10(I1+1) = TOPD10(I1)
ENDDO

* then calculate leaf turnover rate as the mean of leaf loss
TOPD = SUM(TOPD10(1:10)) / 10.

Before using the available reserves required to replace lost biomass, a check is performed to verify whether the weight of the reserve pool (WRES) plus the increase in weight due to today’s growth (GRES) is larger than the minimum reserve weight that should be maintained (MINRES). If this is the case, the amount of reserves (WRES1) available for the replacement of lost biomass is calculated. If not, no reserves will be available for replacement or net growth of plant parts. In that case, the model tree will decrease in size, as lost biomass cannot be replaced.

* Use reserve pool to replace dead biomass of these organs
* First check whether available reserve mass is more than
* the minimum reserve size
IF ((WRES + GRES * DELT) GT. (MINRES)) THEN
  WRES1 = WRES + GRES * DELT - MINRES
ELSE
  WRES1 = 0
ENDIF

Next, the available reserves (WRES1) are compared with the turnover requirements. There are three possibilities: (1) the available reserves are sufficient to cover all replacement “costs”; (2) the reserves are not sufficient to cover all replacement “costs”, but may cover part of the replacement costs; and (3) there are no reserves to cover any replacement cost.

(1) The first IF statement is used when available reserves (per time step of the model, which is 1 day) are larger than the carbohydrates required for the replacement of all lost biomass due to
turnover. The latter is calculated by multiplying the loss of biomass (TO…) by the assimilate requirements for growth (ASRQ..) for each plant part. The assimilation reduction factor (PCEW, indicating the relative water availability) is used for leaves as not all lost leaf area is replaced in case of water stress. Growth of the different plant parts is simply equal to the amount of biomass lost due to turnover. In the case of leaves, leaf growth is multiplied by the assimilation reduction factor (PCEW) to account for reduced leaf growth during periods of water shortage.

(2) The first ELSEIF statement is used if the available reserves (WRES1/DELT) are not sufficient to cover the complete requirements of turnover, but may cover part of the costs. In this case, the reserves are distributed proportional to the carbohydrate requirements for each of the plant parts. To do so, first the total amount of carbohydrates required for replacement is calculated (TOREQ). Then, the growth of the different plant parts is calculated as the carbohydrate requirements of each plant part (turnover weight × assimilation requirements, TO.. × ASRQ..), divided by the total assimilation requirements (TOREQ) and multiplied by the available reserves (WRES1).

(3) The second ELSEIF statement is used if the available reserves (WRES1) are zero. In that case growth of all plant parts is zero.

```fortran
* Then check whether available reserve mass is sufficiently large
* to replace the lost part of all organs.
IF (WRES1/DELT GT. ((TOWURT+TOLRT)*ASRQLRT + TOLV*ASRQLV*PCEW + TOWD*ASRQWD + TOPD*ASRQPD)) THEN
GWURT1 = TOWURT ![kg DW ha-1 d-1]1
GLRT1 = TOLRT ![kg DW ha-1 d-1]
GLV1 = TOLV * PCEW ![kg DW ha-1 d-1]
GWD1 = TOWD ![kg DW ha-1 d-1]
GPD1 = TOPD ![kg DW ha-1 d-1]
GTOT1 = GWURT1 + GLV1 + GWD1 + GPD1 + GLRT1 ![kg DW ha-1 d-1]2
* If not, reserve weight is distributed proportional to turnover
ELSEIF ((WRES1/DELT .GT. 0.).AND.(WRES1/DELT .LE. ((TOWURT+TOLRT)*ASRQLRT + TOLV*ASRQLV*PCEW + TOWD*ASRQWD + TOPD*ASRQPD))) THEN
* total required CH2O to account for turnover of organs = TOREQ
TOREQ = (TOWURT+TOLRT)*ASRQLRT + TOLV*ASRQLV*PCEW
+ TOWD*ASRQWD + TOPD*ASRQPD
GWURT1 = ((TOWURT*ASRQLRT)/TOREQ * WRES1/DELT)/ ASRQLRT
GLRT1 = ((TOLRT*ASRQLRT)/TOREQ * WRES1/DELT)/ ASRQLRT
GLV1 = ((TOLV*ASRQLV*PCEW)/TOREQ * WRES1/DELT)/ ASRQLV
GWD1 = ((TOWD*ASRQWD)/TOREQ * WRES1/DELT)/ ASRQWD
GPD1 = ((TOPD*ASRQPD)/TOREQ * WRES1/DELT)/ ASRQPD
GTOT1 = GWURT1 + GLV1 + GWD1 + GPD1 + GLRT1 ![all (kg DW ha-1 d-1)]2
ELSE
GWURT1 = 0. ![kg DW ha-1 d-1]
GLRT1 = 0. ![kg DW ha-1 d-1]
GLV1 = 0. ![kg DW ha-1 d-1]
GWD1 = 0. ![kg DW ha-1 d-1]
GPD1 = 0. ![kg DW ha-1 d-1]
GTOT1 = 0. ![kg DW ha-1 d-1]
ENDIF
```

The total amount of reserves used for growth of plant parts to account for turnover is calculated. This total decrease rate of the reserved (DRES1) is used to determine the reserves left for net growth of plant parts.

```fortran
DRES1 = (GWURT1+GLRT1)*ASRQLRT+GLV1*ASRQLV+GWD1*ASRQWD +GPD1*ASRQPD ![kgCH2O ha-1 d-1]
```

---

2 Note that in the code of version 2.2 (released February 2002), the term + GLRT1 is missing in these two lines of the program code. The consequences of this error are very small: bean yield and biomass production change by 0-0.4%. A new version of the Fortran CASE2 file can be obtained from the authors, if required.
9.5.4 Actual growth of plant parts

The second step in the calculation of the growth of plant parts involves the actual growth of all plant parts. (The first step - replacement of lost biomass - is discussed in the previous Section). The principles of this way of modelling are explained in Section 4.3.3.

The distribution of available assimilates over the different plant parts depends on the actual and the ideal proportion of biomass in each plant part. First, the actual proportion of biomass in each plant part (organ) is determined (PR..AC), by dividing the actual weight (W..) by the total weight (WTOT). The CHKPART1 variable is calculated to check whether all proportions sum to exactly 1 (with a tolerance of 5%). If this is not the case, an error message is shown and the program is halted (using the FATALERR function from the TTUTIL library).

* 2. Actual growth of all organs.
* First determine actual proportions of total DW in organs
PRLVAC = WLV / WTOT ![-]
PRWDAC = WWD / WTOT ![-]
PRPDAC = WPD / WTOT ![-]
PRTRTAC = WTRT / WTOT ![-]
PRLRTAC = WLRT / WTOT ![-]
CHKPART1 = PRLVAC + PRWDAC + PRPDAC + PRTRTAC + PRLRTAC ![-]
* Terminate program if CHKPART1 is NOT 1
IF ((CHKPART1 .GT. 1.005) .OR. (CHKPART1 .LT. 0.995))
&  CALL FATALERR ('CASE2','FE18 - Actual allometry is wrong:
&    sum of proportions (CHKPART1) does not equal 1')

Secondly, the ideal proportion of biomass in each plant part is calculated (PR..ID), using allometric relations of the cacao tree (see Section 4.3.1). This is done differently for (1) small trees with a per-plant weight (WTOTPP) lower than the minimum reproductive size (WTOTMIN), than for (2) large, reproductive, trees.

(1) First, a scaling factor is calculated (PRSCALE), to assure that the proportions sum to 1.

PRSCALE is calculated by adding the ideal proportions of all plant parts, except for pods. Each of these proportions is calculated by filling in the linear regression equation of plant part weight vs. total plant weight (WTOTPP) and dividing this again by the total plant weight (WTOTPP).
The ideal weights of leaves and lateral roots are adjusted by the PCEW factor that indicates the relative water availability: the ideal proportion of leaves is reduced in case of water shortage (low PCEW value) whereas the ideal lateral roots fraction increases with water shortage. Then, the ideal proportions (PR..ID) of each of the plant parts is calculated using the linear regressions mentioned and divided by the PRSCALE value in order to sum to exactly 1. For pods, the ideal proportion is set to zero.

(2) The PRSCALE factor and the ideal proportions (PR..ID) are calculated as explained under (1), with the difference that pods are also included.

* Then determine "ideal" proportions of total DW in different organs, based on allometric relations. For leaves and fine roots, the ideal proportion is modified by the water availability over the last 10 days. Note that the ideal proportions are calculated using the total dry weight per plant (WTOTPP), as the regression equations are on a per-plant basis.
* In two cases:
  * 1. For small plants not bearing pods. The ideal proportion of biomass in pods PRPID = 0.
  * IF ((WTOTPP).LT.WTOTMIN) THEN
    PRSCALE = (FLVRA*WTOTPP+FLVRB)/WTOTPP*PCEW +
    (FWDRA*WTOTPP+FWDRB)/WTOTPP +
    (FTRTRA*WTOTPP+FTRTRB)/WTOTPP +
    (FLRTRA*WTOTPP+FLRTRB)/WTOTPP*(2-PCEW) ![-]
    PRLVID =((FLVRA*WTOTPP+FLVRB)/WTOTPP*PCEW)/PRSCALE ![-]
Chapter 9. The CASE2 subroutine

PRWDID = ((FWDRA*WTOTPP+FWDRB)/WTOTPP)/PRSCALE  ![-]
PRPDID = 0.  ![-]
PRTRTID = ((FTRTRA*WTOTPP+FTRTRB)/WTOTPP)/PRSCALE  ![-]
PRLRTID = ((FLRTRA*WTOTPP+FLRTRB)/WTOTPP*(2-PCEW))/PRSCALE  ![-]

2. For larger plants bearing pods.
ELSE
   PRSCALE = (FLVRA*WTOTPP+FLVRB)/WTOTPP*PCEW + 
                (FWDRA*WTOTPP+FWDRB)/WTOTPP  + 
                (FPDRA*WTOTPP+FPDRB)/WTOTPP  + 
                (FTRTRA*WTOTPP+FTRTRB)/WTOTPP  +
                (FLRTRA*WTOTPP+FLRTRB)/WTOTPP*(2-PCEW)  ![-]
   PRLVID = ((FLVRA*WTOTPP+FLVRB)/WTOTPP * PCEW) / PRSCALE   ![-]
   PRWDID = ((FWDRA*WTOTPP+FWDRB)/WTOTPP) / PRSCALE          ![-]
   PRPDID = ((FPDRA*WTOTPP+FPDRB)/WTOTPP) / PRSCALE          ![-]
   PRTRTID = ((FTRTRA*WTOTPP+FTRTRB)/WTOTPP) / PRSCALE        ![-]
   PRLRTID = ((FLRTRA*WTOTPP+FLRTRB)/WTOTPP*(2-PCEW))/PRSCALE ![-]
ENDIF

A check is performed to verify that none of the ideal proportions is lower than zero. If this is the case, an error message is shown and the program is halted.

Terminate program if one of ideal proportions is below 0 (this is possible when total biomass is low.)

IF ((PRLVID.LT.0.).OR.(PRWDID.LT.0.).OR.(PRTRTID.LT.0.).OR.(PRLRTID.LT.0.).OR.(PRPDID.LT.0.)) CALL FATALERR
   ('CASE2','FE19 - The ideal biomass fraction of one or more organs is below 0')

Now, the ideal and actual biomass proportions of the plant parts, the water availability factor and the regression coefficient of allometric relation are used to determine the fraction of biomass growth partitioned to each of the plant organs. Again, this is done differently for (1) small trees with a per-plant weight (WTOTPP) lower than the minimum reproductive size (WTOTMIN), than for (2) large, reproductive, trees.

(1) First, a scaling factor (FSCALE) is calculated as the sum of the calculated fractions for all organs except for pods. FSCALE is used to adjust the calculated partitioning fractions in order to sum to 1. Then, each of the partitioning fractions is calculated as the maximum value of zero or a value calculated as the slope of the linear regression line between the organ biomass and total biomass (F..RA), multiplied by the difference between ideal and actual biomass proportion (PR..ID – PR..AC) and divided by actual biomass proportion (PR..AC). In this calculation, the slope of the regression is used to take into account that the increase in organ weight with a certain increase in total plant weight differs between organs, e.g. wood weight increases more per kg extra plant weight than pod weight. The difference between the ideal and actual biomass proportion (standardised by the actual proportion) is used to allow for extra partitioning to organs with a lower biomass than expected based on the total plant weight.

The maximum function is used to ensure that in case the actual proportion is higher than the ideal proportion (more biomass is the organ than would be expected on the basis of the ideal allometric relation), the partitioning fraction does not become negative, but is set to zero. This implies that no biomass is invested in this plant part and thus prevents that the actual biomass of a plant part deviates too much from the ideal value. In this way, a realistic distribution of biomass over the plant organs is maintained. Lastly, the value of a check variable (CHKPART2) is calculated as the sum of all partitioning fractions. This should equal 1.

(2) For reproductive trees, the same general procedure is followed as explained above, now including calculations of the partitioning fraction for pods. Several extra IF statements are included in these calculations. The first IF statement prevents the actual biomass fraction of pods to equal zero (this may be the case when the total plant weight (WTOTPP) exceeds the minimum reproductive size (WTOTMIN) for the first time). If this is the case, a division by zero occurs in the calculation of the partitioning fraction. This problem is solved by setting the actual biomass fraction (PRPDAC) to a very small value (0.001). The second IF statement
Chapter 9. The CASE2 subroutine

Deals with the (very rare) case that the actual biomass proportions are larger than the ideal proportions for all plant organs. In this situation, the partitioning fraction is based only on the slopes of the linear regressions of organ weights vs. total plant weight (and not on the actual or ideal weights). CHKPART2 is calculated to check whether all partitioning fractions sum to 1.

Correct partitioning fractions for deviations from the "ideal" proportions. In two cases:

1. For small plants not bearing pods.
   
   IF ((WTOTPP).LT.WTOTMIN) THEN
   
   FSCALE= MAX(0.,FLVRA*(PRLVID-PRLVAC)/PRLVAC) +
   MAX(0.,FWDRA*(PRWDID-PRWDAC)/PRWDAC) +
   MAX(0.,FTRTRA*(PRTRTID-PRTRTAC)/PRTRTAC) +
   MAX(0.,FLRTRA*(PRLRTID-PRLRTAC)/PRLRTAC)  ![--]
   
   FLV = MAX(0.,(FLVRA *(PRLVID-PRLVAC)/PRLVAC)/FSCALE)  ![--]
   FWD = MAX(0.,(FWDRA * (PRWDID-PRWDAC)/PRWDAC)/FSCALE)  ![--]
   FPD = 0.  ![--]
   FTRT = MAX(0.,(FTRTRA*(PRTRTID-PRTRTAC)/PRTRTAC)/FSCALE)  ![--]
   FLRT = MAX(0.,(FLRTRA*(PRLRTID-PRLRTAC)/PRLRTAC)/FSCALE)  ![--]
   
   CHKPART2 = FLV + FWD + FPD + FTRT + FLRT  ![--]
   
2. For larger plants bearing pods.
   ELSE
   
   The below if statement prevents PRPDAC from being zero and
   PRPDID/PRPDAC from being infinitely large.
   IF (PRPDAC.EQ.0.) PRPDAC = 0.001
   
   FSCALE= MAX(0.,FLVRA*(PRLVID-PRLVAC)/PRLVAC) +
   MAX(0.,FWDRA*(PRWDID-PRWDAC)/PRWDAC) +
   MAX(0.,FTRTRA*(PRTRTID-PRTRTAC)/PRTRTAC) +
   MAX(0.,FLRTRA*(PRLRTID-PRLRTAC)/PRLRTAC) +
   MAX(0.,FPDRA *(PRPDID-PRPDAC)/PRPDAC)  ![--]
   
   IF (FSCALE .EQ. 0.) THEN
   
   FLV = FLVRA / (FLVRA + FWDRA +FPDRA +FTRTRA +FLRTRA)  ![--]
   FWD = FWDRA / (FLVRA + FWDRA +FPDRA +FTRTRA +FLRTRA)  ![--]
   FPD = FPDRA / (FLVRA + FWDRA +FPDRA +FTRTRA +FLRTRA)  ![--]
   FTRT= FTRTRA / (FLVRA + FWDRA +FPDRA +FTRTRA +FLRTRA)  ![--]
   FLRT = FLRTRA / (FLVRA + FWDRA +FPDRA +FTRTRA +FLRTRA)  ![--]
   
   CHKPART2 = FLV + FWD + FPD + FTRT + FLRT  ![--]
   ELSE
   
   FLV = MAX(0.,(FLVRA *(PRLVID-PRLVAC)/PRLVAC)/ FSCALE)
   FWD = MAX(0.,(FWDRA * (PRWDID-PRWDAC)/PRWDAC)/ FSCALE)
   FPD = MAX(0.,(FPDRA  * (PRPDID-PRPDAC)/PRPDAC)/ FSCALE)
   FTRT = MAX(0.,(FTRTRA *(PRTRTID-PRTRTAC)/PRTRTAC)/ FSCALE)
   FLRT = MAX(0.,(FLRTRA * (PRLRTID-PRLRTAC)/PRLRTAC)/ FSCALE)
   
   CHKPART2 = FLV + FWD + FPD + FTRT + FLRT  ![all --]
   ENDIF

In case the sum of all partitioning fractions (CHKPART2) does not equal 1, an error message is shown and the program is halted.

Terminates program if CHKPART2 is NOT 1
   IF ((CHKPART2 .GT. 1.005) .OR. (CHKPART2 .LT. 0.995))
   & CALL FATALERR ('CASE2','FE20 - Partitioning is wrong,
   & total partitioning (CHKPART2) is not equal to 1')

The overall value of assimilate requirement for the conversion of carbohydrates into dry matter (ASRQ) for the crop as a whole is calculated as the weighted mean of the ASRQ values of the different plant parts.

Determine assimilate requirements for growth
ASRQ = ASRQWD*FWD + ASRQLV*FLV + ASRQPD*FPD +
& ASRQRT*FTRT + ASRQTRT*FLRT  ![kg CH2O kg-1 DW]

Then, the size of the reserve pool for net growth of plant parts (WRES2) is calculated. In case the available reserves for replacement of lost plant parts (WRES1) equals zero, there are no reserves left for net growth (WRES2). In that case, the decrease rate of reserves for net growth (DRES2) and the total net growth rate of the plants (GTOT2) will be zero. If WRES1 is larger than zero, the amount of available reserves for net growth is calculated as the available reserves for replacement
Chapter 9. The CASE2 subroutine

(WRES1) minus the amount of reserves used for replacement (DRES1) during the model time step (1 day). The decrease rate of reserves for net growth (DRES2) is then determined as the available reserves for net growth (WRES2) divided by a time coefficient (specified in plant.dat), that spreads the reserve use over various days and thus avoids a sudden depletion of reserves. Lastly, the total net growth of the plant (GTOT2) is calculated using the reserves decrease rate (DRES2) and the average assimilation requirements for plant growth.

* Distribute remaining reserve pool (WRES2) to net organ growth

IF (WRES1 .EQ. 0.) THEN
  WRES2 = 0.                             ![kg CH2O ha-1]
  DRES2 = 0.                             ![kg CH2O ha-1 d-1]
  GTOT2 = 0.                             ![kg DW ha-1 d-1]
ELSE
  WRES2 = WRES1 - DRES1*DELT             ![kg CH2O ha-1]
  DRES2 = WRES2 / TAU                    ![kg CH2O ha-1 d-1]
  GTOT2  = DRES2 / ASRQ                  ![kg DW ha-1 d-1]
ENDIF

9.5.5 Total growth and death rates

Growth and death (or decrease) rates of biomass and reserves are calculated in the following lines. The total decrease rate of the reserves is calculated by adding the reserves used for replacement (DRES1) and those used for net growth of plant parts (DRES2).

* Total decrease rate of reserves

DRES   = DRES1 + DRES2                   ![kg CH2O ha-1 d-1]

Then, the growth is summed. Growth rates of which names end with "1" indicate growth due to replacement of lost biomass (see Section 9.5.3). GTOT2 is the total net growth rate of the entire tree, which is partitioned to the plant parts according to the calculated fractions (F...). The growth rate of lateral roots consists of the replacement growth of water-uptaking and coarse lateral roots (GWURT1 and GLRT1) and the net growth (FLRT × GTOT2). The rates of root growth (GRT) is calculated by adding lateral root and taproot growth. The total biomass growth (GTOT) is calculated by adding rates of all plant parts.

* Determine total growth of organs and plant as a total

GWD    = GWD1 + FWD * GTOT2              ![kg DW ha-1 d-1]
GLV    = GLV1 + FLV * GTOT2              ![kg DW ha-1 d-1]
GPD    = GPD1 + FPD * GTOT2              ![kg DW ha-1 d-1]
GTRT   = FTRT * GTOT2                    ![kg DW ha-1 d-1]
GLRT   = GWURT1 + GLRT1 + FLRT * GTOT2   ![kg DW ha-1 d-1]
GRT    = GTRT + GLRT                     ![kg DW ha-1 d-1]
GTOT   = GTOT1 + GTOT2                   ![kg DW ha-1 d-1]

Death (or decrease) rates are calculated based on turnover in the case of lateral roots (DLRT) and wood (DWD), and as leaf loss (DLV) for leaves (calculated in the leaf subroutine). The “death rate” of pods, i.e. the harvest of pods, is discussed in the next Section. Note that no biomass loss is assumed for the taproot.

* Death rates

DLRT  = TOWURT + TOLRT                   ![kg DW ha-1 d-1]
DWD   = TOWD                            ![kg DW ha-1 d-1]

* Leaf death rate

CALL LEAF (ITASK, IUNITD, IUNITL, FILEII1, TERMNL, DELT, AGE, NPL, &
TRMIS, GLV, PCEWMN, WTOTPP, &
WLV, DLV, DLV1, DLV2, LAI(1))
9.5.6 Pod and bean yield

Daily pod yield (YLDPD), butter hardness of the harvested beans (BHYLD) and pod ripening period (IPOD) are calculated in the pod subroutine.

* Pod yield
  CALL POD (ITASK, IUNITD, IUNITL, FILEI1, TERMNL, DELT, TMAV, & GPD, WPD, YLDPD, IPOD, BHYLD)

Subsequently, the commercial bean yield (YLDBN) is calculated using the fraction beans per pod (FBEANS), a factor of loss due to the length of the fermentation process (FMTLOS) and a factor which accounts for the moisture content after drying (MOISTC, all specified in the basic.dat file).

The daily number of harvested pods (HARPODS) is calculated using the bean yield (YLDBN) pod value or index (PODVALUE, specified in basic.dat).

* Commercial bean yield (YLDBN) is determined by the fractions of beans per pod (FBEANS), a factor of loss due to the length of the fermentation process (FMTLOS) and a factor which accounts for the moisture content after drying (MOISTC).
  FMTLOS = FMTDUR * FMTA + FMTB  ![-]
  YLDBN = YLDPD * FBEANS * FMTLOS * (1.+ MOISTC) ![kg fermented beans ha-1 d-1]
  HARPODS= YLDBN * PODVALUE ![ha-1 d-1]

9.5.7 Ten-day and annual totals

Ten-day (D10…) and annual (Y…) total values are calculated for a number of rate variables. Ten-day total values are included in the model output in case output is generated each 10 days (OUTPUTFQ = 2, specified in basic.dat). The 10-day totals are set to zero at every 1st, 11th, 21st, etc. day after the start time (usually day 1).

* Calculation of 10-day and annual totals
  10-day totals are set to zero after each 10 day period
  IF ((TIME-STTIME) .EQ. (D10COUNT*10.+1.)) THEN
    D10GTOT  = 0.  ![kg DW ha-1 10d-1]
    D10YLDPD = 0.  ![kg DW ha-1 10d-1]
    D10YLDBN = 0.  ![kg DW ha-1 10d-1]
    D10RAIN  = 0.  ![mm 10d-1]
    D10RDD   = 0.  ![mm 10d-1]
    D10HARPD = 0.  ![10d-1]
    D10COUNT = D10COUNT + 1.
  ENDIF

The 10-day totals are updated each day with today's value of the particular rate, using Euler integration (the INTGRL function from the TTUTIL library). The integration is over the time step (DELT) of the model (this is set to 1 day).

* 10-day totals for selected output parameters
  IF (TIME.NE.STTIME) THEN
    D10GTOT  = INTGRL (D10GTOT, GTOT, DELT)  ![kg DW ha-1 10d-1]
    D10YLDPD = INTGRL (D10YLDPD, YLDPD, DELT) ![kg DW ha-1 10d-1]
    D10YLDBN = INTGRL (D10YLDBN, YLDBN, DELT) ![kg DW ha-1 10d-1]
    D10RAIN  = INTGRL (D10RAIN, RAIN, DELT)  ![mm 10d-1]
    D10RDD   = INTGRL (D10RDD, RDD, DELT)    ![J m-2 10d -1]
    D10HARPD = D10YLDBN * PODVALUE           ![10d-1]
  ENDIF

For annual rainfall (YRAIN), the total value is checked after one year and a warning message appears on the screen in case rainfall is lower than 1000. The program is not halted, though.

* Check on rainfall: warning in case annual precipitation is low
  IF (YRAIN.LT.1000..AND.IDOY.EQ.IDOYO.AND.DOY.NE.STTIME) & CALL WARNING('CASE2','WA1 - Very low annual rainfall,<1000 mm')
The annual totals (Y....) are included in the model output in case output is generated annually (OUTPUTFQ = 1, specified in basic.dat). The annual totals are set to zero when the day of the year (IDOY) equals the day of the year at the start of the simulation (IDOYO, specified in timer.dat, usually day 1).

* Annual totals are set to zero at the start day of simulations
  IF (IDOY.EQ.IDOYO) THEN
  YGPHOT = 0.                            ![kg CH2O ha-1 y-1]
  YGTOT  = 0.                            ![kg DW ha-1 y-1]
  YGTOTAB= 0.                            ![kg DW ha-1 y-1]
  YYLDPD = 0.                            ![kg DW ha-1 y-1]
  YYLD BN = 0.                           ![kg DW ha-1 y-1]
  YLVD   = 0.                            ![kg DW ha-1 y-1]
  YWDD   = 0.                            ![kg DW ha-1 y-1]
  YRAIN  = 0.                            ![mm y-1]
  YTRANS = 0.                            ![mm y-1]
  YRDD   = 0.                            !([MJ m-2 y-1]
  BHSUM  = 0.                           ![kg DW fermented beans]
  LAISUM = 0.                            ![ha leaf ha-1 ground]
  IPODSUM= 0.                           ![kg DW fermented beans]
  YNLOSS = 0.                            !([kg N ha-1 yr-1]
  YPLOSS = 0.                            !([kg P ha-1 yr-1]
  YKLOSS = 0.                            !([kg K ha-1 yr-1]
  ENDIF

The annual totals (Y....) are updated each day with that day’s value of the particular rate, using Euler integration (the INTGRL function from the TTUTIL library). The integration is over the time step (DELT) of the model (this is set to 1 day).

