

The program of the model DYNAMITE  
DYnamics of Nutrients And Moisture  
In Tropical Ecosystems

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# Preface

This report forms together with an updated version of the software program of DYNAMITE the result of a four-months project financed by Tropenbos and carried out at the Department of Soil Science and Plant Nutrition of the Agricultural University of Wageningen, The Netherlands. The purpose of the project was to revise the program DYNAMITE and to carry out a sensitivity analysis. The model DYNAMITE itself was the output of a former Tropenbos project, entitled *Understanding Nutrient and Moisture Cycling in Humid Tropical Forest Land (Phase I)*.

There were a number of reasons why the present project was initiated. After the program of the model DYNAMITE and the related publication by Noij, Janssen, Wesselink and Van Grinsven (1993) had been issued, some concepts about the relevant soil and vegetation processes were improved. This made it desirable to introduce a number of modifications in the model. Further the nutrient part of the model still had not been submitted to a sensitivity analysis, because no time was left to do such in the first project. Finally, it was felt necessary to improve the structure, surveyability and accessibility of the computer program, because the original version was made by and for the authors, and it was certainly not user-friendly yet.

The programming and the sensitivity analysis were carried out by K.G. Eikelboom, M.Sc., computer scientist. Dr. B.H. Janssen, soil scientist and coordinator of the two consecutive projects is responsible for the theoretical considerations underlying the modifications of the model and for the interpretation of the results of the sensitivity analysis.

# 1 Introduction

DYNAMITE is a program that simulates moisture and nutrient cycling in tropical forests. It is derived from a model with the same name described in:

- Noij, I. G. A. M., Janssen, B. H., Wesselink, L. G. and Van Grinsven, J. J. M., 1993: Modeling Nutrient and Moisture Cycling in Tropical Forests, Tropenbos Series 4, The Tropenbos Foundation, Wageningen, The Netherlands.

In the rest of this document we shall refer to this publication as the Model Description. The equations in the Model Description are referred to by their number, e.g. Equation **II.3**.

This document is intended to accompany DYNAMITE. Hence, it should not be seen as an independent publication.

During our programming process some modifications have been made in the Model Description. These are rationalized and described in Section 2. Section 3 is for the person that wants to use the program. Section 4 contains some documentation of the source code. This is of interest for programmers who want to alter the source code or to copy some ideas to other models. The normal user can skip it.

The Model Description contains a number of typing errors. The corrections in the Model Description are listed in the Appendix.

## 2 Modifications

In implementing the model we encountered a number of problems. The model was modified to solve the problems. In the following sections we describe the problems and the way they were solved, and give the new model equations. The same sequence is kept up as in the Model Description.

### 2.1 Conversions and transfers of forest floor wood and coarse root debris

[ Model Description page 137, 2nd paragraph ]

We have divided the forest floor wood pool into two subpools:

- hard forest floor wood (*hardFFW*), containing organic matter that is not subjected to decay;
- soft forest floor wood (*FFW*), of which the organic matter is converted and, after a stay of one year in this pool, transferred to ORLA and ORML.

Each year about  $\frac{1}{15}$  of the hard pool is transferred to the soft pool ( $J_{woodremoval}$ ). Flux 8 in Fig III.1 is also split into two fluxes.



$J_{woodremoval}$  is calculated as follows:

$$J_{woodremoval} = 1 - e^{-RRFFWR \cdot \delta t} \quad (2.1)$$

The coarse root debris pool is split up in a analogous way.

### 2.2 Negative pool of nutrients in the soil solution, and negative uptake

[ Model Description page 145 ]

The amount of nutrients that leave the soil solution by immobilization is calculated independently of the quantity of nutrients that is available. Under certain conditions, this may result in a negative pool of nutrients in the soil solution.

Such can be prevented by specifying constraints for the immobilization. Immobilization is modeled as negative mineralization. A lowerbound must be calculated for the total mineralization.

Let  $in_i$  be a flux that carries nutrients to the solution pool and  $out_i$  a flux that removes nutrients from the solution pool.

If

$$SSOL + \sum in_i - \sum out_i < 0 \quad (2.2)$$

the pool is asked to provide more nutrients than it actually contains. A new outgoing flux  $out'_i$  is calculated that is less greedy.

$$out'_i = out_i \cdot \frac{\sum in_i + SSOL}{\sum out_i} \quad (2.3)$$

Immobilization is a negative constituent of  $\sum in_i$  implying that  $out'_i$  may have a negative value. This would mean that the uptake may become negative. Also Equation III.63 can lead to a negative value for uptake. Therefore it is replaced by:

$$UP_{max,i} = \max(0, SSOL_{i,b} + \sum in_i - NAN_i) \quad (2.4)$$

## 2.3 Nutrient distribution between leaves and fine roots

[ Model Description page 147-149 ]

The distribution of nutrients between leaves and fine roots as dealt with in the Model Description proved sometimes unsatisfactory. It may result in a very high fraction of nutrients that go to the fine roots, leaving too little for leaf growth. Therefore we have changed the method to calculate the distribution of nutrients. It replaces the first part of Section 3.4.3.2.

The rationale behind it is derived from Table II.1, page 51 of the Model Description. The table shows that the root-shoot ratio and the fine root-total root ratio are higher on infertile soils than on fertile soils. This implies that on infertile soils relatively more nutrients must be allocated to roots, and especially to fine roots, than on fertile soils. The fraction of the available nutrients that is allocated to the fine roots was therefore related to soil fertility which, in the model, is indicated by the soil fertility index ( $SFI$ ) with values between 0 and 1 (see below Equation 2.23). The fraction allocated to fine roots lies between a minimum ( $FUFRA_{min}$ ) value on very fertile soils with  $SFI = 1$ , and a maximum ( $FUFRA_{max}$ ) value on very low fertility soils with  $SFI = 0$ . Thus the nutrients for fine-root uptake can be calculated by:

$$UPFR_{av,i} = (FUFRA_{max} - (FUFRA_{max} - FURFRA_{min}) \cdot SFI) \cdot UP_{act,i} \quad (2.5)$$

where

$UPFR_{av,i}$	=	nutrients available for fine root uptake
$FURFRA_{max}, FURFRA_{min}$	=	maximum and minimum fractions of nutrients that go to the fine roots
$SFI$	=	soil fertility index
$UP_{act,i}$	=	nutrients available for total uptake.



Values of  $FUFRA_{min}$  and  $FUFRA_{max}$  could not be found in the literature. They were derived in an indirect way from the root-shoot ratios of Table II.1 of the Model Description. The reasoning was as follows.

In the model, the nutrients that are present in the below-ground plant parts, i.e. fine and coarse roots, have originally been allocated to the fine roots, and the nutrients present in the above-ground plant parts, i.e. leaves and wood, have originally been allocated to the leaves. So, for the purpose of simplicity it can be said that the available nutrients are distributed between  $ROOT$  and  $SHOOT$ , where  $ROOT$  comprises the below-ground plant parts, and  $SHOOT$  comprises the above-ground plant parts. The proportional nutrient distribution per time step between  $ROOT$  and  $SHOOT$  is only equal to the proportional nutrient distribution in the total mass of  $ROOT$  and  $SHOOT$ , if  $ROOT$  and  $SHOOT$  have the same relative turnover rates, and the same nutrient concentrations. By analogy with the assumption that the fraction of coarse-roots turnover per time step is twice as high as the fraction of wood fall per time step (Equation III.118; page 156 of Model Description), the fraction of root turnover ( $FRTR$ ) was set twice as high as that of shoot turnover ( $FSTR$ ), in formula:

$$FRTR = 2 \cdot FSTR \quad (2.6)$$

Further, it was assumed that  $ROOT$  and  $SHOOT$  have the same (weighted average) nutrient concentrations (cfr Table II.8 of the Model Description), in formula:

$$ROOTC_i = SHOOTC_i \quad (2.7)$$

Also it was supposed that the data of Table II.1 refer to steady state. In that case it holds:

$$GROWROOT = ROOT_{DM} \cdot FRTR \quad (2.8)$$

and

$$GROWSHOOT = SHOOT_{DM} \cdot FSTR \quad (2.9)$$

To arrive at equations for the allocation of nutrients, the general expression for uptake is used (Model Description, page 147):

$$UPTAKE = GROWTH \cdot CONCENTRATION \quad (2.10)$$

Hence,

$$\begin{aligned} UPROOT &= \\ \frac{GROWROOT \cdot ROOTC_i}{ROOT_{DM} \cdot FRTR \cdot ROOTC_i} &= \end{aligned} \quad (2.11)$$

$$\begin{aligned} UPSHOOT &= \\ \frac{GROWSHOOT \cdot SHOOTC_i}{SHOOT_{DM} \cdot FSTR \cdot SHOOTC_i} &= \end{aligned} \quad (2.12)$$

Substituting  $FRTR = 2 \cdot FSTR$  and  $ROOTC_i = SHOOTC_i$  results in the following ratio of  $UPROOT$  to  $UPSHOOT$ :

$$\frac{UPROOT}{UPSHOOT} = 2 \cdot \frac{ROOT_{DM}}{SHOOT_{DM}} \quad (2.13)$$

The lowest root-shoot ratios in Table II.1 are 0.04 and 0.11 (Site 2, Costa Rica and Site 1, Ghana) and the highest is 0.71 (Site 8, Venezuela). So, the ratio  $UPROOT/UPSHOOT$  would lie between  $2 \cdot 0.04 = 0.08$ , and  $2 \cdot 0.71 = 1.42$ . This means that  $FUFRA_{min}$  would be  $0.08/1.08 = 0.074$ , and  $FUFRA_{max}$  would be  $1.42/2.42 = 0.59$ . These values were rounded to 0.1 and 0.6, respectively.

