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

WAGENINGEN UNIVERSITY
PLANT SCIENCES

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 agro-technological 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.

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P.A. Zuidema, W. Gerritsma, L. Mommer & P.A. Leffelaar
A physiological production model for cacao: Model description and technical program manual of CASE2 version 2.2, 2003. Department of Plant Sciences, Wageningen University, the Netherlands.

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

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"*

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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).

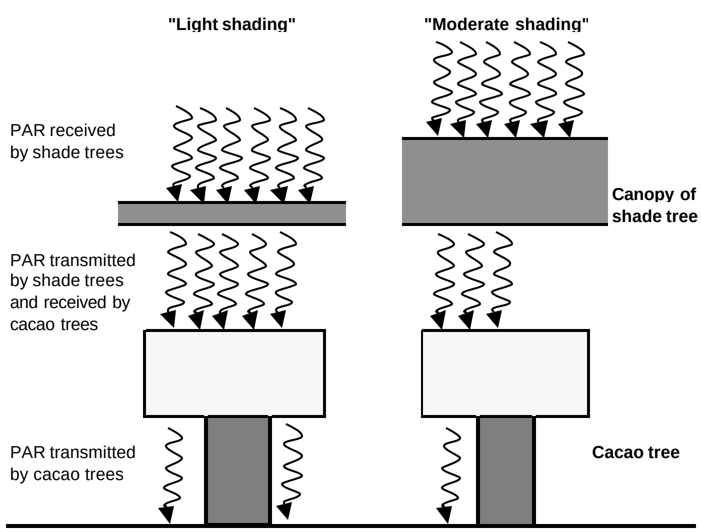

Figure 2.1. Shading and transmission of light in shaded cacao plantations, as modelled in CASE2. Arrows denote photosynthetically active radiation .

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.

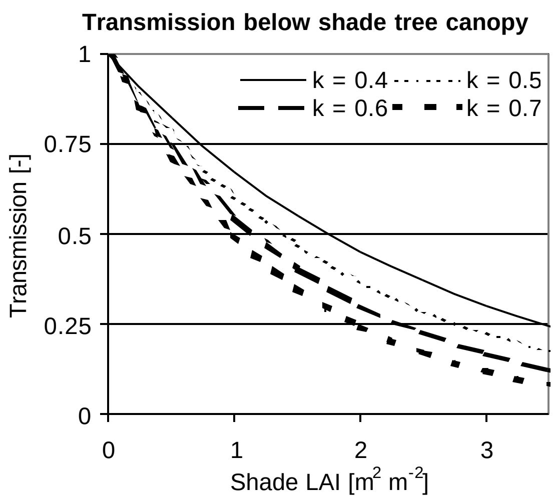

Figure 2.2. Transmission of light through shade canopy as a function of leaf area index (LAI) and extinction coefficient (k) of shade trees. Both LAI and k of shade trees can be adjusted in CASE2.

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.

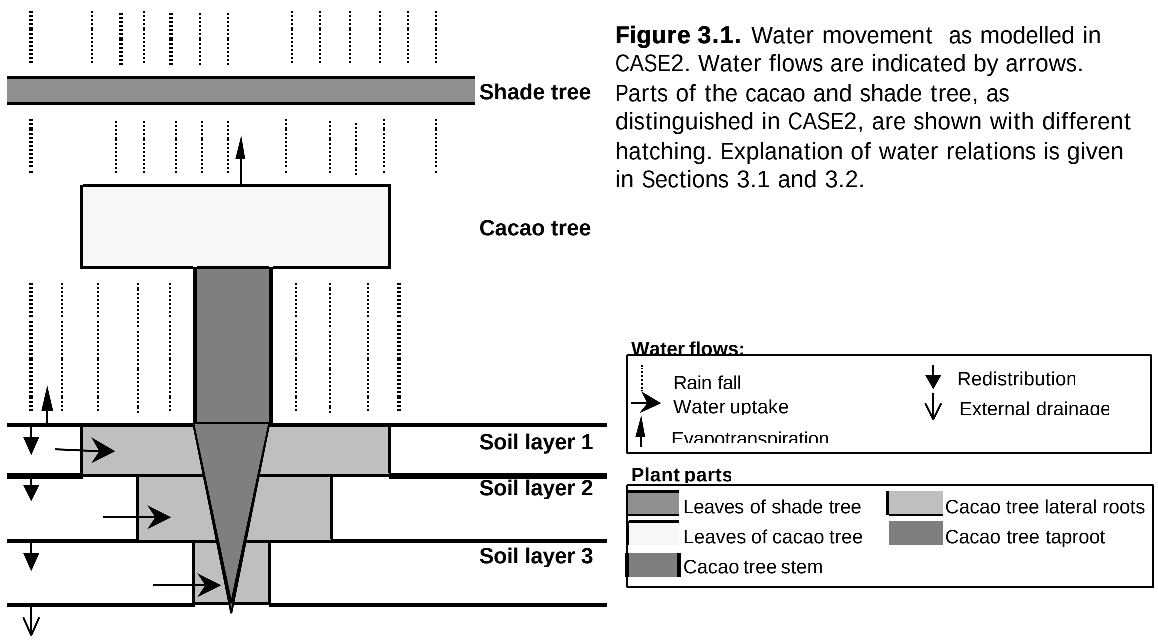

Figure 3.1. Water movement as modelled in CASE2. Water flows are indicated by arrows. Parts of the cacao and shade tree, as distinguished in CASE2, are shown with different hatching. Explanation of water relations is given in Sections 3.1 and 3.2.

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.

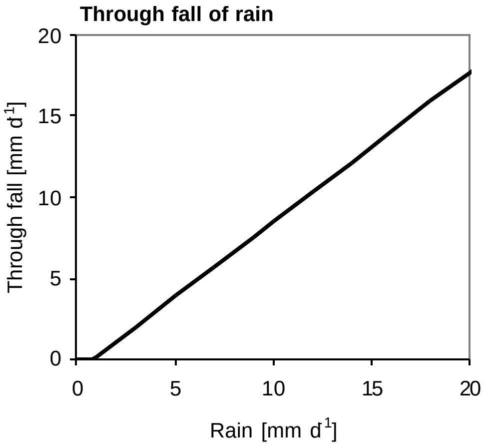

Figure 3.2. Through fall of rain in cacao canopies in relation with rainfall, as modelled in CASE2. The linear relation is based on empirical data from a plantation in Cameroon. Relation: Throughfall = 0.93 * Rainfall -0.8. Source: Boyer, 1970.

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 (φ) is calculated as $\varphi = ET_a/ET_p$, 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).

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

In this equation *ET* is the daily potential evapotranspiration (in mm d^{-1}); Δ is the slope of the vapour pressure curve (kPa $°C^{-1}$); R_n is the net radiation flux at canopy surface (kW m^{-2}); ρ 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); γ is the psychrometer coefficient (kPa $°C^{-1}$); λ 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 s m^{-1}, 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 s m^{-1} for a situation without water stress; 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.

Code	Description	Gamma	Volumetric water content (WC, mm H_2O mm^{-1} soil) at			
			Saturated	field capacity	wilting point	air dry
1	Coarse sand	0.0853	0.395	0.065	0.000	0.000
2	Medium coarse sand	0.045	0.365	0.141	0.005	0.000
3	Medium fine sand	0.0366	0.350	0.161	0.011	0.000
4	Fine sand	0.0255	0.364	0.212	0.033	0.000
5	Humous loamy medium coarse sand	0.0135	0.470	0.353	0.133	0.014
6	Light loamy medium coarse sand	0.0153	0.394	0.285	0.094	0.007
7	Loamy medium coarse sand	0.0243	0.301	0.180	0.031	0.001
8	Loamy fine sand	0.0299	0.439	0.233	0.027	0.000
9	Sandy loam	0.0251	0.465	0.273	0.044	0.001
10	Loess loam	0.0156	0.465	0.334	0.108	0.008
11	Fine sandy loam	0.0186	0.504	0.340	0.088	0.004
12	Silt loam	0.0165	0.509	0.359	0.108	0.007
13	Loam	0.0164	0.503	0.355	0.108	0.007
14	Sandy clay loam	0.0101	0.432	0.349	0.168	0.031
15	Silty clay loam	0.0108	0.475	0.378	0.173	0.029
16	Clay loam	0.0051	0.445	0.399	0.276	0.118
17	Light clay	0.0085	0.453	0.378	0.204	0.050
18	Silty clay	0.0059	0.507	0.447	0.292	0.109
19	Heavy clay	0.0043	0.540	0.493	0.361	0.177
20	Peat	0.0108	0.863	0.686	0.314	0.052

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).

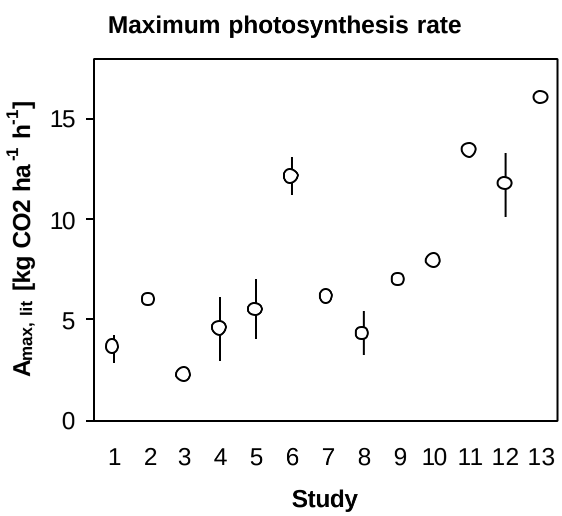

Figure 4.1. Maximum photosynthesis rates for cacao as obtained in 13 studies. Maximum photosynthesis rates were generally measured in high-light conditions. In case of multiple measurements, bars denote the range of observed rates and circles the average value. The studies are in chronological order. 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).

The maximum photosynthetic rate at light saturation (A_{max}) is calculated as the highest rate found in studies on cacao trees ($A_{max, lit}$, 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

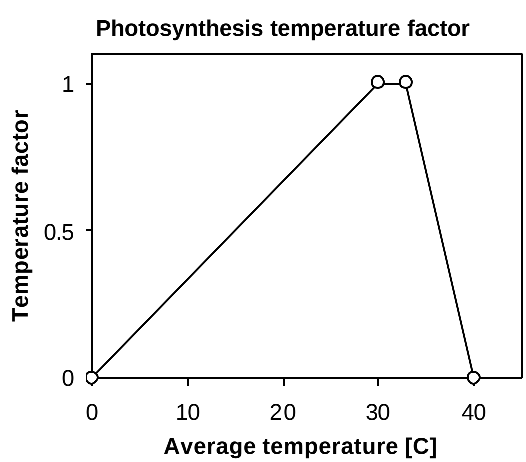

Figure 4.2. Relation between a temperature factor and average temperature, as used to account for the effect of temperature on maximum photosynthesis rate in CASE2 for low (Joly & Hahn, 1991) and high temperatures (temperatures above 33ºC are assumed to reduce photosynthesis rates).

leaves, but for layers of leaves in the canopy.

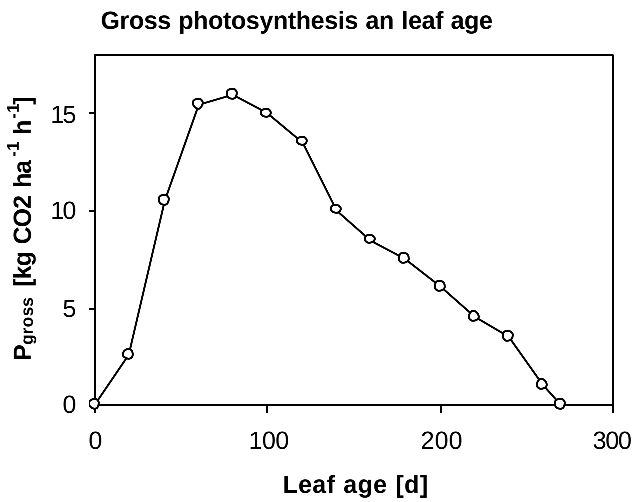

Figure 4.3. Relation between gross photosynthesis and leaf age for cacao leaves in high light conditions in a Brazilian plantation. The initial lower photosynthesis for new leaves is taken into account in CASE2, by a photosynthesis reduction factor. Source: Miyaji et al 1997. The data in the graph are based on the information on net photosynthesis and respiration as given in the source.

The rate of photosynthesis for cacao leaves is calculated using the maximum photosynthesis rate at light saturation (A_{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 4.1 Nitrogen and mineral composition of cacao tree organs and the computed maintenance coefficients. The mineral fraction is based on the sum of P, K, Ca and Mg concentrations. These calculations are for a temperature of 27 ^oC. Sources: Alpizar *et al.* 1986, Boyer 1973, Lotodé & Jadin 1981, Santana & Cabala-Rosand 1982, Thong & Ng 1978, and Teoh *et al.* 1986.

Plant organ	N	Minerals	Maintenance coefficient
	[%]	[%]	[$gCH_2O\ g^{-1}\ d^{-1}$]
leaves	1.91	2.7	$6.9\ 10^{-3}$
sapwood	0.43	1.8	$2.4\ 10^{-3}$
roots	1.08	2.5	$4.7\ 10^{-3}$
fruits	3.62	8.7	$1.6\ 10^{-2}$

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.

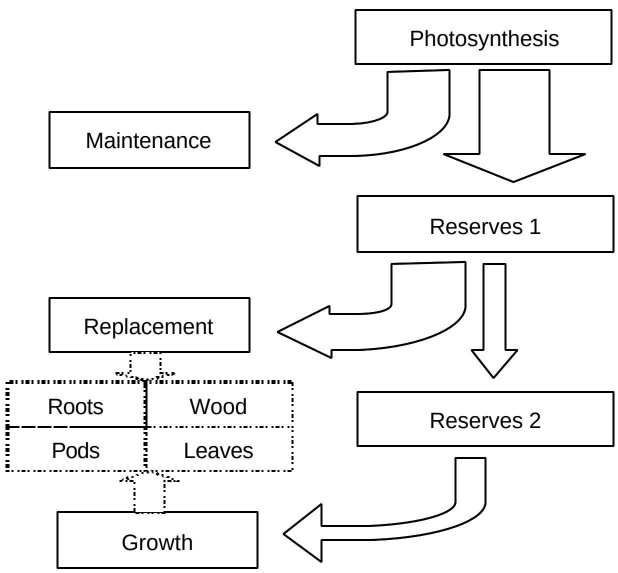

Figure 4.4. Flow diagram showing the sequence of carbohydrate (assimilate) use as modelled in CASE2. Boxes with full borders denote amounts of carbohydrates; those with dotted borders denote amounts of biomass. Full arrows denote fluxes of carbohydrates; dotted arrows denote conversions from carbohydrates to biomass and allocation to the different organs.

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.

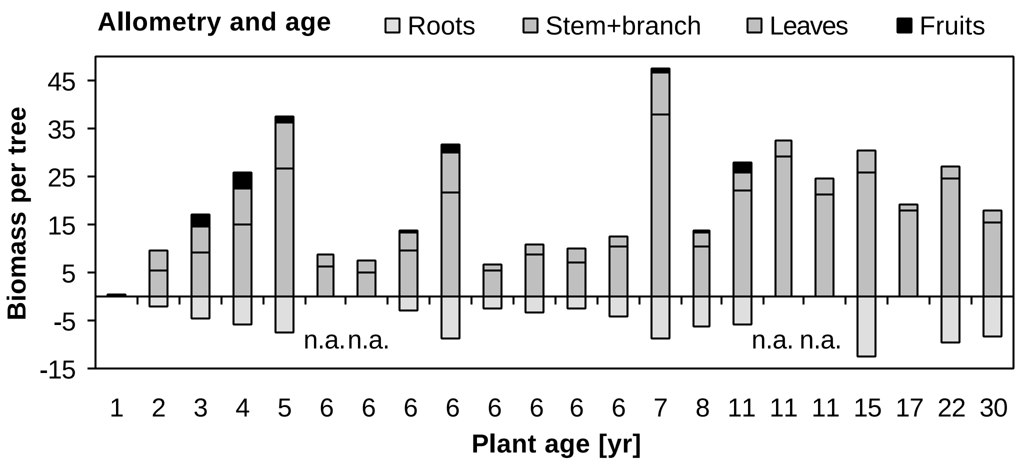

Figure 4.5. Distribution of biomass of cacao trees over different plant part, in relation to their age. The data for this graph are derived from various field studies, in which cacao trees were completely (or partially) cut down, divided in different plant parts and weighted. The measured cacao trees 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.