* Annual totals for selected output parameters
  YGPHOT = INTGRL (YGPHOT, GPHOT, DELT)    ![kg CH2O ha-1 y-1]
  YGTOT  = INTGRL (YGTOT, GTOT, DELT)      ![kg DW ha-1 y-1]
  YGTOTAB= INTGRL (YGTOTAB, GTOT-GRT, DELT)  ![kg DW ha-1 y-1]
  YYLDPD = INTGRL (YYLDPD, YLDPD, DELT)    ![kg DW ha-1 y-1]
  YYLD BN = INTGRL (YYLD BN, YLDBN, DELT)   ![kg DW ha-1 y-1]
  YLVD   = INTGRL (YLVD, DLV, DELT)        ![kg DW ha-1 y-1]
  YWDD   = INTGRL (YWDD, DWD, DELT)        ![kg DW ha-1 y-1]
  YRAIN  = INTGRL (YRAIN, RAIN, DELT)      ![mm y-1]
  YRDD   = INTGRL (YRDD, (RDD/1000000), DELT)  !([MJ m-2 y-1]
  YTRANS = INTGRL (YTRANS, ATRANS, DELT)   ![mm y-1]

Some annual summary variables are derived from the annual yield: the annual number of harvested pods (YHARPD), the loss of N, P and K from the cacao plantation due to the harvest of beans (YNLOSS, YPLOSS and YKLOSS). Rain and radiation efficiency (YRNEFF and YRDEFF) are calculated using yield and annual rain or radiation totals. Two harvest indices are calculated: the classical Harvest Index (YHI) based on yield and above-ground plant weight; and the harvest increment (YHIINCR) based on the yield and the above-ground biomass production.

* Variables derived from annual yield
  YHARPD = YYLD BN * PODVALUE            ![y-1]
  YNLOSS = YYLD BN * NCONTBN             ![kg N ha-1 yr-1]
  YPLOSS = YYLD BN * PCONTBN             ![kg P ha-1 yr-1]
  YKLOSS = YYLD BN * KCONTBN             ![kg K ha-1 yr-1]

* Rain and radiation use efficiency
  YRDEFF = YYLD BN / YRDD                !([kg DW ha -1 (MJ m-2)-1]
  YRNEFF = YYLD BN / NOTNUL(YRAIN)       !([kg DW ha -1 mm]

* Harvest increment, annual value
  YHI   = YYLD BN / (WTOT - WRT)         ![-]

* HINCR is Harvest increment following Cannell 1985
  YHINCR = YYLD BN / NOTNUL(YGTOTAB)     ![-]

Then, some average values are calculated: the average ripening period (YMNIPOD) is calculated based on a sum (IPODSUM) of daily values of IPOD × YLD BN (IPOD is the ripening period; YLD BN is the daily dry bean yield). The annual average is thus weighted for yield. A similar procedure is
applied for the calculation of the average annual butter hardness (YMNBH), also weighted for yield. Lastly, the annual average leaf area index (YMNLAI) of the cacao trees is calculated.

\* Annual average of ripening time (IPOD)
IPODSUM = IPODSUM + IPOD * YLDBN  \!\![d]
YMNIPOD = IPODSUM / NOTNUL(YLDBN)  \!\![d]

\* Annual average of butter hardness
BHSUM  = BHSUM + BHYLD * YLDBN          \!\![kg DW fermented beans]
YMNBH  = BHSUM / NOTNUL(YLDBN)          \!\![\-]

\* Annual average of cocoa LAI
LAISUM = LAISUM + LAI(1)                \!\![ha leaves ha-1 ground]
YMNLAI = LAISUM / DOY                   \!\![ha leaves ha-1 ground]

9.5.8 Finish conditions

The program is terminated when the maximum tree age (AGEYR = 40 y) or tree biomass (WTOTPP = 70 kg per tree) is passed, or when the reserve mass (WRES) is below zero (reserves have been depleted). In all cases, a warning is returned to the screen and the program is halted, but output is generated.

Finish conditions
IF (AGEYR .GE. 40.) THEN
WRITE (*,*) IYEAR,IDOY
CALL WARNING ('CASE2',
&W 'WA2 - Maximum tree age (40 yr) is reached')
TERMNL = .TRUE.
ENDIF
IF (WTOTPP .GE. 70.) THEN
CALL WARNING ('CASE2',
&W 'WA3 - Maximum tree size (70 kg DW) is reached')
TERMNL = .TRUE.
ENDIF
IF (WRES .LT.    0.) THEN
WRITE (*,*) IYEAR,IDOY
CALL WARNING ('CASE2','WA4 - Reserves depleted')
TERMNL = .TRUE.
ENDIF

9.5.9 Output

Output is generated at the end of the rate calculation section, depending on the settings in the timer.dat file and the value of TIME. If the output variable (OUTPUT) is .TRUE., output is generated and written to a temporary file. A selection of the parameters is included in the res.dat file, which is shown in the tables in FSEWin (and can be imported in a spreadsheet program). This selection depends on the specified output frequency (OUTPUTFQ) in basic.dat and on the PRSEL.. arrays in timer.dat.

The program code defining output starts with:
\* Output of
IF (OUTPUT) THEN
and ends with:
CALL OUTDAT (2, 0, 'EVSC' , EVSC )
END IF

The code itself is not shown (see the CASE2.for file on the CD-ROM).

The first part, which starts with:
\* Chart output for all three output types (OUTPUTFQ)
and ends with:
CALL ChartOutputRealScalar('HARPODS',HARPODS)
END IF
Chapter 9. The CASE2 subroutine

defines the output that is generated for charts in FSEWin, using the subroutines named “ChartOutput...”. Chart output is generated for the following variables: IYEAR, AGEYR, WTOT, WTOTPP, WRT, WTRT, WLRT, WLV, WWD, WPD, WPDCUM, WBNMCUM, PENMAN, CROPF, YRDD, YRAIN, YTRANS, YGPHOT, YGTOT, YLVD, YYLDPD, YYLDBN, YHI, YHINCR, YMNBH, YMNPDP, YHARPD, YRDEFF, YRNFEF, YNLOSS, YPLOSS, YKLOSS, D10RDD, D10RAIN, D10YLDPD, D10YLDBN, D10GTOT, DOY, RAIN, RDD, LAI, TMAV, MAINT, GTOT, GTOT1, GTOT2, GRT, GTRT, GLRT, GLV, GWD, GPD, FTRT, FLR, FLV, FWD, FPD, DLR, DLD, DLV, DLY, WWURT, AWURT, ATWURT, TTWURT, TRWL, TTRANS, PTRANS, ATRANS, PCEW, YLDBN, YLDPD, BHYLD, HARPDS.

Then, the output for the table in FSEWin and the res.dat file is generated. This is done for the following variables (or arrays): AGE, AGEYR, WTOTCUM, WTOT, WTOTPP, WRT, WTRT, WLRT, WLV, WWD, WPD, WPDCUM, WRES, WRES1, WRES2, WLV, WWD, WLLTD, TNASS, LAI, GAI, FRABS,TMAV, TMAVD, GPHOT, MAINT, GRES, DRES, DRES1, DRES2, MINRES, ASRQ, GTOT, GTOT1, GTOT2, GRT, GTRT, GLRT, GWURT1, GWD, GLV, GLV1, GPD, GPD1, DLRT, DLD, DLY, DLV1, DLV2, DTLR, TOWURT, TOLV, TDP, FTRT, FLR, FWD, FPD, YLDBN, YLDPD, HARPDS, WBNCUM, PENMAN, CROPF, YRDD, YRAIN, YTRANS, YGPHOT, YGTOT, YGTOTAB, YLVD, YYLDPD, YYLDBN, YHI, YHINCR, YMNBH, YMNLAI, YMNPDP, YHARPD, YRDEFF, YRNFEF, YNLOSS, YPLOSS, YKLOSS, D10RDD, D10RAIN, D10YLDPD, D10YLDBN, D10GTOT, CUMTKL, WWURT, AWURT, WSERT, ATWURT, LTWURT, WPD, LAP, PTRANS, ATRANS, PCEW, ATRANS, BHYLD, DOY, IYEAR, RAIN, RDD, ETRD, ETAE, EVSC.

9.6 Integration section

In the integration section (ITASK=3), state variables of the models are updated by integrating the rates calculated in the previous section. The integration section starts with calls to the root, leaf and pod subroutines. In the root subroutine the length of the taproot and the number of available soil layers is updated. In the leaf subroutine, the leaves are shifted one age class (in the boxcar train) and the leaf area index is updated. In the pod subroutine, biomass growth is added to the pods in the various categories, the development stage of the pods is increased and pods are moved to the next category. The value of the total leaf area index of cacao and shade trees is updated, using the new value of LAI of the cacao trees calculated in the leaf subroutine.

```
ELSE IF (ITASK.EQ.3) THEN
*       -------------------
*       Integration section
*       -------------------

CALL ROOT (ITASK,IUNITD,IUNITL,FILEI1,DELT,NL, NLA, NLXM, NLBM,
&             I1,TKL, CUMTKL, WCLQT, WCMPX, AGE, NPL, FWURT,
&             WLRT, WRT, LTRT,
&             WWURT, WTWURT, LTRT, ATWURT, AWURT, WSERT)
CALL LEAF (ITASK,IUNITD,IUNITL,FILEI1,TERMNL,DELT,AGE,NPL,
&             TRMIS,GLV,PCEWMN,WTOTPP,
&             WLV, DLV, DLV1, DLV2, LAI(1))
CALL POD (ITASK,IUNITD,IUNITL,FILEI1,TERMNL,DELT,TMAV,
&             GPD, WPD, YLDPD, IPOD, BHYLD)

*       Green Area Index of shade and cocoa trees
GAI = 0.      ![ha leaf ha-1 ground]
DO I1=1,INS
  GAI = GAI + LAI(I1)      ![ha leaf ha-1 ground]
ENDDO
```

Next, the state variables on living and dead biomass (dry matter) and on reserves are updated. Euler integration is performed using the INTGRL functions of the TTUTIL library, over a period
equal to the time step of the model (DELT, this is 1 day). The first value mentioned between parenthesis in the INTGRL function is the old value of the state variable, then the growth and decrease (death) rates are mentioned (the latter with a minus sign), followed by the integration period (DELT). Maximum functions (MAX) are used in some cases to avoid state variables to have negative values due to rounding errors. Root weight and total plant weight are calculated as the sum of the integrals of the components.

The cumulative biomass production (WTOTCUM) without taking into account biomass loss is calculated, as well as the cumulative dry weight of lost plant parts (leaves: WLVD; wood: WWDD and lateral roots: WLRTD). The reserve mass is integrated and a new value of the minimum reserve weight is calculated. Lastly, cumulative values of pod and bean production is calculated by integration.

```
*       Dry matter
WLV    = MAX(0.,INTGRL (WLV, GLV-DLV, DELT)) ![kg DW ha-1]
WWD    = INTGRL (WWD , GWD-DWD, DELT) ![kg DW ha-1]
WTRT   = INTGRL (WTRT, GTRT, DELT) ![kg DW ha-1]
WLRT   = INTGRL (WLRT, GLRT-DLRT, DELT) ![kg DW ha-1]
WRT    = WLRT + WTRT ![kg DW ha-1]
WPD    = MAX(0.,INTGRL (WPD , GPD-YLDPD, DELT)) ![kg DW ha-1]
WTOT   = WWD   + WLV  + WPD + WTRT + WLRT ![kg DW ha-1]
WTOTPP = WTOT/NPL ![kg DW per plant]
WTOTCUM= INTGRL (WTOTCUM, GTOT, DELT) ![kg DW ha-1]
*       Dead dry matter
WLVD   = INTGRL (WLVD, DLV , DELT) ![kg DW ha-1]
WWDD   = INTGRL (WWDD, DWD , DELT) ![kg DW ha-1]
WLRTD  = INTGRL (WLRTD , DLRT, DELT) ![kg DW ha-1]
*       Reserves
WRES   = INTGRL (WRES, GRES-DRES, DELT) ![kg CH2O ha-1]
MINRES = MINCON * WTOT
*       Cumulative harvested pods and beans
WPDCUM = INTGRL (WPDCUM, YLDPD, DELT) ![kg DW ha-1]
WBNCUM = INTGRL (WBNCUM, YLDBN, DELT) ![kg DW ha-1]
```

### 9.6.1 Carbon balance check

The carbon balance check (CHKDIF) compares the amount of carbon present in all organs and at any point in time (CHKIN), with the amount of carbon collected in the integral (CHKFL) of net carbon assimilation rate (TNASS). This rate consists of the balance of daily gross CH₂O assimilation (GPHOT), maintenance respiration (MAINT), growth and decrease rate of reserves (GRES, DRES) and the growth respiratory losses of C due to growth respiration for each tissue (growth × CO₂ factor). The two terms CHKIN and CHKFL should not differ more than a fraction. A larger relative deviation is an indication of omission of a term somewhere in the program. The same applies for the C input check for each plant part (CHKLV, CHKWD, ...). In case CHKDIF is larger than 0.01 or smaller than -0.01 (and ifCHKIN>10 to prevent warning in case of very low assimilation), an error message is shown and the program is halted. Similarly, error messages are returned when the CHK... variables for any of the plant parts are not zero.

```
*       Carbon balance check - for entire tree
TNASS  = INTGRL (TNASS,((GPHOT - MAINT - GRES + DRES)
&   "*44./30.) -
&   (GLRT*CO2LRT + GTRT*CO2TRT + GLV*CO2LV
&   + GWD*CO2WD + GPD*CO2PD),DELT) ![kg CO2 ha-1]
CHKFL  = TNASS * (12./44.) ![kg C ha-1]
CHKIN  = (WLV + WLVD - WLVI)*CFLV + (WWD + WWDD - WWDDI)*CFWD
&   + (WTRT - WTRTI)*CFTRT + (WTRT + WLRTD - WLRTTI)*CFRT
&   + (WPD + WPDCUM - WPDI)*CFPD ![kg C ha-1]
CHKDIF = (CHKIN-CHKFL)/NOTNU(CHKIN) ![9.6.1]
```
CHKLRT = GLRT*CFLRT + GLRT*CO2LRT*12./44. - GLRT*ASRQLRT*12./30.

Terminate program if CHK** for one of the organs is too large

IF ((ABS(CHKLRT).GT.0.001).OR.(ABS(CHKTRT).GT.0.001).OR.
    (ABS(CHKPD) .GT. 0.001)) CALL FATALERR
& ('CASE2',' FE22 - Carbon balance is wrong for one organ,
& CHK** larger than 0.001')

9.7 Terminal section

No tasks have been defined for the terminal section of the CASE2 subroutine. Program control is
dropped back to the calling MODELS subroutine.

ELSE IF (ITASK.EQ.4) THEN
* ----------------
* Terminal section
* ----------------
* No tasks defined for terminal section

END IF

RETURN
END
Chapter 10. The LEAF subroutine

10. The LEAF subroutine

10.1 Purpose

This subroutine simulates leaf growth and senescence of leaves. Leaves are contained in age classes (so called 'box cars') with a width of one day. The principles used are described in Section 4.4.

10.2 Input and output

This subroutine is included in the CASE2.FOR file. The following input and output variables are used by this subroutine (see Table 10.1 for explanation):

```
SUBROUTINE LEAF (ITASK, IUNITD, IUNITL, FILEI1, TERMNL, DELT, AGE, NPL,
                 TRMIS, GLV, PCEWMN, WTOTPP,
                 WLV, DLV, DLV1, DLV2, LAI)
```

Table 10.1. Names and description of the formal parameters used in the LEAF subroutine.

<table>
<thead>
<tr>
<th>Code</th>
<th>Type</th>
<th>Description</th>
<th>Unit</th>
<th>Input/output</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITASK</td>
<td>I4</td>
<td>Task that subroutine should perform</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>IUNITD</td>
<td>I4</td>
<td>Unit that can be used for input files</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>IUNITL</td>
<td>I4</td>
<td>Unit used for log file</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>FILEI1</td>
<td>C*</td>
<td>Name of first file with plant data</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>TERMNL</td>
<td>L4</td>
<td>Flag to indicate if simulation is to stop</td>
<td>-</td>
<td>I/O</td>
</tr>
<tr>
<td>DELT</td>
<td>R4</td>
<td>Time step of integration</td>
<td>d</td>
<td>I</td>
</tr>
<tr>
<td>AGE</td>
<td>R4</td>
<td>Age of trees</td>
<td>d</td>
<td>I</td>
</tr>
<tr>
<td>NPL</td>
<td>R$</td>
<td>Density of cacao trees</td>
<td>ha-1</td>
<td>I</td>
</tr>
<tr>
<td>TRMIS</td>
<td>R4</td>
<td>Proportion of light transmitted by shade tree</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>GLV</td>
<td>R4</td>
<td>Growth rate of leaves</td>
<td>kg ha-1 d-1</td>
<td>I</td>
</tr>
<tr>
<td>PCEWMN</td>
<td>R4</td>
<td>Reduction factor for photosynthesis</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>WTOTPP</td>
<td>R4</td>
<td>Total dry weight per plant</td>
<td>kg</td>
<td>I</td>
</tr>
<tr>
<td>WLV</td>
<td>R4</td>
<td>Weight of leaves</td>
<td>kg ha-1</td>
<td>0</td>
</tr>
<tr>
<td>DLV</td>
<td>R4</td>
<td>Death rate of leaves</td>
<td>kg ha-1 d-1</td>
<td>0</td>
</tr>
<tr>
<td>DLV1</td>
<td>R4</td>
<td>Death rate of leaves, due to ageing</td>
<td>kg ha-1 d-1</td>
<td>0</td>
</tr>
<tr>
<td>DLV2</td>
<td>R4</td>
<td>Death rate of leaves, due to drought</td>
<td>kg ha-1 d-1</td>
<td>0</td>
</tr>
<tr>
<td>LAI</td>
<td>R4</td>
<td>Leaf Area Index</td>
<td>m2 m-2</td>
<td>0</td>
</tr>
</tbody>
</table>

10.3 Initialisation section

After the declaration of variable names (the model code of this part is not shown), the initialisation section (ITASK = 1) starts.

```
  IF (ITASK.EQ.1) THEN
    * ----------------------
    * Initialization section
    * ----------------------
```

Parameters related to leaf life time (maximum leaf life time: AVGLVAGE; minimum leaf life time: MINLVAGE) and to the specific leaf area (regression parameters SLAR.. for the relation between
specific leaf area and plant weight or light level) are read from the plant.dat file, using the RDINIT and RDSREA functions from the TTUTIL library. Then, the number of leaf classes is determined using the maximum leaf life time and the leaf life time adjusted for water shortage (ADJLVAGE) is initialised using information on maximum and minimum leaf life time and relative water availability (averaged over 10 days: PCEWMN).

```
CALL RDINIT (IUNITD, IUNITL, FILEI1)
CALL RDSREA ('AVGLVAGE', AVGLVAGE) ![d]
CALL RDSREA ('MINLVAGE', MINLVAGE) ![d]
CALL RDSREA ('SLAR1A', SLAR1A)     ![ha kg-1 leaf DW kg-1 plant DW]
CALL RDSREA ('SLAR1B', SLAR1B)     ![ha kg-1 leaf DW]
CALL RDSREA ('SLAR2A', SLAR2A)     ![-]
CALL RDSREA ('SLAR2B', SLAR2B)     ![-]
CLOSE (IUNITD)
```

Then, the number of leaf classes is determined using the maximum leaf life time and the leaf life time adjusted for water shortage (ADJLVAGE) is initialised using information on maximum and minimum leaf life time and relative water availability (averaged over 10 days: PCEWMN).

```
*       Leaf ages
ILD = INT(AVGLVAGE)                      ![-]
ADJLVAGE = NINT(MINLVAGE - PCEWMN*MINLVAGE + PCEWMN*AVGLVAGE) ![d]
```

A modifier for the calculation of the specific leaf area (SLA, the leaf area per unit leaf mass) is calculated (SLAMOD). This parameter accounts for the adjustment of leaf thickness in shaded conditions: shade leaves are thinner than leaves in high light conditions. SLAMOD equals 1 (thus, no modification of SLA) when the proportion of light transmitted by the shade trees (TRMIS) is higher than 0.8 (thus, less than 20% shading). If TRMIS is lower than 0.80, the value of SLAMOD becomes >1.

```
*       Calculate SLA modifier to account for higher SLA in shaded
*       conditions. Only when light transmission below shade tree
*       canopy <0.80 (at higher values there is no effect)
IF (TRMIS.LE.0.80) THEN
   SLAMOD = SLAR2A * LOG(TRMIS) + SLAR2B
ELSE
   SLAMOD = 1.
ENDIF
```

The boxcar train with leaf weights and areas is initialised. Each boxcar contains leaves of a certain age (in days). The total number of boxcars (ILD) is thus equal to the maximum leaf life time (AVGLVAGE), as shown above. Initially, each of the boxcars contains a leaf weight (WLEAF(I1)) equal to the 1/AVGLVAGE part of the total leaf weight (WLV). The specific leaf area of each boxcar (SLA(I1)) is calculated using a regression equation with the total plant weight (WTOTPP), and then modified for the effect of shading using SLAMOD. The leaf area per boxcar (LA(I1)) is simply calculated as the product of weight (WLEAF(I1)) and specific leaf area (SLA(I1)). The leaf area index (LAI) of the cacao trees is determined by summing the leaf areas of all boxcars. The total leaf weight (WLEAFTOT) is calculated by adding leaf weights of all boxcars, and is used for checking.

```
*       Initialise boxcar train with leaf weights and leaf areas
LAI   = 0.
WLEAFTOT= 0.
DO 10 I1 = 1,ILD
   WLEAF(I1)  = WLV/AVGLVAGE              ![kg DW leaf]
   SLA(I1)    = (SLAR1A * WTOTPP + SLAR1B) * SLAMOD
              ![ha leaf kg-1 DW leaf]
   LA(I1)     = WLEAF(I1) * SLA(I1)       ![ha leaf ha-1 ground]
   LAI        = LAI + LA(I1)              ![ha leaf ha-1 ground]
   WLEAFTOT   = WLEAFTOT +WLEAF(I1)       ![kg DW leaf]
10      CONTINUE
```

A number of checks are performed. Maximum leaf life time should not exceed 365 days; minimum leaf life time should not be lower than zero and minimum leaf life time should not be larger than
maximum leaf life time. In case these conditions are not met, an error message is shown and the program is halted without generating output. (Note that the text in error message of the last check is wrong. This should read: "Maximum leaf life time less than min. leaf life time"). A fourth check is carried out to verify that the total leaf weight in all boxcars (WLEAFTOT) equals the total leaf weight that was obtained from the CASE2 subroutine (WLV). If not, a warning message is shown and the program is halted, but output is generated.

* Fatal error checks

```
*       Fatal error checks
IF (AVGLVAGE.GT.365.) CALL FATALERR
&     ('CASE2','FE23 - Maximum leaf age greater than one year')
IF (MINLVAGE.LT.0.) CALL FATALERR
&     ('CASE2','FE24 - Minimum leaf age less than zero (0)')
IF (AVGLVAGE.LT.MINLVAGE) CALL FATALERR
&     ('CASE2','FE25 - Maximum leaf age less than min. leaf age')

* Check whether leaf weight in boxcars equals leaf weight

CHKTLV = NOTNUL(WLV) / NOTNUL(WLEAFTOT)
IF ((CHKTLV.LT.0.95) .OR. (CHKTLV.GT.1.05)) THEN
  WRITE (*,*) IYEAR,IDOY
  CALL WARNING ('CASE2 - LEAF',
&    'WA5 - Sum leaf class weights not equal to total leaf weight')
  TERMNL = .TRUE.
ENDIF
```

10.4 Rate calculation section

The rate calculation section (ITASK = 2) starts with the calculation of SLA (SLA(0)) and leaf area (LA(0)) of the newly produced leaves (in boxcar 0). Leaf weight of the new leaves is equal to the growth of leaf weight (GLV as calculated in the CASE2 subroutine) and the time step of the model (DELT, this equals 1 day). Then, the SLA of new leaves is calculated using a regression equation with the total plant weight (WTOTPP), and then multiplied by the SLA modifier (SLAMOD) that accounts for shading effects. The leaf area (LA(0)) is the product of leaf weight (WLEAF(0)) and the specific leaf area (SLA(0)).

```
ELSE IF (ITASK.EQ.2) THEN
*       ------------------------
*       Rate calculation section
*       ------------------------
*       Characteristics of new leaves

WLEAF(0) = GLV * DELT                   ![kg DW ha-1]
SLA(0)  = (SLAR1A * WTOTPP + SLAR1B) * SLAMOD
         ![ha leaf kg-1 leaf DW]
LA(0)   = WLEAF(0)*SLA(0)              ![ha leaf ha-1 ground]
```

The number of boxcars (ILD) is calculated using the maximum leaf life time (AVGLVAGE). The adjusted leaf life time is calculated using information on the relative water availability (PCEWMN; average of 10 days) and the minimum and maximum leaf life time (MINLVAGE and AVGLVAGE).

```
*       Adjust leaf age for water stress sensitivity
ILD = AVGLVAGE                           ![d]
ADJLVAGE = NINT(MINLVAGE - PCEWMN*MINLVAGE + PCEWMN*AVGLVAGE)
         ![d]
```

Leaf death rates are calculated for senescing leaves (DLV1) and leaves dying due to water shortage (DLV2). The first leaf death rate (DLV1) is due to the fact that the leaves can not become older than a certain maximum age and this is simply calculated by "emptying" the last boxcar (that for the maximum leaf life time): the entire weight of leaves in this boxcar (the ILDth boxcar) is added to the leaf death rate DLV1. The leaf area and leaf weight of this boxcar are "zeroed". The second leaf death rate due to water stress is calculated using a relative death rate (RDLV) which is calculated as the difference between the daily proportion of dying leaves due to water shortage.
1/ADJLVAGE (ADJLVAGE = adjusted leaf life time) and that due to ageing 1/AVGLVAGE (AVGLVAGE = maximum leaf life time). In the case of no water shortage, this difference equals zero as AVGLVAGE = ADJLVAGE. In the case of water shortage, the first term is larger as ADJLVAGE < AVGLVAGE. Then, the leaf death rate due to water stress (DLV2) is calculated as the relative death rate (RDLV) multiplied by the total leaf weight (WLV) and by a factor that accounts for the leaf loss due to ageing (as the leaves in the last boxcar that were lost due to ageing cannot die again). The total leaf death rate (DLV) is the sum of the death rate due to ageing (DLV1) and that due to water shortage (DLV2).

```
*       Determine leaf death rates for senescing leaves (DLV1) and
*       leaves dying due to water shortage (DLV2)
DLV  = 0.                                 ![kg DW ha-1 d-1]
DLV1 = 0.                                ![kg DW ha-1 d-1]
DLV2 = 0.                                ![kg DW ha-1 d-1]
DLV1 = WLEAF(ILD)/DELT                   ![kg DW ha-1 d-1]
LA(ILD) = 0.                             ![ha leaf ha-1 ground]
WLEAF(ILD) = 0.                          ![kg DW ha-1]
RDLV = (1./ADJLVAGE - 1./AVGLVAGE)       ![d-1]
DLV2 = RDLV * WLV * (AVGLVAGE-1)/AVGLVAGE! [kg DW ha-1 d-1]
DLV  = DLV1 + DLV2                       ![kg DW ha-1 d-1]
```

10.5 Integration section

The integration section (ITASK = 3) starts with shifting the contents of each boxcar to the next. The specific leaf area (SLA(I1)), leaf weights (WLEAF(I1)) and leaf areas (LA(I1)) of each boxcar are moved to the next. Boxcar 1 is now filled with the newly produced leaves and the last (ILDth) boxcar is filled again with the contents of the one-but-last boxcar. Totals for leaf area (LAI) and leaf weight (WLEAFTOT) are calculated, the latter for checking purposes. The contents of boxcar 0 that contained the new leaves is "zeroed".

```
ELSE IF (ITASK.EQ.3) THEN
  ------------------------
  Integration section
  ------------------------
  Shift all the leaves, weights and areas one class
  and account for extra leaf loss due to water shortage
LAI = 0.                                 ![ha leaf ha-1 ground]
WLEAFTOT = 0.
DO 30 I1=ILD-1,0,-1
  SLA(I1+1)    = SLA(I1)                 ![ha leaf kg-1 leaf DW]
  WLEAF(I1+1)  = WLEAF(I1) * (1-RDLV)    ![kg DW ha-1]
  LA(I1+1)    = WLEAF (I1) * SLA(I1)    ![ha leaf ha-1 ground]
  WLEAFTOT    = WLEAFTOT + WLEAF(I1)    ![kg DW ha-1]
30      CONTINUE
WLEAF(0)  = 0.                           ![kg DW ha-1]
LA(0)     = 0.                           ![ha leaf ha-1 ground]
SLA(0)    = 0.                           ![ha leaf kg-1 leaf DW]
```

A check is performed to verify that the total leaf weight in all boxcars (WLEAFTOT) equals the total leaf weight that was obtained from the CASE2 subroutine (WLV). If not, a warning message is shown and the program is halted, but output is generated. The warning message is only generated for WLEAFTOT >10, to prevent warnings due to rounding errors when total leaf mass is very low.

```
CHKTLV = NOTNUL(WLV + GLV*DELT - DLV*DELT) / NOTNUL(WLEAFTOT)
IF (WLEAFTOT .GT. 10. .AND. ((CHKTLV.LT.0.95) .OR. &
   (CHKTLV.LT.1.05))) THEN
  WRITE (*,*) IYEAR,IDOY
  CALL WARNING ('CASE2 - LEAF', &
    'WA6 - Sum leaf class weights not equal to total lf weight')
  TERMNL = .TRUE.
ENDIF
```
END IF

Program control is handed back to the calling CASE2 subroutine.
RETURN
END
11. The ROOT subroutine

11.1 Purpose

To calculate the number of layers from which water can be extracted as well as the biomass and area of water-uptaking roots in each of these layers. The principles used are described in Section 4.5.