Part II, Section 5, describes how the concentration of newly formed fine roots can be derived from the leaf concentration ( $LEAFC_i$ ).

$$FRNC_i = a_i + b_i \cdot LEAFC_i \quad (2.14)$$

The ratio  $UPFR_{av,i}/FRNC_i$  gives the growth of the new fine roots if  $i$  is limiting. The growth of fine roots is calculated with:

$$GROWFR = MINIMUM\left(\frac{UPFR_{av,i}}{FRNC_i}\right) \quad (2.15)$$

The uptake of the fine roots is:

$$UPFR_i = GROWFR \cdot FRNC_i \quad (2.16)$$

The surplus of the nutrients is available for leaf uptake:

$$UPL_{av,i} = UP_{act,i} - UPFR_i \quad (2.17)$$

For each of the nutrients, a range of possible leaf growth can be calculated. These ranges are between  $GROWLA$  and  $GROWLD$ .

$$GROWLA_i = \frac{UPL_{av,i}}{LEAFCA_i} \quad (2.18)$$

$$GROWLD_i = \frac{UPL_{av,i}}{LEAFCD_i} \quad (2.19)$$

where:

$LEAFCA_i$  = maximum ( $A$  stands for accumulation) concentration of nutrient  $i$  in leaves.  
 $LEAFCD_i$  = minimum ( $D$  stands for dilution) concentration of nutrient  $i$  in leaves

The remainder of Page 149 is valid up to and including Equation III.78

## 2.4 Maximum growth

[ Model Description page 149 ]

Equation III.79 defines the maximum growth of the leaves. It depends on the amount of water available for transpiration, and the transpiration ratio, being the minimum amount of water required per kg of dry matter production. Not only the leaves, however, produce dry matter. The other vegetation components must also be taken into account.

The total dry matter production  $GROW_{tot}$  is calculated as follows:

$$GROW_{tot} = \sum_{c \in \{leaf, wood, froot, croot\}} RCE_c \cdot GROW_c \quad (2.20)$$

where

$RCE$  is the *relative conversion efficiency*, and subscript  $c$  stands for vegetation component.

The values of  $RCE$  are set at 1 for leaves and fine roots, and at 0.5 for wood and coarse roots. These values reflect that the conversion of assimilates into lignin, which forms the major constituent of woody material, requires about twice as much assimilates as the conversion into carbohydrates, which form the major constituents of leaves and fine roots (Penning de Vries 1974).

Equation **III.79** is now used to calculate the maximum growth of all components together instead of the maximum growth of the leaves only.

$$GROW_{max} = \frac{T_{act}}{TRR} \quad (2.21)$$

If  $GROW_{tot}$  is greater than  $GROW_{max}$ , new growth rates  $GROW'_c$  must be calculated:

$$GROW'_c = GROW_c \cdot \frac{GROW_{max}}{GROW_{tot}} \quad (2.22)$$

where  $GROW_c$  is the growth in vegetation component  $c$ . The Soil Fertility Index ( $SFI$ ) is now defined as

$$SFI = \frac{GROW_{tot}}{GROW_{max}}. \quad (2.23)$$

Its value is between 0 and 1. For the first time step  $SFI$  is an input value, in the following time steps it is calculated.

If the reduced growth results in a nutrient concentration higher than the maximum concentration, the uptake must also be reduced. This means that the uptakes for the leaves and fine roots are:

$$UPL'_i = LEAFCA_i \cdot GROW'_{leaf} \quad (2.24)$$

$$UPFR'_i = FROOTCA_i \cdot GROW'_{fine\ root} \quad (2.25)$$

where  $FROOTCA_i$  is the maximum concentration of nutrient  $i$  in the fine roots. The nutrients that form the difference between  $UPL'_i$  and  $UPL_i$ , and between  $UPFR'_i$  and  $UPFR_i$  are thus not taken up and remain in the soil solution. For wood and coarse root, Equation **III.91** and, Equation **III.102** are still valid.

## 2.5 Leaf fall rate

[ Model Description page 154, Equation **III.105** ]

In the Model Description, page 86, a leaf life span range of 0.5 to 1.25 year is assumed, and consequently the value of the relative rate of leaf fall ( $RRLF_i$ ; Model Description Table **II.11**, page 88; Equation **III.105**, page 154) should lie between 2.0 and 0.8 year<sup>-1</sup>, respectively. Working with the model and getting some more information, we arrived at the conclusion that the average leaf life times vary between 1 and 2 years, and hence the values of  $RRLF_i$  should lie between 1.0 and 0.5 year<sup>-1</sup>, respectively. The parameter  $A$  used in Equation **III.105** for the calculation of  $RRLF_i$  is the minimum concentration of nutrients in the leaf, and the parameter  $B$  is the difference between the maximum and

minimum concentrations. In the Model Description accidentally still some old values for  $A$  and  $B$  were remaining. Also this has been corrected now. The values of  $r$  and  $s$  are taken such that  $RRLF_i$  is 0.5 when  $LEAFC_i$  equals  $A_i$  ( $= LEAFCD_i$ ) and  $RRLF_i$  is 1.0 when  $LEAFC_i$  is  $A_i + B_i$  ( $= LEAFCA_i$ ).

Hence, the new version of Equation III.105 is

$$RRLF_i = r + s \cdot \frac{LEAFC_i - LEAFCD_i}{LEAFCA_i - LEAFCD_i} \quad (2.26)$$

In Table II.11 of the Model Description, lines 3 to 5 should be replaced by:

$$RRLF_N = 0.5 < 0.5 + 0.5 \cdot \frac{(LEAFC_N - 7.5)}{17.5} < 1.0$$

$$RRLF_P = 0.5 < 0.5 + 0.5 \cdot \frac{LEAFC_P - 0.3}{1.7} < 1.0$$

$$RRLF_K = 0.5 < 0.5 + 0.5 \cdot \frac{(LEAFC_K - 4)}{16} < 1.0$$

Remark that the unit used in this table is g/kg instead of kg/kg that is used in Table III.4. For further explanation see Model Description pages 86-88.

## 2.6 Leaching and capillary rise of nutrients

[ Model Description  
page 158 ]

The amount of water that leaches from the layer in which the soil solution pool is located,  $J_{out}$  can be larger than the amount of water the layer actually contains. In the water model this poses no problem, because new water is supplied by precipitation. Such a process, however, does not exist for nutrients, and also in this case the result may be a negative pool of nutrients in the soil solution (cfr. Section 2.2).

We solved this problem by placing an upperbound on the  $a$  defined in Equation III.133.  $J_{out}$  is not altered, so the water model is not changed. Only its effect on the leaching of nutrients is limited. We introduce the condition that the value of  $a$  must be such that the solution pool is always positive.

$$\begin{aligned} \frac{SSOL_{i,b} \cdot (K_d + 1 - a) + \sum in_i - UP_{act,i}}{K_d + a + 1} > 0 &\equiv \\ SSOL_{i,b} \cdot (K_d + 1 - a) + \sum in_i - UP_{act,i} > 0 &\equiv \\ SSOL_{i,b} \cdot (K_d + 1) - a \cdot SSOL_{i,b} + \sum in_i - UP_{act,i} > 0 &\equiv \\ \frac{SSOL_{i,b} \cdot (K_d + 1) + \sum in_i - UP_{act,i}}{SSOL_{i,b}} > a & \end{aligned} \quad (2.27)$$

This gives a new definition for  $a$ .

$$a = \max\left(\frac{J_{out}}{D \cdot (\Theta_b + \Theta_e)}, \frac{SSOL_{i,b} \cdot (K_d + 1) + \sum in_i - UP_{act,i}}{SSOL_{i,b}}\right) \quad (2.28)$$

In the case of capillary rise, water from the second layer enters the top layer, and  $J_{out}$  in Equation III.132 is negative. The nutrient concentration in Equation III.133 refers to the water in the top layer. The model does not calculate the nutrient concentration in the second layer. Therefore we prevent the entrance of nutrients from this side by forcing  $a$  in Equation III.133 to  $a > 0$ .

## 3 Usage

### 3.1 Installing

Place the floppy with DYNAMITE in drive a:. Type

```
a:install
```

DYNAMITE will be installed on the hard disk in a directory `\dynamite`.

Add `\dynamite\bin` to your load path. (The load path is defined by the `PATH` variable that is set in the `autoexec.bat` file).

Create a directory from which you want to run DYNAMITE. Go to that directory. For a directory named `run` this is done as follows:

```
md run
```

```
cd run
```

Run `copydn` to copy a number of DYNAMITE files to this directory.

DYNAMITE is ready to run.

### 3.2 Getting started

Dynamite can be called from the DOS prompt like:

```
dynamite <inputfile> [<deccons>]
```

Where:

- `<inputfile>`: file with the initial state and intrinsic system parameters;
- `[<deccons.>]`: file with the values of the decomposition constants. This argument is optional. When the constants are not read, they are calculated.

Examples:

```
dynamite dynamite.inp deccons  
dynamite dynamite.inp
```

### 3.3 Input

DYNAMITE takes plain ascii text as input. The input can be created and adapted with the use of an editor like the norton commander or the Turbo Pascal editor.

The first part of the input is used to tell DYNAMITE the period it has to simulate and the time step for the calculations. For the rest it consists of the contents Tables III.3, III.4 and III.5.

DYNAMITE is only interested in numbers in the input. Text is considered to be comment and ignored in the calculations. An exception is the first line. That must be in square brackets ([]) and is copied to the output. It can be used to identify the input from which an output is generated.

All characters in parentheses (()) are completely ignored. If a number is comment and not a part of the input, it must be enclosed in parentheses.

An example input file is `dynamite.inp`. The most easy way to make your input is to alter this file. But a file with only numbers works as well.