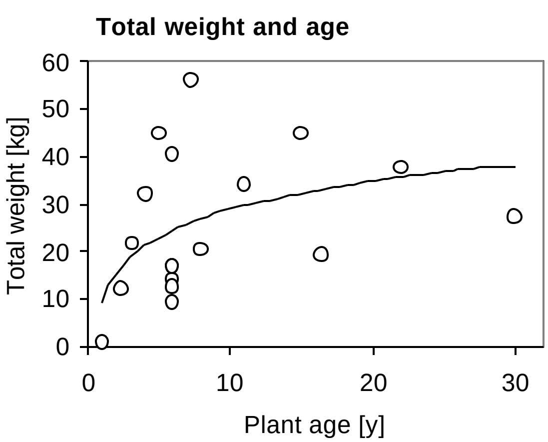

Figure 4.6. Relation between total dry weight and age of cacao trees from plantations in different countries. Circles denote individuals trees (or average value for several trees), as reported in the sources, the drawn line is a logarithmic regression line through the data points. The regression line explains 21% of the variation in total weight by plant age (R^2 = 0.2097). The equation is: $y = 8.46Ln(x) + 9.40$. 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.

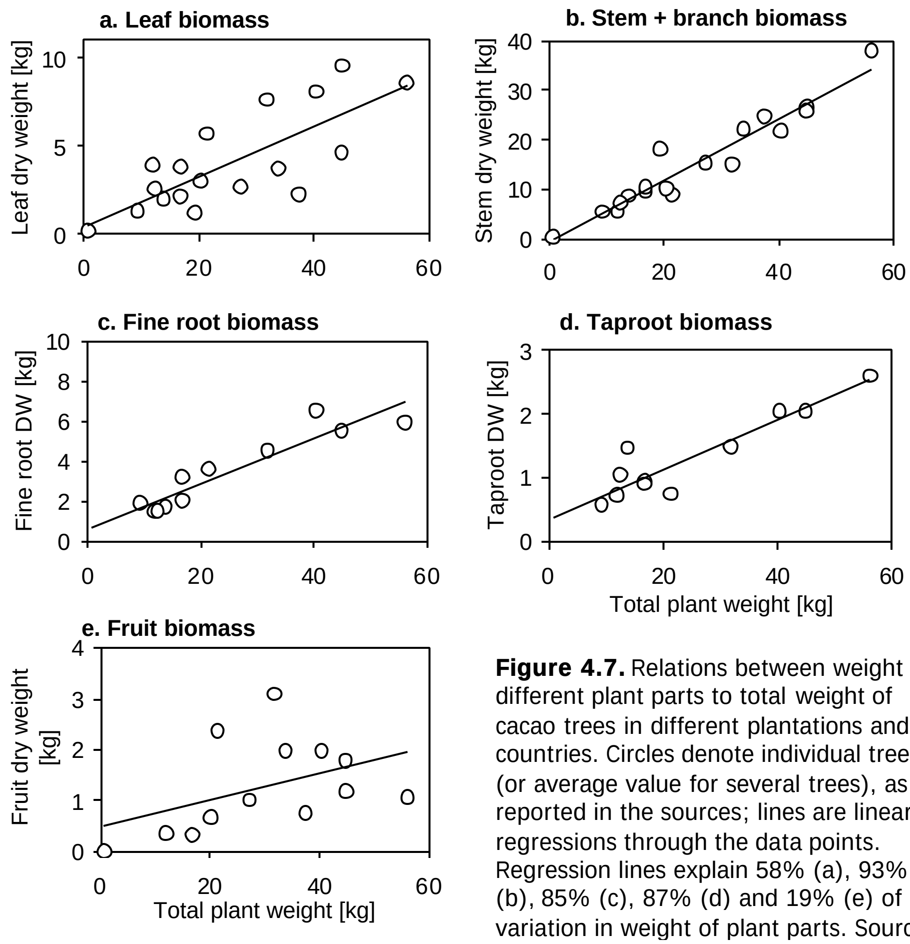

Figure 4.7. Relations between weight of different plant parts to total weight of cacao trees in different plantations and countries. Circles denote individual trees (or average value for several trees), as reported in the sources; lines are linear regressions through the data points. Regression lines explain 58% (a), 93% (b), 85% (c), 87% (d) and 19% (e) of the variation in weight of plant parts. Sources: as in Figure 4.5, but excluding Alpizar et al. 1996 and Beer et al 1990.

This rate of turnover differs between plant organs. The partitioning of carbohydrates in CASE2 takes the turnover into account and is done is 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: $dW_{lost}/dt = R_{turnover} * W$, in which dW_{lost}/dt is the daily loss rate of dry weight (kg d^{-1}), $R_{turnover}$ is the relative turnover rate (d^{-1}, Muñoz & de Beer 2001) and W is the fine root dry weight. For leaves and fruits dW_{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).

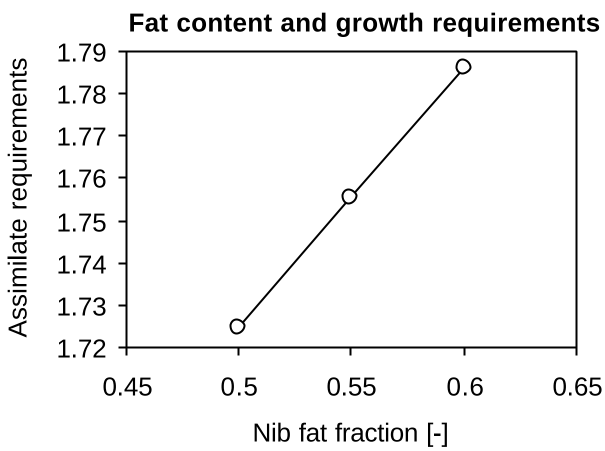

Figure 4.8. Relation between assimilation requirements for the production of pods and fat fraction in nibs (cotyledons of the cacao bean), as used in CASE2. The assimilation requirements are expressed in kg carbohydrates required for the production of 1 kg of pods. These values are calculated based on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

Table 4.2. Biochemical composition and energetic production costs for different plant parts of cocoa: leaves, roots, wood and pods. The carbon content (C) [kg C kg^{-1}], assimilate requirement (G) [kg CH_2O kg^{-1}] and CO_2 production factor (F) [kg CO_2 kg^{-1}] are derived from the chemical composition, using conversion factors for each of the chemical components (Penning de Vries & van Laar 1982). The assimilate requirement is used to convert available carbohydrates into biomass in CASE2. For pods, the assimilate requirement, CO_2 production factor and carbon content depend on the fat content of the beans (see Figure 4.8). Source: Valle *et al*. (1990) for pods, and Goudriaan and van Laar (1994) for other plant parts (based on characteristic composition for plants in general).

	Chemical components						Derived parameters		
	Carbo-hydrates	Protein	Lipids	Lignin	Organic acids	Minerals	C	G	F
Leaves	0.53	0.25	0.05	0.05	0.06	0.06	0.4674	1.656	0.715
Wood	0.49	0.02	0.01	0.38	0.05	0.05	0.5200	1.569	0.394
Roots	0.57	0.02	0.01	0.30	0.05	0.05	0.5008	1.494	0.355
Fruits	0.59	0.13	0.18	0.05	0.05	0.05	0.5090	1.756	0.709

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: $p_{ideal} = p_{allo} * E_{act} / E_{pot}$ and for leaves $p_{ideal} = p_{allo} * (2- E_{act} / E_{pot})$, in which p_{ideal} is the ideal proportion of biomass in roots or leaves, p_{allo} is the proportion of biomass in the allometric relations, E_{act} is the actual evapotranspiration and E_{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: $f = slope * (p_{ideal} – p_{act}) / p_{act}$, 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.

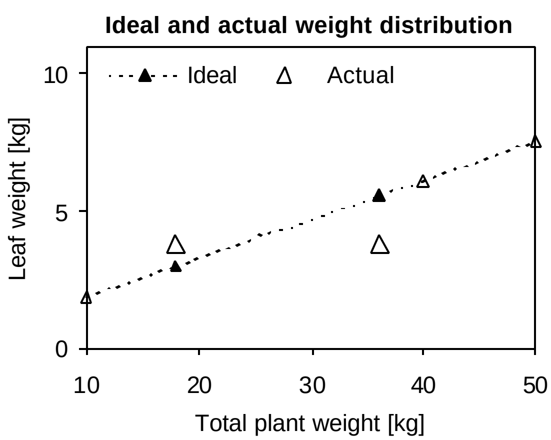

Figure 4.9. Illustration of the calculation of net growth of plant parts, as modelled in CASE. For this calculation, ideal and actual distributions of dry weight over the different plant parts are used. The ideal biomass proportion (p_{ideal}) is determined by the allometric relations as shown in Figure 4.7. The actual biomass proportion (p_{actual}) is the actual proportion of biomass in a plant part during at a certain time in the simulation. The graph shows two examples of leaf weights. The left symbols for a model tree in which the actual weight (open triangle) is higher than the ideal weight (closed triangle). In this case, the partitioning of carbohydrates to the laves is zero. The right symbols show the reverse situation, in which the partitioning of carbohydrates depends on the difference between actual and ideal proportion of weight and the slope of the ideal regression line (see text for further explanation).

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).

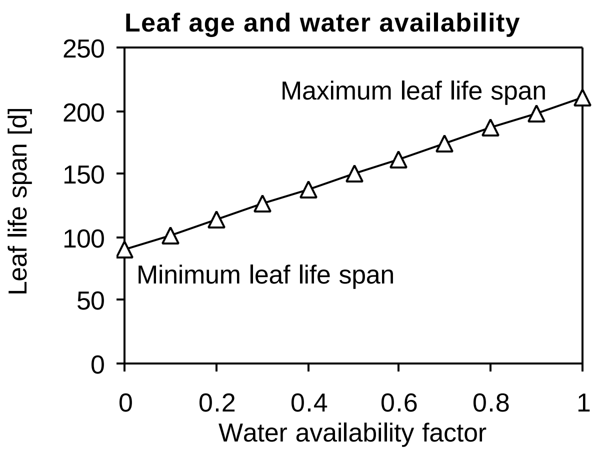

Figure 4.10. Hypothetical relation between leaf life span and relative water availability factor (PCEW in CASE2). This relation is used to adjust leaf loss for the effects of water stress, see Figure 4.11. The water availability factor is the quotient of actual and potential evapotranspiration (1=no 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 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) is shown in Figure 4.10. The additional leaf loss due to water shortage is calculated as: $dW_{lost}/dt = D_{water} * W_L$ in which dW_{lost}/dt is the daily weight of lost leaves due to drought (kg d^{-1}), D_{water} is the relative death rate of leaves due to drought (d^{-1}) and W_L is the leaf weight. D_{water} is calculated as: $D_{water} = 1/L_{adj} – 1/L_{max}$ in which L_{adj} is the adjusted leaf life span and

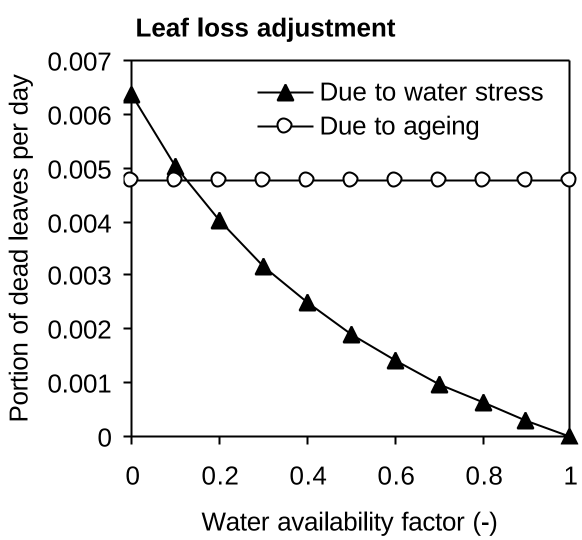

Figure 4.11. Two causes of leaf loss and their relation with water availability, as modelled in CASE2. The water availability factor is the quotient of actual and potential evapotranspiration (1=no water shortage; 0=actual evapotranspiration equals zero). Leaf loss due to ageing is not affected by water 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_{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: $LA = SLA * W_L$, 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.

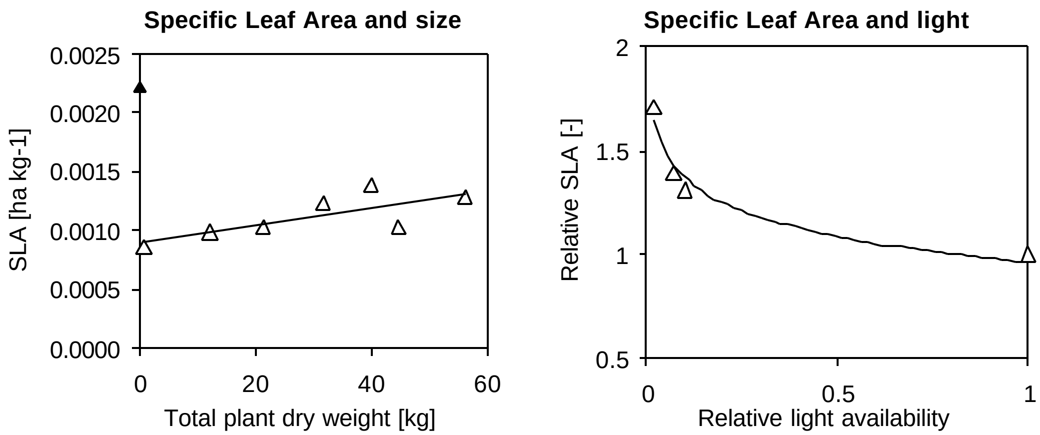

Figure 4.12. Empirical relations of the specific leaf area (SLA, the area of leaf per unit leaf weight) with total weight (left graph), and relative light availability (right graph). The relation in the left graph is based on measurements on cacao trees in a Malaysian plantation. The linear relation 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 Cameroon. 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 posses 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 * base * height. The base is calculated as πr^2 and the proportion of diameter (2*r*) and length (*l*) are taken to be 1 to 10. The base can then be calculated as: $1/3 * \pi * l^3 * 1/400$. The calculation of the taproot length then is: $l_{tap} = [(W_{tap} * 1200) / (sw * \pi)]^{(1/3)}$, in which l_{tap} is the taprooot length (m), W_{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: $W_{i,ideal} = b * d_i^a * Dd_i$, in which $W_{i,ideal}$ 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 Dd_i is the thickness of the soil layer (m). The real weight of fine roots in soil layer *i* is calculated as: $W_{i,real} = W_{i,ideal} * W_{real} / W_{ideal}$ in which W_{ideal} is the sum of ideal weights for all layers, W_{real} is the total weight of fine roots that may be distributed.

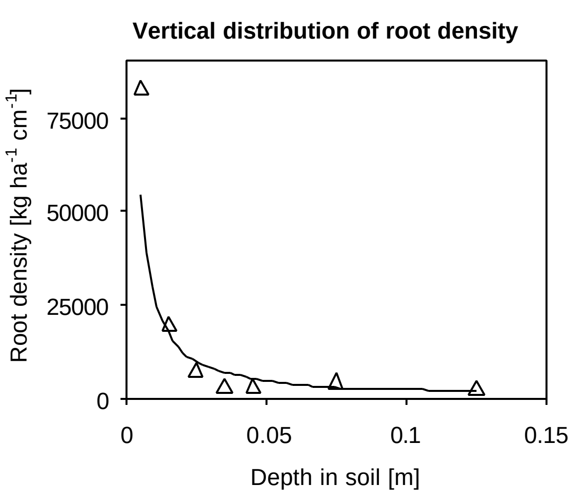

Figure 4.13. Empirical data on the vertical distribution of fine roots (< 2 mm diameter) of cacao trees in a plantation in Brazil. Shown is the amount of dry weight per unit soil volume at different depth in the soil. The exponential regression line, drawn through the data is used in CASE2 to distribute 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_{tot} , m^2) is used to determine the potential water extraction per unit root surface (in mm d^{-1} m^{-2}): $WU_{pot} = ET / A_{tot}$, in which ET is the potential evapotranspiration (mm d^{-1}, see Section 3.2).
A *maximum* water uptake per soil layer ($WU_{i,\ max}$, mm d^{-1}) is calculated based on the root surface and the potential water extraction: $WU_{i,\ max} = A_i * f_{drought} * WU_{pot}$ in which A_i is the total root surface in soil layer i (m^2), and $f_{drought}$ (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 ($WC_{i,avail}$, mm) is calculated as: $WC_{i,avail} = (WC_{field} - WC_{wilting}) * \Delta d_{\boldsymbol{i}}$, in which WC_{field} is the volumetric water content of the soil type of layer i at field capacity (unitless) and $WC_{wilting}$ is that at wilting point (unitless, see Section 3.3), and $\Delta d_{\boldsymbol{i}}$ 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.