11.2 Input and output

This subroutine is included in the CASE2.FOR file. The following input and output variables are used by this subroutine (see Table 11.1 for explanation):

```
SUBROUTINE ROOT (ITASK, IUNITD, IUNITL, FILEI1, DELT, NL, NLA, NLXM, NLBM,
&                  I1, TKL, CUMTKL, WCLQT, WCWPX, AGE, NPL, FWURT,
&                  WLRT, WTRT, LTRT,
&                  WWURT, WTWURT, LTWURT, ATWURT, AWURT, WSERT)
```

Table 11.1. Names and description of the formal parameters used in the ROOT subroutine.

<table>
<thead>
<tr>
<th>Code</th>
<th>Type</th>
<th>Description</th>
<th>Unit</th>
<th>Input/output</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLTMOD</td>
<td>C*</td>
<td>Name of plant module</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>ITASK</td>
<td>I4</td>
<td>Task that subroutine should perform</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>IUNITD</td>
<td>I4</td>
<td>Unit number that is used for input files</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>IUNITL</td>
<td>I4</td>
<td>Unit number that is used for log file</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>FILEI1</td>
<td>C*</td>
<td>File name with which plant parameters are read</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>DELT</td>
<td>R4</td>
<td>Time interval of integration</td>
<td>d</td>
<td>I</td>
</tr>
<tr>
<td>NL</td>
<td>I4</td>
<td>Actual number of soil compartments</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>NLA</td>
<td>I4</td>
<td>No of soil comp. from which water can be extracted</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>NLBM</td>
<td>I4</td>
<td>Maximum no of soil comp.</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>NLXM</td>
<td>I4</td>
<td>No. of layers as declared in calling program</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>I1</td>
<td>I4</td>
<td>DO-loop counter</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>TKL</td>
<td>R4</td>
<td>Thicknesses of soil compartments</td>
<td>m</td>
<td>I</td>
</tr>
<tr>
<td>CUMTKL</td>
<td>R4</td>
<td>Cumulative thickness of rooted soil layers</td>
<td>m</td>
<td>O</td>
</tr>
<tr>
<td>WCLQT[]</td>
<td>R4</td>
<td>Volumetric soil water content per layer</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>WCWPX[]</td>
<td>R4</td>
<td>Vol. water content at wilting point per layer</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>AGE</td>
<td>R4</td>
<td>Age of tree</td>
<td>d</td>
<td>I</td>
</tr>
<tr>
<td>NPL</td>
<td>R4</td>
<td>Cacao tree density</td>
<td>ha-1</td>
<td>I</td>
</tr>
<tr>
<td>FWURT</td>
<td>R4</td>
<td>Fraction of lateral roots that may take up water</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>WLRT</td>
<td>R4</td>
<td>Weight of lateral roots</td>
<td>kg DW ha-1</td>
<td>I</td>
</tr>
<tr>
<td>WTRT</td>
<td>R4</td>
<td>Weight of taproot</td>
<td>kg DW ha-1</td>
<td>I</td>
</tr>
<tr>
<td>LTRT</td>
<td>R4</td>
<td>Length of taproot</td>
<td>m</td>
<td>I</td>
</tr>
<tr>
<td>WWURT</td>
<td>R4</td>
<td>Weight of water-uptaking roots per layer</td>
<td>kg DW ha-1</td>
<td>I</td>
</tr>
<tr>
<td>WTWURT</td>
<td>R4</td>
<td>Total weight of water-uptaking roots</td>
<td>kg DW ha-1</td>
<td>I</td>
</tr>
<tr>
<td>LTWURT</td>
<td>R4</td>
<td>Total length of water-uptaking roots</td>
<td>m ha-1</td>
<td>I</td>
</tr>
<tr>
<td>ATWURT</td>
<td>R4</td>
<td>Total area of water-uptaking roots</td>
<td>m2 ha-1</td>
<td>I</td>
</tr>
<tr>
<td>AWURT</td>
<td>R4</td>
<td>Area of water-uptaking roots per layer</td>
<td>m2 ha-1</td>
<td>I</td>
</tr>
<tr>
<td>WSERT</td>
<td>R1</td>
<td>Auxiliary variable to calculate root extension</td>
<td>-</td>
<td>O</td>
</tr>
</tbody>
</table>
11.3 Initialisation section

After the declaration of variable names (the model code of this part is not shown), the initialisation section (ITASK = 1) starts.

```
 IF (ITASK.EQ.1) THEN
   * ----------------------
   * Initialisation section
   * ----------------------

Parameters related to the vertical distribution of fine roots (VDWURTR.), wood density (SW), diameter (DIAM.) and specific length (SPRTL.) of fine roots are read from the plant.dat file, using the RDINIT and RDSREA functions from the TTUTIL library. Then, the values of several variables and arrays are set to zero.

   * Read plant parameters from file
   CALL RDINIT (IUNITD  , IUNITL, FILEI1)
   CALL RDSREA ('VDWURTR', VDWURTRA)       ![kg DW ha-1 m-2]
   CALL RDSREA ('SW', SW)                   ![kg ha-1]
   CALL RDSREA ('DIAM1', DIAM1)             ![m]
   CALL RDSREA ('DIAM2', DIAM2)             ![m]
   CALL RDSREA ('SPRTL1', SPRTL1)           ![m kg-1 DW]
   CALL RDSREA ('SPRTL2',SPRTL2)            ![m kg-1 DW]
   CLOSE (IUNITD)

   NLA     = 0                              ![-]
   CUMTKL  = 0                              ![-]
   LTWURT  = 0.                             ![m ha-1]
   WTWURTR = 0.                             ![kg DW ha-1]
   ATWURT  = 0.                             ![m2 ha-1]

   * Arrays are set to zero.
   DO I1=1, NLXM
     WWURT(I1)  = 0.                        ![kg DW ha-1]
     WWURTR(I1) = 0.                        ![kg DW ha-1]
     LWURT1(I1) = 0.                        ![m ha-1]
     LWURT2(I1) = 0.                        ![m ha-1]
   END DO

   DO I1=1, NLBM
     AWURT(I1) = 0.                         ![m2 ha-1]
   END DO
```

The total weight of the fine roots that can extract water (water-uptaking roots; WTWURTR) is calculated using the fraction of water-uptaking roots (FWURT; specified in plant.dat) and the weight of lateral roots (WLRT; obtained from the CASE2 subroutine).

```python
   * Total weight of water-uptaking roots
   WTWURTR = FWURT * WLRT                   ![kg DW ha-1]
```

The length of the taproot is determined using information on its weight (WTRT), the specific weight of the wood (SW), the planting density (NPL) and the value of \( \pi \) (PI). The taproot is assumed to have the form of a cone. Next, the number of soil layers (NLA) from which water can be extracted is determined, using the taproot length (LTRT) and information on the thickness of each of the soil layers (TKL(I1)) and the cumulative thickness of soil layers (CUMTKL).

```python
   * Calculation of length of taproot, from known weight.
   * The shape of the taproot is assumed to be that of a cone.
   * Number of layers of which water can be taken up depends on length of taproot
   LTRT = ((WTRT * 1200)/(NPL * SW * PI))**0.3333    ![m]
   DO I1 = 1, NL
     IF (LTRT.GT.CUMTKL) THEN
       NLA = NLA + 1                      ![-]
       CUMTKL = CUMTKL + TKL(I1)         ![m]
     END IF
   END DO
```
11.4 Rate calculation section

The rate calculation section (ITASK = 2) starts with the calculation of the vertical distribution of water-uptaking roots. This is done in two steps: (1) calculate a first estimate of fine root biomass in each of the soil layers based on a regression equation; (2) adjust these estimates to the known total weight of fine roots.

(1) The regression equation used to determine the distribution of fine roots, relates the root density (root weight per unit soil volume) to depth in the soil. A power-relation is assumed \( y = b \times \text{depth}^a \). By multiplying this density with the depth of a soil layer, the root weight per unit area is obtained. The procedure for the calculation is as follows. First, several parameters are set to zero: the cumulative thickness of soil layers (CUMTKL), the total weight of water uptaking roots as estimated using the regression equation for vertical distribution (WTWURTR) and the length of the taproot in the lowest soil layer (LTRTLL). Then, the regression equations are applied for two situations.

(a) In case only one soil layer is penetrated by the taproot (NLA=1), the estimated amount of fine roots in soil layer 1 (WWURTR(1)) is calculated using the regression equation with depth equalling half of the taproot length (LTRT). Total estimated fine root weight in the soil (WTWURTR) is then equal to that in the first layer (WWURTR(1)) and cumulative soil thickness (CUMTKL) equals the thickness of layer 1 (TKL(1)).

\[ \text{ELSE IF (ITASK.EQ.2) THEN} \]
\[ \text{------------------------} \]
\[ \text{Rate calculation section} \]
\[ \text{------------------------} \]

\[ \text{Calculate vertical distribution of wateruptaking roots.} \]
\[ \text{First determine distribution based on regression, for all} \]
\[ \text{except the lowest available layer.} \]
\[ \text{CUMTKL} = 0. \quad \text{[m]} \]
\[ \text{WTWURTR} = 0. \quad \text{[kg DW ha}^{-1}] \]
\[ \text{LTRTLL} = 0. \quad \text{[m]} \]
\[ \text{in case the taproot penetrates only one soil layer (NLA=1)} \]
\[ \text{IF (NLA.EQ.1) THEN} \]
\[ \text{WWURTR(1)} = (\text{VDWURTRB} \times (0.5 \times \text{LTRT})^{	ext{VDWURTRA}}) \times \text{LTRT} \]
\[ \text{WTWURTR} = \text{WWURTR(1)} \]
\[ \text{CUMTKL} = \text{TKL(1)} \quad \text{[m]} \]
\[ \text{ELSE} \]

(b) In case several soil layers are penetrated by the taproot, the calculation is performed in two steps: (b1) for soil layers 1 to NLA-1 (the one-but-last soil layer penetrated by the taproot) and (b2) for the last soil layer. (b1) The cumulative soil thickness (CUMTKL) is calculated by adding the thickness of all soil layers (TKL(I)), except for the last. The estimated weight of the water-uptaking roots in each layer (WWURTR(I)) is first set to zero and then calculated using the power-regression, with the depth equalling the cumulative thickness of all previous layers (CUMTKL) plus half of the present layer (TKL(I)). The total estimated weight of water-uptaking roots (WTWURTR) is calculated by adding the estimated weights (WWURTR) of all layers (except for the last). (b2) For the last layer, the length of the taproot in that layer (LTRTLL) is first calculated using the cumulative thickness of the previous soil layers (CUMTKL) and the taproot length (LTRT). Then, the weight of water-uptaking roots in this layer (WWURTR(NLA)) is estimated using the power-regression with the depth equalling the cumulative thickness of the previous layers (CUMTKL) plus half of the length of the taproot in this layer (LTRTLL). The total estimated weight of water-uptaking roots (WTWURTR) is updated with the estimate for the last layer and the cumulative
thickness of available soil layers (CUMTKL) is updated with the thickness of the last layer (TKL(NLA)).

* - in case that several layers are available
DO I1=1,NLA-1
CUMTKL = CUMTKL + TKL(I1) ![m]
WWURTR(I1) = 0. ![kg DW ha\(^{-1}\)]
WWURTR(I1) = (VDWURTRB*(CUMTKL-0.5*TKL(I1))**(VDWURTRA)*TKL(I1)) ![kg DW ha\(^{-1}\)]
& WTWURTR = WTWURTR + WWURTR(I1) ![kg DW ha\(^{-1}\)]
END DO
* - for last layer: only the extend of taproot in that layer
LTRTLL = LTRT - CUMTKL ![m]
WWURTR(NLA) = (VDWURTRB*(CUMTKL+0.5*LTRTLL)**VDWURTRA)*LTRTLL ![kg DW ha\(^{-1}\)]
WTWURTR = WTWURTR + WWURTR(NLA) ![kg DW ha\(^{-1}\)]
CUMTKL = CUMTKL + TKL(NLA) ![m]
ENDIF

(2) The second step in the calculation of the fine root weight per soil layer involves the adjustment of the estimates from step 1, to the known total weight of fine roots. This known total (WTWURT) is calculated using the fraction of water-uptaking roots (FWURT; specified in plant.dat) and the weight of lateral roots (WLRT; from the CASE2 subroutine). The total weight (WTWURT) is then distributed over the available soil layer (NLA) using the share of estimated weights for each of the soil layers (WWURTR(I1)/WTWURTR).

* Then adjust total from regression to actual DW of water-uptaking roots
WTWURT = FWURT * WLRT ![kg DW ha\(^{-1}\)]
DO I1=1, NLA
WWURT(I1) = WWURTR(I1) / WTWURTR * WTWURT ![kg DW ha\(^{-1}\)]
END DO

The following lines are not used.

* --------
DO I1=1, NLA
WSERT(I1) = 1. ![\text{-}]
IF (WCLQT(I1).LT.WCWPX(I1)) THEN
WSERT(I1) = 0. ![\text{-}]
END IF
END DO

The length of water-uptaking roots per soil layer (LWURT..(I1)) is calculated for two categories of fine roots (category 1 containing the finest roots; and 2 the somewhat coarser roots). Each of these two categories contains half of the total weight of fine roots. Fine root length of category 1 and 2 for each of the soil layers (LWURT1(I1) and LWURT2(I2)) is summed to obtain the total fine root length (LTWURT).

* Determine length of water uptaking roots
LTWURT=0. ![m ha\(^{-1}\)]
DO I1=1,NLA
LWURT1(I1) = 0.5 * WWURT(I1) * SPRTL1 ![m ha\(^{-1}\)]
LWURT2(I1) = 0.5 * WWURT(I1) * SPRTL2 ![m ha\(^{-1}\)]
LTWURT = LTWURT + LWURT1(I1) + LWURT2(I1) ![m ha\(^{-1}\)]
END DO

The area of water-uptaking roots per soil layer (AWURT(I1)) is calculated using the diameter (DIAM..) of the two categories of water-uptaking roots and the value of \(\pi\) (PI). The fine root area per soil layer (AWURT(I1)) is summed to obtain the total fine root area (ATWURT).

* Determine area of water uptakeing roots
ATWURT=0.
DO I1=1, NLA
AWURT(I1) = (PI*DIAM1)*LWURT1(I1)+(PI*DIAM2)*LWURT2(I1) ![m\(^2\) ha\(^{-1}\)]
ATWURT = ATWURT + AWURT(I1) ![m\(^2\) ha\(^{-1}\)]
END DO
11.5 Integration section

In the integration section (ITASK = 3) the length of the taproot is calculated (LTRT), based on the new value of the taproot weight (WTRT) and the values for the planting density (NPL), the specific wood weight (SW) and \( \pi \) (PI). Using the new value of the taproot length (LTRT), the number of soil layers from which water can be extracted (NLA) is updated.

```
ELSE IF (ITASK.EQ.3) THEN
  * Calculation of length of taproot, from known weight.
  * The shape of the taproot is assumed to be that of a cone.
  LTRT = ((WTRT * 1200)/(NPL * SW * PI))**0.3333

  * Determine the number of soil layers available to the trees.
  DO I1 = NLA, NL
    IF (LTRT.GT.CUMTKL) THEN
      NLA = NLA + 1                        ![-]
      CUMTKL = CUMTKL + TKL(I1)            ![m]
    ELSE
      NLA = NLA                            ![-]
    ENDIF
  END DO
END IF
```

Finally, program control is handed back to the calling CASE2 subroutine.

```
RETURN
END
```
12. The WUPT subroutine

12.1 Purpose

To calculate potential and actual transpiration, and water uptake from the separate soil layers. The principles used are described in Section 4.5.3.

12.2 Input and output

This subroutine is included in the CASE2.FOR file. The following input and output variables are used by this subroutine (see Table 12.1 for explanation):

```fortran
SUBROUTINE WUPT (ITASK, IUNITD, IUNITL, FILEI1, NLXM, NL, NLA, NLBM,
&                   TKL   , WCLQT , WCWPX , WCFCX , WCSTX , ATWURT ,
&                   AWURT, ETRD  , ETAE  , EVSC  , GAI   ,
&                   TRWL  , PINT, PTRANS, ATRANS, PCEW ,
&                   PENMAN, CROPF )
```

Table 12.1. Names and description of the formal parameters used in the WUPT subroutine.

<table>
<thead>
<tr>
<th>Code</th>
<th>Type</th>
<th>Description</th>
<th>Unit</th>
<th>Input/output</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITASK</td>
<td>I4</td>
<td>Task that subroutine should perform</td>
<td></td>
<td>I</td>
</tr>
<tr>
<td>IUNITD</td>
<td>I4</td>
<td>Unit that can be used for input files</td>
<td></td>
<td>I</td>
</tr>
<tr>
<td>IUNITL</td>
<td>I4</td>
<td>Unit used for log file</td>
<td></td>
<td>I</td>
</tr>
<tr>
<td>FILEI1</td>
<td>C*</td>
<td>Name of file with plant data</td>
<td></td>
<td>I</td>
</tr>
<tr>
<td>NLXM</td>
<td>I4</td>
<td>no. of layers as declared in calling program</td>
<td></td>
<td>I</td>
</tr>
<tr>
<td>NL</td>
<td>I4</td>
<td>number of layers specified in input file</td>
<td></td>
<td>I</td>
</tr>
<tr>
<td>NLA</td>
<td>I4</td>
<td>Nr of soil comp. from which water can be ext</td>
<td></td>
<td>I</td>
</tr>
<tr>
<td>NLBM</td>
<td>I4</td>
<td>Maximum no of soil comp.</td>
<td></td>
<td>I</td>
</tr>
<tr>
<td>TKL[]</td>
<td>R4</td>
<td>thickness of soil compartments</td>
<td>m</td>
<td>I</td>
</tr>
<tr>
<td>WCLQT[]</td>
<td>R4</td>
<td>volumetric soil water content per layer</td>
<td></td>
<td>I</td>
</tr>
<tr>
<td>WCWPX[]</td>
<td>R4</td>
<td>volumetric water content at wilting point</td>
<td></td>
<td>I</td>
</tr>
<tr>
<td>WCFCX[]</td>
<td>R4</td>
<td>volumetric water content at field capacity</td>
<td></td>
<td>I</td>
</tr>
<tr>
<td>WCSTX[]</td>
<td>R4</td>
<td>volumetric water content at saturation</td>
<td></td>
<td>I</td>
</tr>
<tr>
<td>ATWURT</td>
<td>R4</td>
<td>Total area of water-uptaking roots</td>
<td>m² ha⁻¹</td>
<td>I</td>
</tr>
<tr>
<td>AWURT</td>
<td>R4</td>
<td>Area of water-uptaking roots per layer</td>
<td>m² ha⁻¹</td>
<td>I</td>
</tr>
<tr>
<td>ETRD</td>
<td>R4</td>
<td>Radiation driven part of ETPMD</td>
<td>mm d⁻¹</td>
<td>I</td>
</tr>
<tr>
<td>ETAE</td>
<td>R4</td>
<td>Dryness driven part of ETPMD</td>
<td>mm d⁻¹</td>
<td>I</td>
</tr>
<tr>
<td>EVSC</td>
<td>R4</td>
<td>actual (realized) evaporation rate</td>
<td>mm d⁻¹</td>
<td>I</td>
</tr>
<tr>
<td>GAI</td>
<td>R4</td>
<td>total leaf area index</td>
<td>ha ha⁻¹</td>
<td>I</td>
</tr>
<tr>
<td>ZRT</td>
<td>R4</td>
<td>rooted depth</td>
<td>m</td>
<td>I</td>
</tr>
<tr>
<td>TRWL[]</td>
<td>R4</td>
<td>Actual transpiration rate per layer</td>
<td>mm d⁻¹</td>
<td>O</td>
</tr>
<tr>
<td>PINT</td>
<td>R4</td>
<td>Rain intercepted by the canopy</td>
<td>mm d⁻¹</td>
<td>I</td>
</tr>
<tr>
<td>PTRANS</td>
<td>R4</td>
<td>Potential transpiration rate</td>
<td>mm d⁻¹</td>
<td>O</td>
</tr>
<tr>
<td>ATRANS</td>
<td>R4</td>
<td>Actual transpiration rate</td>
<td>mm d⁻¹</td>
<td>O</td>
</tr>
<tr>
<td>PCEW</td>
<td>R4</td>
<td>Factor that accounts for reduced photosynthesis due to water stress</td>
<td></td>
<td>O</td>
</tr>
<tr>
<td>PENMAN</td>
<td>R4</td>
<td>Penman reference value for potential evapotranspiration</td>
<td>mm d⁻¹</td>
<td>O</td>
</tr>
</tbody>
</table>


### 12.3 Initialisation section

After the declaration of variable names (the model code of this part is not shown), a check on the number of soil layer (NL) is performed. In case this is larger than the maximum number of layers (NLBM), an error message is shown and the program is halted. After this check, the initialisation section (ITASK = 1) starts.

```fortran
IF (NL .GT. NLBM) CALL FATALERR
   & ('CASE2','FE26 - Too many layers in external arrays')
IF (ITASK .EQ. 1) THEN
   * ----------------------
   * Initialization section
   *
   Two variables are read from the plant.dat file: the characteristic transpiration rate (TRANSC) and the water content when water logging occurs. Next, the transpiration rate per soil layer (TRWL(I1)) is "zeroed".
   CALL RDINIT (IUNITD , IUNITL, FILEI1)
   CALL RDSREA ('TRANSC', TRANSC)           ![mm d-1]
   CALL RDSREA ('WCWET', WCWET )           ![cm3 H2O cm-3 soil]
   CLOSE (IUNITD)
   *
   * Transpiration rate per layer is 'zeroed'
   DO 20 I1=1,NL
      TRWL(I1) = 0.                         ![mm d-1]
   20      CONTINUE
```

### 12.4 Rate calculation section

The rate calculation section (ITASK = 2) starts with the calculation of potential transpiration. The potential transpiration rate is determined using the radiation term (ETRD) and the aerodynamic term (ETAE) of the potential evapotranspiration, which were calculated in the evapotranspiration subroutine (SETPMD). The radiation term (ETRD) is multiplied by an exponential factor including GAI (the total leaf area index of shade trees and cacao trees) and a value of 0.5 representing the average extinction coefficient for visible and infrared light. This exponential factor takes into account that in case of an open stand, not all radiation will be intercepted by the crops. The aerodynamic term is multiplied by the minimum value of GAI or 2.0 as the drying power of air is not effective if more than two leaf layers are present. Half of the daily intercepted rain (0.5 * PINT) is subtracted from the potential transpiration, as the direct evaporation of water from the leaf surface reduces the transpiration requirements (as it dissipates excess energy).

```fortran
ELSE IF (ITASK.EQ.2) THEN
   *
   * Rate calculation section
   *
   * Transpiration and water uptake
   *
   Potential transpiration
   PTRANS = MAX(0., (ETRD*(1.-EXP(-0.5*GAI)) + ETAE*MIN(2.0, GAI)
   &                   - 0.5*PINT))            ![mm d-1]
```

Then, the potential water uptake rate per unit fine root area (PRWU) is calculated by dividing the potential transpiration (PTRANS) by the total fine root area (AWURTT). The available water level in
the soil at which the plant can attain potential transpiration (P), depends on the potential transpiration (PTRANS) and the crop characteristic transpiration rate (TRANSC). For shade-grown cacao trees, this rate is rather low.

\[ \text{Potential water uptake rate} \]
\[ \text{PRWU} = \max (0., \frac{\text{PTRANS}}{\text{ATWURT}}) \quad \text{[mm m}^{-2} \text{ root area]} \]

\[ \text{Soil water depletion factor} \]
\[ P = \frac{\text{TRANSC}}{\text{TRANSC} + \text{PTRANS}} \quad \text{[-]} \]

The actual transpiration rate (ATRANS) is calculated next. Its value depends on the water availability in the soil layers (WCLQT) and the rate at which it can be extracted (PRWU). For each soil layer the contribution to the transpiration rate (TRWL(I1)) is calculated, depending on the potential transpiration (PTRANS), the area of roots able to take up water in that layer (AWURT(I1)) and a water uptake reduction factor (WSEL(I1)). This reduction factor is calculated separately for each soil layer in the subroutine SWSE (Soil Water Extraction Subroutine, see Chapter 13). The water uptake reduction factor (WSEL(I1)) is based on the water content of the soil layer and the water depletion factor (P). The transpiration rate per layer (TRWL(I1)) is checked against the water availability (AVAIL). The lowest one is the determining factor. The actual transpiration rate (ATRANS) is the sum of the realised transpiration all soil layers (TRWL(I1)).

\[ \text{Calculate actual transpiration (ATRANS) from} \]
\[ \text{ATRANS} = 0. \quad \text{[mm d}^{-1}] \]
\[ \text{DO 50 I1 = 1, NLA} \]
\[ \text{CALL SWSE (WCLQT(I1), P, WCWET, WCWPX(I1), WCFCX(I1), WCSTX(I1), WSEL(I1))} \]
\[ \text{TRWL(I1) = PRWU * WSEL(I1) * AWURT(I1)} \quad \text{[mm d}^{-1}] \]
\[ \text{AVAIL} = \max (0., (\text{WCLQT(I1)} - \text{WCWPX(I1)}) * \text{TKL(I1)} * 1000.) \quad \text{[mm]} \]
\[ \text{IF (TRWL(I1) .GT. AVAIL) TRWL(I1) = AVAIL} \]
\[ \text{ATRANS = ATRANS + ABS(TRWL(I1))} \quad \text{[mm d}^{-1}] \]
\[ 50 \text{ CONTINUE} \]

In case water availability is not sufficient to cover the demands for transpiration (ATRANS < PTRANS), plants will reduce the transpiration rate by closing the stomata in the leaves. This leads to lower levels of photosynthesis. A relative water availability factor (PCEW) is calculated to account for this growth-reducing effect. PCEW is calculated as the ratio between actual (ATRANS) and potential evapotranspiration (PTRANS).

\[ \text{Calculate water availability factor} \]
\[ \text{IF (PTRANS.GT.0.) THEN} \]
\[ \text{PCEW} = \frac{\text{ATRANS}}{\text{PTRANS}} \quad \text{[-]} \]
\[ \text{ELSE} \]
\[ \text{ATRANS} = 0. \quad \text{[mm d}^{-1}] \]
\[ \text{PCEW} = 1. \]
\[ \text{END IF} \]

Finally, two water-related variables are calculated: the Penman reference evapotranspiration (PENMAN) that is indicative for the crop's water requirements and the ‘crop factor’ (CROPF).

\[ \text{Miscellaneous water related variables} \]
\[ \text{CROPF} = \frac{\text{PTRANS} + \text{EVSC}}{\text{ETRD} + \text{ETAE}} \quad \text{[-]} \]
\[ \text{PENMAN} = \text{ETRD} + \text{ETAE} \quad \text{[mm d}^{-1}] \]

\[ \text{END IF} \]

Finally, program control is handed back to the calling CASE2 subroutine.

\[ \text{RETURN} \]
\[ \text{END} \]
13. The SWSE subroutine

13.1 Purpose

The subroutine SWSE (Soil water extraction) calculates a reduction factor on water uptake (SWE) accounting for the effect of drought in each soil layer. This is not the same as the water availability factor (PCEW) which is equal to the quotient of actual (realised) and potential evapotranspiration. The latter is indicative for the availability of water, the former for the process of water extraction from the soil, which is hampered under low moisture conditions.