### 3.4 Displaying output

DYNAMITE prints the value of certain variables at regular intervals to a number of output files. These output files are text files and can be viewed with a text viewer or an editor.

The number of output files is quite large; therefore an utility is supplied to browse through the output more easily. It is called HYPLUS and it is a *hypertext* reader. It was created by Larson (1989).

A hypertext is designed to make a large amount of text more accessible. Hypertext consists of *text frames* and *links*. A text frame is a text file that contains links. A link is a reference to another text frame. It is noted down as the name of the file, that contains the textframe, in sharp brackets (<>).

HYPLUS is started from the DOS prompt by typing:

`hyplus`

The hypertext reader, HYPLUS displays a textframe on the screen. It starts with the textframe `start.txt`. One link is highlighted. This is the *active link*. It can be executed by pressing `>` or `return`; then the frame to which the link references is displayed. With the keys `△` and `▽` other links can be made active.

Other keys in HYPLUS are :

`<` or `ESC` Go back to the previous text frame. Frames are stacked. By repeating this key it is possible to go back to the first frame.

`P` Print the current text frame.

`Q` or `X` Quit the program.

### 3.5 Error messages

DYNAMITE generates a couple of errors messages. They have the following pattern:

DYNAMITE ERROR *error message*

The error message can be as follows:

- **Not enough values supplied**  
DYNAMITE expects more values in the input file.
- **Numerical value expected**  
DYNAMITE tried to read a number but found a string.
- **String value expected**  
DYNAMITE tried to read a string but found a number. Strings are enclosed in [].
- **BISECT : could not resolve equation.** The algorithm that resolves the waterbalance Equation III.133 was not successful. This may happen in rare occasions when the input values for the waterbalance model are uncommon.

Sometimes an obscure error is displayed. These are produced by the Turbo Pascal runtime library. There was no way to change this. Mostly such errors are caused by an unlucky choice of the input values. They can lead to an calculation the computer cannot perform. The error may disappear with other input.

The most important is:

Runtime error 203 at 0000:0018

The 0000:0018 is arbitrary chosen. 203 means a heap overflow error; the computer calculated to many data to keep in the memory. This can be prevented by choosing a larger output interval.

Other errors are:

Runtime error 200 at 0000:0081

Runtime error 205 at 0000:0081

Runtime error 207 at 0000:0081

The numbers mean:

200 :Division by zero.

205 :Floating point overflow.

207 :Invalid floating point operation.

A complete list of all run time errors can be found in the Turbo Pascal documentation (see Borland, 1990).

### 3.6 Lotus 123 support

Graphs are more easy to interpret than numerical data in tables. A popular tool to plot such graphs is the spreadsheet program Lotus 123. With DYNAMITE a customized spreadsheet is supplied to make graphs from an DYNAMITE output. An output set can be examined as follows:

- Run DYNAMITE to produce the output.
- Start Lotus 123.
- Retrieve the spread sheet dynamite.wp1 from \dynamite\123.

- Make the directory where the output files can be found the current directory for Lotus 123.
- Load the output files by pressing **Alt-L**.

In Section 4.5.2 is described how other spreadsheets can be generated.



# 4 Documentation

## 4.1 Contents of the subdirectories

- `\dynamite\bin` contains the simulation program and the hypertext browser as described in Section 3.4.
- `\dynamite\src` contains the source code of the program. (See Section 4.2).
- `\dynamite\inputs` contains the sample input `dynamite.inp`.
- `\dynamite\tools` contains tools that generate part of the source code and the spreadsheet macro's. (See Section 4.5).
- `\dynamite\doc` contains the  $\text{\LaTeX}$  source of this document.  $\text{\LaTeX}$  is a typesetting program. It works like a compiler. It defines a language to formulate typeset directions and produces output that can be printed directly.
- `\dynamite\view` contains the text frames that are needed by HYPLUS but not directly generated by DYNAMITE.

## 4.2 Source code

The model DYNAMITE can be distinguished in primary routines that perform the calculations of the model, and secondary routines, that organize the input and the output.

The primary routines are programmed pretty straightforward. A Fortran programmer should understand it, and after a short introduction in Pascal, he must be able to modify the primary routines.

The secondary routines are more complicated and use more advanced techniques. This code is documented below.

## 4.3 Units

An unit contains a number of coherent routines that can be compiled separately. Below we give a short description of the contents of each unit. The Sections that are referred sub primary units are those in Part III of the Model Description. Sub secondary units is referred to this report.

**primary units:** The sections that are referred to below are in Noij et al. (1993).

**dynamite.pas:** the main program that invokes the subroutines (Section 2.3).

**declar.pas:** declaration of the global variables and data types.  
**init.pas:** reads the input file.  
**water.pas:** calculates the moisture cycling model (Section 3.1).  
**deperwea.pas:** calculates the inorganic pools and fluxes (Section 3.2).  
**litter.pas:** calculates the sizes and fluxes of the litter pools (Section 3.3).  
**orgdecom.pas:** calculates the sizes and fluxes of the other organic pools (Section 3.3).  
**dec.pas:** calculates the dissimilation and transfer constants (Section 3.3.2.2).  
**growth2.pas:** calculates nutrient uptake and growth (Section 3.4).  
**leach.pas:** calculates the chemical balance and adjustment of the soil solution (Section 3.5).  
**nwptotch.pas:** calculates the chemical balance and adjustment of the other soil pools (Section 3.5).  
**ratios.pas:** calculates the  $C/N$  and the  $C/P$  ratios.  
**misc.pas:** Miscellaneous

**secondary units: inp.pas:** defines the input routines. This file can be generated from **inp.1**. (Section 4.4.1).

**lexlib.pas:** contains lowlevel routines used by **inp.pas** to split the input is digestible pieces.

**out.pas:** defines the output routines. Part of these are generated by tools described in Section 4.5.

**bigstore.pas:** defines an internal data structure to store the intermediate results of the calculation (See Section 4.4.2).

## 4.4 Requirements to compile DYNAMITE

DYNAMITE is developed with Borland Pascal 7.0. We suppose it can be also compiled with Turbo Pascal 6.0.

DYNAMITE uses the unit **objects**. This is Turbo Vision, that must be installed. DYNAMITE can be compiled by invoking **make** in `\dynamite\src`. A makefile is supplied in this directorie. **make** is a tool that helps to compile a number of files in the correct order. The makefile contains instructions for **make** how to do this.

### 4.4.1 inp.pas

**inp.pas** contain the input routines. This file is generated from **inp.1** by a tool called **lex**.

A special version of **lex** was used that generates Pascal code. It was created by Greaf (1991). More theory about **lex** can be found in Aho, Sethi and Ulmann (1986).

**inp.pas** can be used through the following interface:

**procedure inp\_init(s:string) :** initializes the input. **s** is the name of the inputfile.

**procedure inp\_float(var f:tfloat) :** reads a float from the input into variable **f**.

`procedure inp_integer(var i:integer) : reads an integer from the input into variable i.`

`procedure inp_string(var s:string) : reads an string from the input into variable s.`

#### 4.4.2 bigstore.pas

`bigstore.pas` provides an datastructure that looks like a two dimensional array and can be used to store floats and strings. It can be used by the following interface.

`procedure BS^.store(f:tfloat; i,j:integer) : stores f on position (i,j).`

`function BS^.retrieve(i,j:integer):tFloat : retrieves the float on position (i,j).`

`procedure BS^.storestring(s:string; i,j:integer) : stores the string s on position (i,j).`

`function BS^.retrievestring(i,j:integer):string : retrieves the the string s on position (i,j).`

#### 4.4.3 Comments

The equations of the book are marked in the Pascal code. For example Equation III.78 is marked as `{form*78}`.

### 4.5 Tools

In the programming of DYNAMITE a number of tools were used. They can be found in the directory `dynamite\tools`. They are used to tune the output to the spreadsheets in `dynamite\123`.

The output consists of a lot files. Each file is table. Above the columns a label is printed that contains a description of a variable. The first column contains the time, and the other columns contain the values of the particular variable at that time.

In section 3.6 it is described how these output files can be imported into an customized spreadsheet. For each column in the table a graph can be shown. To achieve this, the output routines and the spreadsheet must be tuned to each other. This is done by three tools, `MKSRC` `MKSPLIT` and `MK123` that take the same input file.

In that input file each graph is defined by six lines:

**1st line** : first title of the graph.

**2nd line** : second title of the graph.

**3rd line** : name that the graph has in the spreadsheet.

**4th line** : label above the output column.

**5th line** : name of the variable in Pascal.

The graph definitions are separated by an empty line. A number (mostly 3 or 4) of descriptions are grouped together in a cluster. These will make one output file. These clusters are preceded by a 3-line header with the following format:

**1st line** : the two characters @@. They make the cluster header distinct from a graph description.

**2nd line** : name of the file.

**3th line** : This line can be used to give a description of the cluster.

The current code is generated from the file `dynamite.mrc`. If the need exists to monitor more, or other variables this file can be modified.

The following subsections describe how new output routines and new spreadsheets can be created.

#### 4.5.1 MKSRC and MKSPLIT

MKSRC and MKSPLIT generate output routines. MKSRC makes `outlabel.pas` and `outdata.pas`. These pieces of code determine which intermediate results are stored in memory. MKSRC and MKSPLIT can be run from the DOS prompt and take no arguments (`DYNAMITE.mcr` is standard). Invoking `make` in `\dynamite\tools` will run both tools and copy the code to the `\dynamite\src` directory.

Take into account that if the output routines alter the hypertext browser will not work correctly anymore.

#### 4.5.2 MK123

MK123 can be called from the DOS prompt with one argument. If no argument is given `DYNAMITE.mrc` is default.

Unfortunately MK123 cannot create a spreadsheet directly, only in an indirect way.