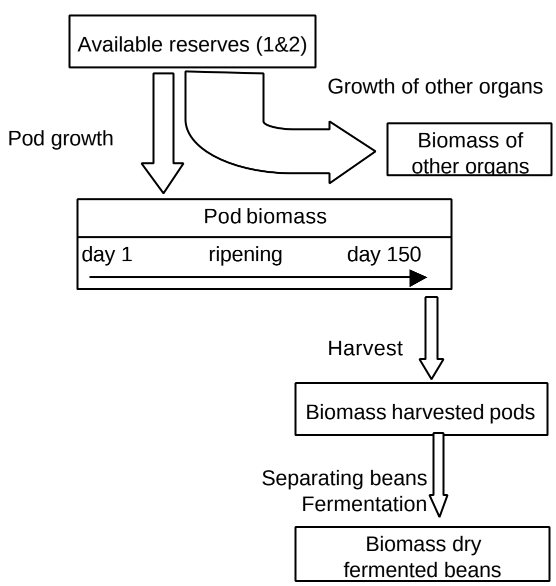

Figure 4.14. Flow diagram showing the sequence of calculations to obtain dry fermented beans from a certain amount of available reserves, as modelled in CASE2. Boxes denote amounts of carbohydrates or biomass. Arrows denote fluxes of carbohydrates or biomass. The arrow within the "Pod biomass" box represents the ripening process of pods. In this graph, pods of 150 days are taken to be ripe, but this may vary depending on temperature (see Figure 4.15).

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.

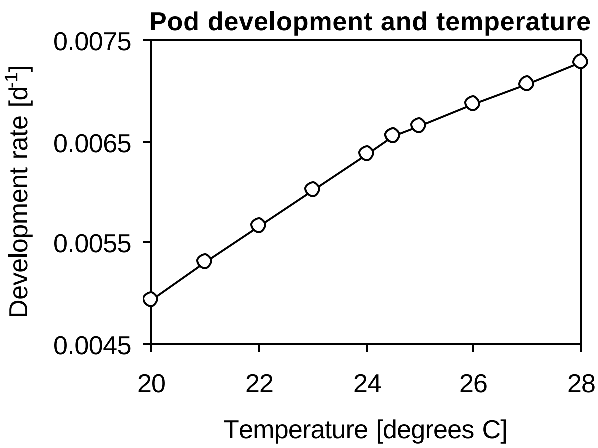

Figure 4.15. Empirical relations between development rate of cacao pods and average temperature. The development rate is expressed as 1 divided by the total period (in days) it takes to develop from pollinated flower to ripe pod. Source: Hadley *et al.* 1994.

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.
$\mathrm{d}W_i/\mathrm{d}t = s_i / s_{sum} * dW_{all}/\mathrm{d}t$, in which $\mathrm{d}W_i/\mathrm{d}t$ 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), $dW_{all}/\mathrm{d}t$ is the increment in biomass of all pod classes (kg d^{-1}). 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.

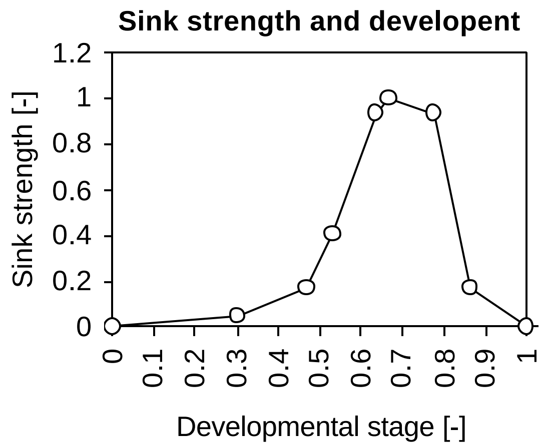

Figure 4.16. Empirical relation between sink strength and development rate of cacao pods. Sink strength is a measure that indicates the relative growth of pods, which depends on the ripening status (development stage) of the pods. Sink strength is used in CASE2 to distribute the total weight growth of pods over the pod categories. Source: Hutcheon 1977.

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: $f_{ferm} = a * t_{ferm}$

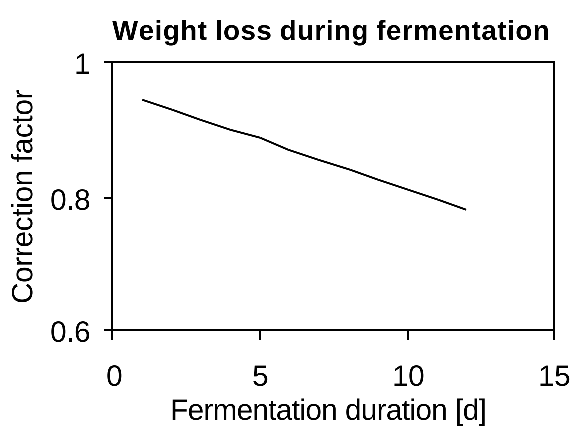

Figure 4.17. Empirical relation between duration of fermentation and a correction for bean weight after fermentation. This correction factor is multiplied by the dry bean weight to obtain the weight of fermented beans, taking into account the weight loss in fermented beans. Source: Humphries 1944.

+ b , in which a (d^{-1}) and b (unitless) are regression coefficients and t_{ferm} is the fermentation duration (days, see Figure 4.17).

4.7.2 Butter hardness

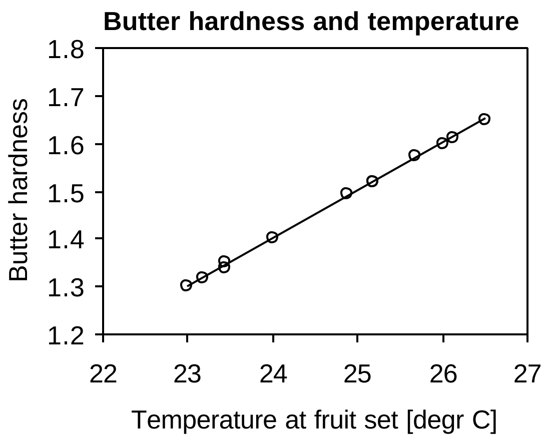

Figure 4.18. Empirical relation between butter hardness of cacao beans and temperature at the onset of the fruiting. Butter hardness is calculated as the ratio of saturated and unsaturated fatty acids, and is related to the melting point of cocoa butter. The regression line in the graph is used in CASE2 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.

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.

4.7.3 Harvest indices

Two harvest indices are calculated in CASE2. The “classical” harvest index (H.I.) is calculated as: $HI = W_{harv} / W_{above}$, in which W_{harv} is the annual commercial bean yield (kg) and W_{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: $Hincr$ = $(dW_{harv}/dt)/(dW_{above}/dt)$, in which DW_{harv} is the annual commercial bean yield (kg y^{-1}) and DW_{above} 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.

Nutrient	**Nutrient weight per unit bean dry weight [g kg^{-1}]**
N	21.0
P	4.0
K	9.5

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.

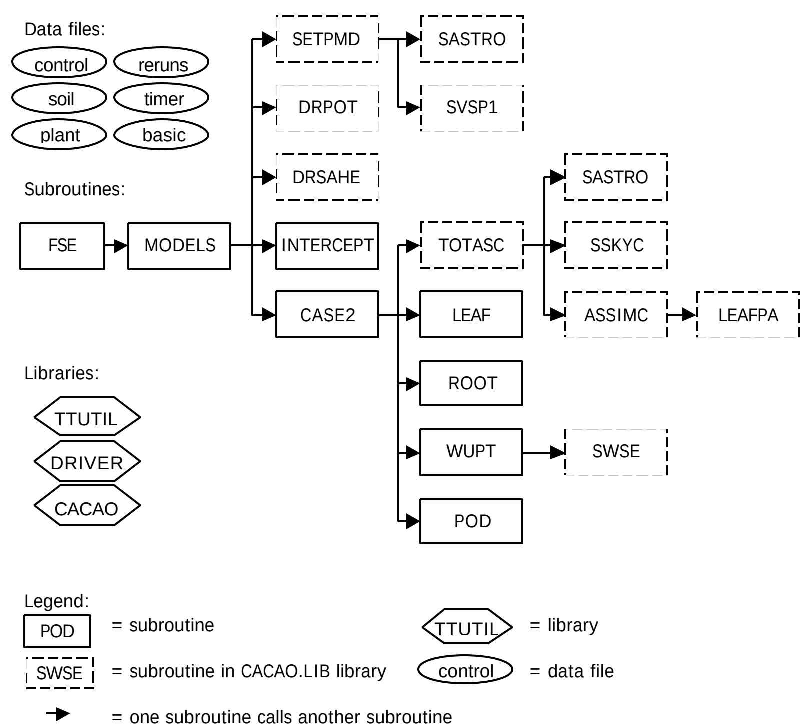

Figure 5.1. Relationships between the most important subroutines of the CASE2 model. Note that this Figure is not complete: calls to subroutines related to data input and output, errors and warnings, chart output in FSEWin are all not included. These subroutines are contained in the TTUTIL, DRIVERS and CACAO libraries. Many of those subroutines are called from the FSE driver.

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.

Subroutine	Calculates or conducts	Included in Fortran file	In library	Documented in
ASSIMC	Canopy assimilation	TOTASC.FOR	CACAO.LIB	Kropff & van Laar 1993
CASE2	Cacao tree growth and production	CASE2.FOR		Chapter 9
CLIMRD	Reading of monthly or long-term weather data	CLIMRD.FOR	CACAO.LIB	Hijmans *et al.* 1994
DRPOT	Water balance for potential production	DRPOT.FOR	CACAO.LIB	Chapter 15
DRSAHE	Water balance for water-limited production	DRSAHE.FOR	CACAO.LIB	Van Kraalingen 1994, Chapter 16
FSE	Control of program execution, intput/output and time	FSE.FOR		Van Kraalingen 1995; Chapter 6
INTERCEPT	Rain interception	MODEL2.FOR		Chapter 8
LEAF	Leaf growth and senescence	CASE2.FOR		Chapter 10
LEAFPA	Parabolic leaf distribution	TOTASC.FOR		Kropff & van Laar 1993
METEO	Control of weather data reading and generation	METEO.FOR	CACAO.LIB	Van Kraalingen *et al.* 1997
MODELS	Regulation of modules on crop growth, evapotranspiration and water balance	MODEL2.FOR		Chapter 7
POD	Pod growth	CASE2.FOR		Chapter 14
RNDIS	Rain distribution	RNDIS.FOR	CACAO.LIB	Hijmans *et al.* 1994
RNGEN	Rain generation	RNGEN.FOR	CACAO.LIB	Hijmans *et al.* 1994
ROOT	Root distribution	CASE2.FOR		Chapter 11
SASTRO	Basic astronomic data	SASTRO.FOR	CACAO.LIB	Kropff & van Laar 1993
SETPMD	Evapotranspiration	SETMPD.FOR	CACAO.LIB	Van Kraalingen & Stol 1997, Chapter 17
SSKYC	Fluxes of diffuse and direct radiation	TOTASC.FOR		Kropff & van Laar 1993
SVSP1	Saturated vapour pressure	SVSP1.FOR	CACAO.LIB	Van Kraalingen & Stol 1997
SWSE	Water uptake reduction due to drought	SWSE.FOR	CACAO.LIB	Chapter 13
TOTASC	Total daily canopy assimilation	TOTASC.FOR	CACAO.LIB	Kropff & van Laar 1993
WEATHR	Reading of daily weather data	WEATHR.FOR	TTUTIL.LIB	Van Kraalingen *et al.* 1997
WUPT	Water uptake	CASE2.FOR		Chapter 12

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.

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

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.

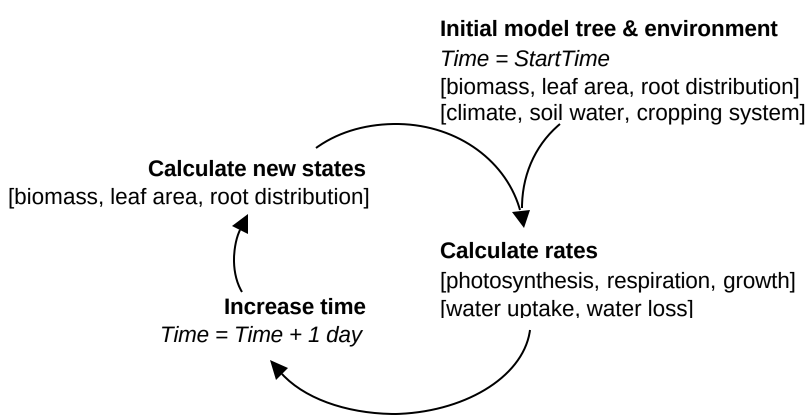

Figure 5.2. Representation of the simulation procedure followed in CASE2. The arrows denote the sequence of calculations in the model. This sequence of procedures is applied in many related models (e.g. SUCROS). See main text for further explanation. Based on van Kraalingen 1995.

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.

```
      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   , IURA  , 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, PRODLEVL
```

```
*-----Declarations for output
      INTEGER   OUTPUTFQ

*-----Declarations for location selection
      INTEGER   LOCATION, STRTYR, ENDYR

*     Declarations for higher IWEATH selections
*     CHARACTER GEODIR*80, DRVDIR*80, DBRDIR*80, DBMDIR*80
*     CHARACTER STNAM*80 , RAFILE*80

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

*-----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 ('FILEON', FILEON)
      CALL RDSCHA ('FILEOL', FILEOL)
      CALL RDSCHA ('FILEIR', FILEIR)

*     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
```

```
      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
c      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).

```
*======================================================================*
*                                                                      *
*                        Initialization section                        *
*                                                                      *
*======================================================================*
```

```
      ITASK  = 1
      TERMNL = .FALSE.
      WTRTER = .FALSE.
```

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.

```
      RSETRG = .TRUE.
      RSETRD = .TRUE.

*-----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)
      IF (RDINQR ('FILEI1')) CALL RDSCHA ('FILEI1', FILEI1)
      IF (RDINQR ('FILEI2')) CALL RDSCHA ('FILEI2', FILEI2)
      IF (RDINQR ('FILEI3')) CALL RDSCHA ('FILEI3', FILEI3)
      IF (RDINQR ('FILEI4')) CALL RDSCHA ('FILEI4', FILEI4)
      IF (RDINQR ('FILEI5')) 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 RDSCHA ('DELTMP', DELTMP)
      CALL RDSREA ('FRPAR' , FRPAR)
      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
    ENDIF
        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 (OUTPUTFQ.EQ.1) THEN
        PRDEL = 0.
        CALL RDAINT ('IOBSD' , IOBSD, IMNOD, INOD)
        CALL RDACHA ('PRSEL1',PRSEL,IMNPRS,INPRS)
      ELSE IF (OUTPUTFQ.EQ.2) THEN
        PRDEL = 10.
        CALL RDACHA ('PRSEL2',PRSEL,IMNPRS,INPRS)
      ELSE IF (OUTPUTFQ.EQ.3) THEN
        PRDEL = 1.
        CALL RDACHA ('PRSEL3',PRSEL,IMNPRS,INPRS)
      ELSE
       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 RDACHA ('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  , ISTN  ,
     &            CLFILE, IRNDAT, RSETRG, RSETRD, IUWE  ,
     &            IURA  , IYEARR, RAFILE,
     &            ANGA  , ANGB  , LAT   , LONG  , ELEV  ,
     &            RDD   , TMMN  , TMMX  , RAIN  , WN    , VP    )

c*-----initialize OBSSYS routine
c      IF (ITASK.EQ.1) CALL OBSINI
*-----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  , STTIME, FINTIM, DELT  ,
     &             ANGA  , ANGB  , FRPAR ,
     &             LAT   , LONG  , ELEV  , WSTAT , WTRTER,
     &             RDD   , TMMN  , TMMX  , VP    , WN, RAIN)
```

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.