13.2 Input and output

This subroutine is included in the SWSE.FOR file. The following input and output variables are used by this subroutine (see Table 13.1 for explanation):

SUBROUTINE SWSE (WCL, P, WCWET, WCWP, WCFC, WCST, WSE)

Table 13.1. Names and description of the formal parameters used in the SWSE subroutine.

<table>
<thead>
<tr>
<th>Code</th>
<th>Type</th>
<th>Description</th>
<th>Unit</th>
<th>Input/output</th>
</tr>
</thead>
<tbody>
<tr>
<td>WCL</td>
<td>R4</td>
<td>Volumetric water content in compartment</td>
<td>cm³/cm³</td>
<td>I</td>
</tr>
<tr>
<td>P</td>
<td>R4</td>
<td>Soil water depletion factor</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>WCWET</td>
<td>R4</td>
<td>Volumetric water content at which water stress starts to affect water uptake</td>
<td>cm³/cm³</td>
<td>I</td>
</tr>
<tr>
<td>WCWP</td>
<td>R4</td>
<td>Volumetric water content at wilting point</td>
<td>cm³/cm³</td>
<td>I</td>
</tr>
<tr>
<td>WCFC</td>
<td>R4</td>
<td>Volumetric water content at field cap</td>
<td>cm³/cm³</td>
<td>I</td>
</tr>
<tr>
<td>WCST</td>
<td>R4</td>
<td>Volumetric water content at saturation</td>
<td>cm³/cm³</td>
<td>I</td>
</tr>
<tr>
<td>WSE</td>
<td>R4</td>
<td>Reduction factor on soil water uptake</td>
<td>-</td>
<td>O</td>
</tr>
</tbody>
</table>

13.3 Source code

First, the critical water content (WCCR) is calculated. It is the soil water content at which the transition from water limited to potential transpiration rate occurs. The calculation is based on the soil water depletion factor (P), and the water content at wilting point (WCWP) and at field capacity (WCFC). An check is performed to verify that the critical water content (WCCR) is lower than the water content at which water logging occurs (WCWET). If this is not the case, an error message is shown and the program is halted.

* Calculation of critical water content, transition point from water-limited to potential transpiration rate
  WCCR = WCWP + (1. - P) * (WCFC - WCWP)

  IF (WCWET.LT.WCCR) CALL FATALERR ('SWSE', 'WCWET < WCCR')

Next, the water stress factor WSE is computed depending on the current water content in each soil layer (WCL) and several characteristic values of the soil water content. First for the situation in which water content (WCL) exceeds the water content at which water logging occurs (WCWET). Then, at water content lower than wilting point (WCWP) or lower than the critical level but not lower than wilting point.

  IF (WCL.GT.WCWET) THEN

```
* Water content larger than optimal
  * growth reduction occurs
  \[ WSE = \frac{WCST-WCL}{WCST-WCWT} \]
ELSE
  IF (WCL.GE.WCCR) THEN
    * Water content is at optimal level
    * no growth reduction
    \[ WSE = 1. \]
  ELSE IF (WCL.LT.WCWP) THEN
    * Water content is below wilting point
    * growth reduction occurs
    \[ WSE = 0. \]
  ELSE IF (WCCR.NE.WCWP) THEN
    * Water content is at suboptimal level
    * growth reduction occurs
    \[ WSE = \frac{WCL-WCWP}{WCCR-WCWP} \]
  END IF
END IF

The water reduction factor (WSE) is limited between 0 and 1.
* Limit reduction between valid range
  \[ WSE = \text{LIMIT} (0., 1., \text{WSE}) \]

RETURN
END
14. The POD subroutine

14.1 Purpose

This subroutine simulates growth and ripening of pods and calculates rates of pod harvest. Pods are contained in age classes (boxcars) with a width of one day. The principles used are described in Section 4.6.

14.2 Input and output

This subroutine is included in the CASE2.FOR file. The following input and output variables are used by this subroutine (see Table 14.1 for explanation):

```
SUBROUTINE POD (ITASK, IUNITD, IUNITL, FILEI1, TERMNL, DELT, TMAV, GPD, WPD, YLDPD, IPOD, BHYLD)
```

Table 14.1. Names and description of the formal parameters used in the POD subroutine.

<table>
<thead>
<tr>
<th>Code</th>
<th>Type</th>
<th>Description</th>
<th>Unit</th>
<th>Input/output</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITASK</td>
<td>I4</td>
<td>Task that subroutine should perform</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>IUNITD</td>
<td>I4</td>
<td>Unit that can be used for input files</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>IUNITL</td>
<td>I4</td>
<td>Unit used for log file</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>FILEI1</td>
<td>C*</td>
<td>Name of first file with plant data</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>TERMNL</td>
<td>L4</td>
<td>Flag to indicate if simulation is to stop</td>
<td>-</td>
<td>I/O</td>
</tr>
<tr>
<td>DELT</td>
<td>R4</td>
<td>Time step of integration</td>
<td>d</td>
<td>I</td>
</tr>
<tr>
<td>TMAV</td>
<td>R4</td>
<td>Daily Average Temperature</td>
<td>°C</td>
<td>I</td>
</tr>
<tr>
<td>GPD</td>
<td>R4</td>
<td>Growth rate of pods</td>
<td>kg DW ha-1 d-1</td>
<td>I</td>
</tr>
<tr>
<td>WPD</td>
<td>R4</td>
<td>Weight of pods</td>
<td>kg DW ha-1</td>
<td>O</td>
</tr>
<tr>
<td>YLDPD</td>
<td>R4</td>
<td>Weight of harvested pods</td>
<td>kg DW ha-1 d-1</td>
<td>O</td>
</tr>
<tr>
<td>IPOD</td>
<td>R4</td>
<td>Number of pod classes</td>
<td>-</td>
<td>O</td>
</tr>
<tr>
<td>BHYLD</td>
<td>R4</td>
<td>Butter hardness of harvested beans</td>
<td>-</td>
<td>O</td>
</tr>
</tbody>
</table>

14.3 Initialisation section

After the declaration of variable names (the model code of this part is not shown), the initialisation section (ITASK = 1) starts.

```
IF (ITASK.EQ.1) THEN

*       Initialization section

Regression parameters related to the relation between development rate and temperature (DEVRR..), data on sink strength of pods (SSTB) and butter hardness regression parameters are read from the plant.dat file.

CALL RDINIT (IUNITD, IUNITL, FILEI1)
CALL RDSREA ('DEVRR1A',DEVRR1A)   ![d-1 degr C -1]
CALL RDSREA ('DEVRR1B',DEVRR1B)   ![d-1]
CALL RDSREA ('DEVRR2A',DEVRR2A)   ![d-1 degr C -1]
CALL RDSREA ('DEVRR2B',DEVRR2B)   ![d-1]
```
CALL RDAREA ('SSTB'  , SSTB  ,  ITABLE, ISSN ) ![-]  
CALL RDSREA ('BHRA'   , BHRA)            ![-]  
CALL RDSREA ('BHRB'   , BHRB)            ![-]  
CLOSE (IUNITD)

The initial number of boxcars (age classes, IPOD) is determined based on two calculations of the development rate (DEVRL and DEVRH). The development rate is calculated as the maximum of zero and a value calculated using a linear regression equation with average daily temperature (TMAV) as independent variable. The first calculated development rate (DEVRL) is valid for temperatures lower than 24.5°C; the other (DEVRH) for higher temperatures. Then, the lowest of the two rates is used and inverted to obtain the duration of the ripening period (IPOD). The INT function is used to convert the value to an integer and 1 is added to round up the value of the ripening period.

* Determine initial number of boxcars

\[
\begin{align*}
\text{DEVRL} &= \max(0., \text{DEVRR1A} \times \text{TMAV} + \text{DEVRR1B}) \\
\text{DEVRH} &= \max(0., \text{DEVRR2A} \times \text{TMAV} + \text{DEVRR2B}) \\
\text{IPOD} &= \text{INT}(1/\min(\text{DEVRL}, \text{DEVRH})) + 1
\end{align*}
\]

Now, the boxcars are initialised. First, the development stage (STAGE) of each of the pod classes (I1) is determined. This is done by dividing the category number (I1) by the total number of categories (IPOD; this is also the total ripening period). Both values are converted to real numbers to obtain a real value for STAGE. The weights (WPOD) and growth rates (GPOD) of each of the pod classes are set to zero. In the IF statement, each of the pod classes is given a certain 'sink strength' (SSPOD). This value determines the strength with which each pod class pulls resources and therefore determines the portion of total pod growth that is captured by a certain pod class. The value of the sink strength (SSPOD) depends on the development stage (STAGE) and the relation between sink strength and development stage which is described in a sink strength table (SSTB) included in the plant.dat file. The LINT function linearly interpolates the sink strength of each pod class based on the development stage. Sink strength values of all pod classes are summed to obtain a total sink strength (TSS). The ELSIF statement ensures that pod classes with a development stage (STAGE) of 1 (this implies that pods are ripe) are given a STAGE value of zero, as these pods have been harvested.

* Initialise stage distributions

\[
\begin{align*}
\text{TSS} &= 0. \\
\text{DO 10 I1 = 1,IPOD} \\
\text{STAGE(I1)} &= \text{REAL(I1)}/\text{REAL(IPOD)} \\
\text{WPOD(I1)} &= 0. \\
\text{GPOD(I1)} &= 0. \\
\text{SSPOD(I1)} &= 0. \\
\text{IF (STAGE(I1).LT.1.) THEN} \\
\text{SSPOD(I1)} &= \text{LINT}(\text{SSTB}, \text{ISSN}, \text{STAGE(I1)}) \\
\text{TSS} &= \text{TSS} + \text{SSPOD(I1)} \\
\text{ELSEIF (STAGE(I1).GE.1.) THEN} \\
\text{STAGE(I1)} &= 0.
\end{align*}
\]

10 CONTINUE

Second, the pod classes (boxcars) are filled with biomass. The dry weight of each of the pod classes (WPOD) is calculated by distributing the total weight of all pods (WPD, this is an input into the subroutine) over all boxcars according to the relative sink strength (SSPOD / TSS; or the sink strength for each class divided by the total sink strength of all classes). The butter hardness value (BH) of all classes is set to 1.6. The development stage (STAGE), pod weight (WPOD) and pod growth rate (GPOD) of class 0 is set to zero. This boxcar does not contain pods.

* Initialise boxcar train with pod weights

\[
\begin{align*}
\text{DO 20 I1 = 1,IPOD} \\
\text{WPOD(I1)} &= \text{WPD} \times \text{SSPOD(I1)}/\text{TSS} \\
\text{BH(I1)} &= 1.6
\end{align*}
\]

20 CONTINUE

STAGE(0) = 0.  ![-]
14.4 Rate calculation section

The rate calculation section (ITASK = 2.) starts with the calculation of the pod development rate (DEVR), based on the current daily average temperature (TMAV). As described in Section 14.3, two development rates are calculated, using different linear regression equations and valid for different temperature ranges (DEVRL for temperatures lower than 24.5°C; DEVRH for higher temperatures).

The final development rate (DEVR) is the minimum of the two values.

```
ELSE IF (ITASK.EQ.2) THEN
*       ------------------------
*       Rate calculation section
*       ------------------------
*       Development rate
DEVRL = MAX(0., DEVRR1A * TMAV + DEVRR1B) ![d-1]
DEVRH = MAX(0., DEVRR2A * TMAV + DEVRR2B) ![d-1]
DEVR  = MIN(DEVRL,DEVRH) ![d-1]
```

Then, the pod growth per unit sink strength (PGRUSS) is calculated as total pod growth (GPD, an input into this subroutine) divided by the total sink strength of all pod classes (TSS).

```
*       Growth per unit sink strength
PGRUSS = GPD/TSS ![kg DW ha-1 d-1]
```

The growth rate of pods per class (GPOD) is calculated as the sink strength of a class (SSPOD) multiplied by the growth per unit sink strength (PGRUSS). If the development stage (STAGE) in a certain class equals zero, pod growth (GPOD) for that class is also zero. The growth rate of all pod classes (GPOD) is summed to obtain the total growth rate (GPODTOT), which is used for checking purposes.

```
*       Growth rate of pods per class
GPODTOT = 0. ![kg DW ha-1 d-1]
DO 30 I1 = 1,IPOD
  IF (SSPOD(I1) .GT. 0.) THEN
    GPOD(I1) = SSPOD(I1)*PGRUSS ![kg DW ha-1 d-1]
  ELSE
    GPOD(I1) = 0. ![kg DW ha-1 d-1]
  ENDIF
  GPODTOT = GPODTOT + GPOD(I1) ![kg DW ha-1 d-1]
30      CONTINUE
```

A check is performed to verify that the summed growth in all classes (GPODTOT) equals the overall pod growth (GPD) which was an input into the subroutine. If this is not the case (CHKGPOD deviates from 1), a warning message is shown and the program is halted, but model output is generated. The warning message is only generated for GPODTOT >10, to prevent warnings due to rounding errors when total pod growth is very low.

```
*       Check whether growth in pod classes equals overall pod growth
*       Warning not for very low values of GPODTOT
CHKGPOD = NOTNUL(GPODTOT)/NOTNUL(GPD)
IF (GPODTOT.GT.10 .AND. (
  ((CHKGPOD.LT.0.99) .OR. (CHKGPOD .GT.1.01)))) THEN
  WRITE (*,*) IYEAR,IDOY
  CALL WARNING ('CASE2 - POD',
    'WA7 - Sum pod class growth not equal to total pod growth')
  TERMNL = .TRUE.
ENDIF
```

The butter hardness (BH) of pods that will be formed during the next day is calculated and stored in class zero (which does not contain pods). This is only done when new pods have been formed (total pod growth (GPD) >0).

```
*       Initialise the first boxcar
```
Yield of pods (YLDPD) is calculated in the following lines. First, the yield value (YLDPD) is set to zero, to avoid accumulation of yield from previous days or runs. Then, the weight of pods that can be harvested is calculated. Pods can only be harvested from pod classes of which the developmental stage (STAGE) is equal or higher than 1. If this is the case, the weight of the harvested pods equals that of the pods in the class (WPOD) plus the biomass growth (GPOD) attained during one time step (DELT). The butter hardness of the beans in the harvested pods (BHYLD) equals the butter hardness of the pod class that was determined when the pod class (boxcar) was initialised. Values for the pod weight (WPOD), developmental stage (STAGE), sink strength (SSPOD) and butter hardness (BH) of the class from which pods are harvested, are all subsequently set to zero. The number of pod classes (IPOD) is decreased by one for each class which is 'emptied' by pod harvest.

```
*       Calculate yield
YLDPD = 0.
DO 40 I1 = IPOD,0,-1
   IF (STAGE(I1).GE.1.) THEN
      YLDPD = YLDPD + WPOD(I1)/DELT +GPOD(I1) !$[kg DW ha-1 d-1]
      BHYLD = BH(I1) ![-]
      WPOD(I1) = 0. ![-]
      STAGE(I1) = 0. ![-]
      SSPOD(I1) = 0. ![-]
      BH(I1) = 0. ![-]
      IPOD = I1 - 1 ![-]
   ENDIF
40      CONTINUE
```

### 14.5 Integration section

In the integration section of the subroutine (ITASK = 3) growth is added to the weight of pods in all pod classes, the developmental stage of the pod classes is updated and pods are moved to the next class (as their age has increased by one day). First, total sink strength (TSS) and summed pod weight (WPODTOT) are set to zero, as the value of both will be updated. Then, the contents (weight, WPOD) and characteristics (developmental stage, STAGE; butter hardness, BH) of each pod class is moved to the next class. At the same time, biomass growth (GPOD) attained during one time step (DELT) is added to the new pod weight (WPOD) and the development rate (DEVR) realised within one time step (DELT) is added to the developmental stage. The sink strength for each of the pod classes (SSPOD) is updated using the new value for developmental stage (STAGE) and the table with sink strength values for different stages (SSTB). New values of total sink strength (TSS) and summed pod weight (WPODTOT) are calculated by summing sink strength (SSPOD) and pod weight (WPOD) values for all pod classes. The number of pod classes is increased by one as all pods are moved forward by one class.

```
ELSE IF (ITASK.EQ.3) THEN
   *       ------------------------
   *       Integration section
   *       ------------------------
   *       Add DW growth, increase stage and move pod classes one boxcar
   TSS    = 0. ![-]
   WPODTOT = 0. ![kg DW ha-1]
   DO 50 I1 = IPOD,0,-1
      WPOD(I1+1) = WPOD(I1) + GPOD(I1) * DELT ![kg DW ha-1]
      STAGE(I1+1) = STAGE(I1)+ DEVR * DELT ![-]
```
A check is performed to verify that the summed pod weight in all classes (WPODTOT) equals the overall pod weight (WPD) which was an input into the subroutine. If this is not the case (CHKWPOD deviates from 1), a warning message is shown and the program is halted, but model output is generated. The warning message is only generated for WPODTOT >10, to prevent warnings due to rounding errors when total pod weight is very low.

```fortran
* Give warning if WPODTOT differs from WPD
* Warning not for very low values of WPODTOT
CHKWPOD = NOTNUL(WPODTOT)/NOTNUL(WPD+GPD*DELT-YLDPD*DELT) ![-]
IF (WPODTOT.GT.10 .AND.
& ((CHKWPOD.LT.0.99) .OR. (CHKWPOD .GT.1.01))) THEN
  WRITE (*,*) IYEAR,IDAY
  CALL WARNING ('CASE2 - POD',
  & 'WAR8 - Sum pod class weight not equal to total pod weight')
  TERMNL = .TRUE.
ENDIF
```

The tasks of the subroutine have been completed and program control is handed back to the calling subroutine.

```fortran
END IF
RETURN
END
```
15. The DRPOT subroutine

15.1 Purpose

The purpose of this subroutine is to set the soil moisture content of all soil layers to field capacity, thus simulating a situation without water limitation. The principles used are described in Section 3.3.

15.2 Input and output

This subroutine is included in the DRPOT.FOR file. The following input and output variables are used by this subroutine (see Table 15.1 for explanation):

```fortran
SUBROUTINE DRPOT (ITASK, NLXM, NL, &
                  TKLX, ZRTMS, WCADX, WCWPX, WCFCX, WCSTX, &
                  WCLQT)
```

Table 15.1. Names and description of the formal parameters used in the DRPOT subroutine.

<table>
<thead>
<tr>
<th>Code</th>
<th>Type</th>
<th>Description</th>
<th>Unit</th>
<th>Input/output</th>
</tr>
</thead>
<tbody>
<tr>
<td>WCADX</td>
<td>R4</td>
<td>volumetric water content at air dry of layer</td>
<td>cm³ H₂O/cm³ soil</td>
<td>I,O</td>
</tr>
<tr>
<td>WCFCX</td>
<td>R4</td>
<td>volumetric water content at field capacity of layer</td>
<td>cm³ H₂O/cm³ soil</td>
<td>I,O</td>
</tr>
<tr>
<td>WCLQT</td>
<td>R4</td>
<td>volumetric soil moisture content of layer</td>
<td>cm³ H₂O/cm³ soil</td>
<td>O</td>
</tr>
<tr>
<td>WCWPX</td>
<td>R4</td>
<td>volumetric water content at wilting point of layer</td>
<td>cm³ H₂O/cm³ soil</td>
<td>I,O</td>
</tr>
<tr>
<td>WCSTX</td>
<td>R4</td>
<td>volumetric soil moisture content of layer at saturation</td>
<td>cm³ H₂O/cm³ soil</td>
<td>I,O</td>
</tr>
<tr>
<td>NLXM</td>
<td>I4</td>
<td>no. of layers as declared in calling program</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>NL</td>
<td>I4</td>
<td>number of layers specified in input file</td>
<td>-</td>
<td>O</td>
</tr>
<tr>
<td>TKLX</td>
<td>R4</td>
<td>thickness of soil compartments</td>
<td>m</td>
<td>I</td>
</tr>
<tr>
<td>ITASK</td>
<td>I4</td>
<td>Task that subroutine should perform</td>
<td>-</td>
<td>I</td>
</tr>
<tr>
<td>ZRTMS</td>
<td>R4</td>
<td>Maximum rooting depth as soil characteristic</td>
<td>m</td>
<td>O</td>
</tr>
</tbody>
</table>

15.3 Source code

Following the declarations of variables used, the water content in the soil (WCLQT) is set to field capacity (optimal water content). This is carried out in the initialisation section only (ITASK=1). In the rate calculation and integration section, no changes are made in the water content: each time DRPOT is called, the water content at field capacity is returned to the calling subroutine. Water content of air dry soil (WCADX), at wilting point (WCWPX), at field capacity (WCFCX) and at saturation (WCSTX) are also set. Only 1 soil layer is used (NL=1), with a depth of 10 m (TKLX). The ZRTMS (maximum rooting depth) variable is not used. The X is added to the variable names for water content to avoid changes in their values: the values of these variables should be kept fixed to simulate potential production (without water limitation).

```fortran
IF (ITASK.EQ.1) THEN
    NL = 1
    DO 10 IL=1,NL
        TKLX(IL) = 10.
        WCADX(IL) = 0.1
        WCWPX(IL) = 0.12
        WCFCX(IL) = 0.30
        WCSTX(IL) = 0.40
        WCLQT(IL) = WCFCX(IL)
    CONTINUE
```
ZRTMS = 10.
END IF
RETURN
END
16. Adapations to the DRSAHE subroutine

16.1 General

The purpose of this subroutine is to calculate the infiltration of rainfall in the soil, the water transport among soil layers and the water content in each soil layer. The principles used are described in Section 3.3.

This subroutine is included in the DRSAHE. FOR file. Version 1.4 of DRSAHE.FOR (version 1.1 is documented in Van Kraalingen 1994) was the basis for the adapted version used in the CASE2 model.

16.2 Adaptations

The adaptations are related to the retrieval of information from the soil.dat file. The following adaptations were made (by Pieter Zuidema).

Declaration for new variables string name (STRING) and significant length of a string (SIGLEN):

* Local variables
  * REAL RAINCU, RNOFCU, RNOFF, INF, WEFF
  * Variables used to read soil.dat file
    CHARACTER STRING*80
    INTEGER   SIGLEN

In the initialisation section, the soil.dat input file is opened:

* ------------------------
* Initialization section
* ------------------------

Read input file
CALL RDINIT (IUNIT, IUNLOG, FILIN)

The number of soil layers (NL) of the soil type (SOILTYPE) specified in basic.dat is read. The string NL is first extended with a number indicating the specified soil type, e.g. NL1 if SOILTYPE equals 1. This is done using the LEN_TRIM command to determine the significant length of the string and the TTUTIL function ADDINT to add an integer to the string. Then, the value of NL* is read from soil.dat (using the TTUTIL function RDSINT). An error message is returned in case the number of soil layers equals zero.

* read number of layers and thickness for one of the
  * 3 standard Driessen soils specified or 5 user-defined
  * soil types in soil.dat. (Added PAZ, 1-2002)
  * read number of soil layers
  * STRING = 'NL'
  * SIGLEN = LEN_TRIM(STRING)
  * CALL ADDINT(STRING,SIGLEN,SOILTYPE)
  * CALL RDSINT (STRING, NL)
  * IF (NL.EQ.0) CALL FATALERR
    & ('DRSAHE', 'No information for this SOILTYPE in soil.dat')

Next the thickness of each of the soil layers is read from soil.dat. The string TKL is first extended with a number indicating the specified soil type, e.g. TKL1 if SOILTYPE equals 1. Then, the values in the array TKL* variable are read from soil.dat (using the TTUTIL function RDFREA).

* read number of thickness of soil layers
  * STRING = 'TKL'
  * SIGLEN = LEN_TRIM(STRING)
  * CALL ADDINT(STRING,SIGLEN,SOILTYPE)
CALL RDFREA (STRING, TKL, NLLM, NL)

Error messages are returned in case the number of soil layers is larger than NLLM (this equals 10) or is smaller than NLXM.

IF (NL.GT.NLLM) CALL FATALERR
   & ('DRSAHE','too many layers defined in data file')
IF (NLXM.LT.NL) CALL FATALERR
   & ('DRSAHE','too few layers in external arrays')

Next, the evaporation proportionality factor and the values of two switches for the water balance type are read from soil.dat.

*        Read evaporation proportionality factor and switches
*        Note: for CASE2 2.2, the standard values for SWIT8 = 1
*        and for SWIT9 = 2 (Driessen type soil).
CALL RDSREA ('EES', EES)
CALL RDSINT ('SWIT9', SWIT9)
CALL RDSINT ('SWIT8', SWIT8)

Some lines below in the initialisation section, the physical properties of the soil layers (TYL) are read from the soil.dat file. Again, the string TYL is first extended with a number indicating the soil type specified in basic.dat, e.g. TYL1 if SOILTYPE equals 1. Then, the values in the array TYL* variable are read from soil.dat.

ELSE IF (SWIT9.EQ.2) THEN

*        Physical properties from soil type number
*        Read soil type numbers depending on the value of SOILTYPE
*        (Added PAZ 1-2002)
*        read texture type of soil layers
STRING = 'TYL'
SIGLEN = LEN_TRIM(STRING)
CALL ADDINT(STRING, SIGLEN, SOILTYPE)
CALL RDFREA (STRING, TYL, NLLM, NL)

*        CALL RDFREA ('TYL', TYL, NLLM, NL)
Chapter 17. The SETPMD subroutine

17. Adaptations to the SETPMD subroutine

17.1 General

This subroutine is included in the SETPMD.FOR file. Version 1.1 of SETPMD.FOR (documented in Van Kraalingen & Stol 1997) was the basis for the adapted version used in the CASE2 model.

The purpose of this subroutine is to calculate the potential evapotranspiration for cacao. The principles used are described in Section 3.2.

17.2 Adaptations

The following adaptations have been made to adjust the model for the simulation of evapotranspiration in tree crops (by Liesje Mommer, see Mommer 1999). Adaptations are in bold.

Declarations for new variables:

```
REAL DUMR1,DUMR2,DUMR3,DUMR4,DUMR5,DUMR6,DUMR7
REAL RCAN, RLEAF, RAE
LOGICAL EQUIL
```

Parameter values for leaf resistance (RLEAF) and aerodynamic resistance (RAE), both taken from Radersma & de Ridder (1996):

```
PARAMETER (LHVAP = 2454.E3, PSCH = 0.067, SIGMA = 5.668E-8)
PARAMETER (RHOCP = 1240., RBGL = 8.31436)
PARAMETER (RLEAF = 150., RAE = 38.)
SAVE
```

The warning message for low wind speed is not returned anymore, as wind speed is not used:

```
* IF (WN.LT.0.2) WRITE (*,'(1X,A,G12.5,A)')
* & 'WARNING from SETPMD: Low wind speed =',WN,' m/s'
```

The regression parameters for the Angstrom formula (ANGA and ANGB) equal zero in the data and weather files of CASE2: the Swinbank formula is thus used.

The wind function is not used (* added at first position). The variable ISURF (type of surface used for the wind function) therefore not used.