In Lotus 123 the keystrokes of the user can be intercepted and stored in a column of the spreadsheet. These keystrokes are as it were recorded and together they are called a macro. Later on this macro can be played back: Lotus 123 takes the keystroke from the column and acts as if they came from the keyboard.

Macros can be imported from file. This feature is used by MK123. It creates two files `load.123` and `graph.123` that can be executed as macros and so create the spreadsheet.

The command `make 123` invokes MK123 and copies the macros to the `dynamite\123` directory. This directory contains a prototype spreadsheet `proto.wks`. In this spreadsheet a macro is defined to load the macro files `load.123` and `graph.123`. It can be invoked by pressing `ALT M`. After that `graph.123` can be executed by pressing `ALT G` to define all the graphs of the spreadsheet. Further `load.123` makes the load macro that can be invoked by pressing `ALT L`.

A reason to make another spreadsheet is that the capacity of the spreadsheet is not large enough to contain all the output variables. Then a file can be created from `dynamite.mcr` by deleting graph description. The output routines do not have to be adapted on condition that complete clusters are deleted.

## 4.6 Future improvements

- The comments in the code are not up to date yet, because not sufficient time was available to revise them.

- The moisture cycling submodel must take its input in with the same time step as the model. It may be worthwhile to make the timesteps in the two submodels independent of each other.

# 5 Sensitivity analysis

## 5.1 Introductory remarks

The objective of sensitivity analysis is to get insight in the relative importance of the various model input parameters. The sensitivity of a model output parameter ( $Y$ ) for a model input parameter ( $I$ ) can be defined as the change of  $Y$  with  $I$ , when  $I$  is changed.

In general, ecosystems will change in course of time till a steady state has been reached for all variables. Sometimes it is practically impossible to get simultaneously a steady state for all fluxes and state variables of all nutrients. Often variables will oscillate within rather narrow ranges which can be considered as approximate steady-state values.

To be able to measure the importance of a certain model input parameter, the value of the output parameter after a certain time, must be compared with the value obtained after that time under standard conditions. In this connection, the concept of relative sensitivity  $S_r$  is used:

$$S_r = \frac{\frac{\delta Y}{Y_s}}{\frac{\delta I}{I_s}}$$

where the subscript  $s$  stands for standard.

The moisture cycling sub-model of DYNAMITE was already submitted to such a sensitivity analysis by [citeasnounmodeldescription](#) and hence the present analysis deals with the nutrient submodel only.

Noij et al. (1993) subdivide the required input data of the nutrient sub-model into three categories. They have characteristic effects on the model output parameters and are therefore discussed per category. The categories of model input parameters are:

1. boundary fluxes and boundary flux regulating variables.
2. initial values for state variables.
3. intrinsic system variables.

In our sensitivity analysis, we studied the effects of introduced changes for a period of 100 years. Model input parameters were changed only one at a time, while all other model input parameters kept the standard values. Upon a change in a model input parameter, in principal all model output parameters (some hundreds) may change but it is neither possible nor relevant to consider all of them. The model output parameters that are considered are the four vegetation components wood, leaves, coarse roots and fine roots. In case other parameters

are useful in explaining the responses of the vegetation components to changes in the value of the particular input parameter, such other parameters are discussed too. In the discussion we will regularly refer to the flow numbers and acronyms as mentioned in Fig 5.2

## 5.2 Standard situation

### 5.2.1 Modified input data

For the standard situation, the model variables received the values that have been presented in Tables III.3, III.4 and III.5 (pages 163-168) of the Model Description. There were, however, some modifications made. They are accounted for below in the same sequence as they appear in Table 5.1.

The initial value of Leaf N was changed a little.

In the Model Description (page 141-142), it is explained that the initial age of the *ORST* is calculated assuming that the ecosystem is in a steady state. This is often not true. Hence, it is more convenient to allocate a fixed initial age to *ORST*. Applying Equations III.48, III.49 and III.50, and allocating values of 1270 and 27000 to *ORMLC* and *ORSTC*, respectively, an initial age of 26.8 years for *ORST* is found in the present standard situation. As this value corresponds well with values that can be derived from other studies (Janssen 1992), it was decided to consider it as standard value for the initial age of *ORST*.

The fractions of nutrients in the soil solution that are leached during the time step ( $SSOL_{i,b}$ ) probably are not similar for N, P and K, as was assumed originally for convenience sake. The original value of 0.5 was maintained for N only, whereas lower values were assigned to K and P expecting that larger portions of these nutrients are sorbed during the time step and are thus rescued from leaching.

In the Model Description no value was given for the minimum concentration of K in the soil solution required for uptake (page 164). This negligence has now been made up.

The maximum value of the  $P/K$  and  $K/N$  uptake ratios were accidentally taken from the line "Maize above ground + roots" of Table II.6.

In Section 2.3, it is explained why the values of the parameters  $r$ ,  $s$ ,  $A$  and  $B$  for the calculation of the relative rate of leaf fall have been changed.

The values of  $s$  and  $t$  in Equation III.128 for the calculation of specific leaf area were changed a little.

The study by Stoorvogel (1993) showed that deposition rates were lower than originally assumed, and hence their values were brought in accordance with his results.

### 5.2.2 New input data

Table 5.2 gives the standard values of the newly introduced parameters. They are accounted for below in the same sequence as they appear in Table 5.2. Their meanings are explained in Chapter 2 of this report.

The sums of the values for hard and soft *FFW*, and those for hard and soft *CRD* equal the original values of *FFW* and *CRD*, respectively. The values for the relative rates of erosion of these pools, as given in Table III.5 of the Model Description, are now applied to soft *FFW* and soft *CRD*, assuming that hard

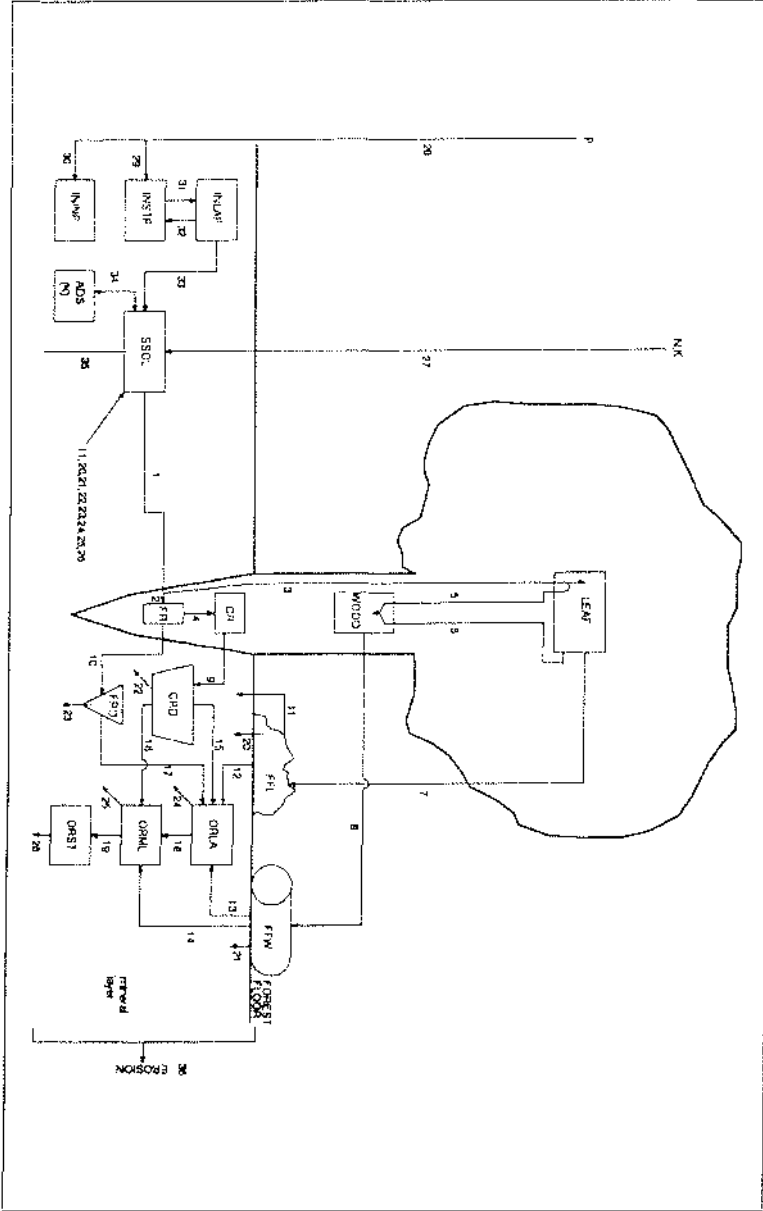


Figure 3.1:

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Schematic representation of the processes incorporated in the model DYNAMITE.