```
*======================================================================*
*                                                                      *
*                      Dynamic simulation section                      *
*                                                                      *
*======================================================================*

      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, OUTPUTFQ, 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

*----------------------------------------------------------------------*
*                Calculation of driving variables section              *
```

```
*----------------------------------------------------------------------*

      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,
     &            IFLAG , WTRDIR, CNTR  , ISTN  ,
     &            CLFILE, IRNDAT, RSETRG, RSETRD, IUWE  ,
     &            IURA  , IYEARR, RAFILE,
     &            ANGA  , ANGB  , LAT   , LONG  , ELEV  ,
     &            RDD   , TMMN  , TMMX  , RAIN  , WN    , 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, 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)

      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
         OUTPUT = .TRUE.
         CALL OUTDAT (2, 0, 'TIME', TIME)
         CALL ChartNewGroup
         CALL ChartOutputRealScalar('TIME', TIME)
         CALL 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)
      END IF

*----------------------------------------------------------------------*
*                             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  , STTIME, 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):

```
   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 7.1. Formal parameters of the MODELS subroutine (MODEL2.FOR).

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

Code	Type	Description	Unit	Input/ output
ANGA	R4	Regression coefficient in Angstrom formula	-	I
ANGB	R4	Regression coefficient in Angstrom formula	-	I
FRPAR	R4	Fraction PAR in shortwave radiation	-	I
LAT	R4	Latitude of site	dec.degr.	I
LONG	R4	Longitude of site	dec.degr.	I
ELEV	R4	Elevation of site	m	I
WSTAT	C6	Status code from weather system	-	I
WTRTER	L4	Flag whether weather can be used by model	-	O
RDD	R4	Daily shortwave radiation	J/m2/d	I
TMMN	R4	Daily minimum temperature	°C	I
TMMX	R4	Daily maximum temperature	°C	I
VP	R4	Early morning vapour pressure	kPa	I
WN	R4	Average wind speed	m/s	I
RAIN	R4	Daily amount of rainfall	mm/d	I

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
*           Is there an error in the I1-th weather variable ?
            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 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 RDINIT (IUNITD, IUNITL, FILEIT)
            CALL RDSCHA ('PLTMOD', PLTMOD)
            CALL UPPERC (PLTMOD)
            CALL RDSCHA ('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 RDINIT (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)') '*'
            WRITE (IUNITO,'(A)') '* FSE driver info:'
            WRITE (IUNITO,'(A,T7,A,I5,A,I4,A)')
        &     '*','Year:',IYEAR,', day:',IDOY,', System start'
            WRITE (IUNITO,'(A)') '*'
            WRITE (IUNITO,'(A)') '* Modules used:'

   *        Choose and check evapotranspiration modules
            IF (ETMOD.EQ.'PENMAN') THEN
               WRITE (IUNITO,'(A,T7,A)')
        &        '*','SETPMD: 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
        &      ('MODELS','unknown module name for evapotranspiration')
            END IF

   *        Choose and check water balance modules
            IF (PRODLEVL.EQ.1) THEN
               WRITE (IUNITO,'(A,T7,A)')
        &        '*','DRPOT : Water balance for potential situations'
            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
        &      ('MODELS','Wrong value for PRODLEVL')
            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
```

```
*            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, 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
```

7.6 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 (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

*     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):

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

Table 8.1. Formal parameters of the MODELS subroutine (MODEL2.FOR).

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

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.

```
   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]

      END IF

      RETURN
      END
```

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 , WCWPX , WCFCX , WCSTX ,
        &                  EVSC  , ETRD  , ETAE  , PINT,
        &                  GAI   , RAIN )
```

Table 9.1. Names and description of the formal parameters used in the crop subroutine CASE2.

Code	Type	Description	Unit	Input/output
PLTMOD	C*	Name of plant module used (cocoa or no crop)	-	I
ITASK	I4	Task that subroutine should perform	-	I
IUNITD	I4	Unit that can be used for input files	-	I
IUNITO	I4	Unit used for output file	-	I
IUNITL	I4	Unit used for log file	-	I
FILEI1	C*	Name of first file with plant data	-	I
FILEI3	C*	Name of second file with plant data	-	I
OUTPUT	L4	Flag to indicate if output should be done	-	I
TERMNL	L4	Flag to indicate if simulation is to stop	-	I/O
OUTPUTFQ	L4	Type of output requested (daily, 10-day, annual)	-	I
DOY	R4	Day number within year of simulation (REAL)	d	I
IDOY	I4	Day number within year of simulation (INTEGER)	d	I
IYEAR	I4	Year of simulation (INTEGER)	y	I
DELT	R4	Time step of integration	d	I
TIME	R4	Time of simulation	d	I
STTIME	R4	Start time of the simulation	d	I
LAT	R4	Latitude of site	dec. degr.	I
FRPAR	R4	Fraction PAR in shortwave radiation	-	I
RDD	R4	Daily shortwave radiation	J m2 d-1	I
TMMN	R4	Daily minimum temperature	°C	I
TMMX	R4	Daily maximum temperature	°C	I
NLXM	I4	no. of layers as declared in calling program	-	I
NL	I4	number of layers specified in input file	-	I
TRWL[]	R4	actual transpiration rate per layer	mm/d	I

Code	Type	Description	Unit	Input/output
TKL[]	R4	thickness of soil compartments	m	I
WCLQT[]	R4	volumetric soil water content per layer	-	I
WCWPX[]	R4	volumetric water content at wilting point	-	I
WCFCX[]	R4	volumetric water content at field capacity	-	I
WCSTX[]	R4	volumetric water content at saturation	-	I
EVSC	R4	actual (realized) evaporation rate	mm/d	O
ETRD	R4	Radiation driven part of ETPMD	mm/d	O
ETAE	R4	Dryness driven part of ETPMD	mm/d	O
PINT	R4	Daily amount of intercepted rain	mm/d	O
GAI	R4	Green area index of cocoa and shade crop	m2/m2	O
RAIN	R4	Daily amount of rainfall	mm/d	I

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).

```
      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.

```
   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:

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

   *         Send title(s) to output file
             CALL OUTCOM (PLTMOD)
             CALL OUTCOM ('CASE2, CAcao Simulation Engine     Version 2.2')
             CALL OUTCOM ('       February 2002')

   *         Read plant parameters from plant.dat with UNchangeble 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, KCONTBN, FMTA, FMTB, RTOWURT, WDLVDR, LRTWURTDR, FTRTRA, FLRTRA, FLVRA, FWDRA, FPDRA, FTRTRB, FLRTRB, FLVRB, FWDRB, FPDRB, AVGLVAGE, 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.

```
   *         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 I1 = 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 changeble 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 extiction 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
*           and 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')
            IF (HGHT(2).LE.HGHL(2)) CALL FATALERR ('CASE2',
     &     'FE8 - Upper shade tree height <= lower height')

*           Check value of cacao tree height: should not exceed 20 m
*           and 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')
            IF (HGHT(1).LE.HGHL(1)) CALL FATALERR ('CASE2',
     &     '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 (AGBIORA and AGBIORB) derived from empirical data. If age is used, 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]
*          Check value of initial size: should be >= 18.5 and <70 kg
           IF (WTOTI.LT.18.5) CALL FATALERR ('CASE2',
     &       'FE11 - Intitial tree biomass too low: < 18.5 kg')
           IF (WTOTI.GE.70.) CALL FATALERR ('CASE2',
     &       'FE12 - Intitial tree biomass too high: > 70.0 kg')
           AGEI = EXP((WTOTI-AGBIORB)/AGBIORA)   ![d]
         ELSEIF (SWINPUT.EQ.1) THEN
*          Input is age
           CALL RDSREA ('AGEIYR'  , AGEIYR    )   ![d]
*          Check value of initial age: should be >= 3 and < 40. yr
           IF (AGEIYR.LT.3.) CALL FATALERR ('CASE2',
     &       'FE13 - Initial tree age too low: < 3 y')
           IF (AGEIYR.GT.39.) CALL FATALERR ('CASE2',
     &       'FE14 - Initial tree age too high: > 39 y')
*          calculate age in days and round to get entire days
           AGEI  = REAL(INT(AGEIYR * 365.))      ![d]
           WTOTI = AGBIORA * LOG(AGEI) + AGBIORB ![kg DW plant-1]
         ELSE
           CALL FATALERR ('CASE2','FE15 - Value of input switch SWINPUT
     &     is wrong, should be 1 or 2')
         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)
           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
         WLV   = WLVI   ![kg DW ha-1]
         WWD   = WWDI   ![kg DW ha-1]
         WTRT  = WTRTI  ![kg DW ha-1]
         WLRT  = WLRTI  ![kg DW ha-1]
         WRT   = WTRT + WLRT                    ![kg DW ha-1]
         WPD   = WPDI   ![kg DW ha-1]
         WTOT   = WLV + WWD + WPD + WRT         ![kg DW ha-1]
         WTOTPP = WTOT / NPL                    ![kg DW plant-1]

*        Plant age in days and years
         AGE = AGEI     ![d]
         AGEYR = AGE / 365.                     ![yr]
```

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
         CALL 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)
         CALL 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  )
```

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
         DO I1 = 1,10
           PCEW10(I1) = 1.                      ![-]
         ENDDO
         PCEWMN = SUM(PCEW10(1:10)) / 10.       ![-]

*        Calculate fraction light transmission through shade canopy,
*        assuming that cocoa and shade crowns do not overlap.
         TRMIS = EXP(-KDF(2) * LAI(2))

         CALL LEAF (ITASK,IUNITD,IUNITL,FILEI1,TERMNL,DELT,AGE,NPL,
     &              TRMIS,GLV,PCEWMN,WTOTPP,
     &              WLV, DLV, DLV1, DLV2, LAI(1))
```

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 * (TMMX + TMMN)             ![degr C]

      CALL POD (ITASK,IUNITD,IUNITL,FILEI1,TERMNL,DELT,TMAV,
&              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.

```
*         Determing initial value for leaf turnover (TOLV), using given
*         maximum leaf age (MAXLAG) and leaf weight (WLV).
          DO I1 = 1,10
            DLV10(I1) = WLV/AVGLVAGE              ![kg DW ha-1 d-1]
          ENDDO
          TOLV = SUM(DLV10(1:10)) / 10.           ![kg DW ha-1 d-1]

*         Determing initial value for pod turnover (TOPD), using pod
*         weight per pod category.
          DO I1 = 1,10
            TOPD10(I1) = WPD/REAL(IPOD)            ![kg DW ha-1 d-1]
          ENDDO
          TOPD = SUM(TOPD10(1:10)) / 10.          ![kg DW ha-1 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, WLVD, WLRTD, WWDD, YRDD, YRAIN, YTRANS, YYLDPD, YYLDBN, YGPHOT, YGTOT, YLVD, YWDD, YHARPD, YRDEFF, YRNEFF, YHI, YHINCR, BHSUM, YMNBH, YNLOSS, YPLOSS, YKLOSS, LAISUM, YMNLAI, IPODSUM, YMNIPOD, D10GTOT, D10YLDPD, D10YLDBN, D10RAIN, D10RDD, D10HARPD, D10COUNT, WTOTCUM, WPDCUM, WBNCUM, TNASS, CHKDIF, CHKIN, CHKFL, CHKLV, CHKWD, CHKLRT, 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.

```
*         Green Area Index is total leaf area of cocoa and shade crop
          GAI = 0.       ![m2 green leaves m2 soil]
          DO I1=1,INS
             GAI    = GAI + LAI(I1)             ![m2 green leaf m-2 soil]
          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.

```
*         Reserve weights
          WRES   = MINCON * WTOT                  ![kg CH2O ha-1]
          MINRES = WRES  ![kg CH2O ha-1]
```

The assimilate requirements for pod growth (ASRQPD) 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 (ASRQPDTB and CFPDTB in the plant.dat file), using the linear interpolation function (LINT) from the TTUTIL library.

```
*         Determine assimilate requirement and C content of pods as
*         a function of nib fat content
          ASRQPD = LINT(ASRQPDTB, IASRQPDN, FATCONTENT)![kg CH2O kg-1 DW]
          CFPD   = LINT(CFPDTB , ICFPDN  , FATCONTENT)  ![kg C kg-1 DW]
```

Next, the CO2 production factors for each of the plant parts is calculated. Growth respiration involves losses of C in the form of CO_2. This loss, or CO_2 production factors (CO2..) 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), CO_2 (44) and CH_2O (30). The CO_2 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)             ![degr C]
            TMAVD = TMMX - 0.25 * (TMMX-TMMN)       ![degr C]
             IF (TMAV.GT.40.) CALL FATALERR
        &     ('CASE2','FE16 - Av. Temp greater than 40 C.')
            IF (TMMN.LT.10.) CALL FATALERR
        &     ('CASE2','FE17 - Minimum temperature below 10 C.')
```

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 evapotranspiration 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, NLXM,NLBM,
        &             I1,TKL, CUMTKL, WCLQT, WCWPX, AGE, NPL, FWURT,
        &             WLRT, WTRT, LTRT,
```

```
     &            WWURT, WTWURT, LTWURT, ATWURT, AWURT, WSERT)
         CALL 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 )

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

9.5.1 Photosynthesis

The maximum rate of photosynthesis is calculated (AMAX(1)) taking into account the average daytime temperature (TMAVD) and the low photosynthetic rates of young leaves (AMINIT). The reduction factor for temperature (AMTMP) is obtained by linear interpolation of values in the AMTMPT table (specified in the plant.dat file). The literature value of the maximum rate of photosynthesis (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 (AMAX(1)) from table (AMPTP)
         AMTMP   = LINT(AMTMPT, IAMTMN, TMAVD)    ![-]
         AMAX(1) = AMX * AMTMP * AMINIT           ![kgCO2 ha-1 h-1]
```

The leaf area index (LAI) of the cocoa trees as used for the calculation of photosynthesis, is limited to a maximum value (MAXLAI, specified in the plant.dat file). When LAI is larger than 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.

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

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

```
         CALL TOTASC (IDOY, INS, LAT, RDD, FRPAR, KDF, KS,
     &                AMAX, EFF, LAIF, SAI, HGHT, HGHL,
     &                FRABS, DTGA)
```

Now, the daily production of carbohydrates (GPHOT) can be calculated. To do so, the assimilated CO_2 is converted to carbohydrates CH_2O: for every kg of CO_2 taken up 30/44 kg of CH_2O is formed (the numbers represent the molecular weight of CH_2O (30) and CO_2 (44), respectively). The reduction of photosynthesis by water stress (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
         GPHOT = DTGA(1) * 30./44. * PCEW        ![kgCH2O ha-1 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              ![kg DW ha-1 d-1]
```

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            ![kg DW ha-1 d-1]
```

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)              ![kg DW ha-1 d-1]
          ENDDO
          DLV10(1)    = DLV                      ![kg DW ha-1 d-1]
*         then calculate leaf turnover rate as the mean of leaf loss
          TOLV = SUM(DLV10(1:10)) / 10.          ![kg DW ha-1 d-1]
```

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                   ![kg DW ha-1 d-1]
```

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)            ![kg DW ha-1 d-1]
          ENDDO
          TOPD10(1)    = YLDPD                   ![kg DW ha-1 d-1]
          TOPD   = SUM(TOPD10(1:10)) / 10.       ![kg DW ha-1 d-1]
```

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![kgCH2O ha-1]
          ELSE
            WRES1    = 0                         ![kgCH2O ha-1]
          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.

```
*        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]
           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
           GWD1    = ((TOWD*ASRQWD)   /TOREQ * WRES1/DELT)/ ASRQWD
           GLV1    = ((TOLV*ASRQLV*PCEW)/TOREQ * WRES1/DELT)/ASRQLV
           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.

```
         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 PRPDID = 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        ![-]
```

```
              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 biomassfraction
     &        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

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
        ENDIF
```

In case the sum of all partitioning fractions (CHPART2) does not equal 1, an error message is shown and the program is halted.