```
* IF (ISURF.EQ.1.OR.ISURF.EQ.2) THEN
    ... 
* EA = VPD*FU2
```

A line on the canopy resistance (RCAN) is added and the calculations of the radiation (ETRD) and aerodynamic (ETAE) part of the evapotranspiration are changed. Canopy resistance (RCAN) is calculated as one third of the leaf resistance (RLEAF) for cacao (its value is specified at the beginning of the subroutine). The calculations of ETRD and ETAE are different due to the inclusion of canopy resistance (RCAN) and aerodynamic resistance (RAE). The lines on RE and DT calculations are not used (* added at first position).

```
RCAN = RLEAF/3
ETRD = (VPSL*RDN)/(LHVAP*(VPSL + PSCH*(1+RCAN/RAE)))
ETAE = ((RHOCP*VPD)/RAE)/(LHVAP*(VPSL + PSCH*(1+RCAN/RAE)))
ETD  = ETRD+ETAE
* RE   = 86400.*1000.*0.018016/(FU2*RBGL*(TMDA+273.16))
* DT   = RE*((RDN-LHVAP*ETD)/86400.)/RHOCP
```

The “iteration on surface temperature” part is not used (* added at first position).

```
* IF (TMDI.GT.0.) THEN
    ...
```
*         GOTO 10
*      END IF
*      END IF
Part III  Data and weather files

Note: Most of the data included in the four data files used by CASE2 mostly are briefly explained in the data files. The explanation given in the following chapters is therefore limited. A short description of each of the parameters included in the data files is provided in the Appendix.
18.

Data files

18.1 Basic.dat

18.1.1 Purpose and usage

The basic.dat file contains the basic data for CASE2 which can be changed to configure the model. In basic.dat the location, duration of the simulation, soil type, type of output, production level and cropping system are specified.

18.1.2 File listing

The complete listing of the basic.dat file is printed below. Further explanation on changing values in this file can be found in the User's Manual (Zuidema & Leffelaar 2002).

************************************************************************
* File name: BASIC.DAT                                                  *
*                                                                      *
* Use      : With CASE2 (Cacao Simulation Engine), version 2.2           *
* Author(s): Pieter Zuidema                                            *
* Date      : January 2002                                              *
* Purpose   : Contains values of input parameters that can be changed.  *
*             For instance, location, and planting density              *
************************************************************************

!======================================================================!

!                                                                      !
! PART A. Specify information on location, simulation duration,        !
!         soil type, production level and output frequency here.        !
!                                                                      !
!======================================================================!

!---------------------------------
! Location                        !
!---------------------------------

* Specify location number
* Possible values:
* 1-50 for daily or monthly weather data (1-18 are included with program)
* >50  for long-term weather data (51-69 are included with program)
* For location numbers see the table at the end of this file or in the Manual.
* LOCATION = 15

!---------------------------------

! Start and duration of simulation!
!---------------------------------

* Specify the start year of the simulation (IYEAR) and the number of
* years for which simulations should be carried out.
* Possible values for IYEAR:
* for daily/monthly weather data:
*   Years for which weather data are available. Check the availability
*   of weather data for the location in Table 5.1 in the User's or the
*   table at the end of this file.
* for long-term weather data:
*   enter the value 1000
*
*Possible values for NRYEARS:
* for daily/monthly weather data:
* This depends on the period of years for which weather data are
* available. Check this in Table 5.1 in the User's or the table at
* the end of this file.
* for long-term weather data:
* any period of years
  
  IYEAR = 1983
  NRYEARS = 11              ! [y]

!----------------------------------!
! Output frequency                !
!----------------------------------!

* Specify the frequency at which output is generated in table and graph format.
* Choose 1 for annual output; 2 for output every 10 days
* and 3 for daily output
  
  OUTPUTFQ = 1

!----------------------------------!
! Soil type                       !
!----------------------------------!

* Specify the soil type.
* Possible values: 1-3 for soil types included with the program
* (1=Loamy soil, 2=Sandy soil, 3=Clayey soil); >3 for user-defined soils
  
  SOILTYPE = 1

!----------------------------------!
! Potential or water-limited      !
!----------------------------------!

* Specify whether simulations should be carried out for a potential or water-
* limited
* situation.
* Possible values: 1=Potential; 2=Water-limited
  
  PRODLEVL = 2

!======================================================================!
!                                                                      !
! PART B. Specify cropping system characteristics here                 !
! (planting density, cacao tree age and shade tree information)!       !
!======================================================================!

!----------------------------------!
! Cropping system                 !
!----------------------------------!

* Specify density at which cacao trees are planted in trees per ha.
* Possible values: 700.-2500. Note that number should be followed
* by a period sign (e.g. "1000.").
  
  NPL = 1000.             ! [trees ha-1]

* Specify leaf area index (LAI) of shade trees in ha leaf per ha ground.
* Possible values: 0.-3. Note that number should include
* a period sign (e.g. "1." or "0.2").
  
  SLAI = 0.2                ! [ha leaf ha-1 ground]

* Specify extinction coefficient for shade trees.
* Possible values: 0.4 - 0.8.
  
  SKDFL = 0.6                ! [-]

* Specify height of the shade tree canopy in m. SHGHL for height of lower
* canopy boundary; SHGHT for height of upper canopy boundary
* Possible values: 0.-40. Note that number should include
* a period sign (e.g. "5." or "7.5").
* Note that SHGHL should be less than SHGHT
  
  SHGHL = 4.0               ! [m] Lower height of shade tree crowns
  SHGHT = 10.               ! [m] Upper height of shade tree crowns
! Cacao tree !
!---------------------------------!

* Specify height of the cacao tree in m: HGHL for height of lower canopy boundary; HGHT for height of upper canopy boundary
* Possible values: 0.-20. Note that number should include a period sign (e.g. "1." or "2.5").
* Note that HGHL should be less than HGHT
HGHL = 0.75        ![m]
HGHT = 3.50        ![m]

* Specify whether tree size or age is used for initial input
* Both plant size (biomass) and plant age can be used as input.
* The switch parameter SWINPUT determines which of the two is used.
* Possible values: 1-age is used as input; 2-size is used as input.
SWINPUT = 1                ![-]

* Specify initial tree age in years.
* Note: this value is only used in case SWINPUT = 1
* Possible values: 3. - 40. Note that number should include a period sign (e.g. "5." or "12.5").
AGEIYR = 4.11             ![y]

* Specify initial tree size (biomass per tree).
* Note: this value is only used in case SWINPUT = 2
* Possible values: 18.5 - 70.0. Note that number should include a period sign (e.g. "20." or "22.5").
WTOTI = 18.5            ![kg DW tree-1]; NOTE: Minimum size=18.5 kg

! Pod characteristics and processing !
!------------------------------------!

* Specify the fat content of nibs
* The standard value is 0.55 (Wood and Lass 1985)
FATCONTENT = 0.55                         ![-]

* Specify the fraction of beans per pod
* The standard value is 0.55
FBEANS = 0.55                             ![-]

* Specify the pod index or pod value
* This is the number of pods needed for one kg of dry beans
* The standard value is 30.
PODVALUE = 30.                   ![kg-1 DW]

* Specify the fermentation duration in hours.
* The standard value is 5.(Humphries, 1944)
FMTDUR = 5.                        ![d]

* Specify the moisture content of the beans
* The standard value is 0.075 (Wood & Lass 1985)
MOISTC = 0.075                   ![[-]

!======================================================================!
! TABLE WITH LOCATION NUMBERS AND PERIODS WITH AVAILABLE WEATHER DATA  !
!======================================================================!

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>Country</th>
<th>Site</th>
<th>Start Yr</th>
<th>End Yr</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Brazil</td>
<td>Maceio (Alagoas)</td>
<td>1961</td>
<td>1969</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>Costa Rica</td>
<td>El Carmen</td>
<td>1974</td>
<td>1991</td>
<td>18</td>
</tr>
<tr>
<td>3</td>
<td>Costa Rica</td>
<td>La Lola</td>
<td>1973</td>
<td>1990</td>
<td>18</td>
</tr>
<tr>
<td>4</td>
<td>Costa Rica</td>
<td>La Mola</td>
<td>1980</td>
<td>1989</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>Costa Rica</td>
<td>Puerto Limon</td>
<td>1970</td>
<td>1990</td>
<td>21</td>
</tr>
<tr>
<td>7</td>
<td>Indonesia</td>
<td>Bah Lias</td>
<td>1979</td>
<td>1993</td>
<td>15</td>
</tr>
<tr>
<td>8</td>
<td>Ivory Coast</td>
<td>Abidjan</td>
<td>1987</td>
<td>1996</td>
<td>10</td>
</tr>
</tbody>
</table>
18.2 Control.dat

18.2.1 Purpose and usage

The control.dat file contains the file names that are used during the execution of an FSE model.

18.2.2 File listing

The complete listing of the control.dat file is printed below. Further information on the use of this file can be found in the documentation on the FSE system (van Kraalingen 1995).
18.3 Plant.dat

18.3.1 Purpose and usage

The plant.dat file contains plant characteristics of cacao trees, as used by CASE2. The data in this file should not be changed without having a thorough understanding of the model. Changes in the data may cause the model to run not properly and generate errors.

18.3.2 File listing

The complete listing of the plant.dat file is printed below.

AVGLAGE and MINLVAGE refer to leaf ages as shown in Figure 4.10; see explanation in Section 4.4.2.

The regression for which the parameters are listed below is shown in Figure 4.12.

AVGLAGE = 210. ! [d] maximum
MINLVAGE = 90. ! [d] minimum

Specific leaf area (SLA) versus size. Based on regression of data Thong & Ng (1978)
Regression parameters for linear regression: y = ax + b (a=SLAR1A, b=SLAR1B, x=WTOTPP, y=SLA)
SLAR1A=0.00000732 ! [ha leaf kg-1 leaf DW kg-1 plant DW]
The regression for which the parameters are listed below is shown in Figure 4.12.

- Relative value of the Specific leaf area (SLA) versus relative light availability for cacao trees.
- Based on regression of data Guers (1971)
- Regression parameters for logarithmic regression: \( y = a \cdot \ln(x) + b \) (\( a = \text{SLAR2A} \), \( b = \text{SLAR2B} \), \( x = \text{TRMIS} \))
- (transmission of light below shade canopy), \( y \)-modifier for SLA value

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLAR1B</td>
<td>0.000898</td>
<td>ha leaf kg(^{-1}) leaf DW</td>
</tr>
<tr>
<td>SLAR2A</td>
<td>-1.772</td>
<td>[-]</td>
</tr>
<tr>
<td>SLAR2B</td>
<td>0.9651</td>
<td>[-]</td>
</tr>
</tbody>
</table>

***************

- Wood

Wood loss relative to that of leaves. (Ling 1986)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>WDLVDR</td>
<td>0.077</td>
<td>kg dead wood kg(^{-1}) dead leaves</td>
</tr>
</tbody>
</table>

- Heartwood formation (Comparable with other tree species; Hillis 1987)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>HRTWDAGE</td>
<td>3650.</td>
</tr>
</tbody>
</table>

***************

- Roots

The regression model on which the values are based is shown in Figure 4.13.

- Vertical distribution of water uptaking roots
- Based on fit of DW / vol of fine roots vs. depth
- Data sources: Kummerow 1981 and 1982 combined and expressed per volume

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>VDWURTRA1</td>
<td>-1.06</td>
</tr>
<tr>
<td>VDWURTRB</td>
<td>199.9</td>
</tr>
</tbody>
</table>

The weight fraction of lateral roots that is fine roots which are able to take up water.

- Fraction roots of fine roots able to take up water (Kummerow, 1981)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>FWURT</td>
<td>0.2</td>
<td>[-]</td>
</tr>
</tbody>
</table>

- Turnover rate of water-uptaking roots (< 2 mm diameter). (Muñoz & de Beer 2001)
- All fine roots are estimated to be replaced once per year.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTOWURT</td>
<td>0.00274</td>
</tr>
</tbody>
</table>

- Mean diameter (m) and specific root length (m kg\(^{-1}\)) of the two root classes able to take up water (Kummerow, 1981)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIAM1</td>
<td>0.00022</td>
</tr>
<tr>
<td>DIAM2</td>
<td>0.0015</td>
</tr>
<tr>
<td>SRTL1</td>
<td>36000.</td>
</tr>
<tr>
<td>SRTL2</td>
<td>3000.</td>
</tr>
</tbody>
</table>

- Adding 10\% to average value of 550 gives around 600.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW</td>
<td>600.</td>
<td>kg m(^{-3})</td>
</tr>
</tbody>
</table>

- Loss of non-water uptaking lateral roots relative to that of water uptaking roots. (No source - estimated guess)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>LRTWURTDR</td>
<td>0.10</td>
<td>kg dead lateral roots kg(^{-1}) dead water-uptaking roots</td>
</tr>
</tbody>
</table>

***************

- Pods

Pods minimal dry weight for production of pods [kg DW]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>WTOTMIN</td>
<td>10.</td>
</tr>
</tbody>
</table>

The graph including the data mentioned below is shown in Figure 4.16.

- Sink strength for pod growth, based on Hadley et al. (1994)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSTB</td>
<td>0.0, 0.0, 0.300, 0.05, 0.467, 0.17, 0.533, 0.41, 0.633, 0.94, 0.667, 1.0, 0.778, 0.94, 0.867, 0.17, 1.0, 0.0, 1.1, 0.0</td>
</tr>
</tbody>
</table>

The values are derived in Table 4.2.
* Butter hardness regression coefficients (Berbert 1976 in Wood & Lass 1986)
  \[ y = a \times x + b \ (a = BH_{A}; \ b = BH_{B}); \ y = BH \ [-]; \ x = temp \ [\text{degr C}] \]
  \[ BH_{RA} = 0.10 \]  ![degr C -1]
  \[ BH_{RB} = -1.01 \]  ![-]

The regression model on which the values are based is shown Figure 4.18.

* Fermentation parameters (Humphries, 1944)
  \[ FMTA = -0.015 \]  ![d-1]
  \[ FMTB = 0.96 \]  ![-]

The regression model on which the values are based is shown Figure 4.15.

* Pod development rate parameters, depending on temperature (Hadley et al 1994)
  \[ y = a \times x + b \ (a = DEVRR1A or DEVRR2A; b = DEVRR1B or DEVRR2B); \ y = DEVR \ [d-1]; \ x = temp \ [\text{degr C}] \]
  * Regression set 1 is for temperatures lower than 24.5 degr C
    \[ DEVRR1A = 3.600E-4 \]  ![d-1 degr C -1]
    \[ DEVRR1B = -0.00226 \]  ![d-1]
    \[ DEVRR2A = 2.048E-4 \]  ![d-1 degr C -1]
    \[ DEVRR2B = 0.00154 \]  ![d-1]

* NPK content of beans (average from Wood & Lass 1986; based on Boyer 1973, Thong & Ng 1978, Omotoso 1975)
  * Note that these values are for BEANS and not for BEANS+HUSKS.
  \[ NCONTBN = 0.021 \]  ![kg N kg-1 bean DW]
  \[ PCONTBN = 0.0040 \]  ![kg P kg-1 bean DW]
  \[ KCONTBN = 0.0095 \]  ![kg K kg-1 bean DW]

More estimations of the maximum photosynthesis rate are given in Figure 4.1.

* Photosynthesis parameters
  AMX = 16.0  ![kg CO2 ha-1 leaf h-1] (Miyaji et al 1997)
  EFF = 0.45  ![CO2 ha-1 h-1)/(J m-2 s-1)] = 12.5 microgram CO2/J
  AMINIT = 0.91  ![Correction factor for Amax due to low Amax values for young leaves (Miyaji et al. 1997)]
  AMTMPT = 0.,0., 30.,1., 33.,1., 40.,0.  ![influence of temperature]
  MAXLAI = 10.  ![m2 leaves m-2 ground] this is the maximum LAI that is
  * ! used in the photosynthesis modules. Larger values give
  * ! computational errors as in that case light availability*
  * ! in large part of the canopy is very low.

The below text should read: " Light extinction coefficients for cacao trees (Boyer 1971, Alvim 1977, Wills & Yegappan 1981, Yapp & Hadley 1994)".

* Light absorption parameters (### SOURCE ###)
  KDFL = 0.60  ![leaves]
  KDFT = 0.50  ![trunk]

Maintenance

* Maintenance respiration parameters
  Q10 = 2.  ![q10]
  TREF = 25.  ![degr C] reference temperature

The basis for the below values is in Table 4.1

* Maintenance coefficients
  MAINLV = 0.0069  ![kg CH2O kg-1 DW d-1] leaves
  MAINWD = 0.0024  ![kg CH2O kg-1 DW d-1] wood
  MAINLRT = 0.0047  ![kg CH2O kg-1 DW d-1] lateral roots
  MAINTRT = 0.0024  ![kg CH2O kg-1 DW d-1] taproot
  MAINPD = 0.016  ![kg CH2O kg-1 DW d-1] pods
These values are derived in Table 4.2.

**Growth respiration parameters**
- ASRQLRT = 1.49415 \([\text{kg CH}_2\text{O kg}^{-1} \text{DW d}^{-1}]\) lateral roots
- ASRQTRT = 1.56871 \([\text{kg CH}_2\text{O kg}^{-1} \text{DW d}^{-1}]\) taproot
- ASRQWD = 1.56871 \([\text{kg CH}_2\text{O kg}^{-1} \text{DW d}^{-1}]\) wood
- ASRQLV = 1.65600 \([\text{kg CH}_2\text{O kg}^{-1} \text{DW d}^{-1}]\) leaves

These values are derived in Table 4.2.

**Carbon content plant components**
- CFLRT = 0.50080 \([\text{kg C kg}^{-1} \text{DW d}^{-1}]\) lateral roots
- CFTRT = 0.51996 \([\text{kg C kg}^{-1} \text{DW d}^{-1}]\) taproot
- CFWD = 0.51996 \([\text{kg C kg}^{-1} \text{DW d}^{-1}]\) wood
- CFLV = 0.46737 \([\text{kg C kg}^{-1} \text{DW d}^{-1}]\) leaves

These values are depicted in Figure 4.8.

**Table of assimilate requirements of pods as a function on fat content**
- ASRQPDTB = 0.50, 1.72479, 0.55, 1.75554, 0.60, 1.78599 \([\text{kg CH}_2\text{O kg}^{-1} \text{DW d}^{-1}]\)

**Table of C-content of pods as a function on fat content**
- CFPDTB = 0.50, 0.50370, 0.55, 0.50895, 0.60, 0.51413 \([\text{kg C kg}^{-1} \text{DW d}^{-1}]\)

These values are derived from the regression models in Figure 4.7.

**Biomass partitioning parameters**
- FTRTRA = 0.039 \([\text{kg DW taproot kg}^{-1} \text{DW whole plant}]\)
- FLRTRA = 0.11 \([\text{kg DW lateral roots kg}^{-1} \text{DW whole plant}]\)
- FLVRA = 0.14 \([\text{kg DW leaf kg}^{-1} \text{DW whole plant}]\)
- FWDRRA = 0.62 \([\text{kg DW wood kg}^{-1} \text{DW whole plant}]\)
- FPDRA = 0.026 \([\text{kg DW pod kg}^{-1} \text{DW whole plant}]\)
- FTRTRB = 0.36 \([\text{kg DW taproot}]\)
- FLRTRB = 0.67 \([\text{kg DW lateral root}]\)
- FLVRB = 0.43 \([\text{kg DW leaves}]\)
- FWRDB = -0.7 \([\text{kg DW wood}]\)
- FPDFR = 0.5 \([\text{kg DW pod}]\)

**Miscellaneous parameters**
- MINCON = 0.07 \([\text{kg CH}_2\text{O kg}^{-1} \text{DW}]\)
- TAU = 5 \([\text{d}]\)

These regression values are based on the regression model in Figure 4.6.

- AGBIORA = 8.4648 \([\text{kg DW d}^{-1}]\)
- AGBIORB = 40.54 \([\text{kg DW}]\)
Chapter 18. Data files

The regression line is shown in Figure 3.2.

* Regression parameters for the through fall of rain through the cacao canopy.
  Based on Boyer (1970)
  \[ TFLA = 0.927; \quad TFLB = -0.789 \]
* Stem flow is currently not considered as no good estimates are available
  \[ STFLA = 0.0; \quad STFLB = 0.0 \]
* Characteristic potential transpiration for cacao
  \[ TRANSC = 1.5 \quad !\text{[mm day}^{-1}\text{]} \]
* Volumetric water content at which water logging occurs
  \[ WCWET = 0.50 \quad !\text{[cm}^{3}\text{ cm}^{-3}\text{]} \]

18.4 Reruns.dat

18.4.1 Purpose and usage

The reruns.dat file specifies whether the model should be run several times in a row with different values for certain parameters. The values of parameters that are to be changed between reruns are specified in reruns.dat. For instructions on using reruns with the CASE2 model, see the User's manual (Zuidema & Leffelaar 2002b). For general background information on reruns within the FSE system, see Van Kraalingen (1995).

18.4.2 Explanation of parameters

The complete listing of the reruns.dat file is printed below. This file already contains some examples of possible reruns for different parameters. New lines can be added, following the instructions in the User's Manual of CASE2 (Zuidema & Leffelaar 2002b) or the FSE documentation (Van Kraalingen 1995). Existing lines can be inactivated by putting a “*” at the start of the line. If the reruns file is empty (or all lines start with “*”), the model will execute one single run, using the data from the standard data files. If reruns are specified, the total number of runs made by the model is always one more than the number of rerun sets (or lines which do not start with “*”) in reruns.dat.

************************************************************************
* File name: RERUNS.DAT                                                *
*                                                                      *
* Use      : With CASE2 (Cacao Simulation Engine), version 2.2         *
* Purpose  : Contains values of input parameters that can be changed.  *
*            For instance, location, and planting density              *
************************************************************************

!======================================================================!
!                                                                      !
! PART A. EXAMPLE RERUNS                                               !
!         To use one of the example reruns, simply remove the "*"-sign !
!         at the start of the line. Do not forget to place an "*" again! 
!         when you do not wish to do reruns for that parameter.        !
!======================================================================!

!---------------------------------!
! Production level                !
!---------------------------------!
*When removing the "*" in the below line, an extra run will be performed
*for PRODLEVEL = 1 (potential production).
18.5 Soil.dat

18.5.1 Purpose and usage

The soil.dat file specifies the soil characteristics used in CASE2. In part A of the file, three example soils are included and new soils can be added. For instructions on adding new soil types in soil.dat, see the User's Manual (Zuidema & Leffelaar 2002b).

Part B of the file contains information that can only be changed by skilled users. Some explanation on the parameters specified in this part is provided below with the listing.

18.5.2 Explanation of parameters

Below the complete listing of part A is printed.

```
*PRODLEVL = 1

!----------------------------------------------------------!
! Soil type                                              !
!----------------------------------------------------------!
*When removing the * in the below lines, 2 extra runs will be performed  
*for SOILTYPE = 2 and 3 (sandy and clayey soils).          
* SOILTYPE = 2                                           
* SOILTYPE = 3                                           
!----------------------------------------------------------!

! Shade level                                           !
!----------------------------------------------------------!
*When removing the * in the below lines, 7 extra runs will be performed  
*for LAI of the shade tree SLAI = 0 ... 3 (no shading to heavy shading).  
*SLAI = 0.                                              
*SLAI = 0.5                                             
*SLAI = 1.                                              
*SLAI = 1.5                                             
*SLAI = 2.                                              
*SLAI = 2.5                                             
*SLAI = 3.                                              

!----------------------------------------------------------!