The numbers refer to:

- 1 plant nutrient uptake from solution (SSOL)
- 2 nutrient uptake in fine-roots (FR)
- 3 nutrient transport from fine-roots to leaves
- 4 nutrient transition from fine to coarse roots
- 5 nutrient overflow from leaves to wood
- 6 nutrient retranslocation from leaves to wood
- 7 leaf fall
- 8 wood fall
- 9 coarse-root dying
- 10 fine-root sloughing
- 11 K-leaching from forest-floor leaves (FFL)
- 12 nutrient transfer from forest-floor leaves to organic labile pool
- 13 nutrient transfer from forest-floor wood (FFW) to organic labile pool (ORLA)
- 14 nutrient transfer from forest-floor wood to organic moderately labile pool (ORML)
- 15 nutrient transfer from coarse-root debris (CRD) to organic labile pool
- 16 nutrient transfer from coarse-root debris to moderately labile organic pool
- 17 nutrient transfer from fine-root debris (FRD) to organic labile pool
- 18 nutrient transfer from organic labile to organic moderately labile pool
- 19 nutrient transfer from organic moderately labile to organic stable pool (ORST)
- 20 mineralization of leaf litter
- 21 mineralization of wood litter
- 22 mineralization of coarse-root debris
- 23 mineralization of fine-root debris
- 24 mineralization of organic labile pool
- 25 mineralization of organic moderately labile pool
- 26 mineralization of organic stable pool
- 27 wet deposition of N and K
- 28 dry deposition of P
- 29 dry deposition of P to inorganic stable phosphorus (INSTP)
- 30 dry deposition of P to inorganic inert phosphorus (ININP)
- 31 transfer of P from inorganic stable to inorganic labile phosphorus (INLAP)
- 32 transfer of P from inorganic labile to inorganic stable phosphorus
- 33 transfer of P from inorganic labile pool to soil solution
- 34 desorption and adsorption of K
- 35 leaching of nutrients from soil solution (SSOL)
- 36 erosion of organic and inorganic nutrient pools

Table 5.1: Values of model parameters as used for the sensitivity analyses and differing from the values presented in Tables III.3, III, 4 and III.5 of the Model Description

Description	Symbol	Component	Original value	New value
Leaf	$LEAF$	N	16.5	15.19
Initial age of organic pools	$a$	$ORST$	25.19	26.81 <sup>1</sup>
Fraction of nutrients in soil solution leached during time	$SSOL_{i,b}$	N	0.5	0.5
		P	0.5	0.1
		K	0.5	0.4
Min. concentration for uptake from solution	$C_{min}$	K	1.0	$10^{-9}$
Maximum values of uptake ratios		$P/K$	0.6	0.75
		$K/N$	2.6	2.3
Parameters for the calculation of the relative rate of leaf fall ( $RRLFA$ )	$r$		0.8	0.5
	$s$		1.2	0.5
	$A$	N	0.0100	0.0075
		P	0.0005	0.0003
		K	0.0050	0.0040
	$B$	N	0.010	0.0175
P		0.001	0.0017	
K		0.010	0.0160	
Parameters for the calculation of specific leaf area	$s$	2.51	2.22	
	$t$	6804	66.32	
Annual rate of deposition	$ARDEP_i$	N	30.0	15.0
		P	0.897	0.33

Table 5.2: Standard values of the new model parameters, as used in the sensitivity analyses

Variable description	Symbol	Elements or components			
		N	P	K	C
Forest floor wood	hard <i>FFW</i>	98.9	18.8	203.4	34477
	(soft) <i>FFW</i>	7.07	1.33	14.53	2463
Coarse root debris	hard <i>CRD</i>	4.39	4.25	39.98	6964
	(soft) <i>CRD</i> 0.31	0.30	2.86	497.4	
Fractions of nutrients that go to the roots	<i>FUFRA<sub>min</sub></i>	0.1			
	<i>FUFRA<sub>max</sub></i>	0.6			
Rate of conversion efficiency	<i>RCE</i>	<i>LEAF</i>	<i>WOOD</i>	<i>FROOT</i>	<i>CROOT</i>
		1.0	0.5	1.0	0.5
Initial soil fertility index	<i>SFI</i>	0.8 <sup>†</sup>			

<sup>†</sup> In the original version such a value was not used (See Equation 2.23)

*FFW* and *hard CRD* are not prone to erosion.

*SFI* is calculated per time step in the model, using data of the former time step (see Section 2.4). Therefore it is necessary to give an initial value of *SFI* for the first time step.

### 5.2.3 Course of model output in the standard situation

The values of the model parameters as used for the standard situation in the sensitivity analyses, do not correspond to a steady state. As a consequence, the state parameters and the fluxes change in the course of time. The initial sizes (in kg organic matter per ha) of the vegetation components were 2650, 450000, 3000 and 50000, for *LEAF*, *WOOD*, *FROOT* (= fine roots) and *CROOT* (= coarse roots), respectively. Fig 5.3 shows the courses of the values of *LEAF* and *FROOT*, and Fig 5.4 those of *WOOD* and *CROOT* for the standard situation during the first 100 years. The sizes of *LEAF* and *WOOD* increase considerably and those of *FROOT* and *CROOT* decrease sharply. One of the reasons is that the introduced initial values were derived from a version of the model in which far more nutrients were allocated to the roots and far less to the leaves than in the present model (this was the reason for the model modifications discussed in Section 5.5.2). The high values for *LEAF* and *WOOD* are further due to the fact that in the present version of the model the assumed minimum nutrient concentrations are below those assumed in the preceding versions.

Figure 5.3: Courses of the dry matter of *LEAF* and *FROOT*, during the first 100 years after the starting with the standard parameter values as discussed in Section 5.2.

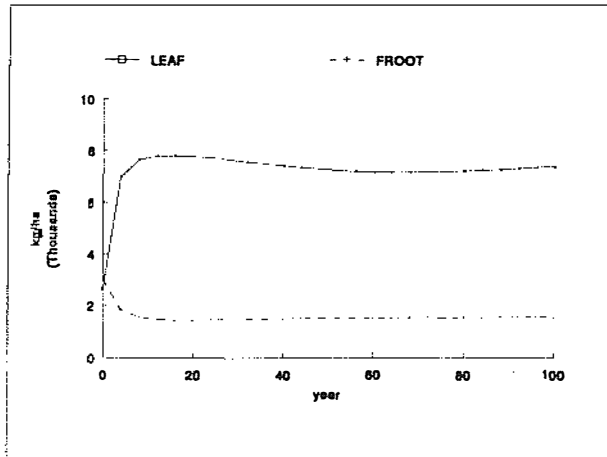
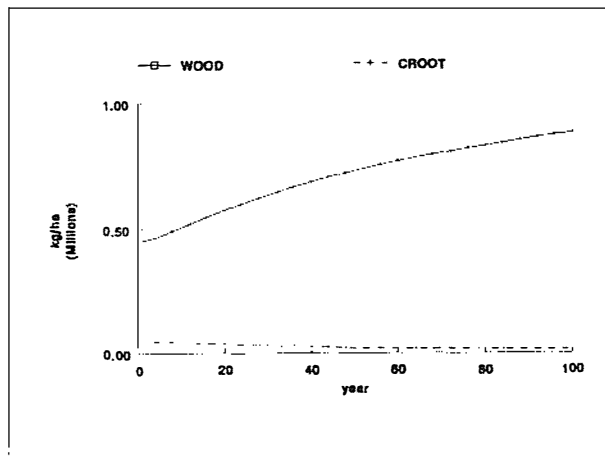


Figure 5.4: Courses of the dry matter of *WOOD* and *CROOT*, during the first 100 years after the starting with the standard parameter values as discussed in Section 5.2.



### 5.3 Boundary fluxes and boundary flux regulating variables

The boundary fluxes and boundary flux regulating variables of the nutrient cycling sub-model of DYNAMITE comprise nutrient input fluxes (e.g. atmospheric deposition), and nutrient output fluxes (e.g. erosion). The impact of an imposed change in such a model input parameter is proportional to the fraction of that flux in the sum of all nutrient input fluxes or all nutrient output fluxes. All depending flows and state variables in the model will then accordingly increase or decrease until a steady state has been reached. This was shown for atmospheric deposition, leaching and erosion by Noij et al. (1988). The present sensitivity analysis does not include boundary fluxes because no new information is to be expected from it.

### 5.4 State variables

When the initial size allocated to a state variable is altered and all other model input parameters keep their original values, finally the same steady state will be obtained as in the case the size of the state variable is not changed. The time required to reach steady state depends on the relative rates of turnover of the state variables in the model. The lower these rates are, the more time is required. Before steady state has been reached, effects of the altered state variable are visible primarily in a change of the sizes of the fluxes leaving the altered state variable and the sizes of the next state variables to where these fluxes go first.

#### 5.4.1 Inorganic stable pool of P (*INSTP*)

The model input state variable examined in this study was the inorganic stable pool of P (*INSTP*). The values given to it were 30, 70.85 (the original value) and 100 kg/ha. Table 5.3 shows the absolute and relative sizes of the vegetation components after 40 and 100 years. The relative values hardly deviate from 100 initially 70.85 kg *INSTP* per ha. This is because *INSTP* contributes only a little to the pool of P in the soil solution from where the nutrients are taken up (Flow 1) and allocated to *FROOT* ( $UPFR_P$ , Flow 2) and *LEAF* ( $UPL_P$ , Flow 3). The effect of *INSTP* on plant growth is thus indirect through a transfer of P to the inorganic labile pool (*RISILP*, Flow 31), and from there to the soil solution (*RILSSP*, Flow 33). Table 5.4 shows that the fluxes *RISILP* and *RILSSP* are small compared to those of  $UPFR_P$  and  $UPL_P$ , thus explaining the small effect of *INSTP* on plant growth.

Fig. 5.5 shows the courses of *INSTP*. Gradually the values for the three variants come together. *INSTP* decreases in all cases, although *INSTP* was in steady state in the standard situation of the former versions of the model. The reason is that the rate of P deposition was lowered from 0.897 to 0.33 (Table 5.1). The new steady-state value of *INSTP* will be reduced proportionally, and hence the final value to be expected is  $70.83 * 0.33/0.897 = 26.06$ .

#### 5.4.2 *WOOD*

Sensitivity analysis was also applied to the major component of the vegetation, *WOOD*. although it is not an input but an output parameter. The purpose

Table 5.3: Absolute and relative sizes of vegetation components at 40 and 100 years for three initial sizes of INSTP.