```
*       Terminate 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 +
     &           ASRQLRT*FLRT + ASRQTRT*FTRT     ![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

(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-]
          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 $\times$ 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,FILEI1,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 d10-1]
          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]
          YYLDBN = 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]
        YYLDBN = INTGRL (YYLDBN, 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 = YYLDBN * PODVALUE               ![y-1]
        YNLOSS = YYLDBN * NCONTBN                ![kg N ha-1 yr-1]
        YPLOSS = YYLDBN * PCONTBN                ![kg P ha-1 yr-1]
        YKLOSS = YYLDBN * KCONTBN                ![kg K ha-1 yr-1]

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

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

*       HINCR is Harvest increment following Cannell 1985
        YHINCR  = YYLDBN / 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 $\times$ YLDBN (IPOD is the ripening period; YLDBN 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 riping time (IPOD)
        IPODSUM = IPODSUM + IPOD * YLDBN         ![d]
        YMNIPOD = IPODSUM / NOTNUL(YYLDBN)       ![d]

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

*       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 condtions
        IF (AGEYR .GE. 40.) THEN
          WRITE (*,*) IYEAR,IDOY
          CALL WARNING ('CASE2',
     &        'WA2 - Maximum tree age (40 yr) is reached')
          TERMNL = .TRUE.
        ENDIF
        IF (WTOTPP  .GE. 70.) THEN
          CALL WARNING ('CASE2',
     &        '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
```

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, WBNCUM, PENMAN, CROPF, YRDD, YRAIN, YTRANS, YGPHOT, YGTOT, YLVD, YWDD, YYLDPD, YYLDBN, YHI, YHINCR, YMNBH, YMNIPOD, YHARPD, YRDEFF, YRNEFF, YNLOSS, YPLOSS, YKLOSS, D10RDD, D10RAIN, D10YLDPD, D10YLDBN, D10GTOT, DOY, RAIN, RDD, LAI, TMAV, FRABS, GPHOT, MAINT, GTOT, GTOT1, GTOT2, GRT, GTRT, GLRT, GLV, GWD, GPD, FTRT, FLRT, FLV, FWD, FPD, DLRT, DWD, DLV, DLV1, DLV2, WWURT, AWURT, ATWURT, LTWURT, WTWURT, TRWL, PTRANS, ATRANS, PCEW, YLDBN, YLDPD, BHYLD, HARPODS.

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, WLVD, WWDD, WLRTD, 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, DWD, DLV, DLV1, DLV2, TOREQ, TOWURT, TOLV, TOPD, FTRT, FLRT, FLV, FWD, FPD, YLDBN, YLDPD, ,HARPODS, WBNCUM, PENMAN, CROPF, YRDD, YRAIN, YTRANS, YGPHOT, YGTOT, YGTOTAB, YLVD, YWDD, YYLDPD, YYLDBN, YHI, YHINCR, YMNBH, YMNLAI, YMNIPOD, YHARPD, YRDEFF, YRNEFF, YNLOSS, YPLOSS, YKLOSS, D10RDD, D10RAIN, D10YLDPD, D10YLDBN, D10GTOT, CUMTKL, WWURT, AWURT, WSERT, ATWURT, LTWURT, WTWURT, LTRT, TRWL, PTRANS, ATRANS, PINT, PCEW, PCEWMN, 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, WCWPX, AGE, NPL, FWURT,
     &             WLRT, WTRT, LTRT,
     &             WWURT, WTWURT, LTWURT, 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 CH_2O 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 if CHKIN>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 - WWDI)*CFWD
     &         + (WTRT - WTRTI)*CFTRT + (WLRT + WLRTD - WLRTI)*CFLRT
     &         + (WPD + WPDCUM - WPDI)*CFPD              ![kg C ha-1]
        CHKDIF = (CHKIN-CHKFL)/NOTNUL(CHKIN)     ![-]
```

```
*       Carbon balance check - for plant organs separately
        CHKLV  = GLV*CFLV   + GLV*CO2LV*12./44.  - GLV*ASRQLV*12./30.
        CHKWD  = GWD*CFWD   + GWD*CO2WD*12./44.  - GWD*ASRQWD*12./30.
        CHKLRT = GLRT*CFLRT + GLRT*CO2LRT*12./44.- GLRT*ASRQLRT*12./30.
        CHKTRT = GTRT*CFTRT + GTRT*CO2TRT*12./44.- GTRT*ASRQTRT*12./30.
        CHKPD  = GPD*CFPD   + GPD*CO2PD*12./44.  - GPD*ASRQPD*12./30.
                                                 !all [kg C ha-1]

*       Terminate program if CHKDIF is too large
        IF (CHKIN.GT.10. .AND. ABS(CHKDIF) .GT. 0.01) CALL FATALERR
     &     ('CASE2',' FE21 - Carbon balance is wrong
     &     CHKDIF larger than 0.01')

*       Terminate program if CHK** for one of the organs is too large
        IF ((ABS(CHKLV).GT.0.001).OR.(ABS(CHKWD).GT.0.001).OR.
     &     (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 handed back to the calling MODELS subroutine.

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

      END IF

      RETURN
      END
```

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.

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

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
        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]
          LAI          = LAI + LA(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.GT.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.

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

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 ('VDWURTRA', VDWURTRA)      ![-]
         CALL RDSREA ('VDWURTRB', VDWURTRB)      ![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; WTWURT) 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).

```
*        Total weight of water-uptaking roots
         WTWURT = 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 π (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).

```
*        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    ![m]

*        Number of layers of which water can be taken up depends on
*        length of taproot
         DO I1 = 1, NL
            IF (LTRT.GT.CUMTKL) THEN
               NLA = NLA + 1                     ![-]
               CUMTKL = CUMTKL + TKL(I1)         ![m]
```

```
          ELSE
            NLA = NLA                          ![-]
          ENDIF
        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 ($y = b \times depth^a$). 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)).

```
      ELSE IF (ITASK.EQ.2) THEN
*     ------------------------
*     Rate calculation section
*     ------------------------

*       Calculate vertical distribution of wateruptaking roots.
*       First determine distribution based on regression, for all
*       except the lowest available layer.
        CUMTKL  = 0.                           ![m]
        WTWURTR = 0.                           ![kg DW ha-1]
        LTRTLL = 0.                            ![m]
*       - in case the taproot penetrates only one soil layer (NLA=1)
        IF (NLA. EQ .1) THEN
          WWURTR(1)    = (VDWURTRB*(0.5*LTRT)**VDWURTRA)*LTRT
          WTWURTR      = WWURTR(1)
          CUMTKL       = TKL(1)                ![-]
        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(I1)), except for the last. The estimated weight of the water-uptaking roots in each layer (WWURTR(I1)) 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(I1)). 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.                         ![-]
              IF (WCLQT(I1).LT.WCWPX(I1)) THEN
              WSERT(I1) = 0.                     ![-]
              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 π (PI). The fine root area per soil layer (AWURT(I1)) is summed to obtain the total fine root area (ATWURT).

```
*       Determine area of water uptaking roots
        ATWURT=0.
        DO I1=1, NLA
          AWURT(I1) = (PI*DIAM1)*LWURT1(I1)+
     &                (PI*DIAM2)*LWURT2(I1)      ![m2 ha-1]
          ATWURT = ATWURT + AWURT(I1)            ![m2 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 π (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
*     -------------------
*     Integration section
*     -------------------

*       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

*       Detemine 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):

```
      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.

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

Code	Type	Description	Unit	Input/output
CROPF	R4	Crop factor for crop water requirement	-	O

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.

```
         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).

```
         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.

```
   *       Potential water uptake rate
           PRWU = MAX (0., PTRANS / ATWURT)          ![mm m-2 root area]

   *       Soil water depletion factor
           P    = TRANSC / (TRANSC + PTRANS)         ![-]
```

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)).

```
   *       Calculate actual transpiration (ATRANS) from
           ATRANS = 0.                               ![mm d-1]
           DO 50 I1 = 1, NLA
             CALL SWSE (WCLQT(I1), P, WCWET, WCWPX(I1), WCFCX(I1),
        &              WCSTX(I1), WSEL(I1))
             TRWL(I1) = PRWU * WSEL(I1) * AWURT(I1) ![mm d-1]
             AVAIL = MAX(0., (WCLQT(I1) - WCWPX(I1)) * TKL(I1) * 1000.)
                                                             ![mm]
             IF (TRWL(I1) .GT. AVAIL) TRWL(I1) = AVAIL
             ATRANS = ATRANS + ABS(TRWL(I1))         ![mm d-1]
   50      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).

```
   *       Calculate water availability factor
           IF (PTRANS.GT.0.) THEN
             PCEW = ATRANS/PTRANS                    ![-]
           ELSE
             ATRANS = 0.                             ![mm d-1]
             PCEW   = 1.
           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).

```
   *       Miscellaneous water related variables
           CROPF  = (PTRANS+EVSC)/(ETRD+ETAE)        ![-]
           PENMAN = ETRD+ETAE                        ![mm d-1]

         END IF
```

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

```
         RETURN
         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.

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

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 = (WCST-WCL)/(WCST-WCWET)
      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 = (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 = LIMIT (0., 1., 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.

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

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 inital number of boxcars
          DEVRL = MAX(0., DEVRR1A * TMAV + DEVRR1B)![d-1]
          DEVRH = MAX(0., DEVRR2A * TMAV + DEVRR2B)![d-1]
          IPOD  = INT(1/MIN(DEVRL,DEVRH)) + 1      ![d]
```

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
          TSS = 0.                                 ![-]
          DO 10 I1 = 1,IPOD
            STAGE(I1) = REAL(I1)/REAL(IPOD)        ![-]
            WPOD(I1)  = 0.                         ![kg DW ha-1]
            GPOD(I1)  = 0.                         ![kg DW ha-1 d-1]
            SSPOD(I1) = 0.                         ![-]
            IF (STAGE(I1).LT.1.) THEN
              SSPOD(I1) = LINT(SSTB,ISSN,STAGE(I1))![-]
              TSS = TSS + SSPOD(I1)                ![-]
            ELSEIF (STAGE(I1).GE.1.) THEN
              STAGE(I1) = 0.                       ![-]
            ENDIF
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
          DO 20 I1 = 1,IPOD
            WPOD(I1) = WPD * SSPOD(I1)/TSS         ![kg DW ha-1]
            BH(I1)   = 1.6                         ![-]
20        CONTINUE
          STAGE(0) = 0.                            ![-]
```

```
          WPOD(0)  = 0.                           ![kg DW ha-1]
          GPOD(0)  = 0.                           ![kg DW ha-1 d-1]
```

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 stregth
          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
```

```
          IF (GPD.GT.0.) THEN
            BH(0)    = BHRA*TMAV+BHRB              ![-]
          ELSE
            BH(0)    = 0.                          ![-]
          ENDIF
```

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.                       ![kg DW ha-1]
            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   ![-]
```

```
          SSPOD(I1+1) = LINT(SSTB,ISSN,STAGE(I1+1)) ![-]
          TSS         = TSS + SSPOD(I1+1)          ![-]
          BH(I1+1)    = BH(I1)                     ![-]
          WPODTOT     = WPODTOT + WPOD(I1+1)       ![kg DW ha-1]
 50     CONTINUE
        IPOD = IPOD + 1
```

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.

```
*       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,IDOY
          CALL WARNING ('CASE2 - POD',
     &    'WA8 - 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.

```
      ENDIF

      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):

```
      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.

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

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).

```
      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)
10       CONTINUE
```

```
   ZRTMS = 10.
END IF

RETURN
END
```

16. Adaptations 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)
```

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

!---------------------------------------------------------------------!
! A.DAILY AND MONTHLY WEATHER DATA                                     !
!---------------------------------------------------------------------!
!LOCATION    Country           Site            Start Yr  End Yr Period!
! 1          Brazil            Maceio (Alagoas)   1961      1969   8  !
! 2          Costa Rica        El Carmen          1974      1991  18  !
! 3          Costa Rica        La Lola            1973      1990  18  !
! 4          Costa Rica        La Mola            1980      1989  10  !
! 5          Costa Rica        Puerto Limon       1970      1990  21  !
! 6          Ghana             Tafo               1963      1997  35  !
! 7          Indonesia         Bah Lias           1979      1993  15  !
! 8          Ivory Coast       Abidjan            1987      1996  10  !
```

```
! 9          Ivory Coast        Adiake             1987      1995   9  !
! 10         Ivory Coast        Daloa              1987      1996  10  !
! 11         Ivory Coast        Dimbokro           1987      1996  10  !
! 12         Ivory Coast        Gagnoa             1986      1997  12  !
! 13         Ivory Coast        Man                1987      1996  10  !
! 14         Ivory Coast        San  Pedro         1987      1996  10  !
! 15         Malaysia           Tawau (Sabah)      1951      1993  43  !
! 16         Malaysia           Telok Chengai      1978      1988  11  !
! 17         Papua New Guinea   Dami               1970      1991  22  !
! 18         Philippines    IRRI wet station site  1979      1995  17  !
! 19         - user-defined -                                          !
! 20         - user-defined -                                          !
! 21         - user-defined -                                          !
! 22         - user-defined -                                          !
! 23         - user-defined -                                          !
! etc.                                                                 !
!----------------------------------------------------------------------!

!----------------------------------------------------------------------!
! B.LONG-TERM WEATHER DATA                                             !
!----------------------------------------------------------------------!
!LOCATION    Country            Site                                   !
! 51         Brazil             Belem                                  !
! 52         Brazil             Salvador                               !
! 53         Brazil             Vitoria                                !
! 54         Cameroon           Batouri                                !
! 55         Cameroon           Douala                                 !
! 56         Colombia           Andagoya                               !
! 57         Colombia           Villavicencio                          !
! 58         Ghana              Hon                                    !
! 59         Ghana              Kumasi                                 !
! 60         Ghana              Tafo                                   !
! 61         Ivory Coast        Abidjan                                !
! 62         Ivory Coast        Gagnoa                                 !
! 63         Ivory Coast        Man                                    !
! 64         Malaysia           Kuala Trengganu                        !
! 65         Malaysia           Penang                                 !
! 66         Malaysia           Sandakan                               !
! 67         Malaysia           Tawau                                  !
! 68         Papua New Guinea   Madang                                 !
! 69         Papua New Guinea   Rabaul                                 !
! 70         - user-defined -                                          !
! 71         - user-defined -                                          !
! 72         - user-defined -                                          !
! 73         - user-defined -                                          !
! 74         - user-defined -                                          !
! etc.                                                                 !
!----------------------------------------------------------------------!
```

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).

```
************************************************************************
* CONTROL.DAT                                                          *
*                                                                      *
* To be used with CASE2 (CAcao Simulation Engine), version 2.2         *
* This data file contains the names of the data files used by CASE2.   *
*                                                                      *
************************************************************************

************************************************************************
* THE INFORMATION IN THIS DATA FILE SHOULD NOT BE CHANGED              *
************************************************************************

  FILEON = 'RES.DAT'        ! Output file
  FILEOL = 'MODEL.LOG'      ! Log file
  FILEIR = 'RERUNS.DAT'     ! Reruns file
  FILEIT = 'TIMER.DAT'      ! File with timer data and weather data
  FILEI1 = 'PLANT.DAT'      ! Cacao plant data file
  FILEI2 = 'SOIL.DAT'       ! Soil data file
  FILEI3 = 'BASIC.DAT'      ! Data file with values that can be changed
```

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.

```
************************************************************************
* PLANT.DAT                                                            *
*                                                                      *
* To be used with CASE2 (CAcao Simulation Engine), version 2.2         *
* This data file contains plant information on cacao used by CASE2.    *
*                                                                      *
************************************************************************

************************************************************************
* THE VALUES IN THIS DATA FILE SHOULD NOT BE CHANGED                   *
************************************************************************

***********************************
* Leaves                          *
***********************************
```

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

```
* Estimated maximum and minimum leaf age [days]. (Miyaji et al. 1997; Sale 1968)
  AVGLVAGE = 210.              ![d] maximum
  MINLVAGE =  90.              ![d] minimum
```

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

```
* 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]
```

```
    SLAR1B=0.000898             ![ha leaf kg-1 leaf 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*Ln(x) + b (a=SLAR2A,
  b=SLAR2B, x=TRMIS
  * (transmission of light below shade canopy), y=modifier for SLA value)
    SLAR2A=-1.772              ![-]
    SLAR2B=0.9651              ![-]

  ***********************************
  * Wood                            *
  ***********************************

  * Loss of wood relative to that of leaves. (Ling 1986)
    WDLVDR = 0.077              ![kg dead wood kg-1 dead leaves]

  * Heartwood formation (Comparable with other tree species; Hillis 1987)
    HRTWDAGE = 3650.            ![d] age at which sapwood transforms into heartwood

  ***********************************
  * 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
    VDWURTRA=-1.06                   ![-]
    VDWURTRB=199.9                   ![kg DW ha-1 m-2]
```

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)
    FWURT = 0.2                      ![-]

  * Turnover rate of water-uptaking roots (< 2 mm diameter). (Muñoz & de Beer 2001)
  * All fine roots are estimated to be replaced once per year.
    RTOWURT = 0.00274                ![d-1]

  * Mean diameter (m) and specific root length (m kg-1) of the two root
  * classes able to take up water (Kummerow, 1981)
    DIAM1 = 0.00022                  ![m]
    DIAM2 = 0.0015                   ![m]
    SPRTL1 = 36000.                  ![m kg-1]
    SPRTL2 = 3000.                   ![m kg-1]

  * Specific weight of wood (Fanshawe 1986, Favrichon 1994, Poorter & Werger 1998)
  * Adding 10% to average value of 550 gives around 600.
    SW = 600.                        ![kg m-3]

  * Loss of non-water uptaking lateral roots relative to that of water
  * uptaking roots. (No source - estimated guess)
    LRTWURTDR = 0.10                 ![kg dead lateral roots kg-1 dead water-
  uptaking roots]

  ***********************************
  * Pods                            *
  ***********************************

  * Minimal dry weight for production of pods [kg DW]
    WTOTMIN=10.                ![kg DW plant-1]
```

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

```
  * Sink strength for pod growth, based on Hadley et al. (1994)
    SSTB  =    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
```

The values are derived in Table 4.2.

```
* Butter hardness regression coefficients (Berbert 1976 in Wood & Lass 1986)
* y = a*x +b (a=BHA; b= BHB); y= BH [-]; x = temp [degr C]
  BHRA =  0.10                                ![degr C -1]
  BHRB = -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*x +b (a=DEVRR1A or DEVR2A; b= DEVRR1B or DEVR2B); y= DEVR [d-1]; x = temp
[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]

***********************************
* Photosynthesis                  *
***********************************
```

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

***********************************
```

```
* Growth                                                    *
***********************************
```

These values are derived in Table 4.2.