! PART B. USER-DEFINED RERUNS                            !
! To add a user-defined rerun, simply write one line of the  !
! type:     <PARNAME> = <VALUE>                          !
! in which <PARNAME> is the name of an input parameter and !
! <VALUE> is the value for which a rerun is wanted.        !
! To de-select the rerun, simply put an "*" mark in front of !
! the line. More instructions in the User's manual        !
!----------------------------------------------------------!
```
!---------------------------------------------------------------------!
! PART A. Information may be added to this part of the file.          !
! Please follow the instructions in the User's Manual               !
!---------------------------------------------------------------------!

! Soil type specifications !
!---------------------------------------------------------------------!

* Soil type 1
* Loamy soil with 4 layers, soil characteristics from Wessel (1971)
* Nigeria
NL1   = 4               ! Number of layers
TKL1  = 0.10, 0.30, 0.30, 1.50   ! Thickness of layers (m)
TYL1  = 12., 9., 8., 8.               ! Driessen texture classes for layers
! See table in User's Manual or below

* Soil type 2
* Sandy soil taken from Wood & Lass (1985), Table 3.8
* Brazil, Rondonia
NL2   = 4               ! Number of layers
TKL2  = 0.09, 0.14, 0.12, 1.19   ! Thickness of layers (m)
TYL2  = 1., 7., 9., 14.               ! Driessen texture classes for layers
! See table in User's Manual or below

* Soil type 3
* Clayey soil taken from Wood & Lass (1985), Table 3.17
* Malaysia, Tawau
NL3   = 4               ! Number of layers
TKL3  = 0.02, 0.54, 0.48, 0.52   ! Thickness of layers (m)
TYL3  = 12., 17., 19., 19.               ! Driessen texture classes for layers
! See table in User's Manual or below

* Soil type 4
* < specify type of soil and information source here >
* < specify country and area here >
NL4   = 0               ! Number of layers
TKL4  = 0., 0., 0., 0.               ! Thickness of layers (m)
TYL4  = 0., 0., 0., 0.               ! Driessen texture classes for layers
! See table in User's Manual or below

* Soil type 5
* < specify type of soil and information source here >
* < specify country and area here >
NL5   = 0               ! Number of layers
TKL5  = 0., 0., 0., 0.               ! Thickness of layers (m)
TYL5  = 0., 0., 0., 0.               ! Driessen texture classes for layers
! See table in User's Manual or below

* Soil type 6
* < specify type of soil and information source here >
* < specify country and area here >
NL6   = 0               ! Number of layers
TKL6  = 0., 0., 0., 0.               ! Thickness of layers (m)
TYL6  = 0., 0., 0., 0.               ! Driessen texture classes for layers

* Soil type 7
* < specify type of soil and information source here >
* < specify country and area here >
NL7   = 0               ! Number of layers
TKL7  = 0., 0., 0., 0.               ! Thickness of layers (m)
TYL7  = 0., 0., 0., 0.               ! Driessen texture classes for layers

* Soil type 8
* < specify type of soil and information source here >
* < specify country and area here >
NL8   = 0               ! Number of layers
TKL8  = 0., 0., 0., 0.               ! Thickness of layers (m)
TYL8  = 0., 0., 0., 0.               ! Driessen texture classes for layers
The listing of part B of the soil.dat file is shown below, and followed by some explanation of the different parameters and their possible values.

* Evaporation proportionality factor
EES = 20.     ! m-1

* Type of equation used
SWIT8 = 1     ! (1) Driessen equation
            ! (2) van Genuchten equation
            ! (3) Linear interpolation

* Type of soil input
SWIT9 = 2     ! Use predefined texture classes

* Initialization
SWIT6 = 1     ! (1) Initial water content field capacity
            ! (2) Initial water content user defined
            ! (3) Initial water content wilting point

There are several options to calculate the soil moisture characteristics. These are specified with the SWIT8 and SWIT9 parameters. In all cases, three variables related to soil texture are used for the calculation of soil water dynamics; the volumetric soil moisture content at field capacity (pF 2.0; represented in array WCFC), at wilting point (pF 4.2; represented in array WCWP) and at air dry (pF 7.0, represented in array WCAD). These three values are calculated from the soil moisture characteristic, the soil's pF curve. There are four methods included to establish the pF-curve: (1) the Driessen method (1986), (2) the Van Genuchten method (1980), (3) linear interpolation on user-defined log scale and (4) a completely user-defined pF-curve. In CASE2, the Driessen method (1) is used. The four methods are briefly presented below (see van Kraalingen 1994).

(1) **Driessen equation (SWIT8 = 1; SWIT9=2).** Standard values for the parameters needed in the Driessen equation can be obtained from a small parameter set which is included in the DRSAHE module. For each soil layer from top to bottom a texture type is specified as shown in the listing of part A. The texture types are included in Table 3.1.

(2) **Van Genuchten equation (SWIT8 = 2; SWIT9=2).** The Van Genuchten equation defines the pF curve by four parameters. Parameter sets for two Dutch soil series are included in the DRASHE module. For tropical soils this method is therefore not very suitable.
(3) Linear interpolation on a user-defined log scale (SWIT8 = 3; SWIT9 = 1). In this case the soil moisture characteristic is calculated by means of linear interpolation on a user-defined log scale. User-specific values of pF should then be specified in eleven arrays in the input file. The pF value at a relative moisture content of 0.0 for each layer should be specified in the array PFWC00, the values of pF at a relative moisture content of 0.1 for each layer in the array PFWC01, etc. Values of pF at a relative moisture content of 1.0 at last are for each layer specified in the array PFWC10. The volumetric soil moisture contents at field capacity, wilting point and air dry are calculated by means of linear interpolation in the initial section of the water balance.

(4) User specified pF curve parameters (SWIT8 = 4; SWIT9 = 1). The last option enables the user to specify directly the volumetric soil moisture content at field capacity per layer in the array WCFC, the volumetric soil moisture content at wilting point in the array WCWP and the volumetric soil moisture content at air dry in the array WCAD. Specified values are without change directly input to the DRSAHE module.

A third switch variable is used for the initialisation of soil water balance (SWIT6). There are three different methods included to initialise the water balance at the start of the simulation with a certain water content.

(1) In hydrostatic equilibrium (SWIT6 = 1). In this case the soil moisture content is initialised in hydrostatic equilibrium. With this value DRSAHE assigns the volumetric soil moisture content at field capacity, within array WCFC, to the value of the array WCLQTM. In addition a warning message is sent to the screen and log file.

(2) At observed moisture contents (SWIT6 = 2). In this case the soil moisture content of the water balance is initialised at observed moisture contents. These are stored in the array WCLQTM in the input data file. For each layer it is checked if the value of WCLQTM not exceed the value of either the soil moisture content at air dry or the soil moisture content at field capacity. If for a certain layer the value of WCLQTM is below air dry, the soil moisture content is assigned the value at air dry. If the value of WCLQTM exceeds field capacity, then its value is restrained to that soil moisture content. In each case a warning message is sent to both screen and log file.

(3) At wilting point (SWIT6 = 3). In this case the soil moisture content of the water balance is initialised at wilting point. For each layer the value of the array WCLQTM is set to the soil moisture content at wilting point in the array WCWP.

18.6 Timer.dat

18.6.1 Purpose and usage

The timer.dat file contains information on the location of weather files, the duration and type of weather data and certain output characteristics. In part A of the file, information on 37 weather files is included, and information on new weather files may be added. For instructions on adding new information on weather files in timer.dat, see the User's Manual (Zuidema & Leffelaar 2002b).

Part B of the file contains information on output parameters, output type, start time and time step of the model. This information can only be changed by skilled users.

For general information on parameters related to weather data and output characteristics, see Van Kraalingen (1995).
18.6.2 Explanation of parameters

Below the complete listing of the timer.dat file is printed. The meaning and possible values of the most important parameters in Part A of this file are explained in the file and in the User's Manual (Zuidema & Leffelaar 2002b). The meaning of most parameters in Part B are explained in Van Kraalingen (1995). Additional explanation on some of the parameters is given below.

************************************************************************
* TIMER.DAT                                                            *
*                                                                      *
* To be used with CASE2 (Cacao Simulation Engine), version 2.2          *
* This data file contains timer and weather information used by CASE2   *
*                                                                      *
************************************************************************
************************************************************************
* INFORMATION IN PART A OF THIS DATA FILE MAY BE CHANGED                *
************************************************************************

!======================================================================!
!                                                                      !
! PART A. Location specifications.                                     !
! Information may be added to this part of the file.                  !
! Please follow the instructions in the User's Manual                 !
!                                                                      !
!======================================================================!

!----------------------------------------------------------------------!

Explanation of parameters:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Possible Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>WTRDIR</td>
<td>Directory of weather data</td>
<td></td>
</tr>
<tr>
<td>CLFILE</td>
<td>File with weather data when IWEATH = 0,1 (WOFOST or longterm weather data)</td>
<td></td>
</tr>
<tr>
<td>IWEATH</td>
<td>Flag indicating the weather system used:</td>
<td>0, 1 for Wofost monthly weather; 2 for Cabo daily weather</td>
</tr>
<tr>
<td>CNTR</td>
<td>Country of weather data; only to be used in combination with Cabo daily weather (IWEATH = 2)</td>
<td></td>
</tr>
<tr>
<td>ISTN</td>
<td>Station number of weather data; only to be used in combination with Cabo daily weather (IWEATH = 2)</td>
<td></td>
</tr>
<tr>
<td>IRNDAT</td>
<td>Flag indicating rainfall system when IWEATH = 0, 1: 0 for generated rain, 1 for distributed rain, 2 for observed rain</td>
<td></td>
</tr>
<tr>
<td>STRTYR1</td>
<td>First year for which weather data are available</td>
<td></td>
</tr>
<tr>
<td>ENDYR1</td>
<td>Last year for which weather data are available</td>
<td></td>
</tr>
</tbody>
</table>

!----------------------------------------------------------------------!

LOCATION 1

<table>
<thead>
<tr>
<th>Country</th>
<th>Location</th>
<th>Start Year</th>
<th>End Year</th>
<th>Rainfall System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>Maceio (Alagoas)</td>
<td>1961</td>
<td>1969</td>
<td>2</td>
</tr>
</tbody>
</table>

WTRDIR1 = 'c:\case2\weather\daily\'
CNTR1 = 'brazil'
ISTN1 = 2
IWEATH1 = 2
IRNDAT1 = 2
STRTYR1 = 1961
ENDYR1 = 1969

LOCATION 2

<table>
<thead>
<tr>
<th>Country</th>
<th>Location</th>
<th>Start Year</th>
<th>End Year</th>
<th>Rainfall System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costa Rica</td>
<td>El Carmen</td>
<td>1974</td>
<td>1991</td>
<td>2</td>
</tr>
</tbody>
</table>

WTRDIR2 = 'c:\case2\weather\daily\'
CNTR2 = 'cr'
ISTN2 = 1
IWEATH2 = 2
Chapter 18. Data files

IRNDAT2 = 2
STRTYR2 = 1974
ENDYR2 = 1991

* LOCATION 3
* Costa Rica La Lola 1973 1990 18 d
WTRDIR3 = 'c:\case2\weather\daily'
CNTR3 = 'cr'
ISTN3 = 4
IWEATH3 = 2
IRNDAT3 = 2
STRTYR3 = 1973
ENDYR3 = 1991

* LOCATION 4
* Costa Rica La Mola 1980 1989 10 d
WTRDIR4 = 'c:\case2\weather\daily'
CNTR4 = 'cr'
ISTN4 = 6
IWEATH4 = 2
IRNDAT4 = 2
STRTYR4 = 1980
ENDYR4 = 1989

* LOCATION 5
* Costa Rica, Puerto Limon 1970 1990 21 d
WTRDIR5 = 'c:\case2\weather\daily'
CNTR5 = 'cr'
ISTN5 = 5
IWEATH5 = 2
IRNDAT5 = 2
STRTYR5 = 1970
ENDYR5 = 1990

* LOCATION 6
* Ghana Tafo 1963 1997 35 m
WTRDIR6 = 'c:\case2\weather\monthly'
CLFILE6 = 'ghataf.wof'
IWEATH6 = 1
IRNDAT6 = 1
STRTYR6 = 1963
ENDYR6 = 1997

* LOCATION 7
* Indonesia Bah Lias 1979 1993 15 m
WTRDIR7 = 'c:\case2\weather\monthly'
CLFILE7 = 'idnbhl.wof'
IWEATH7 = 1
IRNDAT7 = 1
STRTYR7 = 1979
ENDYR7 = 1993

* LOCATION 8
* Ivory Coast Abidjan 1987 1996 10 m
WTRDIR8 = 'c:\case2\weather\monthly'
CLFILE8 = 'civabi.wof'
IWEATH8 = 1
IRNDAT8 = 1
STRTYR8 = 1987
ENDYR8 = 1996

* LOCATION 9
* Ivory Coast Adiake 1987 1995 9 m
WTRDIR9 = 'c:\case2\weather\monthly'
CLFILE9 = 'civadi.wof'
IWEATH9 = 1
IRNDAT9 = 1
STRTYR9 = 1987
ENDYR9 = 1995

* LOCATION 10
* Ivory Coast Daloa 1987 1996 10 m
<table>
<thead>
<tr>
<th>Location</th>
<th>Country</th>
<th>startYear</th>
<th>endYear</th>
<th>m</th>
<th>WTRDIR</th>
<th>CLFILE</th>
<th>IWEATH</th>
<th>IRNDAT</th>
<th>STRTYR</th>
<th>ENDYR</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>Ivory Coast Dimbokro</td>
<td>1987</td>
<td>1996</td>
<td>10</td>
<td>WTRDIR11 - 'c:\case2\weather\monthly'</td>
<td>CLFILE11 - 'civdim.wof'</td>
<td>IWEATH11 = 1</td>
<td>IRNDAT11 = 1</td>
<td>STRTYR11 = 1987</td>
<td>ENDYR11 = 1996</td>
</tr>
<tr>
<td>12</td>
<td>Ivory Coast Gagnoa</td>
<td>1986</td>
<td>1997</td>
<td>12</td>
<td>WTRDIR12 - 'c:\case2\weather\monthly'</td>
<td>CLFILE12 - 'civgag.wof'</td>
<td>IWEATH12 = 1</td>
<td>IRNDAT12 = 1</td>
<td>STRTYR12 = 1986</td>
<td>ENDYR12 = 1997</td>
</tr>
<tr>
<td>13</td>
<td>Ivory Coast Man</td>
<td>1987</td>
<td>1996</td>
<td>10</td>
<td>WTRDIR13 - 'c:\case2\weather\monthly'</td>
<td>CLFILE13 - 'civman.wof'</td>
<td>IWEATH13 = 1</td>
<td>IRNDAT13 = 1</td>
<td>STRTYR13 = 1987</td>
<td>ENDYR13 = 1996</td>
</tr>
<tr>
<td>14</td>
<td>Ivory Coast San Pedro</td>
<td>1987</td>
<td>1996</td>
<td>10</td>
<td>WTRDIR14 - 'c:\case2\weather\monthly'</td>
<td>CLFILE14 - 'civsan.wof'</td>
<td>IWEATH14 = 1</td>
<td>IRNDAT14 = 1</td>
<td>STRTYR14 = 1987</td>
<td>ENDYR14 = 1996</td>
</tr>
<tr>
<td>15</td>
<td>Malaysia Tawau (Sabah)</td>
<td>1951</td>
<td>1993</td>
<td>43</td>
<td>WTRDIR15 - 'c:\case2\weather\monthly'</td>
<td>CLFILE15 - 'mystab.wof'</td>
<td>IWEATH15 = 1</td>
<td>IRNDAT15 = 1</td>
<td>STRTYR15 = 1951</td>
<td>ENDYR15 = 1993</td>
</tr>
<tr>
<td>16</td>
<td>Malaysia Telok Chengai</td>
<td>1978</td>
<td>1988</td>
<td>11</td>
<td>WTRDIR16 - 'c:\case2\weather\monthly'</td>
<td>CLFILE16 - 'mals002a.wof'</td>
<td>IWEATH16 = 1</td>
<td>IRNDAT16 = 1</td>
<td>STRTYR16 = 1978</td>
<td>ENDYR16 = 1988</td>
</tr>
</tbody>
</table>

* LOCATION 18
* Philippines IRRI         1979 1995 17   d
  WTRDIR18 = 'c:\case2\weather\daily\'
  CNTR18  = 'phil'
  ISTN18  = 1
  IWEATH18 = 2
  IRNDAT18 = 2
  STRTYR18 = 1979
  ENDRYR18 = 1995

* LOCATION 19
* < specify location name and period of weather data here >
  WTRDIR19 = ' '  
  CNTR19  = ' '  
  CLFILE19 = ' '  
  ISTN19  = 0  
  IWEATH19 = 0  
  IRNDAT19 = 0  
  STRTYR19 = 0  
  ENDRYR19 = 0

* LOCATION 20
* < specify location name and period of weather data here >
  WTRDIR20 = ' '  
  CNTR20  = ' '  
  CLFILE20 = ' '  
  ISTN20  = 0  
  IWEATH20 = 0  
  IRNDAT20 = 0  
  STRTYR20 = 0  
  ENDRYR20 = 0

* LOCATION 21
* < specify location name and period of weather data here >
  WTRDIR21 = ' '  
  CNTR21  = ' '  
  CLFILE21 = ' '  
  ISTN21  = 0  
  IWEATH21 = 0  
  IRNDAT21 = 0  
  STRTYR21 = 0  
  ENDRYR21 = 0

* LOCATION 22
* < specify location name and period of weather data here >
  WTRDIR22 = ' '  
  CNTR22  = ' '  
  CLFILE22 = ' '  
  ISTN22  = 0  
  IWEATH22 = 0  
  IRNDAT22 = 0  
  STRTYR22 = 0  
  ENDRYR22 = 0

* LOCATION 23
* < specify location name and period of weather data here >
  WTRDIR23 = ' '  
  CNTR23  = ' '  
  CLFILE23 = ' '  
  ISTN23  = 0  
  IWEATH23 = 0  
  IRNDAT23 = 0  
  STRTYR23 = 0  
  ENDRYR23 = 0

!---------------------------------!
! Long-term weather data          
!---------------------------------!

* LOCATION 51
* Brazil   Belem
  CLFILE51 = 'Bra9.ltm'
* LOCATION 52
  * Brazil  Salvador
  CLFILE52 = 'Bra99.ltm'

* LOCATION 53
  * Brazil  Vitoria
  CLFILE53 = 'Bra144.ltm'

* LOCATION 54
  * Cameroon  Batouri
  CLFILE54 = 'Cmr7.ltm'

* LOCATION 55
  * Cameroon  Douala
  CLFILE55 = 'Cmr6.ltm'

* LOCATION 56
  * Colombia  Andagoya
  CLFILE56 = 'Col16.ltm'

* LOCATION 57
  * Colombia  Villavicencio
  CLFILE57 = 'Col27.ltm'

* LOCATION 58
  * Ghana  Hon
  CLFILE58 = 'Gha10.ltm'

* LOCATION 59
  * Ghana  Kumasi
  CLFILE59 = 'Gha8.ltm'

* LOCATION 60
  * Ghana  Tafo
  CLFILE60 = 'Gha99.ltm'

* LOCATION 61
  * Cote d'Ivoire  Abidjan
  CLFILE61 = 'Civ8.ltm'

* LOCATION 62
  * Cote d'Ivoire  Gagnoa
  CLFILE62 = 'Civ7.ltm'

* LOCATION 63
  * Ivory Coast  Man
  CLFILE63 = 'Civ5.ltm'

* LOCATION 64
  * Malaysia  Kuala Trengganu
  CLFILE64 = 'Mys8.ltm'

* LOCATION 65
  * Malaysia  Penang
  CLFILE65 = 'Mys1.ltm'

* LOCATION 66
  * Malaysia  Sandakan
  CLFILE66 = 'Mys37.ltm'

* LOCATION 67
  * Malaysia  Tawau
  CLFILE67 = 'Mys99.ltm'

* LOCATION 68
  * Papua New Guinea  Madang
  CLFILE68 = 'Png3.ltm'

* LOCATION 69
  * Papua New Guinea  Rabaul
  CLFILE69 = 'Png9.ltm'
Three lists of output parameters are defined below: for output per year, per 10 days and per day. These lists determine the output that is saved to the Excel file with output and to the table in case FSEWin is used. (These lists do not determine the parameters for which graphs can be viewed in FSEWin: this is determined in the code by a call to the “ChartOutput...” subroutine).

* per yr

* per 10 days

* per day

The list with years and day numbers is used for determining the day at which the output of cumulative parameters for one year (such as annual bean production) is to be calculated. The year 1000 is included as this is the imaginary start and end year for simulations using long-term average weather data.

* years and days for which output is generated in case of annual output
IOBSD = 1000, 365

! List of observation data for which output
! is required. The list should consist of
! pairs of <year>,<day> combinations.

IPFORM = 5

! Format of output file:
! 0 = no output table,
! 4 = normal table,
! 5 = tab-delimited (Excel),
! 6 = TTPLOT format

COPINF = 'N'

! Switch variable what should be done with
! the inputfiles:
! 'N' = do not copy inputfiles into
! outputfile,
! 'Y' = copy inputfiles into outputfile

DELTMP = 'Y'

! Switch variable what should be done with
! the temporary and binary output file:
! 'N' = do not delete,
! 'Y' = delete

The parameter STTIME (start time) should preferably remain 1 to ensure that cumulative
parameters over one year are comparable. The time step for integration (DELT) cannot be changed
to other values: time steps of >1 day are not accepted by the water balance routine and <1 not by
the CASE2 routine.

STTIME = 1.
DELT = 1.

* Radiation parameter
FRPAR = 0.5

IFLAG = 1101
! Indicates where weather error and warnings
! go (1101 means errors and warnings to log
! file, errors to screen, see FSE manual)

Two “plant modules” can be selected in the model: the standard is ‘CACAO’. When this is selected
the CASE2 subroutine is invoked in the MODELS subroutine and the model is run for cocoa. If ‘NO
CROP’ is selected, the nocrop.for subroutine is invoked in the MODELS subroutine and the model is
run for a situation without crops (thus also without shade trees).

PLTMOD = 'CACAO'
* PLTMOD = 'NO CROP'

In theory, three evapotranspiration modules can be selected in CASE2, but since evapotranspiration
equations for ‘PENMAN’ only have been adapted for the use with cacao trees (see Chapter 17) it is
not recommended to use one of the other modules.

ETMOD = 'PENMAN'
* ETMOD = 'MAKKINK'
* ETMOD = 'PRIESTLEY/TAYLOR'
19. **Weather files**

19.1 Purpose and usage

Weather data for new locations can be used by the CASE2 model. Three types of weather data may be used: (1) daily weather, (2) monthly weather data and (3) long-term weather data. Daily weather data (CABO weather format) contain information on rainfall, radiation, vapour pressure and temperature for every day. Monthly data (WOFOST weather format) contain average values for radiation, temperature, vapour pressure and total values for rainfall for one month. In the latter case, the monthly summary values are used to generate daily values for all weather parameters (using interpolation in the case of monthly averages and random generation of daily values in the case of rainfall). In both cases, weather data should be available for a number of consecutive years, preferably 10 or more years. For long-term weather data, on the other hand, the information is not specific for one year but an average over a (large) number of years. The average values are valid for one month. Thus, 12 values are included for each weather parameter.

For information on adding new weather files: see user’s manual (Zuidema & Leffelaar, 2002b).
Literature used

The following list contains the literature sources referred to in the text of this report and in the data files. In addition it contains a number of other papers and books relevant for understanding and modelling cocoa growth and production.


Duguma, B., 1998, Smallholder cocoa (Theobroma cacao L.) cultivation in agroforestry systems of West and Central Africa: challenges and opportunities,


Holden, M., 1957. An investigation on polyphenolic compounds of the cacao leaf in connection with a chemical method for detecting virus infection. Journal Sci. Food Agric. 10:553-


Legg, J.T., 1981. The cocoa swollen shoot project at the Cocoa Research Institute, Tafo, Ghana. Volume III.
Loue, A., 1961, Etude des carences et des deficiences minerales sur le cacaoyer, troisieme partie, La fumure du cacaoyer en Cote d'Ivoire, Institut Francais du Cafe et du Cacao, bulletin no 1, 41-52.
Maliphant, G.K., 1959, The nutrition of cocoa I, Leaf nitrogen and phosphorus contents, ICLA, Trinidad, pg 76-79.
Maliphant, G.K., 1961, The nutrition of cocoa III, Bark nitrogen and phosphorus levels, ICLA, Trinidad, pg 73-76.
Mommer, L., 1999. The water relations in cacao (Theobroma cacao L): modelling root growth and evapotranspiration. MSc thesis Wageningen Agricultural University, Wageningen, 56 pp. (available upon request from the authors, see page 2 of this report).
Murray, D.B., 1961, Soil moisture and cropping cycles in cacao, Report on Cocoa research, ICTA, St Augustine, Trinidad.
Ng, E.E., 1982. Potential cocoa photosynthetic productivity. Proceedings 8th International Cocoa Research Conference, 235-244


SOFRECO, 1991, Etude pedologique et cartographie d’aptitude des sols a la cacao culture et autres cultures dans le Litime, Rapport definitif, in collaboration with Ministere du developpement rural et SRCC Togo.


Appendix: List of parameters

The Table below includes all parameters used in the most important subroutines of CASE2. All parameters from the Fortran files: FSE, MODEL2, CASE2, SETPMD and DRSAHE are included. A short description and the unit are mentioned and the Fortran file in which the parameters are used is indicated, as well as whether the parameter is an input (I) or output (O) to the entire program. F=fse.for; M=model2.for; C=case2.for; D=drsahe.for; P=drpot.for; N=nocrop.for; S=setpmd.for. Units: DW = dry weight.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Unit</th>
<th>Used in:</th>
<th>In/Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADJLVAGE</td>
<td>Leaf life span adjusted for drought effects</td>
<td>d</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>AGBIORA</td>
<td>Regression coefficient for age-biomass relation</td>
<td>kg DW d-1</td>
<td>C</td>
<td>I</td>
</tr>
<tr>
<td>AGBIORB</td>
<td>Regression coefficient for age-biomass relation</td>
<td>kg DW</td>
<td>C</td>
<td>I</td>
</tr>
<tr>
<td>AGE</td>
<td>Age of the cacao tree</td>
<td>d</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>AGEL</td>
<td>Age of the cacao tree at the start of the simulation</td>
<td>d</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>AGEYR</td>
<td>Age of the cacao tree at the start of the simulation in years</td>
<td>y</td>
<td>C</td>
<td>I</td>
</tr>
<tr>
<td>AGEY</td>
<td>Age of the cacao tree in years</td>
<td>y</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>AIRDR</td>
<td>pF value for airdry soil</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>AMAX</td>
<td>Temperature-dependent maximum photosynthesis rate</td>
<td>kg CO2 ha-1 leaf h-1</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>AMINIT</td>
<td>Factor accounting for lower photosynthesis in young leaves</td>
<td>-</td>
<td>C</td>
<td>I</td>
</tr>
<tr>
<td>AMTMP</td>
<td>Reduction factor for temperature effect on AMX</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>AMTMTPT</td>
<td>Table with reduction factor for temperature effects on AMX</td>
<td>-</td>
<td>C</td>
<td>I</td>
</tr>
<tr>
<td>AMX</td>
<td>Maximum rate of photosynthesis</td>
<td>kg CO2 ha-1 leaf h-1</td>
<td>C</td>
<td>I</td>
</tr>
<tr>
<td>ANGA</td>
<td>Regression coefficient in Angstrom formula</td>
<td>M F S</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ANGB</td>
<td>Regression coefficient in Angstrom formula</td>
<td>M F S</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ANGOT</td>
<td>Daily total extraterrestrial radiation</td>
<td>J m-2 d-1</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>ASRQ</td>
<td>Assimilate requirement for the production of 1 kg biomass</td>
<td>kg CH2O kg-1 DW</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>ASRQLRT</td>
<td>Assimilate requirement for the production of 1 kg lateral roots</td>
<td>kg CH2O kg-1 DW</td>
<td>C</td>
<td>I</td>
</tr>
<tr>
<td>ASRQLV</td>
<td>Assimilate requirement for the production of 1 kg leaves</td>
<td>kg CH2O kg-1 DM</td>
<td>C</td>
<td>I</td>
</tr>
<tr>
<td>ASRQPDTB</td>
<td>Table of pod assimilate requirements depending on fat content</td>
<td>kg CH2O kg-1 DM</td>
<td>C</td>
<td>I</td>
</tr>
<tr>
<td>ASRQTR</td>
<td>Assimilate requirement for the production of 1 kg taproot</td>
<td>kg CH2O kg-1 DM</td>
<td>C</td>
<td>I</td>
</tr>
<tr>
<td>ASRQWD</td>
<td>Assimilate requirement for the production of 1 kg wood</td>
<td>kg CH2O kg-1 DM</td>
<td>C</td>
<td>I</td>
</tr>
<tr>
<td>ATRANS</td>
<td>Total daily actual transpiration rate of the canopy</td>
<td>mm d-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>ATWURT</td>
<td>Total area of water-uptaking roots</td>
<td>m2 ha-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>AVAIL</td>
<td>Soil moisture available for transpiration (per layer)</td>
<td>mm</td>
<td>D C</td>
<td></td>
</tr>
<tr>
<td>AVGLVAGE</td>
<td>Maximum leaf life span without water stress</td>
<td>d</td>
<td>C</td>
<td>I</td>
</tr>
<tr>
<td>AWURT</td>
<td>Area of water-uptaking roots per soil layer</td>
<td>m2 ha-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>BH</td>
<td>Butter hardness of beans</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>BHRA</td>
<td>Butter hardness regression coefficient</td>
<td>°C -1</td>
<td>C</td>
<td>I</td>
</tr>
<tr>
<td>BHRB</td>
<td>Butter hardness regression coefficient</td>
<td>-</td>
<td>C</td>
<td>I</td>
</tr>
<tr>
<td>BHSUM</td>
<td>Sum of butter hardness values</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>BHYLD</td>
<td>Butter hardness of the daily bean production</td>
<td>-</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>CAP</td>
<td>Soil moisture that can be absorbed (per layer)</td>
<td>mm</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>CFLRT</td>
<td>Mass fraction carbon in the lateral roots</td>
<td>kg C kg-1 DM</td>
<td>C</td>
<td>I</td>
</tr>
<tr>
<td>CFLV</td>
<td>Mass fraction carbon in the leaves</td>
<td>kg C kg-1 DM</td>
<td>C</td>
<td>I</td>
</tr>
<tr>
<td>CFPD</td>
<td>Mass fraction carbon in the pods</td>
<td>kg C kg-1 DM</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>CFPDTCB</td>
<td>Table of mass fraction carbon in pods depending on fat content</td>
<td>-</td>
<td>C</td>
<td>I</td>
</tr>
<tr>
<td>CFTRT</td>
<td>Mass fraction carbon in the taproot</td>
<td>kg C kg-1 DM</td>
<td>C</td>
<td>I</td>
</tr>
<tr>
<td>CFWD</td>
<td>Mass fraction carbon in the wood</td>
<td>kg C kg-1 DM</td>
<td>C</td>
<td>I</td>
</tr>
<tr>
<td>Parameter</td>
<td>Description</td>
<td>Unit</td>
<td>Used in:</td>
<td>In/Out</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------</td>
<td>------</td>
<td>----------</td>
<td>--------</td>
</tr>
<tr>
<td>CHECK</td>
<td>Absolute error in water balance</td>
<td>mm</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>CHKDIFF</td>
<td>Carbon check variable</td>
<td>kg C ha(^{-1})</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>CHKFL</td>
<td>Cumulative amount of carbon assimilated</td>
<td>kg C ha(^{-1})</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>CHKGPOD</td>
<td>Check variable for pod growth summation</td>
<td>kg DW ha(^{-1}) d(^{-1})</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>CHKIN</td>
<td>Amount of carbon present in all plant parts at any point in time</td>
<td>kg C ha(^{-1})</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>CHKLRT</td>
<td>Carbon check variable for lateral roots</td>
<td>kg C ha(^{-1})</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>CHKLV</td>