Value	Year	Component	Initial value of <i>INSTP</i>		
			30	70	100
absolute	40	<i>LEAF<sub>DM</sub></i>	7400	7420	7419
		<i>WOOD<sub>DM</sub></i>	685076	686307	686678
		<i>FROOT<sub>DM</sub></i>	1512	1510	1510
		<i>CROOT<sub>DM</sub></i>	25814	25864	25897
	100	<i>LEAF<sub>DM</sub></i>	7401	7388	7360
		<i>WOOD<sub>DM</sub></i>	880592	882225	882024
		<i>FROOT<sub>DM</sub></i>	1556	1564	1567
		<i>CROOT<sub>DM</sub></i>	11877	11909	11976
relative	40	<i>LEAF<sub>DM</sub></i>	99.7	100	100
		<i>WOOD<sub>DM</sub></i>	99.8	100	100.1
		<i>FROOT<sub>DM</sub></i>	100.1	100	100
		<i>CROOT<sub>DM</sub></i>	99.8	100	100.1
	100	<i>LEAF<sub>DM</sub></i>	100.2	100	99.6
		<i>WOOD<sub>DM</sub></i>	99.8	100	100.0
		<i>FROOT<sub>DM</sub></i>	99.5	100	100.2
		<i>CROOT<sub>DM</sub></i>	99.7	100	100.6

Figure 5.5: Courses of the inorganic stable pool of P (*INSTP*) starting with initial values of 30, 70.85 (standard value) and 100 kg/ha.

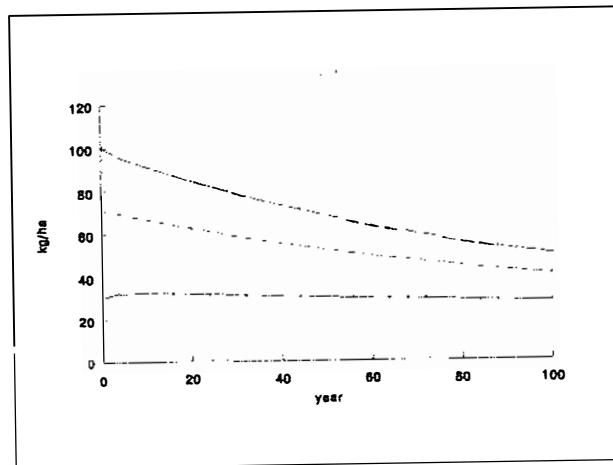


Table 5.4: Values of INSTP (kg P per ha) and of the fluxes *RISILP*, *RILSSP*, *UPFRP*, *UPLP* in kg P per ha per timestep (= 1 month) at 0, 40 and 100 years.

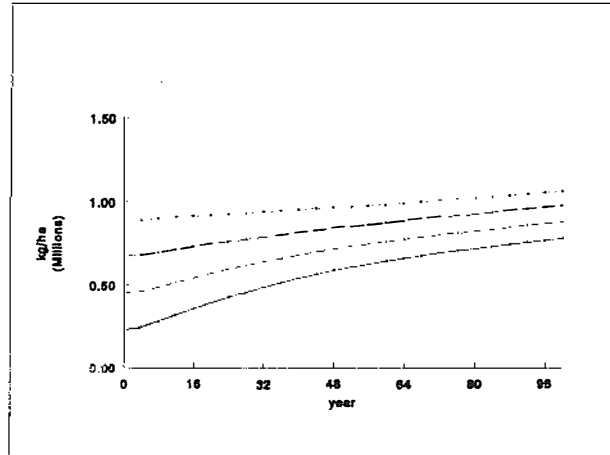
Variable	Year	Initial value of <i>INSTP</i>		
		30	70	100
<i>INSTP</i>	0	30.00	70.85	100
	40	30.25	54.95	72.58
	100	27.60	40.43	49.59
<i>RISILP</i>	0	0.08635	0.20393	0.28784
	40	0.08707	0.16206	0.20892
	100	0.07944	0.11637	0.14273
<i>RILSPP</i>	0	0.07149	0.07149	0.07149
	40	0.02678	0.04920	0.06520
	100	0.02437	0.03602	0.04433
<i>UPFRP</i>	0	0.12381	0.12381	0.12381
	40	0.09236	0.09724	0.10017
	100	0.08275	0.09156	0.09473
<i>UPLP</i>	0	0.49523	0.49523	0.49523
	40	0.35714	0.37402	0.38216
	100	0.30300	0.32961	0.33707

Table 5.5: Absolute (kg/ha) and relative sizes of vegetation components after 4, 40 and 100 years for four initial  $WOOD_{DM}$  sizes of 225000, 450000, 675000 and 900000 kg/ha

value	year	component	Initial $WOOD_{DM}$			
			225000	450000	675000	900000
absolute	4	$LEAF_{DM}$	7126	7020	6913	6809
		$WOOD_{DM}$	248474	464755	681024	897287
		$FROOT_{DM}$	1881	1875	1864	1840
		$CROOT_{DM}$	46909	46908	46905	46902
	40	$LEAF_{DM}$	7405	7420	7394	7334
		$WOOD_{DM}$	546275	686307	822643	956173
		$FROOT_{DM}$	1425	1510	1550	1584
		$CROOT_{DM}$	25617	25864	25960	26022
	400	$LEAF_{DM}$	6874	7388	7869	8325
		$WOOD_{DM}$	783010	882225	975797	1065043
		$FROOT_{DM}$	1550	1564	1550	1524
		$CROOT_{DM}$	11751	11909	12047	12149
relative	4	$LEAF_{DM}$	101.5	100	98.5	97.0
		$WOOD_{DM}$	53.5	100	146.5	193.1
		$FROOT_{DM}$	100.3	100	99.4	98.1
		$CROOT_{DM}$	100.0	100	100.0	100.0
	40	$LEAF_{DM}$	99.8	100	99.6	98.8
		$WOOD_{DM}$	79.6	100	119.9	139.3
		$FROOT_{DM}$	94.4	100	102.6	104.9
		$CROOT_{DM}$	99.0	100	100.4	100.6
	400	$LEAF_{DM}$	93.0	100	106.5	112.7
		$WOOD_{DM}$	88.8	100	110.6	120.7
		$FROOT_{DM}$	99.1	100	99.1	97.4
		$CROOT_{DM}$	98.7	100	101.2	102.0



Figure 5.6: Courses of the vegetation component *WOOD* starting with the initial values of 255,450 (standard value), 675 and 900 tons/ha.



was to study the effects of different initial values of the total mass and nutrients contents of *WOOD*. Table 5.5 shows that the initial size of wood mass has little effect on the growth of the other vegetation components. In the beginning, the impact of increasing *WOOD* on the growth of the other vegetation components is negative. This is caused by increased immobilization by the larger mass of wood litter (forest floor wood). Gradually the effect becomes positive which is due to an increase in *ORLA*, *ORML* and *ORST*.

A similar phenomenon as observed in Fig. 5.5 for *INSTP*, is seen in Fig 5.6 for *WOOD*: gradually the values for the four variants approach each others. They are all exceeding the original value of 450 t/ha for the reasons mentioned in Section 5.2.3.

## 5.5 Intrinsic system variables

The effects of changes in intrinsic system parameters are more difficult to predict. The intrinsic system variables of the nutrient sub-model of DYNAMITE may be distinguished as follows.

### 5.5.1 Relative turnover rates of state variables

They affect only the size of the concerning state variable and, temporarily, the flux(es) leaving that variable. The particular state variable will change reciprocally to the change in the relative rate of turnover. So, after doubling its relative turnover rate, the final size of the component will be half the original size. Such effects are to be expected, unless the change gives rise to an increase in nutrient losses (e.g. increased leaching).

Sensitivity analysis was applied to:

- relative rate of fine-root turnover (*RRFRT*).
- relative rate of removal of forest-floor wood (*RRFFWR*).
- relative rate of removal of coarse-root debris (*RRCRDR*).

Table 5.6: Absolute and relative sizes of vegetation components after 40 and 100 years for relative rates of fine-root turnover ( $RRFRTR$ ) of 0.5, 1.0 and 1.5 kg/kg per year.

Value	Year	Component	$RRFRTR$		
			0.5	1.0	1.5
absolute	40	$LEAF_{DM}$	7057	7420	7547
		$WOOD_{DM}$	654961	686307	695731
		$FROOT_{DM}$	3037	1510	1016
		$CROOT_{DM}$	27787	25864	25251
	100	$LEAF_{DM}$	7127	7388	7480
		$WOOD_{DM}$	842778	882225	894978
		$FROOT_{DM}$	3118	1564	1047
		$CROOT_{DM}$	14931	11909	10965
relative	40	$LEAF_{DM}$	95.1	100	101.7
		$WOOD_{DM}$	95.4	100	101.4
		$FROOT_{DM}$	201.1	100	67.3
		$CROOT_{DM}$	107.4	100	97.6
	100	$LEAF_{DM}$	96.5	100	101.2
		$WOOD_{DM}$	95.5	100	101.4
		$FROOT_{DM}$	199.4	100	66.9
		$CROOT_{DM}$	125.4	100	92.1

Table 5.7: Absolute (kg/ha) and relative sizes of vegetation components after 40 and 100 years for relative rates of removal of forest-floor hard wood ( $RRFFWR$ ) of 0.033, 0.067 and 0.1 kg/kg per year.