```
* Growth respiration parameters
  ASRQLRT = 1.49415            ![kg CH2O kg-1 DW d-1] lateral roots
  ASRQTRT = 1.56871            ![kg CH2O kg-1 DW d-1] taproot
  ASRQWD  = 1.56871            ![kg CH2O kg-1 DW d-1] wood
  ASRQLV  = 1.65600            ![kg CH2O kg-1 DW d-1] leaves
```

These values are derived in Table 4.2.

```
* Carbon content plant components
  CFLRT = 0.50080              ![kg C kg-1 DW d-1] lateral roots
  CFTRT = 0.51996              ![kg C kg-1 DW d-1] taproot
  CFWD  = 0.51996              ![kg C kg-1 DW d-1] wood
  CFLV  = 0.46737              ![kg C kg-1 DW d-1] leaves
```

These values are depicted in Figure 4.8.

```
* Table of assimilate requirements of pods as a
* function on fat content
* (x= fat content, y = growth repsiration (kg CH20.kg DW-1))
  ASRQPDTB = 0.50,1.72479, .55,1.75554, 0.60,1.78599   ![kg CH2O kg-1 DW d-1]

* Table of C-content of pods as a function on fat content
* (x= fat content, y = C-content (kg C.kg DW-1))
  CFPDTB   = 0.50,0.50370 , .55,0.50895, 0.60,0.51413   ![kg C kg-1 DW d-1]
```

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

```
* Biomass partitioning parameters
* This set is used to partition assimilates that are used for organ growth, not
* for renewal of organs. Fractions (F) for roots (RT), leaves (LV), wood in stem
* and branches (WD) and pods (PD), all based on regressions (RE).
* (Thong & Ng 1978, Alpizar et al 1986, Teoh et al 1986, Himme 1959, Opakunle
1991,Aranguren et al 1982)
  FTRTRA=0.039              ![kg DW taproot kg-1 DW whole plant]
  FLRTRA=0.11               ![kg DW lateral roots kg-1 DW whole plant]
  FLVRA=0.14                ![kg DW leaf kg-1 DW whole plant]
  FWDRA=0.62                ![kg DW wood kg-1 DW whole plant]
  FPDRA=0.026               ![kg DW pod kg-1 DW whole plant]
  FTRTRB=0.36               ![kg DW taproot]
  FLRTRB=0.67               ![kg DW lateral root]
  FLVRB=0.43                ![kg DW leaves]
  FWDRB=-0.7                ![kg DW wood]
  FPDRB=0.5                 ![kg DW pod]

*********************************
* Miscellaneous parameters      *
*********************************

* Minimum concentration of reserves (Humphries 1947, Adomako & Hutcheon 1974, Owusu
et al. 1978)
  MINCON = 0.07                                      ![kg CH2O kg-1 DW]

* Time coefficient, delay time
  TAU = 5.                                           ![d]
```

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

```
* Relation between total plant biomass [as y in kg DW] and age [as x, in d], to be
used when age is input in model.
* The relation is of the form y= a*ln(x) + b, where a=AGBIORA and b=AGBIORB
* (Thong & Ng 1978, Alpizar et al 1986, Teoh et al 1986, Himme 1959, Opakunle
1991,Aranguren et al 1982)
  AGBIORA=8.4648              ![kg DW d-1]
  AGBIORB=-40.54             ![kg DW]

***********************************
* Water troughfall                *
***********************************
```

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)
  TFALA = 0.927;   TFALB = -0.789
* Stem flow is currently not considered as no good estimates are available
  STFLA = 0.0  ;   STFLB = 0.0

* Characteristic potential transpiration for cacao
TRANSC = 1.5               ! [mm day-1]

* Volumetric water content at which water logging occurs
WCWET  = 0.50              ! [cm3 cm-3]
```

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 PRODLEVL = 1 (potential production).
```

```
*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             !
!                                                                       !
!=======================================================================!
```

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.

```
************************************************************************
* SOIL.DAT                                                             *
*                                                                      *
* To be used with CASE2 (CAcao Simulation Engine), version 2.2         *
* This data   file contains soil information used by CASE2           .   *
*                                                                      *
************************************************************************

************************************************************************
* INFORMATION IN PART A OF THIS THIS DATA FILE MAY BE CHANGED          *
************************************************************************
```

```
!=======================================================================!
!                                                                       !
! 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.

```
!===================================================================!
!                                                                   !
! PART B. NO changes may be made to this part of the data file.     !
!                                                                   !
!===================================================================!

* 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

!===================================================================!
! TABLE WITH RIJTEMA/DRIESSEN SOIL TEXTURE TYPES (Driessen, 1986)    !
!===================================================================!

!-------------------------------------------------------------------!
!    TYL  Description               TYL  Description                !
!                                                                   !
!      1. Coarse sand                11. Fine sandy loam            !
!      2. Medium coarse sand (mcs)   12. Silt loam                  !
!      3. Medium fine sand           13. Loam                       !
!      4. Fine sand                  14. Sandy clay loam            !
!      5. Humous loamy mcs           15. Silty clay loam            !
!      6. Light loamy mcs            16. Clay loam                  !
!      7. Loamy mcs                  17. Light clay                 !
!      8. loamy fine sand            18. Silty clay                 !
!      9. Sandy loam                 19. Heavy clay                 !
!     10. Loess loam                 20. Peat                       !
!-------------------------------------------------------------------!
```

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).

<u>(1) Driessen equation (SWIT8 = 1; SWIT9=2).</u> 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.
<u>(2) Van Genuchten equation (SWIT8 = 2; SWIT9=2).</u> 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 send 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 send 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 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:
! WTRDIR  = Directory of weather data
! CLFILE  = File with weather data when IWEATH = 0,1 (WOFOST or
!           longterm weather data)
! IWEATH  = Flag indicating the weather system used:
!           Possible values: 0,1 for Wofost monthly weather;
!           2 for Cabo daily weather
! CNTR    = Country of weather data; only to be used in combination
!           with Cabo daily weather (IWEATH = 2)
! ISTN    = Station number of weather data; only to be used
!           in combination with Cabo daily weather (IWEATH = 2)
! IRNDAT  = Flag indicating rainfall system when IWEATH = 0, 1:
!           Possible values: 0 for generated rain,
!           1 for distributed rain, 2 for observed rain.
! STRTYR1 = First year for which weather data are available
! ENDYR1  = Last year for which weather data are available
!----------------------------------------------------------------------!

!---------------------------------!
! Daily or monthly weather data   !
!---------------------------------!

* LOCATION 1
* Brazil, Maceio (Alagoas) 1961  1969 d
  WTRDIR1 = 'c:\case2\weather\daily\'
  CNTR1   = 'brazil'
  ISTN1   = 2
  IWEATH1 = 2
  IRNDAT1 = 2
  STRTYR1 = 1961
  ENDYR1  = 1969

* LOCATION 2
* Costa Rica  El Carmen        1974  1991 d
  WTRDIR2 = 'c:\case2\weather\daily\'
  CNTR2   = 'cr'
  ISTN2   = 1
  IWEATH2 = 2
```

```
  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  = 1990

* 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
```

```
  WTRDIR10 = 'c:\case2\weather\monthly\'
  CLFILE10 = 'civdal.wof'
  IWEATH10 = 1
  IRNDAT10 = 1
  STRTYR10 = 1987
  ENDYR10  = 1996

* LOCATION 11
* Ivory Coast Dimbokro 1987   1996    10      m
  WTRDIR11 = 'c:\case2\weather\monthly\'
  CLFILE11 = 'civdim.wof'
  IWEATH11 = 1
  IRNDAT11 = 1
  STRTYR11 = 1987
  ENDYR11  = 1996

* LOCATION 12
* Ivory Coast Gagnoa       1986        1997    12       m
  WTRDIR12 = 'c:\case2\weather\monthly\'
  CLFILE12 = 'civgag.wof'
  IWEATH12 = 1
  IRNDAT12 = 1
  STRTYR12 = 1986
  ENDYR12  = 1997

* LOCATION 13
* Ivory Coast Man              1987    1996    10       m
  WTRDIR13 = 'c:\case2\weather\monthly\'
  CLFILE13 = 'civman.wof'
  IWEATH13 = 1
  IRNDAT13 = 1
  STRTYR13 = 1987
  ENDYR13  = 1996

* LOCATION 14
* Ivory Coast San  Pedro        1987   1996    10       m
  WTRDIR14 = 'c:\case2\weather\monthly\'
  CLFILE14 = 'civsan.wof'
  IWEATH14 = 1
  IRNDAT14 = 1
  STRTYR14 = 1987
  ENDYR14  = 1996

* LOCATION 15
* Malaysia    Tawau (Sabah)    1951    1993    43       m
  WTRDIR15 = 'c:\case2\weather\monthly\'
  CLFILE15 = 'mystab.wof'
  IWEATH15 = 1
  IRNDAT15 = 1
  STRTYR15 = 1951
  ENDYR15  = 1993

* LOCATION 16
* Malaysia    Telok Chengai1978        1988    11       m
  WTRDIR16 = 'c:\case2\weather\monthly\'
  CLFILE16 = 'mals002a.wof'
  IWEATH16 = 1
  IRNDAT16 = 1
  STRTYR16 = 1978
  ENDYR16  = 1988

* LOCATION 17
* Papua New Guinea     Dami 1970        1991    22       d
  WTRDIR17 = 'c:\case2\weather\daily\'
  CNTR17   = 'png'
  ISTN17   = 1
  IWEATH17 = 2
  IRNDAT17 = 2
  STRTYR17 = 1970
  ENDYR17  = 1991

* LOCATION 18
```

```
* Philippines IRRI         1979        1995    17      d
  WTRDIR18 = 'c:\case2\weather\daily\'
  CNTR18   = 'phil'
  ISTN18   = 1
  IWEATH18 = 2
  IRNDAT18 = 2
  STRTYR18 = 1979
  ENDYR18  = 1995

* LOCATION 19
* < specify location name and period of weather data here >
  WTRDIR19 = ' '
  CNTR19   = ' '
  CLFILE19 = ' '
  ISTN19   = 0
  IWEATH19 = 0
  IRNDAT19 = 0
  STRTYR19 = 0
  ENDYR19  = 0

* LOCATION 20
* < specify location name and period of weather data here >
  WTRDIR20 = ' '
  CNTR20   = ' '
  CLFILE20 = ' '
  ISTN20   = 0
  IWEATH20 = 0
  IRNDAT20 = 0
  STRTYR20 = 0
  ENDYR20  = 0

* LOCATION 21
* < specify location name and period of weather data here >
  WTRDIR21 = ' '
  CNTR21   = ' '
  CLFILE21 = ' '
  ISTN21   = 0
  IWEATH21 = 0
  IRNDAT21 = 0
  STRTYR21 = 0
  ENDYR21  = 0

* LOCATION 22
* < specify location name and period of weather data here >
  WTRDIR22 = ' '
  CNTR22   = ' '
  CLFILE22 = ' '
  ISTN22   = 0
  IWEATH22 = 0
  IRNDAT22 = 0
  STRTYR22 = 0
  ENDYR22  = 0

* LOCATION 23
* < specify location name and period of weather data here >
  WTRDIR23 = ' '
  CNTR23   = ' '
  CLFILE23 = ' '
  ISTN23   = 0
  IWEATH23 = 0
  IRNDAT23 = 0
  STRTYR23 = 0
  ENDYR23  = 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'
```

```
* LOCATION 70
* < specify location name and period of weather data here >
  CLFILE70 = ' '

* LOCATION 71
* < specify location name and period of weather data here >
  CLFILE71 = ' '

* LOCATION 72
* < specify location name and period of weather data here >
  CLFILE72 = ' '

* LOCATION 73
* < specify location name and period of weather data here >
  CLFILE73 = ' '

* LOCATION 74
* < specify location name and period of weather data here >
  CLFILE74 = ' '

* LOCATION 75
* < specify location name and period of weather data here >
  CLFILE75 = ' '

!=====================================================================!
!                                                                     !
! PART B. NO changes may be made to this part of the data file.       !
!
!=====================================================================!

!---------------------------------!
! Output                          !
!---------------------------------!
```

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
PRSEL1 =
'YEAR','ageyr','YRAIN','YRDD','YTRANS','WTOT','WTOTPP','WRT','WLV','WWD','WTRT','WL
RT','WPD','YGPHOT','YGTOT','YYLDPD','YYLDBN','YLVD','YWDD','WPDCUM','WBNCUM','YHI',
'YHINCR','YMNBH','YMNLAI','YMNIPOD','YHARPD','YRDEFF','YRNEFF','YNLOSS','YPLOSS','Y
KLOSS','<TABLE>'

* per 10 days
PRSEL2 =
'year','doy','ageyr','tmav','pcew','lai(1)','WTOT','wtotpp','wrt','wlrt','wtrt','wl
v', 'wwd',
'wpd','WPDCUM','WBNCUM','D10GTOT','D10YLDPD','D10YLDBN','D10RAIN','D10RDD','D10HARP
D','<table>'

* per day
PRSEL3 =
'year','doy','ageyr','rdd','rain','tmav','atrans','ptrans','pcew','frabs(1)','lai(1
)','WTOT','wtotpp','wrt','wlrt','wtrt','wlv', 'wwd', 'wpd',
'gphot','maint','GTOT','gpd','glv','grt','glrt','gtrt','GWD','GTOT1','GTOT2','FLV',
'FWD','FPD',
'FTRT','FLRT','dwd','dlrt','dlv','dlv1','dlv2','ltrt','yldpd','YLDBN','BHYLD','harp
ods','WPDCUM','WBNCUM','<table>'
```

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
```

```
            1956, 366, 1957, 365, 1958, 365, 1959, 365, 1960, 366,
            1961, 365, 1962, 365, 1963, 365, 1964, 366, 1965, 365,
            1966, 365, 1967, 365, 1968, 366, 1969, 365, 1970, 365,
            1971, 365, 1972, 366, 1973, 365, 1974, 365, 1975, 365,
            1976, 366, 1977, 365, 1978, 365, 1979, 365, 1980, 366,
            1981, 365, 1982, 365, 1983, 365, 1984, 366, 1985, 365,
            1986, 365, 1987, 365, 1988, 366, 1989, 365, 1990, 365,
            1991, 365, 1992, 366, 1993, 365, 1994, 365, 1995, 365,
            1996, 366, 1997, 365, 1998, 365, 1999, 365, 2000, 366,
            2001, 365, 2002, 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.                 ! Start day of simulation
DELT   = 1.                 ! Time step of integration

* 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).

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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.