<td>Carbon check variable for leaves</td>
<td>kg C ha(^{-1})</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>CHKPART1</td>
<td>Check variable for partitioning of resources</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>CHKPART2</td>
<td>Check variable for partitioning of resources</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>CHKPD</td>
<td>Carbon check variable for pods</td>
<td>kg C ha(^{-1})</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>CHKTLV</td>
<td>Check variable for leaf biomass summation</td>
<td>kg DW ha(^{-1})</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>CHKTTRT</td>
<td>Carbon check variable for taproot</td>
<td>kg C ha(^{-1})</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>CHKWD</td>
<td>Carbon check variable for wood</td>
<td>kg C ha(^{-1})</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>CHKWPOD</td>
<td>Check variable for pod biomass summation</td>
<td>kg DW ha(^{-1})</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>CLEAR</td>
<td>Fraction of clear sky</td>
<td>-</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>CLFILE</td>
<td>File name for weather files with monthly data</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>CNTR</td>
<td>Country code for weather file</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>CO2LRT</td>
<td>CO2 production factor for lateral roots</td>
<td>kg CO2 kg(^{-1}) DW</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>CO2LV</td>
<td>CO2 production factor for leaves</td>
<td>kg CO2 kg(^{-1}) DW</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>CO2PD</td>
<td>CO2 production factor for pods</td>
<td>kg CO2 kg(^{-1}) DW</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>CO2TRT</td>
<td>CO2 production factor for taproot</td>
<td>kg CO2 kg(^{-1}) DW</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>CO2WD</td>
<td>CO2 production factor for wood</td>
<td>kg CO2 kg(^{-1}) DW</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>COPINF</td>
<td>Switch variable: whether input data should be copied to output file</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>CROPF</td>
<td>Crop factor for crop water requirement</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>CUMTKL</td>
<td>Cumulative thickness of soil layers</td>
<td>m</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>D10COUNT</td>
<td>Counter for 10-day summations</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>D10GTOT</td>
<td>Total biomass growth during 10 days</td>
<td>kg DW ha(^{-1}) (10 d)-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>D10HARPD</td>
<td>Number of harvested pods during 10 days</td>
<td>(10 d)-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>D10RAIN</td>
<td>Amount of rainfall during 10 days</td>
<td>mm (10 d)-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>D10RDD</td>
<td>Amount of short-wave radiation during 10 days</td>
<td>J m(^{-2}) (10 d)-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>D10YLDBN</td>
<td>Yield of dry, fermented beans during 10 days</td>
<td>kg DW ha(^{-1}) (10 d)-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>D10YLDPD</td>
<td>Yield of pods during 10 days</td>
<td>kg DW ha(^{-1}) (10 d)-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>DATCMP</td>
<td>Irrigation parameter</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>DATMTR</td>
<td>Daily atmospheric transmission fraction</td>
<td>-</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>DELT</td>
<td>Time step of integration</td>
<td>d</td>
<td>D M F</td>
<td></td>
</tr>
<tr>
<td>DELTMP</td>
<td>Switch variable what should be done with temporary file</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>DEPTH</td>
<td>Depth of soil compartment (per layer)</td>
<td>m</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>DEVR</td>
<td>Pod development rate</td>
<td>d(^{-1})</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>DEVRH</td>
<td>Pod development rate: high regression estimate</td>
<td>d(^{-1})</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>DEVRL</td>
<td>Pod development rate: low regression estimate</td>
<td>d(^{-1})</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>DEVRR1A</td>
<td>Regression coefficient on relation between temperature and pod ripening</td>
<td>d(^{-1}) °C(^{-1})</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>DEVRR1B</td>
<td>Regression coefficient on relation between temperature and pod ripening</td>
<td>d(^{-1}) °C(^{-1})</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>DEVRR2A</td>
<td>Regression coefficient on relation between temperature and pod ripening</td>
<td>d(^{-1}) °C(^{-1})</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>DEVRR2B</td>
<td>Regression coefficient on relation between temperature and pod ripening</td>
<td>d(^{-1}) °C(^{-1})</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>Parameter</td>
<td>Description</td>
<td>Unit</td>
<td>Used in:</td>
<td>In/Out</td>
</tr>
<tr>
<td>--------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>------------</td>
<td>----------</td>
<td>--------</td>
</tr>
<tr>
<td>pod ripening</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIAM1</td>
<td>Mean diameter of fine roots (diameter &lt; 1 mm)</td>
<td>m</td>
<td>C</td>
<td>I</td>
</tr>
<tr>
<td>DIAM2</td>
<td>Mean diameter of fine roots (diameter between 1 and 2 mm)</td>
<td>m</td>
<td>C</td>
<td>I</td>
</tr>
<tr>
<td>DLRT</td>
<td>Daily death rate of lateral root biomass</td>
<td>kg DW ha-1 d-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>DLV</td>
<td>Daily death rate of leaves biomass</td>
<td>kg DW ha-1 d-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>DLV1</td>
<td>Daily death rate of leaves biomass due to ageing</td>
<td>kg DW ha-1 d-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>DLV10</td>
<td>Leaf death rates for 10 days (array)</td>
<td>kg DW ha-1 d-1</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>DLV2</td>
<td>Daily death rate of leaves biomass due to drought</td>
<td>kg DW ha-1 d-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>DOY</td>
<td>Day number since 1 January within year of simulation</td>
<td>d</td>
<td>C</td>
<td>M F</td>
</tr>
<tr>
<td>DRAFT</td>
<td>Rate of change of drainage</td>
<td>mm d-1</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>DRAICU</td>
<td>Cumulative drainage by drains</td>
<td>mm</td>
<td>M D</td>
<td></td>
</tr>
<tr>
<td>DRAIQT</td>
<td>Daily drainage rate</td>
<td>mm d-1</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>DRES</td>
<td>Total decrease rate of reserves</td>
<td>kg CH2O ha-1 d-1</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>DRES1</td>
<td>Decrease rate of reserves due to maintenance respiration</td>
<td>kg CH2O ha-1 d-1</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>DRES2</td>
<td>Decrease rate of reserves due to replacement of biomass</td>
<td>kg CH2O ha-1 d-1</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>DSLR</td>
<td>Number of days since last rain</td>
<td>d</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>DT</td>
<td>Estimated temperature difference between surface height and reference height</td>
<td>°C</td>
<td>S M</td>
<td></td>
</tr>
<tr>
<td>DTGA</td>
<td>Daily total gross CO2 assimilation</td>
<td>kg CO2 ha-1 d-1</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>DUMMY</td>
<td>Weather error parameter</td>
<td></td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>DWD</td>
<td>Daily death rate of wood biomass</td>
<td>kg DW ha-1 d-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>DY0</td>
<td>Day of previous irrigation</td>
<td>d</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>EES</td>
<td>Evaporation proportionality factor</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>EFF</td>
<td>Initial light use efficiency for individual leaves</td>
<td>(kg CO2 ha-1 h-1)/(J m-2 s-1)</td>
<td>C M F</td>
<td></td>
</tr>
<tr>
<td>ELEV</td>
<td>Elevation of site</td>
<td>m</td>
<td>M F</td>
<td></td>
</tr>
<tr>
<td>ENDRNF</td>
<td>Parameter indicating whether end run number was found</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>ENDRUN</td>
<td>End run number</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>ENDYR</td>
<td>Final year of simulation</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>ETAE</td>
<td>Dryness driven part of potential evapotranspiration</td>
<td>mm d-1</td>
<td>S M C</td>
<td></td>
</tr>
<tr>
<td>ETD</td>
<td>Potential evapotranspiration</td>
<td>mm d-1</td>
<td>S M</td>
<td></td>
</tr>
<tr>
<td>ETMOD</td>
<td>Evapotranspiration module</td>
<td>-</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>ETRD</td>
<td>Radiation driven part of potential evapotranspiration</td>
<td>mm d-1</td>
<td>S M C</td>
<td></td>
</tr>
<tr>
<td>EVSC</td>
<td>Actual (realized) evaporation rate</td>
<td>mm d-1</td>
<td>C D M</td>
<td></td>
</tr>
<tr>
<td>EVSCL</td>
<td>Positive evaporation rate</td>
<td>mm d-1</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>EVSD</td>
<td>Evaporation rate on days without rain</td>
<td>mm d-1</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>EVSH</td>
<td>Evaporation rate on days with rain</td>
<td>mm d-1</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>EVSW</td>
<td>Evaporation parameter</td>
<td>mm d-1</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>EVSW2</td>
<td>Actual evaporation rate</td>
<td>mm d-1</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>EVSWCU</td>
<td>Cumulative evaporation</td>
<td>mm</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>FATCONTENT</td>
<td>Fat content of nibs</td>
<td>-</td>
<td>C</td>
<td>!</td>
</tr>
<tr>
<td>FBEANS</td>
<td>Dry weight fraction of beans in pod</td>
<td>-</td>
<td>C</td>
<td>!</td>
</tr>
<tr>
<td>FHRTWD</td>
<td>Fraction of wood that is heartwood</td>
<td>-</td>
<td>C</td>
<td>!</td>
</tr>
<tr>
<td>FIELD</td>
<td>pF value for field capacity</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>FILEI1</td>
<td>Name of input file no. 1</td>
<td>-</td>
<td>C M F</td>
<td></td>
</tr>
<tr>
<td>FILEI2</td>
<td>Name of input file no. 2</td>
<td>-</td>
<td>M F</td>
<td></td>
</tr>
<tr>
<td>FILEI3</td>
<td>Name of input file no. 3</td>
<td>-</td>
<td>M M F</td>
<td></td>
</tr>
<tr>
<td>FILEI4</td>
<td>Name of input file no. 4</td>
<td>-</td>
<td>M F</td>
<td></td>
</tr>
</tbody>
</table>
# Appendix I. List of parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Unit</th>
<th>Used in:</th>
<th>In/Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>FILEI5</td>
<td>Name of input file no. 5</td>
<td>-</td>
<td>M F</td>
<td>In/Out</td>
</tr>
<tr>
<td>FILEIC</td>
<td>Name of control file</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>FILEIR</td>
<td>Name of reruns file</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>FILEIT</td>
<td>Name of timer data file</td>
<td>-</td>
<td>M F</td>
<td></td>
</tr>
<tr>
<td>FILEOL</td>
<td>Name of log file</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>FILEON</td>
<td>Name of output file</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>FILEP</td>
<td>File name with which plant parameters are read</td>
<td>-</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>FILIN</td>
<td>Name of file with soil data</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>FINTIM</td>
<td>Finish time of simulation</td>
<td>d</td>
<td>M F</td>
<td></td>
</tr>
<tr>
<td>FLOW</td>
<td>Flow of water over compartment boundaries (intermediate variable)</td>
<td>mm d⁻¹</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>FLR</td>
<td>Fraction of biomass production allocated to lateral roots</td>
<td>-</td>
<td>C O</td>
<td></td>
</tr>
<tr>
<td>FLRTRA</td>
<td>Regression coefficient on relation between lateral root and total biomass</td>
<td>kg DW lateral roots kg⁻¹ C</td>
<td>!</td>
<td></td>
</tr>
<tr>
<td>FLRTRB</td>
<td>Regression coefficient on relation between lateral root and total biomass</td>
<td>kg DW lateral root C</td>
<td>!</td>
<td></td>
</tr>
<tr>
<td>FLV</td>
<td>Fraction of biomass production allocated to leaves</td>
<td>-</td>
<td>C O</td>
<td></td>
</tr>
<tr>
<td>FLVRA</td>
<td>Regression coefficient on relation between leaf and total biomass</td>
<td>kg DW leaf kg⁻¹ DW C</td>
<td>!</td>
<td></td>
</tr>
<tr>
<td>FLVRB</td>
<td>Regression coefficient on relation between leaf and total biomass</td>
<td>kg DW leaves C</td>
<td>!</td>
<td></td>
</tr>
<tr>
<td>FLXCU</td>
<td>Cumulative water flux for each layer boundary</td>
<td>mm d⁻¹</td>
<td>D M</td>
<td></td>
</tr>
<tr>
<td>FLXQT</td>
<td>Layer boundary water fluxes</td>
<td>mm d⁻¹</td>
<td>D M</td>
<td></td>
</tr>
<tr>
<td>FMTA</td>
<td>Regression coefficient on biomass loss due to fermentation</td>
<td>-</td>
<td>C</td>
<td>!</td>
</tr>
<tr>
<td>FMTB</td>
<td>Regression coefficient on biomass loss due to fermentation</td>
<td>d⁻¹</td>
<td>C</td>
<td>!</td>
</tr>
<tr>
<td>FMTDUR</td>
<td>Duration of the fermentation process</td>
<td>d</td>
<td>C</td>
<td>!</td>
</tr>
<tr>
<td>FMTLOS</td>
<td>Factor accounting for weight loss due to fermentation</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>FPD</td>
<td>Fraction of biomass production allocated to pods</td>
<td>-</td>
<td>C O</td>
<td></td>
</tr>
<tr>
<td>FPDRA</td>
<td>Regression coefficient on relation between pod and total biomass</td>
<td>kg DW pod kg⁻¹ DW C</td>
<td>!</td>
<td></td>
</tr>
<tr>
<td>FPDDB</td>
<td>Regression coefficient on relation between pod and total biomass</td>
<td>kg DW pod C</td>
<td>!</td>
<td></td>
</tr>
<tr>
<td>FRABS</td>
<td>Fraction of total radiation absorbed by cacao trees</td>
<td>-</td>
<td>C O</td>
<td></td>
</tr>
<tr>
<td>FPAR</td>
<td>Fraction of photosynthetically active radiation (PAR)</td>
<td>-</td>
<td>M F C</td>
<td>!</td>
</tr>
<tr>
<td>FSACE</td>
<td>Scaling factor for partitioning fractions</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>FTRT</td>
<td>Fraction of biomass production allocated to taproot</td>
<td>-</td>
<td>C O</td>
<td></td>
</tr>
<tr>
<td>FTRTRA</td>
<td>Regression coefficient on relation between taproot and total biomass</td>
<td>kg DW taproot kg⁻¹ DW C</td>
<td>!</td>
<td></td>
</tr>
<tr>
<td>FTRTRB</td>
<td>Regression coefficient on relation between taproot and total biomass</td>
<td>kg DW taproot C</td>
<td>!</td>
<td></td>
</tr>
<tr>
<td>FWD</td>
<td>Fraction of biomass production allocated to wood</td>
<td>-</td>
<td>C O</td>
<td></td>
</tr>
<tr>
<td>FWDRA</td>
<td>Regression coefficient on relation between wood and total biomass</td>
<td>kg DW wood kg⁻¹ DW C</td>
<td>!</td>
<td></td>
</tr>
<tr>
<td>FWDDB</td>
<td>Regression coefficient on relation between wood and total biomass</td>
<td>kg DW wood C</td>
<td>!</td>
<td></td>
</tr>
<tr>
<td>FWURT</td>
<td>Fraction of lateral roots that is able to extract water</td>
<td>-</td>
<td>C</td>
<td>!</td>
</tr>
<tr>
<td>GAI</td>
<td>Green area index of cocoa and shade crop</td>
<td>ha leaf ha⁻¹ ground C</td>
<td>M N</td>
<td></td>
</tr>
<tr>
<td>GIVEN</td>
<td>Check for weather data availability</td>
<td>-</td>
<td>M</td>
<td></td>
</tr>
</tbody>
</table>
## Appendix I. List of parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Unit</th>
<th>Used in:</th>
<th>In/Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>GLRT</td>
<td>Daily growth rate of lateral root biomass</td>
<td>kg DW ha(^{-1}) d(^{-1})</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>GLRT1</td>
<td>Daily growth rate of lateral root biomass, replacement</td>
<td>kg DW ha(^{-1}) d(^{-1})</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>GLV</td>
<td>Daily growth rate of lateral leaf biomass</td>
<td>kg DW ha(^{-1}) d(^{-1})</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>GLV1</td>
<td>Daily growth rate of lateral leaf biomass, replacement</td>
<td>kg DW ha(^{-1}) d(^{-1})</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>GPD</td>
<td>Daily growth rate of lateral pod biomass</td>
<td>kg DW ha(^{-1}) d(^{-1})</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>GPD1</td>
<td>Daily growth rate of lateral pod biomass, replacement</td>
<td>kg DW ha(^{-1}) d(^{-1})</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>GPHOT</td>
<td>Daily total gross CH(_2)O assimilation</td>
<td>kg CH(_2)O ha(^{-1}) d(^{-1})</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>GPOD</td>
<td>Growth rate of pods in pod class (array)</td>
<td>kg DW ha(^{-1}) d(^{-1})</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>GPODTOT</td>
<td>Summation of pod growth rate over all pod classes</td>
<td>kg DW ha(^{-1}) d(^{-1})</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>GRES</td>
<td>Growth rate of reserves</td>
<td>kg CH(_2)O ha(^{-1}) d(^{-1})</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>GRT</td>
<td>Daily growth rate of root biomass</td>
<td>kg DW ha(^{-1}) d(^{-1})</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>GTOT</td>
<td>Daily growth rate of total biomass</td>
<td>kg DW ha(^{-1}) d(^{-1})</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>GTOT1</td>
<td>Daily growth rate of total biomass: growth to replace lost biomass</td>
<td>kg DW ha(^{-1}) d(^{-1})</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>GTOT2</td>
<td>Daily growth rate of total biomass: growth leading to net growth in biomass</td>
<td>kg DW ha(^{-1}) d(^{-1})</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>GTRT</td>
<td>Daily growth rate of taproot biomass</td>
<td>kg DW ha(^{-1}) d(^{-1})</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>GWD</td>
<td>Daily growth rate of wood biomass</td>
<td>kg DW ha(^{-1}) d(^{-1})</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>GWD1</td>
<td>Daily growth rate of wood biomass: growth to replace lost biomass</td>
<td>kg DW ha(^{-1}) d(^{-1})</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>GWURT1</td>
<td>Daily growth rate of water-uptaking roots: growth to replace lost biomass</td>
<td>kg DW ha(^{-1}) d(^{-1})</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>HARPODS</td>
<td>Daily number of harvested pods</td>
<td># d(^{-1})</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>HGHL</td>
<td>Lower height of cacao tree crowns</td>
<td>m</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>HGHT</td>
<td>Upper height of cacao tree crowns</td>
<td>m</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>HLP1</td>
<td>intermediate variable in van Genuchten equation</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>HRTWDAGE</td>
<td>Age at which softwood is transformed into non-respiring heartwood</td>
<td>d</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>HUM</td>
<td>Relative humidity</td>
<td>-</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>I1</td>
<td>Counter</td>
<td>-</td>
<td>F M D N C</td>
<td></td>
</tr>
<tr>
<td>I2</td>
<td>Counter</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>IAMTMN</td>
<td>Counter for mean temperatures</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>IASRQPDN</td>
<td>Counter for pod assimilation requirements</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>ICFPDN</td>
<td>Counter for pod carbon fraction</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>IDOY</td>
<td>Day number within year of simulation (integer)</td>
<td>d</td>
<td>M F S D C</td>
<td></td>
</tr>
<tr>
<td>IDOYO</td>
<td>Day number within year of simulation (integer)</td>
<td>d</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>IFLAG</td>
<td>Indicates where weather error and warnings are stored</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>IL</td>
<td>Do-loop counter</td>
<td>-</td>
<td>D F</td>
<td></td>
</tr>
<tr>
<td>ILD</td>
<td>Number of leaf classes</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>ILW</td>
<td>Switch for Brunt or Swinbank formula</td>
<td>-</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>IMNID</td>
<td>Irrigation parameter</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>IMNOD</td>
<td>Parameter for reading observation years</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>IMNPRS</td>
<td>Parameter for output parameter selection</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>INF</td>
<td>Daily infiltration rate</td>
<td>mm d(^{-1})</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>INFCU</td>
<td>Cumulative infiltration</td>
<td>mm</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>INID</td>
<td>number of irrigation</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>INOD</td>
<td>Parameter for reading observation years</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>INPRS</td>
<td>Parameter for output parameter selection</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>Parameter</td>
<td>Description</td>
<td>Unit</td>
<td>Used in:</td>
<td>In/Out</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------</td>
<td>------</td>
<td>----------</td>
<td>--------</td>
</tr>
<tr>
<td>INS</td>
<td>Counter for species (1=cacao; 2=shade tree)</td>
<td>C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>INSETS</td>
<td>Parameter for reruns</td>
<td>F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IOBSD</td>
<td>Lists year-day combinations for which output is requested</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>IOD</td>
<td>Parameter for reading observation years</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>IPC</td>
<td>Counter for days in 10-day summations</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>IPFORM</td>
<td>Format of output file</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>IPOD</td>
<td>Number of pod classes</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>IRNDAT</td>
<td>Indicates type of rainfall data</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>IRR</td>
<td>Daily irrigation rate mm d⁻¹</td>
<td>D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IRRCU</td>
<td>Cumulative irrigation mm</td>
<td>D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IRRTB</td>
<td>table with entries of irrigation applications (year, day, amount)</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>ISET</td>
<td>Parameter for reruns</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>ISSN</td>
<td>Counter for sink strength table</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>ISTN1</td>
<td>Weather station number (only for daily weather data)</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>ISURF</td>
<td>Switch value to choose between different surface types (-)</td>
<td>-</td>
<td>S M</td>
<td></td>
</tr>
<tr>
<td>ITABLE</td>
<td>Declared length of many of the interpolation tables</td>
<td>-</td>
<td>C F</td>
<td></td>
</tr>
<tr>
<td>ITASK</td>
<td>Task that subroutine should perform</td>
<td>-</td>
<td>F M P D C</td>
<td></td>
</tr>
<tr>
<td>ITMP</td>
<td>Intermediate variable in calculation of the soil moisture characteristic</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>ITYL</td>
<td>Intermediate array in calculation of the soil moisture characteristic</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>IUNIT</td>
<td>Unit number for file use</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>IUNTC</td>
<td>Unit that can be used for control file</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>IUNITD</td>
<td>Unit that can be used for input files</td>
<td>-</td>
<td>M F C</td>
<td></td>
</tr>
<tr>
<td>IUNITL</td>
<td>Unit used for log file</td>
<td>-</td>
<td>M F C</td>
<td></td>
</tr>
<tr>
<td>IUNITO</td>
<td>Unit used for output file</td>
<td>-</td>
<td>C F M</td>
<td></td>
</tr>
<tr>
<td>IUNTR</td>
<td>Unit that can be used for rerun file</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>IUNLOG</td>
<td>Unit number in use for log file</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>IUNUNITD</td>
<td>Unit that can be used for input files</td>
<td>-</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>IURA</td>
<td>Parameter used for weather files</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>IUWE</td>
<td>Parameter used for weather files</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>IWEATH</td>
<td>Indicates type of weather data used</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>IYEAR</td>
<td>Year of simulation (integer) y</td>
<td>y</td>
<td>M D F C</td>
<td></td>
</tr>
<tr>
<td>IYARR</td>
<td>Year of simulation (real) y</td>
<td>y</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>KCONTBN</td>
<td>K content of dry beans kg K kg⁻¹ bean DW</td>
<td>C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KDF</td>
<td>Extinction coefficient for leaves (array)</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>KDFL</td>
<td>Extinction coefficient for cacao leaves</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>KDFT</td>
<td>Extinction coefficient for cacao trunk</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>KS</td>
<td>Extinction coefficient for trunk (array)</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>LA</td>
<td>Leaf area ha leaf</td>
<td>C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAI</td>
<td>Leaf area index ha leaf ha⁻¹ ground</td>
<td>C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAI(1)</td>
<td>Leaf area index of the cacao trees ha leaf ha⁻¹ ground</td>
<td>C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAIF</td>
<td>Leaf area index, with maximum value for cacao trees ha leaf ha⁻¹ ground</td>
<td>C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAISUM</td>
<td>Summation of leaf area index used for calculating average LAI ha leaf ha⁻¹ ground</td>
<td>C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAT</td>
<td>Latitude of site dec. degr.</td>
<td>M F S C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LHVAP</td>
<td>Latent heat of water kJ kg⁻¹</td>
<td>S</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOCATION</td>
<td>Location number for which simulations are conducted</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>WTRMES</td>
<td>Indicator of messages from weather system</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>Parameter</td>
<td>Description</td>
<td>Unit</td>
<td>Used in:</td>
<td>In/Out</td>
</tr>
<tr>
<td>----------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>-------------------------------</td>
<td>----------</td>
<td>--------</td>
</tr>
<tr>
<td>LONG</td>
<td>Longitude of site</td>
<td>dec.degr.</td>
<td>M F</td>
<td></td>
</tr>
<tr>
<td>LRTWURTDR</td>
<td>Loss of coarse lateral roots relative to that of water-uptaking roots</td>
<td>kg dead lateral roots kg-1</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>LRTWURTDR</td>
<td></td>
<td>kg dead water-uptaking roots</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LTRT</td>
<td>Length of taproot</td>
<td>m</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>LTRTLL</td>
<td>Length of taproot in lowest soil layer</td>
<td>m</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>LTWURT</td>
<td>Total length of water-uptaking roots</td>
<td>m ha-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>LWURT1</td>
<td>Array with root length (diameter &lt; 1 mm) in different soil layers</td>
<td>m ha-1</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>LWURT2</td>
<td>Array with root length (diameter between 1-2 mm) in different soil layers</td>
<td>m ha-1</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>MAINLRT</td>
<td>Maintenance respiration coefficient for lateral roots</td>
<td>kg CH2O kg-1 DM d-1</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>MAINLV</td>
<td>Maintenance respiration coefficient of leaves</td>
<td>kg CH2O kg-1 DM d-1</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>MAINPD</td>
<td>Maintenance respiration coefficient for pods</td>
<td>kg CH2O kg-1 DM d-1</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>MAINT</td>
<td>Maintenance respiration rate of the crop</td>
<td>kg CH2O ha-1 d-1</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>MAINT</td>
<td></td>
<td>kg CH2O ha-1 d-1</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>MAINTRT</td>
<td>Maintenance respiration coefficient for taproot</td>
<td>kg CH2O kg-1 DM d-1</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>MAINTS</td>
<td>Maintenance respiration, summed over plant parts</td>
<td>kg CH2O kg-1 DM d-1</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>MAINWD</td>
<td>Maintenance respiration coefficient for wood</td>
<td>kg CH2O kg-1 DM d-1</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>MAXLAI</td>
<td>Maximum LAI used in the photosynthesis subroutines</td>
<td>m2 leaves m-2 ground</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>MINCON</td>
<td>Minimum concentration of carbohydrate reserves</td>
<td>kg CH2O kg-1 DW</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>MINLAGE</td>
<td>Minimum leaf age</td>
<td>d</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>MINRES</td>
<td>Minimum size of reserve pool</td>
<td>kg CH2O ha-1</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>MOISTC</td>
<td>Moisture content of dry, fermented beans</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>MSWCA</td>
<td>Gamma in Driessen equation (user-defined)</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>MSWCAT</td>
<td>Gamma in Driessen equation (standard set)</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>NCONTBN</td>
<td>N content of dry beans</td>
<td>kg N kg-1 bean DW</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>NL</td>
<td>Number of soil layers</td>
<td>-</td>
<td>M D D C</td>
<td></td>
</tr>
<tr>
<td>NLA</td>
<td>Number of soil layers, from which water can be extracted</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>NLBM</td>
<td>Maximum number of soil layers</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>NLLM</td>
<td>Counter</td>
<td>-</td>
<td>D C</td>
<td></td>
</tr>
<tr>
<td>NLRT</td>
<td>Maximum number of rooted soil layers</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>NLXM</td>
<td>Maximum number of soil layers</td>
<td>-</td>
<td>D M C D</td>
<td></td>
</tr>
<tr>
<td>NPL</td>
<td>Cacao tree planting density</td>