Value	Year	Component	$RRFFWR$		
			0.033	0.067	0.100
absolute	40	$LEAF_{DM}$	7114	7420	7621
		$WOOD_{DM}$	694819	686307	682460
		$FROOT_{DM}$	1503	1510	1497
		$CROOT_{DM}$	25638	25864	25880
	100	$LEAF_{DM}$	6914	7388	7539
		$WOOD_{DM}$	858656	882225	890534
		$FROOT_{DM}$	1566	1564	1559
		$CROOT_{DM}$	11785	11909	11922
relative	40	$LEAF_{DM}$	95.9	100	102.7
		$WOOD_{DM}$	101.2	100	99.4
		$FROOT_{DM}$	99.5	100	99.1
		$CROOT_{DM}$	99.1	100	100.1
	100	$LEAF_{DM}$	93.6	100	102.0
		$WOOD_{DM}$	97.3	100	100.9
		$FROOT_{DM}$	100.1	100	99.7
		$CROOT_{DM}$	99.0	100	100.1

Table 5.8: Absolute (kg/ha) and relative sizes of vegetation components after 40 and 100 years for relative rates of removal of hard coarse-root debris ( $RRCRDR$ ) of 0.033, 0.067 and 0.1 kg/kg per year.

Value	Year	Component	$RRCRDR$		
			0.033	0.067	0.100
absolute	40	$LEAF_{DM}$	7235	7420	7502
		$WOOD_{DM}$	683559	686307	688077
		$FROOT_{DM}$	1522	1510	1502
		$CROOT_{DM}$	25842	25864	25864
	100	$LEAF_{DM}$	7369	7388	7378
		$WOOD_{DM}$	873990	882225	884383
		$FROOT_{DM}$	1566	1564	1564
		$CROOT_{DM}$	11903	11909	11907
relative	40	$LEAF_{DM}$	97.5	100	101.1
		$WOOD_{DM}$	99.6	100	100.3
		$FROOT_{DM}$	100.8	100	99.5
		$CROOT_{DM}$	99.9	100	100
	100	$LEAF_{DM}$	99.7	100	99.9
		$WOOD_{DM}$	99.1	100	100.2
		$FROOT_{DM}$	100.1	100	100.0
		$CROOT_{DM}$	99.9	100	100.0

Table 5.6 shows that the changes in the sizes of  $FROOT$  are indeed practically reciprocal to the changes in the relative rate of fine-root turnover ( $RRFRTR$ ). Also  $CROOT$  is affected, because coarse roots are formed directly from fine roots. The influence of  $RRFRTR$  on leaves and wood sizes is small and in opposite direction to the change in root growth which can be explained by competition for nutrients between roots and above-ground vegetation components. The relative rates of removal of forest-floor wood ( $RRFFWR$ ) and that of coarse-root debris ( $RRCRDR$ ) affect the sizes of  $FFW$  and  $CRD$ . As long as the final (steady-state) values have not yet been reached, the changes in  $RRFFWR$  and  $RRCRDR$  have some effects on the vegetation components (Tables 5.7 and 5.8), but in the end no other factors than  $FFW$  and  $CRD$  will be affected. Table 5.9 gives some values of  $FFW$  and  $CRD$

### 5.5.2 Distribution ratios or partitioning coefficients

The way nutrients are distributed among the various vegetation components are not fixed but depend on various circumstances. Usually minimum and maximum values are set as lower and upper boundaries of a range of possible distributions. Whether the values of these boundaries indeed affect plant growth depends on whether the actual value of the distribution coefficient is close to one of the boundaries or in the middle of the range. Sensitivity analysis was applied to

Table 5.9: Sizes (kg/ha) of hard  $FFWC$  and hard  $CRD_C$  (kg/ha per month) and N mineralization of soft  $FFW_N$  and soft  $CRD_N$ , at 0, 4, 40, and 100 years for relative rates of removal of hard forest-floor wood ( $RRFFWR$ ) and coarse-root debris ( $RRCRDR$ ) of 0.033, 0.067 and 0.1 kg/kg per year

Variable	Year	$RRFFWR$		
		0.033	0.067	0.100
hard $FFWC$				
	0	34477	34477	34477
	4	38612	34423	30764
	40	76576	45675	31639
	100	116642	63166	43308
N min. of $FFW_N$				
	0	- 0.554	- 0.554	- 0.554
	4	-0.228	- 0.406	-0.541
	40	- 0.162	- 0.152	- 0.133
	100	- 0.078	- 0.062	- 0.057
<hr/>				
Variable	Year	$RRCRDR$		
		0.033	0.067	0.100
hard $CRD_C$				
	0	6964	6964	6964
	4	7875	7035	6293
	40	9334	4936	3115
	100	5286	2174	1347
N min of $CRD_N$				
	0	- 0.554	- 0.554	- 0.554
	4	- 0.228	- 0.406	- 0.541
	40	- 0.162	- 0.152	- 0.133
	100	- 0.078	- 0.062	- 0.057

Table 5.10: Absolute and relative sizes of vegetation components after 40 and 100 years for values of the maximum fraction of nutrients allocated to fine roots ( $FUFRA_{max}$ ) of 0.3, 0.6 and 0.9.

		$FUFRA_{max}$			
		0.3	0.6	0.9	
absolute	40	$LEAF_{DM}$	7593	7420	7243
		$WOOD_{DM}$	698001	686307	673044
		$FROOT_{DM}$	1086	1510	1961
		$CROOT_{DM}$	24962	25864	26849
	100	$LEAF_{DM}$	7529	7388	7245
		$WOOD_{DM}$	900520	882225	862686
		$FROOT_{DM}$	1098	1563	2047
		$CROOT_{DM}$	10381	11909	15311
relative	40	$LEAF_{DM}$	102	100	98
		$WOOD_{DM}$	102	100	98
		$FROOT_{DM}$	72	100	130
		$CROOT_{DM}$	97	100	104
	100	$LEAF_{DM}$	102	100	98
		$WOOD_{DM}$	102	100	98
		$FROOT_{DM}$	70	100	131
		$CROOT_{DM}$	87	100	114

Table 5.11: Absolute (kg/ha) and relative sizes of vegetation components after 40 and 100 years for values of the minimum fraction of nutrients allocated to fine roots ( $FUFRA_{min}$ ) of 0.05, 0.1 and 0.2.

Value	Year	Component	$FUFRA_{min}$			
			0.05	0.1	0.2	
absolute	40	$LEAF_{DM}$	7573	7420	7079	
		$WOOD_{DM}$	697344	686307	661041	
		$FROOT_{DM}$	1112	1510	2362	
		$CROOT_{DM}$	24997	25864	27665	
	100	$LEAF_{DM}$	7504	7388	7129	
		$WOOD_{DM}$	896805	882225	849233	
		$FROOT_{DM}$	1181	1563	2402	
		$CROOT_{DM}$	10663	11909	14616	
	relative	40	$LEAF_{DM}$	102	100	96
			$WOOD_{DM}$	102	100	96
			$FROOT_{DM}$	74	100	156
			$CROOT_{DM}$	97	100	107
100		$LEAF_{DM}$	102	100	96	
		$WOOD_{DM}$	102	100	96	
		$FROOT_{DM}$	76	100	154	
		$CROOT_{DM}$	90	100	123	

- the maximum and minimum values for the fraction of the available nutrients that is assigned to fine roots ( $FUFRA_{max}$  and  $FUFRA_{min}$ ) (see Section of this report)
- $q_r$ , i.e. the factor relating the ratio  $CROOT_{DM}/FROOT_{DM}$  to soil fertility index ( $SFI$ ) (see Model Description, Equation II.10 and Equation III.97, pages 56 and 152, respectively).

Tables 5.10 and 5.11 show that  $FUFRA_{max}$  and  $FUFRA_{min}$  primarily affect  $FROOT$  and related to that also  $CROOT$ . The effect of  $FUFRA_{max}$  is less than the effect of  $FUFRA_{min}$ . This is because the soil fertility index ( $SFI$ ) is rather low (Table 5.12), and hence a relative large portion of the nutrients is allocated to the roots.

The standard value for  $q_r$  was set at 5. At higher values of  $q_r$ , a relative larger portion of fine roots is converted into coarse roots, and hence, at a given soil fertility, the ratio  $CROOT_{DM}/FROOT_{DM}$  is higher with increasing values of  $q_r$ . Table 5.13 shows that  $CROOT$  indeed increases with higher values of  $q_r$ . This goes a little at the expense of the other vegetation components for two major reasons:

- larger quantities of  $CROOT$  result in larger quantities of  $CRD$  and by that in a stronger immobilization of N and P so that less nutrients are available for uptake.

Table 5.12: Nitrogen allocated to fine roots and to leaves (kg/ha per month) after 0, 40 and 100 years, for values of the maximum fraction of nutrients allocated to fine roots ( $FUFRA_{max}$ ) of 0.3, 0.6 and 0.9, and for values of the minimum fraction of nutrients allocated to fine roots ( $FUFRA_{min}$ ) of 0.05, 0.1 and 0.2.

Allocated to	Year	$FUFRA_{max}$		
		0.3	0.6	0.9
fine roots	0	0.715	1.022	1.328
	40	0.546	0.810	1.080
	100	0.545	0.830	1.114
leaves	0	7.874	7.567	7.261
	40	4.078	3.883	3.685
	100	3.445	3.230	3.163
		$FUFRA_{min}$		
		0.05	0.1	0.2
fine roots	0	0.817	1.022	1.430
	40	0.634	0.810	1.184
	100	0.670	0.830	1.851
leaves	0	7.771	7.567	7.158
	40	3.985	3.883	3.647
	100	3.341	3.230	3.199



Table 5.13: Absolute (kg/ha) and relative sizes of vegetation components after 40 and 100 years for values of  $q_r$  of 2.5, 5.0 and 10.0.