Parameter	Description	Unit	Used in:	In/Out
ADJLVAGE	Leaf life span adjusted for drought effects	d	C	
AGBIORA	Regression coefficient for age-biomass relation	kg DW d-1	C	I
AGBIORB	Regression coefficient for age-biomass relation	kg DW	C	I
AGE	Age of the cacao tree	d	C	
AGEI	Age of the cacao tree at the start of the simulation	d	C	
AGEIYR	Age of the cacao tree at the start of the simulation in years	y	C	I
AGEYR	Age of the cacao tree in years	y	C	O
AIRDR	pF value for airdry soil	-	D	
AMAX	Temperature-dependent maximum photosynthesis rate	kg CO2 ha-1 leaf h-1	C	
AMINIT	Factor accounting for lower photosynthesis in young leaves	-	C	I
AMTMP	Reduction factor for temperature effect on AMX	-	C	
AMTMPT	Table with reduction factor for temperature effects on AMX	-	C	I
AMX	Maximum rate of photosynthesis	kg CO2 ha-1 leaf h-1	C	I
ANGA	Regression coefficient in Angstrom formula	-	M F S	
ANGB	Regression coefficient in Angstrom formula	-	M F S	
ANGOT	Daily total extraterrestial radiation	J m-2 d-1	S	
ASRQ	Assimilate requirement for the production of 1 kg biomass	kg CH2O kg-1 DW	C	
ASRQLRT	Assimilate requirement for the production of 1 kg lateral roots	kg CH2O kg-1 DW	C	I
ASRQLV	Assimilate requirement for the production of 1 kg leaves	kg CH2O kg-1 DM	C	I
ASRQPDTB	Table of pod assimilate requirements depending on fat content	kg CH2O kg-1 DM	C	I
ASRQTRT	Assimilate requirement for the production of 1 kg taproot	kg CH2O kg-1 DM	C	I
ASRQWD	Assimilate requirement for the production of 1 kg wood	kg CH2O kg-1 DM	C	I
ATRANS	Total daily actual transpiration rate of the canopy	mm d-1	C	O
ATWURT	Total area of water-uptaking roots	m2 ha-1	C	O
AVAIL	Soil moisture available for transpiration (per layer)	mm	D C	
AVGLVAGE	Maximum leaf life span without water stress	d	C	I
AWURT	Area of water-uptaking roots per soil layer	m2 ha-1	C	O
BH	Butter hardness of beans	-	C	
BHRA	Butter hardness regression coefficient	°C -1	C	I
BHRB	Butter hardness regression coefficient	-	C	I
BHSUM	Sum of butter hardness values	-	C	
BHYLD	Butter hardness of the daily bean production	-	C	O
CAP	Soil moisture that can be absorbed (per layer)	mm	D	
CFLRT	Mass fraction carbon in the lateral roots	kg C kg-1 DM	C	I
CFLV	Mass fraction carbon in the leaves	kg C kg-1 DM	C	I
CFPD	Mass fraction carbon in the pods	kg C kg-1 DM	C	
CFPDTB	Table of mass fraction carbon in pods depending on fat content	-	C	I
CFTRT	Mass fraction carbon in the taproot	kg C kg-1 DM	C	I
CFWD	Mass fraction carbon in the wood	kg C kg-1 DM	C	I

Parameter	Description	Unit	Used in:	In/Out
CHECK	Absolute error in water balance	mm	D	
CHKDIF	Carbon check variable	kg C ha-1	C	
CHKFL	Cumulative amount of carbon assimilated	kg C ha-1	C	
CHKGPOD	Check variable for pod growth summation	kg DW ha-1 d-1	C	
CHKIN	Amount of carbon present in all plant parts at any point in time	kg C ha-1	C	
CHKLRT	Carbon check variable for lateral roots	kg C ha-1	C	
CHKLV	Carbon check variable for leaves	kg C ha-1	C	
CHKPART1	Check variable for partitioning of resources	-	C	
CHKPART2	Check variable for partitioning of resources	-	C	
CHKPD	Carbon check variable for pods	kg C ha-1	C	
CHKTLV	Check variable for leaf biomass summation	kg DW ha-1	C	
CHKTRT	Carbon check variable for taproot	kg C ha-1	C	
CHKWD	Carbon check variable for wood	kg C ha-1	C	
CHKWPOD	Check variable for pod biomass summation	kg DW ha-1	C	
CLEAR	Fraction of clear sky	-	S	
CLFILE	File name for weather files with monthly data	-	F	I
CNTR	Country code for weather file	-	F	I
CO2LRT	CO2 production factor for lateral roots	kg CO2 kg-1 DW	C	
CO2LV	CO2 production factor for leaves	kg CO2 kg-1 DW	C	
CO2PD	CO2 production factor for pods	kg CO2 kg-1 DW	C	
CO2TRT	CO2 production factor for taproot	kg CO2 kg-1 DW	C	
CO2WD	CO2 production factor for wood	kg CO2 kg-1 DW	C	
COPINF	Switch variable: whether input data should be copied to output file	-	F	I
CROPF	Crop factor for crop water requirement	-	C	
CUMTKL	Cumulative thickness of soil layers	m	C	
D10COUNT	Counter for 10-day summations	-	C	
D10GTOT	Total biomass growth during 10 days	kg DW ha-1 (10 d)-1	C	O
D10HARPD	Number of harvested pods during 10 days	(10 d)-1	C	O
D10RAIN	Amount of rainfall during 10 days	mm (10 d)-1	C	O
D10RDD	Amount of short-wave radiation during 10 days	J m-2 (10 d)-1	C	O
D10YLDBN	Yield of dry, fermented beans during 10 days	kg DW ha-1 (10 d)-1	C	O
D10YLDPD	Yield of pods during 10 days	kg DW ha-1 (10 d)-1	C	O
DATCMP	Irrigation parameter	-	D	
DATMTR	Daily atmospheric transmission fraction	-	S	
DELT	Time step of integration	d	C D M F	I
DELTMP	Switch variable what should be done with temporary file	-	F	I
DEPTH	Depth of soil compartment (per layer)	m	D	
DEVR	Pod development rate	d-1	C	
DEVRH	Pod development rate: high regression estimate	d-1	C	
DEVRL	Pod development rate: low regression estimate	d-1	C	
DEVRR1A	Regression coefficient on relation between temperature and pod ripening	d-1 °C -1	C	I
DEVRR1B	Regression coefficient on relation between temperature and pod ripening	d-1	C	I
DEVRR2A	Regression coefficient on relation between temperature and pod ripening	d-1 °C -1	C	I
DEVRR2B	Regression coefficient on relation between temperature and	d-1	C	I

Parameter	Description	Unit	Used in:	In/Out
	pod ripening			
DIAM1	Mean diameter of fine roots (diameter < 1 mm)	m	C	I
DIAM2	Mean diameter of fine roots (diameter between 1 and 2 mm)	m	C	I
DLRT	Daily death rate of lateral root biomass	kg DW ha-1 d-1	C	O
DLV	Daily death rate of leaves biomass	kg DW ha-1 d-1	C	O
DLV1	Daily death rate of leaves biomass due to ageing	kg DW ha-1 d-1	C	O
DLV10	Leaf death rates for 10 days (array)	kg DW ha-1 d-1	C	
DLV2	Daily death rate of leaves biomass due to drought	kg DW ha-1 d-1	C	O
DOY	Day number since 1 January within year of simulation	d	C M F	O
DRAFT	Rate of change of drainage	mm d-1	D	
DRAICU	Cumulative drainage by drains	mm	M D	
DRAIQT	Daily drainage rate	mm d-1	D	
DRES	Total decrease rate of reserves	kg CH2O ha-1 d-1	C	
DRES1	Decrease rate of reserves due to maintenance respiration	kg CH2O ha-1 d-1	C	
DRES2	Decrease rate of reserves due to replacement of biomass	kg CH2O ha-1 d-1	C	
DSLR	number of days since last rain	d	D	
DT	Estimated temperature difference between surface height and reference height	°C	S M	
DTGA	Daily total gross CO2 assimilation	kg CO2 ha-1 d-1	C	
DUMMY	Weather error parameter	-	F	
DWD	Daily death rate of wood biomass	kg DW ha-1 d-1	C	O
DY0	Day of previous irrigation	d	D	
EES	Evaporation proportionality factor	m-1	D	I
EFF	Initial light use efficiency for individual leaves	(kg CO2 ha-1 h-1)/(J m-2 s-1)	C	I
ELEV	Elevation of site	m	M F	
ENDRNF	Parameter indicating whether end run number was found	-	F	
ENDRUN	End run number	-	F	
ENDYR	Final year of simulation	-	F	I
ETAE	Dryness driven part of potential evapotranspiration	mm d-1	S M C	
ETD	Potential evapotranspiration	mm d-1	S M	
ETMOD	Evapotranspiration module	-	M	I
ETRD	Radiation driven part of potential evapotranspiration	mm d-1	S M C	
EVSC	Actual (realized) evaporation rate	mm d-1	C D M	
EVSCL	Positive evaporation rate	mm d-1	D	
EVSD	Evaporation rate on days without rain	mm d-1	D	
EVSH	Evaporation rate on days with rain	mm d-1	D	
EVSW	Evaporation parameter	mm d-1	D	
EVSW2	Actual evaporation rate	mm d-1	D	
EVSWCU	Cumulative evaporation	mm	D	
FATCONTENT	Fat content of nibs	-	C	I
FBEANS	Dry weight fraction of beans in pod	-	C	I
FHRTWD	Fraction of wood that is heartwood	-	C	
FIELD	pF value for field capacity	-	D	
FILEI1	Name of input file no. 1	-	C M F	
FILEI2	Name of input file no. 2	-	M F	
FILEI3	Name of input file no. 3	-	M M F	
FILEI4	Name of input file no. 4	-	M F	

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

Parameter	Description	Unit	Used in:	In/Out
GLRT	Daily growth rate of lateral root biomass	kg DW ha-1 d-1	C	O
GLRT1	Daily growth rate of lateral root biomass, replacement	kg DW ha-1 d-1	C	
GLV	Daily growth rate of lateral leaf biomass	kg DW ha-1 d-1	C	O
GLV1	Daily growth rate of lateral leaf biomass, replacement	kg DW ha-1 d-1	C	
GPD	Daily growth rate of lateral pod biomass	kg DW ha-1 d-1	C	O
GPD1	Daily growth rate of lateral pod biomass, replacement	kg DW ha-1 d-1	C	
GPHOT	Daily total gross CH2O assimilation	kg CH2O ha-1 d-1	C	O
GPOD	Growth rate of pods in pod class (array)	kg DW ha-1 d-1	C	
GPODTOT	Summation of pod growth rate over all pod classes	kg DW ha-1 d-1	C	
GRES	Growth rate of reserves	kg CH2O ha-1 d-1	C	
GRT	Daily growth rate of root biomass	kg DW ha-1 d-1	C	O
GTOT	Daily growth rate of total biomass	kg DW ha-1 d-1	C	O
GTOT1	Daily growth rate of total biomass: growth to replace lost biomass	kg DW ha-1 d-1	C	O
GTOT2	Daily growth rate of total biomass: growth leading to net growth in biomass	kg DW ha-1 d-1	C	O
GTRT	Daily growth rate of taproot biomass	kg DW ha-1 d-1	C	O
GWD	Daily growth rate of wood biomass	kg DW ha-1 d-1	C	O
GWD1	Daily growth rate of wood biomass: growth to replace lost biomass	kg DW ha-1 d-1	C	
GWURT1	Daily growth rate of water-uptaking roots: growth to replace lost biomass	kg DW ha-1 d-1	C	
HARPODS	Daily number of harvested pods	# d-1	C	O
HGHL	Lower height of cacao tree crowns	m	C	I
HGHT	Upper height of cacao tree crowns	m	C	I
HLP1	intermediate variable in van Genuchten equation	-	D	
HRTWDAGE	Age at which softwood is transformed into non-respiring heartwood	d	C	I
HUM	Relative humidity	-	S	
I1	Counter	-	F M D N C	
I2	Counter	-	D	
IAMTMN	Counter for mean temperatures	-	C	
IASRQPDN	Counter for pod assimilation requirements	-	C	
ICFPDN	Counter for pod carbon fraction	-	C	
IDOY	Day number within year of simulation (integer)	d	M F S D C	
IDOYO	Day number within year of simulation (integer)	d	C	
IFLAG	Indicates where weather error and warnings are stored	-	F	I
IL	Do-loop counter	-	D F	
ILD	Number of leaf classes	-	C	
ILW	Switch for Brunt or Swinbank formula	-	S	
IMNID	Irrigation parameter	-	D	
IMNOD	Parameter for reading observation years	-	F	
IMNPRS	Parameter for output parameter selection	-	F	
INF	Daily infiltration rate	mm d-1	D	
INFCU	Cumulative infiltration	mm	D	
INID	number of irrigation	-	D	
INOD	Parameter for reading observation years	-	F	
INPRS	Parameter for output parameter selection	-	F	

Parameter	Description	Unit	Used in:	In/Out
INS	Counter for species (1=cacao; 2=shade tree)	-	C	
INSETS	Parameter for reruns	-	F	
IOBSD	Lists year-day combinations for which output is requested	-	F	I
IOD	Parameter for reading observation years	-	F	
IPC	Counter for days in 10-day summations	-	C	
IPFORM	Format of output file:	-	F	I
IPOD	Number of pod classes	-	C	
IRNDAT	Indicates type of rainfall data	-	F	I
IRR	Daily irrigation rate	mm d-1	D	
IRRCU	Cumulative irrigation	mm	D	
IRRTB	table with entries of irrigation applications (year, day, amount)	-	D	
ISET	Parameter for reruns	-	F	
ISSN	Counter for sink strength table	-	C	
ISTN1	Weather station number (only for daily weather data)	-	F	I
ISURF	Switch value to choose between different surface types (-)	-	S M	
ITABLE	Declared length of many of the interpolation tables	-	C F	
ITASK	Task that subroutine should perform	-	F M P D C	
ITMP	Intermediate variable in calculation of the soil moisture characteristic	-	D	
ITYL	Intermediate array in calculation of the soil moisture characteristic	-	D	
IUNIT	Unit number for file use	-	D	
IUNITC	Unit that can be used for control file	-	F	
IUNITD	Unit that can be used for input files	-	M F C	
IUNITL	Unit used for log file	-	M F C	
IUNITO	Unit used for output file	-	C F M	
IUNITR	Unit that can be used for rerun file	-	F	
IUNLOG	Unit number in use for log file	-	D	
IUNUNITD	Unit that can be used for input files	-	M	
IURA	Parameter used for weather files	-	F	
IUWE	Parameter used for weather files	-	F	
IWEATH	Indicates type of weather data used	-	F	I
IYEAR	Year of simulation (integer)	y	M D F C	
IYEARR	Year of simulation (real)	y	F	
KCONTBN	K content of dry beans	kg K kg-1 bean DW	C	I
KDF	Extinction coefficient for leaves (array)	-	C	
KDFL	Extinction coefficient for cacao leaves	-	C	I
KDFT	Extinction coefficient for cacao trunk	-	C	I
KS	Extinction coefficient for trunk (array)	-	C	
LA	Leaf area	ha leaf	C	
LAI	Leaf area index	ha leaf ha-1 ground	C	
LAI(1)	Leaf area index of the cacao trees	ha leaf ha-1 ground	C	O
LAIF	Leaf area index, with maximum value for cacao trees	ha leaf ha-1 ground	C	
LAISUM	Summation of leaf area index used for calculating average LAI	ha leaf ha-1 ground	C	
LAT	Latitude of site	dec. degr.	M F S C	
LHVAP	Latent heat of water	kJ kg-1	S	
LOCATION	Location number for which simulations are conducted	-	F	I
WTRMES	Indicator of messages from weather system	-	F	

Parameter	Description	Unit	Used in:	In/Out
LONG	Longitude of site	dec.degr.	M F	
LRTWURTDR	Loss of coarse lateral roots relative to that of water-uptaking roots	kg dead lateral roots kg-1 dead water-uptaking roots	C	I
LTRT	Length of taproot	m	C	O
LTRTLL	Length of taproot in lowest soil layer	m	C	
LTWURT	Total length of water-uptaking roots	m ha-1	C	O
LWURT1	Array with root length (diameter < 1 mm) in different soil layers	m ha-1	C	
LWURT2	Array with root length (diameter between 1-2 mm) in different soil layers	m ha-1	C	
MAINLRT	Maintenance respiration coefficient for lateral roots	kg CH2O kg-1DM d-1	C	I
MAINLV	Maintenance respiration coefficient of leaves	kg CH2O kg-1 DM d-1	C	I
MAINPD	Maintenance respiration coefficient for pods	kg CH2O kg-1DM d-1	C	I
MAINT	Maintenance respiration rate of the crop	kg CH2O ha-1 d-1	C	I
MAINT	Daily rate of maintenance respiration	kg CH2O ha-1 d-1	C	O
MAINTRT	Maintenance respiration coefficient for taproot	kg CH2O kg-1DM d-1	C	I
MAINTS	Maintenance respiration, summed over plant parts	kg CH2O kg-1DM d-1	C	
MAINWD	Maintenance respiration coefficient for wood	kg CH2O kg-1DM d-1	C	I
MAXLAI	Maximum LAI used in the photosynthesis subroutines	m2 leaves m-2 ground	C	I
MINCON	Minimum concentration of carbohydrate reserves	kg CH2O kg-1 DW	C	I
MINLVAGE	Minimum leaf age	d	C	I
MINRES	Minimum size of reserve pool	kg CH2O ha-1	C	
MOISTC	Moisture content of dry, fermented beans	-	C	I
MSWCA	gamma in Driessen equation (user-defined)	-	D	
MSWCAT	gamma in Driessen equation (standard set)	-	D	
NCONTBN	N content of dry beans	kg N kg-1 bean DW	C	I
NL	Number of soil layers	-	M D D C	I
NLA	Number of soil layers, from which water can be extracted	-	C	
NLBM	Maximum number of soil layers	-	C	
NLLM	Counter	-	D C	
NLRT	Maximum number of rooted soil layers	-	C	
NLXM	Maximum number of soil layers	-	D M C D	
NPL	Cacao tree planting density	# ha-1	C	I
NRDTYP	Number of Driessen soil types defined	-	D	
NRYEARS	Number of years for which simulation should be conducted	y	F	I
NVGTYP	Number of van Genuchten soil types defined	-	D	
OUTPUT	Flag to indicate if output should be done	-	M D C	
OUTPUTFQ	Frequency at which output is generated	-	M F C	I
P	Soil water depletion factor	-	C	
PCEW	Water availability factor that reduces photosynthesis due to water stress	-	C	O
PCEw10	Water availability factor values over last 10 days (array)	-	C	
PCEWMN	Average water availability factor over last 10 days	-	C	
PCONTBN	P content of dry beans	kg P kg-1 bean DW	C	I
PENMAN	Penman reference value for potential evapotranspiration	mm d-1	C	
PF	relative moisture content as function of pF (array)	-	D	
PFWC00	pF values at a relative water content of 0.0 (array)	-	D	
PFWC01	pF values at a relative water content of 0.1 (array)	-	D	