<td># ha-1</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>NRDTYPE</td>
<td>Number of Driessen soil types defined</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>NRYEARS</td>
<td>Number of years for which simulation should be conducted</td>
<td>y</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>NVGTYP</td>
<td>Number of van Genuchten soil types defined</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>OUTPUT</td>
<td>Flag to indicate if output should be done</td>
<td>-</td>
<td>M D C</td>
<td></td>
</tr>
<tr>
<td>OUTPUTFQ</td>
<td>Frequency at which output is generated</td>
<td>-</td>
<td>M F C</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>Soil water depletion factor</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>PCEW</td>
<td>Water availability factor that reduces photosynthesis due to water stress</td>
<td>-</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>PCEW10</td>
<td>Water availability factor values over last 10 days (array)</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>PCEWXMN</td>
<td>Average water availability factor over last 10 days</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>PCONTBN</td>
<td>P content of dry beans</td>
<td>kg P kg-1 bean DW</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>PENMAN</td>
<td>Penman reference value for potential evapotranspiration</td>
<td>mm d-1</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>PF</td>
<td>relative moisture content as function of pF (array)</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>PFWC00</td>
<td>pF values at a relative water content of 0.0 (array)</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>PFWC01</td>
<td>pF values at a relative water content of 0.1 (array)</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>Parameter</td>
<td>Description</td>
<td>Unit</td>
<td>Used in:</td>
<td>In/Out</td>
</tr>
<tr>
<td>-------------</td>
<td>------------------------------------------------------------------------------</td>
<td>---------------------------</td>
<td>----------</td>
<td>--------</td>
</tr>
<tr>
<td>PFWC02</td>
<td>pF values at a relative water content of 0.2 (array)</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>PFWC03</td>
<td>pF values at a relative water content of 0.3 (array)</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>PFWC04</td>
<td>pF values at a relative water content of 0.4 (array)</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>PFWC05</td>
<td>pF values at a relative water content of 0.5 (array)</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>PFWC06</td>
<td>pF values at a relative water content of 0.6 (array)</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>PFWC07</td>
<td>pF values at a relative water content of 0.7 (array)</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>PFWC08</td>
<td>pF values at a relative water content of 0.8 (array)</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>PFWC09</td>
<td>pF values at a relative water content of 0.9 (array)</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>PFWC10</td>
<td>pF values at a relative water content of 1.0 (array)</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>PGRUSS</td>
<td>Growth per unit sink strength</td>
<td>kg DW ha⁻¹ d⁻¹</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>PI</td>
<td>Value of pi</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>PINT</td>
<td>Daily amount of intercepted rain</td>
<td>mm d⁻¹</td>
<td>M</td>
<td>C</td>
</tr>
<tr>
<td>PLTMOV</td>
<td>Name of plant module</td>
<td>-</td>
<td>C</td>
<td>M</td>
</tr>
<tr>
<td>PODVALUE</td>
<td>Pod index or pod value (number of pods per kg dry beans)</td>
<td># kg⁻¹ DW</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>PRDEL</td>
<td>Time interval between successive outputs</td>
<td>d</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>PRLRTAC</td>
<td>Actual biomass proportion in lateral roots</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>PRLRTID</td>
<td>Ideal biomass proportion in lateral roots</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>PRLVAC</td>
<td>Actual biomass proportion in leaves</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>RPLVID</td>
<td>Ideal biomass proportion in leaves</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>PRODLEVEL</td>
<td>Production level: either potential or water-limited</td>
<td>-</td>
<td>M</td>
<td>F</td>
</tr>
<tr>
<td>PRPDAC</td>
<td>Actual biomass proportion in pods</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>PRPDID</td>
<td>Ideal biomass proportion in pods</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>PRSCALE</td>
<td>Scaling factor for biomass proportions</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>PRSEL</td>
<td>Selection of variables to be included in output and table</td>
<td>-</td>
<td>F</td>
<td>!</td>
</tr>
<tr>
<td>PRTRTAC</td>
<td>Actual biomass proportion in taproot</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>PRTRTID</td>
<td>Ideal biomass proportion in taproot</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>PRWDAC</td>
<td>Actual biomass proportion in wood</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>PRWDID</td>
<td>Ideal biomass proportion in wood</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>PRWU</td>
<td>Potential water uptake rate</td>
<td>mm m⁻² root area</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>PSCH</td>
<td>Psychrometer coefficient</td>
<td>kPa °C⁻¹</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>PTRANS</td>
<td>Daily potential transpiration rate</td>
<td>mm d⁻¹</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>Q10</td>
<td>Factor accounting for increase of maintenance</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>RAE</td>
<td>Aerodynamic resistance</td>
<td>s m⁻¹</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>RAIN</td>
<td>Daily amount of rainfall</td>
<td>mm d⁻¹</td>
<td>M</td>
<td>F</td>
</tr>
<tr>
<td>RAI NCU</td>
<td>Cumulative rainfall</td>
<td>mm</td>
<td>D</td>
<td>M</td>
</tr>
<tr>
<td>RAINS</td>
<td>Daily amount of rain reaching the soil</td>
<td>mm d⁻¹</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>RCAN</td>
<td>Canopy resistance</td>
<td>s m⁻¹</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>RDD</td>
<td>Daily short-wave radiation</td>
<td>J m⁻² d⁻¹</td>
<td>F</td>
<td>M</td>
</tr>
<tr>
<td>RDLI</td>
<td>Net daily longwave radiation</td>
<td>J m⁻² d⁻¹</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>RDLII</td>
<td>Net longwave radiation</td>
<td>J m⁻² s⁻¹</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>RDLO</td>
<td>Daily long-wave radiation</td>
<td>J m⁻² d⁻¹</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>RDLROI</td>
<td>Long-wave radiation</td>
<td>J m⁻² s⁻¹</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>RDLV</td>
<td>Relative death rate of leaves</td>
<td>d⁻¹</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>RDN</td>
<td>Net radiation flux at canopy surface</td>
<td>J m⁻² d⁻¹</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>RDSLr</td>
<td>Rate of state variable days since last rain</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>RESOIL</td>
<td>Relative contribution to evaporation of layer (array)</td>
<td>mm</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>RF</td>
<td>Reflection (albedo) of surface</td>
<td>-</td>
<td>S</td>
<td>M</td>
</tr>
<tr>
<td>RFS</td>
<td>Reflection (albedo) of surface</td>
<td>-</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>Parameter</td>
<td>Description</td>
<td>Unit</td>
<td>Used in:</td>
<td>In/Out</td>
</tr>
<tr>
<td>-----------</td>
<td>------------------------------------------------------------------------------</td>
<td>---------</td>
<td>----------</td>
<td>--------</td>
</tr>
<tr>
<td>RHOCP</td>
<td>Density of dry air</td>
<td>kg m⁻³</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>RLEAF</td>
<td>Leaf resistance</td>
<td>s m⁻¹</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>RNOFCU</td>
<td>Cumulative runoff</td>
<td>mm</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>RNOFF</td>
<td>Daily rate of runoff</td>
<td>mm d⁻¹</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>RSETRD</td>
<td>Parameter used for weather files</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>RSETRG</td>
<td>Parameter used for weather files</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>RTOLV</td>
<td>Relative turnover rate of leaves</td>
<td>d⁻¹</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>RTOPD</td>
<td>Relative turnover rate of pods</td>
<td>d⁻¹</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>RTOWURT</td>
<td>Relative turnover rate of water-upuptaking roots</td>
<td>d⁻¹</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>SHGHL</td>
<td>Lower height of shade tree crowns</td>
<td>m</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>SHGHHT</td>
<td>Upper height of shade tree crowns</td>
<td>m</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>SIGLEN</td>
<td>Length of string</td>
<td>-</td>
<td>D F</td>
<td></td>
</tr>
<tr>
<td>SIGMA</td>
<td>Stefan-Boltzmann constant</td>
<td>J m⁻² d⁻¹ °K⁻¹</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>SKDFL</td>
<td>Extinction coefficient for leaves of shade trees</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>SLA</td>
<td>Specific leaf area of leaf class (array)</td>
<td>ha leaf kg⁻¹ leaf DW</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>SLAI</td>
<td>Leaf area index of shade trees</td>
<td>ha leaf ha⁻¹ ground</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>SLAMOD</td>
<td>Modifier of SLA value, depending on shading</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SLAR1A</td>
<td>Regression coefficient on leaf area per unit leaf biomass</td>
<td>ha leaf kg⁻¹ leaf DW kg⁻¹</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>SLAR1B</td>
<td>Regression coefficient on leaf area per unit leaf biomass</td>
<td>ha leaf kg⁻¹ leaf DW</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>SLAR2A</td>
<td>Regression coefficient on leaf area per unit leaf biomass</td>
<td>ha leaf kg⁻¹ leaf DW kg⁻¹</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>SLAR2B</td>
<td>Regression coefficient on leaf area per unit leaf biomass</td>
<td>ha leaf kg⁻¹ leaf DW</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>SOILTYPE</td>
<td>Soil type to be used in model simulation</td>
<td>-</td>
<td>M F D</td>
<td></td>
</tr>
<tr>
<td>SPRTL1</td>
<td>Specific root length, root diameter &lt; 1 mm</td>
<td>m kg⁻¹ DM</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>SPRTL2</td>
<td>Specific root length, root diameter between 1-2 mm</td>
<td>m kg⁻¹ DM</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>SSPOD</td>
<td>Sink strength of pods in a pod class</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>SSTB</td>
<td>Table with sink strength values for pod growth</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>STAGE</td>
<td>Development stage of pods in a pod class</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>STEMFL</td>
<td>Daily rate of stem flow</td>
<td>mm d⁻¹</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>STFLA</td>
<td>Regression coefficient for stem flow</td>
<td>-</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>STFLB</td>
<td>Regression coefficient for stem flow</td>
<td>mm d⁻¹</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>STRING</td>
<td>String</td>
<td>-</td>
<td>F D</td>
<td></td>
</tr>
<tr>
<td>STRTYR</td>
<td>Start year of the simulation</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>STRUN</td>
<td>Start day of the simulation</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>STRUNF</td>
<td>Whether start day of simulation was found</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>STTIME</td>
<td>Start time of simulation</td>
<td>d</td>
<td>M C F</td>
<td></td>
</tr>
<tr>
<td>SUM</td>
<td>total amount of water available for evaporation</td>
<td>mm</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>SW</td>
<td>Specific weight of wood</td>
<td>kg m⁻³</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>SWINPUT</td>
<td>Switch for initial cacao tree input: either age or biomass</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>SWIT6</td>
<td>Switch for type of initialization in water balance module</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>SWIT8</td>
<td>Switch for type of equation used in water balance module</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>SWIT9</td>
<td>Switch for type of soil input in water balance module</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>TAU</td>
<td>Time coefficient</td>
<td>d</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>TEFF</td>
<td>Temperature effect of maintenance respiration</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>TERMNL</td>
<td>Flag to indicate if simulation is to stop</td>
<td>-</td>
<td>C M F</td>
<td></td>
</tr>
<tr>
<td>TFALA</td>
<td>Regression coefficient for throughfall of rain</td>
<td>-</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>TFALB</td>
<td>Regression coefficient for throughfall of rain</td>
<td>mm d⁻¹</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>Parameter</td>
<td>Description</td>
<td>Unit</td>
<td>Used in:</td>
<td>In/Out</td>
</tr>
<tr>
<td>-------------</td>
<td>------------------------------------------------------------------------------</td>
<td>---------------</td>
<td>----------</td>
<td>--------</td>
</tr>
<tr>
<td>TFALL</td>
<td>Daily throughfall of rain through the canopy</td>
<td>mm d⁻¹</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>TIME</td>
<td>Time of simulation</td>
<td>d</td>
<td>C M F</td>
<td></td>
</tr>
<tr>
<td>TKL</td>
<td>Thickness of soil compartment (array)</td>
<td>m</td>
<td>D M C</td>
<td></td>
</tr>
<tr>
<td>TKLTOT</td>
<td>Summed thickness of soil compartments</td>
<td>m</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>TKLX</td>
<td>thickness of soil compartments</td>
<td>m</td>
<td>P D</td>
<td></td>
</tr>
<tr>
<td>TMAV</td>
<td>Daily average temperature</td>
<td>°C</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>TMAVD</td>
<td>Daytime average temperature</td>
<td>°C</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>TMDA</td>
<td>24 hour average temperature</td>
<td>°C</td>
<td>S M</td>
<td></td>
</tr>
<tr>
<td>TMDI</td>
<td>Temperature tolerance (switches between single and iterative Penman)</td>
<td>-</td>
<td>S M</td>
<td></td>
</tr>
<tr>
<td>TMMN</td>
<td>Daily minimum temperature</td>
<td>°C</td>
<td>C M F</td>
<td></td>
</tr>
<tr>
<td>TMMX</td>
<td>Daily maximum temperature</td>
<td>°C</td>
<td>M F C</td>
<td></td>
</tr>
<tr>
<td>TMP</td>
<td>intermediate variable to check availability of soil moisture for transpiration</td>
<td>mm</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>TNASS</td>
<td>Cumulative CO₂ assimilation</td>
<td>kg CO₂ ha⁻¹</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>TOLRT</td>
<td>Turnover rate for lateral roots</td>
<td>kg d⁻¹</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>TOLV</td>
<td>Turnover rate for leaves</td>
<td>kg d⁻¹</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>TOPD</td>
<td>Turnover rate for pods</td>
<td>kg d⁻¹</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>TOPD10</td>
<td>Turnover rate for pods for 10 days (array)</td>
<td>kg d⁻¹</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>TOREQ</td>
<td>Total required biomass for turnover</td>
<td>kg d⁻¹</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>TOWD</td>
<td>Turnover rate for wood</td>
<td>kg d⁻¹</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>TOWURRT</td>
<td>Turnover rate for water-uptaking roots</td>
<td>kg d⁻¹</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>TRANSC</td>
<td>Characteristic potential transpiration rate</td>
<td>mm d⁻¹</td>
<td>C I</td>
<td></td>
</tr>
<tr>
<td>TRCH</td>
<td>Actual rate of transpiration per soil layer (array)</td>
<td>mm d⁻¹</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>TREF</td>
<td>Reference temperature for calculation of maintenance respiration</td>
<td>°C</td>
<td>C I</td>
<td></td>
</tr>
<tr>
<td>TRMIS</td>
<td>Fraction light transmission through shade canopy</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>TRW</td>
<td>Transpiration rate, summed for all layers</td>
<td>mm d⁻¹</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>TRWCU</td>
<td>Cumulative transpiration in time</td>
<td>mm</td>
<td>D M</td>
<td></td>
</tr>
<tr>
<td>TRWL</td>
<td>Daily actual transpiration rate per soil layer</td>
<td>mm d⁻¹</td>
<td>N D M C</td>
<td>Q</td>
</tr>
<tr>
<td>TSS</td>
<td>Summed sink strength of all pod classes</td>
<td>-</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>TYL</td>
<td>Driessen texture class for soil layer</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>VAR</td>
<td>amount of water available for evaporation of layer (array)</td>
<td>mm</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>VDWURTRA</td>
<td>Regression coefficient on vertical distribution of fine roots</td>
<td>-</td>
<td>C</td>
<td>!</td>
</tr>
<tr>
<td>VDWURTRB</td>
<td>Regression coefficient on vertical distribution of fine roots</td>
<td>kg DW ha⁻¹ m⁻²</td>
<td>C</td>
<td>!</td>
</tr>
<tr>
<td>VGA</td>
<td>parameter of the van Genuchten equation</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>VGAT</td>
<td>parameter of the van Genuchten equation</td>
<td>cm⁻¹</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>VGM</td>
<td>parameter of the van Genuchten equation</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>VGN</td>
<td>parameter of the van Genuchten equation</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>VGNT</td>
<td>parameter of the van Genuchten equation</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>VGR</td>
<td>parameter of the van Genuchten equation</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>VGWRT</td>
<td>parameter of the van Genuchten equation</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>VGWST</td>
<td>parameter of the van Genuchten equation</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>VP</td>
<td>Early morning vapour pressure</td>
<td>kPa</td>
<td>M F S</td>
<td></td>
</tr>
<tr>
<td>VPD</td>
<td>Vapour pressure deficit</td>
<td>kPa</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>VPS</td>
<td>Saturated vapour pressure</td>
<td>kPa</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>VPSL</td>
<td>Vapour pressure slope</td>
<td>kPa °C⁻¹</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td>WBNCUM</td>
<td>Cumulative weight of harvested dry, fermented beans</td>
<td>kg DW ha⁻¹</td>
<td>C</td>
<td>Q</td>
</tr>
<tr>
<td>Parameter</td>
<td>Description</td>
<td>Unit</td>
<td>Used in:</td>
<td>In/Out</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------</td>
<td>------</td>
<td>----------</td>
<td>--------</td>
</tr>
<tr>
<td>WCAD</td>
<td>volumetric water content at air dry of layer (array)</td>
<td>cm³ H₂O cm⁻³ soil</td>
<td>D M</td>
<td></td>
</tr>
<tr>
<td>WCADX</td>
<td>volumetric water content at air dry of layer (copy of array)</td>
<td>cm³ H₂O cm⁻³ soil</td>
<td>P D</td>
<td></td>
</tr>
<tr>
<td>WCFC</td>
<td>volumetric water content at field capacity of layer (array)</td>
<td>cm³ H₂O cm⁻³ soil</td>
<td>D M</td>
<td></td>
</tr>
<tr>
<td>WCFCX</td>
<td>volumetric water content at field capacity of layer (copy of array)</td>
<td>cm³ H₂O cm⁻³ soil</td>
<td>P D C</td>
<td></td>
</tr>
<tr>
<td>WCL</td>
<td>volumetric soil moisture content of layer, locally used (array)</td>
<td>cm³ H₂O cm⁻³ soil</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>WCLCH</td>
<td>rate of change of water content of layer (array)</td>
<td>mm d⁻¹</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>WCLQT</td>
<td>volumetric soil water content per layer (array)</td>
<td>cm³ H₂O cm⁻³ soil</td>
<td>P D M C</td>
<td></td>
</tr>
<tr>
<td>WCLQTM</td>
<td>initial volumetric soil moisture content of layer (array)</td>
<td>cm³ H₂O cm⁻³ soil</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>WCLT</td>
<td>volumetric soil moisture content of layer at saturation (array)</td>
<td>cm³ H₂O cm⁻³ soil</td>
<td>D M</td>
<td></td>
</tr>
<tr>
<td>WCLTT</td>
<td>volumetric soil moisture content at saturation in Driessen eq. (standard set)</td>
<td>cm³ H₂O cm⁻³ soil</td>
<td>D P C</td>
<td></td>
</tr>
<tr>
<td>WCST</td>
<td>volumetric soil moisture content of layer at saturation (array)</td>
<td>cm³ H₂O cm⁻³ soil</td>
<td>D M</td>
<td></td>
</tr>
<tr>
<td>WCSTT</td>
<td>volumetric soil moisture content at saturation in Driessen eq. (user-defined)</td>
<td>cm³ H₂O cm⁻³ soil</td>
<td>D P</td>
<td></td>
</tr>
<tr>
<td>WCTMP</td>
<td>Temporal water content</td>
<td>mm</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>WCUM</td>
<td>cumulative amount of water in the soil profile</td>
<td>mm</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>WCUUMCH</td>
<td>rate of change in cumulative amount of water in the soil profile</td>
<td>mm</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>WCUMO</td>
<td>cumulative amount of water in the soil profile after the previous time step</td>
<td>mm</td>
<td>D M</td>
<td></td>
</tr>
<tr>
<td>WCWET</td>
<td>Volumetric water content where water logging begins</td>
<td>cm³ H₂O cm⁻³ soil</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>WCWP</td>
<td>volumetric water content at wilting point of layer (array)</td>
<td>cm³ H₂O cm⁻³ soil</td>
<td>D M</td>
<td></td>
</tr>
<tr>
<td>WCWPX</td>
<td>volumetric water content at wilting point</td>
<td>cm³ H₂O cm⁻³ soil</td>
<td>P D</td>
<td></td>
</tr>
<tr>
<td>WDLVDR</td>
<td>Loss of wood relative to that of leaves</td>
<td>kg dead wood kg⁻¹ dead leaves</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>WEFF</td>
<td>ratio of transpiration and total use of water in the balance</td>
<td>mm mm⁻¹</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>WILTP</td>
<td>pF value for wilting point</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>WLEAF</td>
<td>Biomass of leaves in leaf class (array)</td>
<td>kg DW ha⁻¹</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>WLEAFTOT</td>
<td>Total biomass of leaves in all leaf classes</td>
<td>kg DW ha⁻¹</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>WLRT</td>
<td>Actual lateral root biomass</td>
<td>kg DW ha⁻¹</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>WLRTD</td>
<td>Weight of dead lateral roots</td>
<td>kg DW ha⁻¹</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>WLRTI</td>
<td>Initial lateral root biomass</td>
<td>kg DW ha⁻¹</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>WLV</td>
<td>Actual leaf biomass</td>
<td>kg DW ha⁻¹</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>WLVD</td>
<td>Weight of dead leaves</td>
<td>kg DW ha⁻¹</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>WLVI</td>
<td>Initial leaf biomass</td>
<td>kg DW ha⁻¹</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>WN</td>
<td>Average wind speed</td>
<td>m s⁻¹</td>
<td>M F S</td>
<td></td>
</tr>
<tr>
<td>WPD</td>
<td>Actual pod biomass</td>
<td>kg DW ha⁻¹</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>WPDCUM</td>
<td>Cumulative weight of harvested pods</td>
<td>kg DW ha⁻¹</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>WPD</td>
<td>Initial biomass of pods</td>
<td>kg DW ha⁻¹</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>WPOD</td>
<td>Biomass of pods in pod category (array)</td>
<td>kg DW ha⁻¹</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>WPDTOT</td>
<td>Total biomass of pods in all pod classes</td>
<td>kg DW ha⁻¹</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>WREL</td>
<td>intermediate variable in calculation of soil characteristic according to Van Genuchten</td>
<td>-</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>WRES</td>
<td>Weight of reserve pool</td>
<td>kg CH₂O ha⁻¹</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>WRES1</td>
<td>Weight of reserve pool after accounting for maintenance costs</td>
<td>kg CH₂O ha⁻¹</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>WRES2</td>
<td>Weight of reserve pool after accounting for replacement costs</td>
<td>kg CH₂O ha⁻¹</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>WRT</td>
<td>Actual root biomass (both lateral and taproot)</td>
<td>kg DW ha⁻¹</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>WRTI</td>
<td>Initial root biomass (both lateral and taproot)</td>
<td>kg DW ha⁻¹</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>WSTAT</td>
<td>Status code from weather system</td>
<td>-</td>
<td>M F</td>
<td></td>
</tr>
<tr>
<td>WTOT</td>
<td>Actual total biomass</td>
<td>kg DW ha⁻¹</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>Parameter</td>
<td>Description</td>
<td>Unit</td>
<td>Used in:</td>
<td>In/Out</td>
</tr>
<tr>
<td>-------------</td>
<td>-------------------------------------------------------</td>
<td>-----------------------</td>
<td>----------</td>
<td>--------</td>
</tr>
<tr>
<td>WTOTCUM</td>
<td>Cumulative total biomass</td>
<td>kg DW ha-1</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>WTOTI</td>
<td>Total initial dry weight of the cacao tree</td>
<td>kg DW tree-1</td>
<td>C</td>
<td>!</td>
</tr>
<tr>
<td>WTOTMIN</td>
<td>Total dry weight of the cacao tree at which fruiting starts</td>
<td>kg DW tree-1</td>
<td>C</td>
<td>!</td>
</tr>
<tr>
<td>WTOTPP</td>
<td>Actual total biomass per tree</td>
<td>kg DW ha-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>WTRDIR</td>
<td>Directory in which weather data are stored</td>
<td>-</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>WTRT</td>
<td>Actual taproot biomass</td>
<td>kg DW ha-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>WTRTER</td>
<td>Flag whether weather can be used by model</td>
<td>-</td>
<td>M F</td>
<td></td>
</tr>
<tr>
<td>WTRTI</td>
<td>Initial weight of tap root</td>
<td>kg DM ha-1</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>WTWURT</td>
<td>Total biomass of water-uptaking roots</td>
<td>kg DW ha-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>WTWURTR</td>
<td>Total biomass of water-uptaking roots, as calculated by regression</td>
<td>kg DW ha-1</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>WUSED</td>
<td>Indicator of used weather variables</td>
<td>-</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>WWD</td>
<td>Actual wood biomass</td>
<td>kg DW ha-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>WWDD</td>
<td>Biomass of dead wood</td>
<td>kg DW ha-1</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>WWDI</td>
<td>Initial wood biomass</td>
<td>kg DW ha-1</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>WWURT</td>
<td>Biomass of water-uptaking roots per soil layer(array)</td>
<td>kg DW ha-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>WWURTR</td>
<td>Biomass of water-uptaking roots per soil layer, as calculated by regression (array)</td>
<td>kg DW ha-1</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>YEAR</td>
<td>Calendar year</td>
<td>-</td>
<td>M F</td>
<td>O</td>
</tr>
<tr>
<td>YGPHOT</td>
<td>Annual total gross CH2O assimilation</td>
<td>kg CH2O ha-1 y-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>YGTOT</td>
<td>Annual total biomass production</td>
<td>kg DW ha-1 y-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>YGTOTAB</td>
<td>Annual total aboveground biomass production</td>
<td>kg DW ha-1 y-1</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>YHARPD</td>
<td>Annual number of harvested pods</td>
<td># y-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>YHI</td>
<td>Annual harvest index</td>
<td>-</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>YHINCR</td>
<td>Annual harvest increment</td>
<td>-</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>YKLOSS</td>
<td>Annual loss of K from harvested beans</td>
<td>kg ha-1 y-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>YLDBN</td>
<td>Daily yield of dry, fermented beans</td>
<td>kg DW ha-1 d-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>YLDPD</td>
<td>Daily yield of pods</td>
<td>kg DW ha-1 d-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>YLVD</td>
<td>Annual production of dead leaf biomass</td>
<td>kg DW ha-1 y-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>YMNBH</td>
<td>Mean annual butter hardness</td>
<td>-</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>YMNIPOD</td>
<td>Mean annual pod ripening period</td>
<td>d</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>YMNLAI</td>
<td>Mean annual leaf area index (LAI)</td>
<td>ha leaf ha-1 ground</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>YNLOSS</td>
<td>Annual loss of N from harvested beans</td>
<td>kg N ha-1 y-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>YPLOSS</td>
<td>Annual loss of P from harvested beans</td>
<td>kg P ha-1 y-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>YRAIN</td>
<td>Annual rainfall</td>
<td>mm y-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>YRDD</td>
<td>Annual short-wave radiation</td>
<td>MJ m-2 y-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>YRDEFF</td>
<td>Radiation &quot;efficiency&quot; of bean production</td>
<td>kg DW ha-1 (MJ m-2)-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>YRNEFF</td>
<td>Rain &quot;efficiency&quot; of bean production</td>
<td>kg DW ha-1 mm</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>YRO</td>
<td>year of previous irrigation</td>
<td>yr</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>YTRANS</td>
<td>Annual amount of actual transpiration</td>
<td>mm y-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>YWDD</td>
<td>Annual production of dead wood biomass</td>
<td>kg DW ha-1 y-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>YYLDBN</td>
<td>Annual yield of dry, fermented beans</td>
<td>kg DW ha-1 y-1</td>
<td>C</td>
<td>O</td>
</tr>
<tr>
<td>YYLDPD</td>
<td>Annual yield of pods</td>
<td>kg DW ha-1 y-1</td>
<td>C</td>
<td>O</td>
</tr>
</tbody>
</table>