Parameter	Description	Unit	Used in:	In/Out
PFWC02	pF values at a relative water content of 0.2 (array)	-	D	
PFWC03	pF values at a relative water content of 0.3 (array)	-	D	
PFWC04	pF values at a relative water content of 0.4 (array)	-	D	
PFWC05	pF values at a relative water content of 0.5 (array)	-	D	
PFWC06	pF values at a relative water content of 0.6 (array)	-	D	
PFWC07	pF values at a relative water content of 0.7 (array)	-	D	
PFWC08	pF values at a relative water content of 0.8 (array)	-	D	
PFWC09	pF values at a relative water content of 0.9 (array)	-	D	
PFWC10	pF values at a relative water content of 1.0 (array)	-	D	
PGRUSS	Growth per unit sink strength	kg DW ha-1 d-1	C	
PI	Value of pi	-	C	
PINT	Daily amount of intercepted rain	mm d-1	M C	
PLTMOD	Name of plant module	-	C M	I
PODVALUE	Pod index or pod value (number of pods per kg dry beans)	# kg-1 DW	C	I
PRDEL	Time interval between successive outputs	d	F	
PRLRTAC	Actual biomass proportion in lateral roots	-	C	
PRLRTID	Ideal biomass proportion in lateral roots	-	C	
PRLVAC	Actual biomass proportion in leaves	-	C	
PRLVID	Ideal biomass proportion in leaves	-	C	
PRODLEVL	Production level: either potential or water-limited	-	M F	I
PRPDAC	Actual biomass proportion in pods	-	C	
PRPDID	Ideal biomass proportion in pods	-	C	
PRSCALE	Scaling factor for biomass proportions	-	C	
PRSEL	Selection of variables to be included in output and table	-	F	I
PRTRTAC	Actual biomass proportion in taproot	-	C	
PRTRTID	Ideal biomass proportion in taproot	-	C	
PRWDAC	Actual biomass proporation in wood	-	C	
PRWDID	Ideal biomass proportion in wood	-	C	
PRWU	Potential water uptake rate	mm m-2 root area	C	
PSCH	Psychrometer coefficient	kPa °C-1	S	
PTRANS	Daily potential transpiration rate	mm d-1	C	O
Q10	Factor accounting for increase of maintenance	-	C	I
RAE	Aerodynamic resistance	s m-1	S	
RAIN	Daily amount of rainfall	mm d-1	M F D C	O
RAINCU	Cumulative rainfall	mm	D M	
RAINS	Daily amount of rain reaching the soil	mm d-1	M	
RCAN	Canopy resistance	s m-1	S	
RDD	Daily short-wave radiation	J m-2 d-1	F M S C	O
RDLI	Net daily longwave radiation	J m-2 d-1	S	
RDLII	Net longwave radiation	J m-2 s-1	S	
RDLO	Daily long-wave radiation	J m-2 d-1	S	
RDLOI	Long-wave radiation	J m-2 s-1	S	
RDLV	Relative death rate of leaves	d-1	C	
RDN	Net radiation flux at canopy surface	J m-2 d-1	S	
RDSLR	Rate of state variable days since last rain	-	D	
RESOIL	Relative contribution to evaporation of layer (array)	mm	D	
RF	Reflection (=albedo) of surface	-	S M	
RFS	Reflection (=albedo) of surface	-	M	

Parameter	Description	Unit	Used in:	In/Out
RHOCP	Density of dry air	kg m-3	S	
RLEAF	Leaf resistance	s m-1	S	
RNOFCU	Cumulative runoff	mm	D	
RNOFF	Daily rate of runoff	mm d-1	D	
RSETRD	Parameter used for weather files	-	F	
RSETRG	Parameter used for weather files	-	F	
RTOLV	Relative turnover rate of leaves	d-1	C	
RTOPD	Relative turnover rate of pods	d-1	C	
RTOWURT	Relative turnover rate of water-uptaking roots	d-1	C	I
SHGHL	Lower height of shade tree crowns	m	C	I
SHGHT	Upper height of shade tree crowns	m	C	I
SIGLEN	Length of string	-	D F	
SIGMA	Stefan-Boltzmann constant	J m-2 d-1 °K-1	S	
SKDFL	Extinction coefficient for leaves of shade trees	-	C	I
SLA	Specific leaf area of leaf class (array)	ha leaf kg-1 leaf DW	C	
SLAI	Leaf area index of shade trees	ha leaf ha-1 ground	C	I
SLAMOD	Modifier of SLA value, depending on shading	-		
SLAR1A	Regression coefficient on leaf area per unit leaf biomass	ha leaf kg-1 leaf DW kg-1 plant DW	C	I
SLAR1B	Regression coefficient on leaf area per unit leaf biomass	ha leaf kg-1 leaf DW	C	I
SLAR2A	Regression coefficient on leaf area per unit leaf biomass	ha leaf kg-1 leaf DW kg-1 plant DW	C	I
SLAR2B	Regression coefficient on leaf area per unit leaf biomass	ha leaf kg-1 leaf DW	C	I
SOILTYPE	Soil type to be used in model simulation	-	M F D	I
SPRTL1	Specific root length, root diameter < 1 mm	m kg-1 DM	C	I
SPRTL2	Specific root length, root diameter between 1-2 mm	m kg-1 DM	C	I
SSPOD	Sink strength of pods in a pod class	-	C	
SSTB	Table with sink strength values for pod growth	-	C	I
STAGE	Development stage of pods in a pod class	-	C	
STEMFL	Daily rate of stem flow	mm d-1	M	
STFLA	Regression coefficient for stem flow	-	M	I
STFLB	Regression coefficient for stem flow	mm d-1	M	I
STRING	String	-	F D	
STRTYR	Start year of the simulation	-	F	I
STRUN	Start day of the simulation	-	F	
STRUNF	Whether start day of simulation was found	-	F	
STTIME	Start time of simulation	d	M C F	I
SUM	total amount of water available for evaporation	mm	D	
SW	Specific weight of wood	kg m-3	C	I
SWINPUT	Switch for initial cacao tree input: either age or biomass	-	C	I
SWIT6	Switch for type of initialization in water balance module	-	D	I
SWIT8	Switch for type of equation used in water balance module	-	D	I
SWIT9	Switch for type of soil input in water balance module	-	D	I
TAU	Time coefficient	d	C	I
TEFF	Temperature effect of maintenance respiration	-	C	
TERMNL	Flag to indicate if simulation is to stop	-	C M F	
TFALA	Regression coefficient for throughfall of rain	-	M	I
TFALB	Regression coefficient for throughfall of rain	mm d-1	M	I

Parameter	Description	Unit	Used in:	In/Out
TFALL	Daily throughfall of rain through the canopy	mm d-1	M	
TIME	Time of simulation	d	C M F	
TKL	Thickness of soil compartment (array)	m	D M C	
TKLTOT	Summed thickness of soil compartments	m	C	
TKLX	thickness of soil compartments	m	P D	
TMAV	Daily average temperature	°C	C	O
TMAVD	Daytime average temperature	°C	C	
TMDA	24 hour average temperature	°C	S M	
TMDI	Temperature tolerance (switches between single and iterative Penman)	-	S M	
TMMN	Daily minimum temperature	°C	C M F	
TMMX	Daily maximum temperature	°C	M F C	
TMP	intermediate variable to check availability of soil moisture for transpiration	mm	D	
TNASS	Cumulative CO2 assimilation	kg CO2 ha-1	C	
TOLRT	Turnover rate for lateral roots	kg d-1	C	
TOLV	Turnover rate for leaves	kg d-1	C	
TOPD	Turnover rate for pods	kg d-1	C	
TOPD10	Turnover rate for pods for 10 days (array)	kg d-1	C	
TOREQ	Total required biomass for turnover	kg d-1	C	
TOWD	Turnover rate for wood	kg d-1	C	
TOWURT	Turnover rate for water-uptaking roots	kg d-1	C	
TRANSC	Characteristic potential transpiration rate	mm d-1	C	I
TRCH	Actual rate of transpiration per soil layer (array)	mm d-1	D	
TREF	Reference temperature for calculation of maintenance respiration	°C	C	I
TRMIS	Fraction light transmission through shade canopy	-	C	
TRW	Transpiration rate, summed for all layers	mm d-1	D	
TRWCU	Cumulative transpiration in time	mm	D M	
TRWL	Daily actual transpiration rate per soil layer	mm d-1	N D M C	O
TSS	Summed sink strength of all pod classes	-	C	
TYL	Driessen texture class for soil layer	-	D	I
VAR	amount of water available for evaporation of layer (array)	mm	D	
VDWURTRA	Regression coefficient on vertical distribution of fine roots	-	C	I
VDWURTRB	Regression coefficient on vertical distribution of fine roots	kg DW ha-1 m-2	C	I
VGA	parameter of the van Genuchten equation	-	D	
VGAT	parameter of the van Genuchten equation	cm-1	D	
VGM	parameter of the van Genuchten equation	-	D	
VGN	parameter of the van Genuchten equation	-	D	
VGNT	parameter of the van Genuchten equation	-	D	
VGR	parameter of the van Genuchten equation	-	D	
VGWRT	parameter of the van Genuchten equation	-	D	
VGWST	parameter of the van Genuchten equation	-	D	
VP	Early morning vapour pressure	kPa	M F S	
VPD	Vapour pressure dificit	kPa	S	
VPS	Saturated vapour pressure	kPa	S	
VPSL	Vapour pressure slope	kPa °C-1	S	
WBNCUM	Cumulative weight of harvested dry, fermented beans	kg DW ha-1	C	O

Parameter	Description	Unit	Used in:	In/Out
WCAD	volumetric water content at air dry of layer (array)	cm3 H2O cm-3 soil	D M	
WCADX	volumetric water content at air dry of layer (copy of array)	cm3 H2O cm-3 soil	P D	
WCFC	volumetric water content at field capacity of layer (array)	cm3 H2O cm-3 soil	D M	
WCFCX	volumetric water content at field capacity of layer (copy of array)	cm3 H2O cm-3 soil	P D C	
WCL	volumetric soil moisture content of layer, locally used (array)	cm3 H2O cm-3 soil	D	
WCLCH	rate of change of water content of layer (array)	mm d-1	D	
WCLQT	volumetric soil water content per layer (array)	cm3 H2O cm-3 soil	P D M C	
WCLQTM	initial volumetric soil moisture content of layer (array)	cm3 H2O cm-3 soil	D	
WCST	volumetric soil moisture content of layer at saturation (array) (user-defined)	cm3 H2O cm-3 soil	D M	
WCSTT	volumetric soil moisture content at saturation in Driessen eq. (standard set)	cm3 H2O cm-3 soil	D P C	
WCTMP	Temporal water content	mm	D	
WCUM	cumulative amount of water in the soil profile	mm	D	
WCUMCH	rate of change in cumulative amount of water in the soil profile	mm	D	
WCUMO	cumulative amount of water in the soil profile after the previous time step	mm	D M	
WCWET	Volumetric water content where water logging begins	cm3 H2O cm-3 soil	C	I
WCWP	volumetric water content at wilting point of layer (array)	cm3 H2O cm-3 soil	D M	
WCWPX	volumetric water content at wilting point	cm3 H2O cm-3 soil	P D	
WDLVDR	Loss of wood relative to that of leaves	kg dead wood kg-1 dead leaves	C	I
WEFF	ratio of transpiration and total use of water in the balance	mm mm-1	D	
WILTP	pF value for wilting point	-	D	
WLEAF	Biomass of leaves in leaf class (array)	kg DW ha-1	C	
WLEAFTOT	Total biomass of leaves in all leaf classes	kg DW ha-1	C	
WLRT	Actual lateral root biomass	kg DW ha-1	C	O
WLRTD	Weight of dead lateral roots	kg DW ha-1	C	
WLRTI	Initial lateral root biomass	kg DW ha-1	C	
WLV	Actual leaf biomass	kg DW ha-1	C	O
WLVD	Weight of dead leaves	kg DW ha-1	C	
WLVI	Initial leaf biomass	kg DW ha-1	C	
WN	Average wind speed	m s-1	M F S	
WPD	Actual pod biomass	kg DW ha-1	C	O
WPDCUM	Cumulative weight of harvested pods	kg DW ha-1	C	O
WPDI	Intial biomass of pods	kg DW ha-1	C	
WPOD	Biomass of pods in pod category (array)	kg DW ha-1	C	
WPODTOT	Total biomass of pods in all pod classes	kg DW ha-1	C	
WREL	intermediate variable in calculation of soil characteristic according to Van Genuchten	-	D	
WRES	Weight of reserve pool	kg CH2O ha-1	C	
WRES1	Weight of reserve pool after accounting for maintenance costs	kg CH2O ha-1	C	
WRES2	Weight of reserve pool after accounting for replacement costs	kg CH2O ha-1	C	
WRT	Actual root biomass (both lateral and taproot)	kg DW ha-1	C	O
WRTI	Initial root biomass (both lateral and taproot)	kg DW ha-1	C	
WSTAT	Status code from weather system	-	M F	
WTOT	Actual total biomass	kg DW ha-1	C	O

Parameter	Description	Unit	Used in:	In/Out
WTOTCUM	Cumulative total biomass	kg DW ha-1	C	
WTOTI	Total initial dry weight of the cacao tree	kg DW tree1	C	I
WTOTMIN	Total dry weight of the cacao tree at which fruiting starts	kg DW tree-1	C	I
WTOTPP	Actual total biomass per tree	kg DW ha-1	C	O
WTRDIR	Directory in which weather data are stored	-	F	I
WTRT	Actual taproot biomass	kg DW ha-1	C	O
WTRTER	Flag whether weather can be used by model	-	M F	
WTRTI	Initial weight of tap root	kg DM ha-1	C	
WTWURT	Total biomass of water-uptaking roots	kg DW ha-1	C	O
WTWURTR	Total biomass of water-uptaking roots, as calculated by regression	kg DW ha-1	C	
WUSED	Indicator of used weather variables	-	M	
WWD	Actual wood biomass	kg DW ha-1	C	O
WWDD	Biomass of dead wood	kg DW ha-1	C	
WWDI	Initial wood biomass	kg DW ha-1	C	
WWURT	Biomass of water-uptaking roots per soil layer(array)	kg DW ha-1	C	O
WWURTR	Biomass of water-uptaking roots per soil layer, as calculated by regression (array)	kg DW ha-1	C	
YEAR	Calendar year	-	M F	O
YGPHOT	Annual total gross CH2O assimilation	kg CH2O ha-1 y-1	C	O
YGTOT	Annual total biomass production	kg DW ha-1 y-1	C	O
YGTOTAB	Annual total aboveground biomass production	kg DW ha-1 y-1	C	
YHARPD	Annual number of harvested pods	# y-1	C	O
YHI	Annual harvest index	-	C	O
YHINCR	Annual harvest increment	-	C	O
YKLOSS	Annual loss of K from harvested beans	kg ha-1 y-1	C	O
YLDBN	Daily yield of dry, fermented beans	kg DW ha-1 d-1	C	O
YLDPD	Daily yield of pods	kg DW ha-1 d-1	C	O
YLVD	Annual production of dead leaf biomass	kg DW ha-1 y-1	C	O
YMNBH	Mean annual butter hardness	-	C	O
YMNIPOD	Mean annual pod ripening period	d	C	O
YMNLAI	Mean annual leaf area index (LAI)	ha leaf ha-1 ground	C	O
YNLOSS	Annual loss of N from harvested beans	kg N ha-1 y-1	C	O
YPLOSS	Annual loss of P from harvested beans	kg P ha-1 y-1	C	O
YRAIN	Annual rainfall	mm y-1	C	O
YRDD	Annual short-wave radiation	MJ m-2 y-1	C	O
YRDEFF	Radiation "efficiency" of bean production	kg DW ha -1 (MJ m-2)-1	C	O
YRNEFF	Rain "efficiency" of bean production	kg DW ha -1 mm	C	O
YRO	year of previous irrigation	yr	D	
YTRANS	Annual amount of actual transpiration	mm y-1	C	O
YWDD	Annual production of dead wood biomass	kg DW ha-1 y-1	C	O
YYLDBN	Annual yield of dry, fermented beans	kg DW ha-1 y-1	C	O
YYLDPD	Annual yield of pods	kg DW ha-1 y-1	C	O