Value	Year	Component	$q_r$		
			2.5	5	10
absolute	40 n	<i>LEAF<sub>DM</sub></i>	7466	7420	7330
		<i>WOOD<sub>DM</sub></i>	687704	686307	683545
		<i>FROOT<sub>DM</sub></i>	1517	1510	1497
		<i>CROOT<sub>DM</sub></i>	24208	25864	29116
	100	<i>LEAF<sub>DM</sub></i>	7424	7388	7317
		<i>WOOD<sub>DM</sub></i>	885951	882225	874874
		<i>FROOT<sub>DM</sub></i>	1571	1564	1549
		<i>CROOT<sub>DM</sub></i>	9360	11909	16926
relative	40	<i>LEAF<sub>DM</sub></i>	100.6	100	98.8
		<i>WOOD<sub>DM</sub></i>	100.2	100	99.6
		<i>FROOT<sub>DM</sub></i>	100.5	100	99.1
		<i>CROOT<sub>DM</sub></i>	93.6	100	112.6
	100	<i>LEAF<sub>DM</sub></i>	100.5	100	99.0
		<i>WOOD<sub>DM</sub></i>	100.4	100	99.2
		<i>FROOT<sub>DM</sub></i>	100.4	100	99.0
		<i>CROOT<sub>DM</sub></i>	78.6	100	142.1

Table 5.14: Sizes of  $CRD_C$ ,  $ORLA_C$  and  $ORML_C$ , and of the mineralization of N from  $CRD$ ,  $ORLA$  and  $ORML$  after 4, 40 and 100 years for values of  $q_r$  of 2.5, 5.0 and 10.0.

Variable	Year	$q_r$		
		2.5	5	10
$CRD_C$	4	7029	7035	7046
	40	4757	4936	5286
	100	1815	2174	2879
N min of $CRD$	4	- 0.406	- 0.406	- 0.406
	40	- 0.146	- 0.152	- 0.162
	100	- 0.050	- 0.062	- 0.084
$ORLA_C$	4	848	837	816
	40	926	915	895
	100	1015	1005	986
N min o $ORLA$	4	0.615	0.606	0.589
	40	0.740	0.730	0.710
	100	0.714	0.705	0.688
N min of. $ORML$	4	0.525	0.519	0.508
	40	0.630	0.624	0.613
	100	0.668	0.663	0.653
$ORML_C$	4	1054	1047	1033
	40	1196	1190	1178
	100	1415	1409	1397

- because the nutrients in  $CROOT$  and  $CRD$  are withdrawn from the circulation, the more nutrients are locked up the larger  $CROOT$  and  $CRD$  are. In the course of time the negative effect on growth diminishes because gradually the soil organic pools  $ORLA$ ,  $ORML$  and  $ORST$  increase again because of the increasing transfer of nutrients to these pools from the increasing  $CRD$  (Table 5.14).

### 5.5.3 Process regulating coefficients

The parameters meant here are coefficients in equations that describe the interdependency of different processes. Sensitivity analysis was applied to the transpiration ratio ( $TRR$ ), which tells how much water must be transpired by the crop per kg of dry matter that is produced. The prediction of the effects of the transpiration ratio is more difficult than that of the effects of the other parameters subjected to sensitivity analysis in this report. This is because  $TRR$  relates processes in the water cycling model to processes in the nutrient cycling submodel. The soil fertility index,  $SFI$ , is one of the factors that is related

Table 5.15: Absolute(kg/ha) and relative sizes of vegetation components after 40 and 100 years for values of  $TRR$  of 150, 300 and 450 kg/kg.

Value	Year	Component	$TRR$			
			150	300	450	
absolute	40	$LEAF_{DM}$	6903	7420	6804	
		$WOOD_{DM}$	642179	686307	572282	
		$FROOT_{DM}$	3699	1510	1082	
		$CROOT_{DM}$	26871	25864	25096	
	100	$LEAF_{DM}$	7030	7388	6266	
		$WOOD_{DM}$	833150	882225	693139	
		$FROOT_{DM}$	3613	1564	985	
		$CROOT_{DM}$	13542	11909	10466	
	relative	40	$LEAF_{DM}$	93.0	100	91.7
			$WOOD_{DM}$	93.5	100	83.4
			$FROOT_{DM}$	245.0	100	71.7
			$CROOT_{DM}$	103.9	100	97.0
100		$LEAF_{DM}$	95.2	100	84.8	
		$WOOD_{DM}$	94.4	100	78.6	
		$FROOT_{DM}$	231.0	100	63.0	
		$CROOT_{DM}$	113.7	100	87.9	

to  $TRR$ , whereas  $SFI$  itself affects the nutrient distribution between fine roots and leaves, and the ratio of coarse to fine roots.

Table 5.15 shows that at both a low and a high  $TRR$ ,  $LEAF_{DM}$  and  $WOOD_{DM}$  are lower than at the standard  $TRR$  300, while the roots are stimulated at low  $TRR$  and reduced at high  $TRR$ . The maximum growth, calculated with Equation 2.21 is high at a low  $TRR$ , and low at a high  $TRR$ . As a consequence, the calculated  $SFI$  (Equation 2.23 ) is low at a low  $TRR$  and high at a high  $TRR$ . At low  $SFI$  more nutrients are allocated to the roots than at high  $TRR$ . This explains the results for  $FROOT$  and  $CROOT$  in Table 5.15. Because so many nutrients are allocated to the roots, less are available for leaves and wood, and hence their size is reduced at low  $TRR$ . Mutates mutandis one would expect that a high  $TRR$ , and thus a high  $SFI$ , stimulates the growth of leaves and wood . This is not the case.  $SFI$  is high indeed at a high  $TRR$  and relative many nutrients are allocated to leaves, but the maximum growth is reduced so much that leaf and wood cannot reach the values under the standard conditions (Table 5.16).

## 5.6 Concluding remarks

Table 5.17 presents the relative sensitivity ( $S_r$ ) of the input parameters analyzed in this study for WOOD. The data refer to a simulated period of 100 years and are presented in an order of decreasing sensitivity. A negative sign of  $\frac{\delta I}{I_s}$  means

Table 5.16: Per time step values of soil fertility index ( $SFI$ ), maximum growth ( $GROW_{max}$ ), total dry matter production ( $GROW_{tot}$ ) and allocation of N to fine roots and to leaves (all in kg/ha per month) at 4, 40 and 100 years for values of  $TRR$  of 150, 300 and 450 kg/kg.

Variable	Year	$TRR$		
		150	300	450
$SFI$	4	0.350	0.725	0.831
	40	0.379	0.787	0.826
	100	0.378	0.765	0.831
$GROW_{max}$	4	6290	3247	2191
	40	6475	3323	2249
	100	6405	3275	2196
$GROW_{tot}$	4	2064	2422	2353
	40	2501	2628	2575
	100	2480	2530	2521
N to fine roots	4	1.685	0.948	0.707
	40	1.796	0.810	0.773
	100	1.783	0.830	0.687
N to leaves	4	2.174	3.390	4.618
	40	2.905	3.883	5.920
	100	2.554	3.230	5.041

Table 5.17: Relative sensitivity ( $S_r$ ) of the model output parameter *WOOD*, after a simulation period of 100 years, for the analyzed input parameters and for the initial value of *WOOD*. Both,  $\frac{\delta I}{I_s}$  and  $S_r$  are expressed in %.

Input parameter	$\frac{\delta I}{I_s}$		
	- 50	+ 50	+ 100
<i>TRR</i>	22.71	- 87.49	
<i>RRFRTR</i>	18.25	5.90	
<i>FUFRA<sub>max</sub></i>	- 8.47	- 9.04	
<i>FUFRA<sub>min</sub></i>	- 6.75		- 7.63
<i>RRFFWR</i>	10.90	3.84	
<i>RRCRDR</i>	3.81	1.00	
$q_r$	- 1.70		- 1.72
<i>INSTP</i>	0.66 <sup>†</sup>	- 0.11 <sup>††</sup>	
<i>WOOD</i>	45.91	43.30	42.30

<sup>†</sup>  $\frac{\delta I}{I_s}$  was - 57.7% instead of - 50%

<sup>††</sup>  $\frac{\delta I}{I_s}$  was + 41.1% instead of + 50%

that the value of the input parameter was lowered, a negative sign of  $S_r$  means that the direction of the change in the size of *WOOD* was opposite to that of the input parameter.

Wood growth proves to be more sensitive to the transpiration ratio than to the other parameters analyzed. Unfortunately it is very difficult to get data of *TRR* for tropical rainforests. This obviously remains a weak point in modeling the growth of tropical forests.

The input parameters *RRFRTR*, *FUFRA<sub>max</sub>* and *FUFRA<sub>min</sub>* affect primarily root growth and only indirectly wood growth, as is explained in Sections 5.5.1 and 5.5.2, but nevertheless their impacts are rather important. Also these parameters are very difficult to determine, as was shown in Section II.2 of the Model Description, and in Section 5.5.2 of this report. The rate of litter removal has a stronger effect for forest floor wood (*RRFFWR*) than for coarse-root debris (*RRCRDR*) which must be ascribed to the fact that the quantity of forest floor wood is much larger than that of coarse-root debris. The effect of  $q_r$ , regulating the ratio of *CROOT<sub>DM</sub>*/*FROOT<sub>DM</sub>* in relation to soil fertility, is not large, which is good luck in view of the very uncertain way of estimating the value of  $q_r$ .

*INSTP* is relatively simple to estimate but its effect on wood growth is not big.

The maximum and minimum concentration of nutrients in leaves (*LEAFCA<sub>P</sub>* and *LEAFCD<sub>P</sub>*) and in the other vegetation components were not included in the sensitivity analysis because of lack of time. In general it can be expected that the lower these concentrations are the more dry matter is produced. As said in Section 5.2.3 of this report, the lower nutrient concentrations form the main reason for the quick increase of the above-ground parts of the vegetation, even in the standard situation.

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# Appendix Errata in the Model Description

III.4  $e^{0.4 \cdot LAI}$  must be replaced by  $e^{-0.4 \cdot LAI}$ .

III.5 212 should be  $21^2$ .

III.8  $ET_{pot}$  should have an accent:  $ET_{pot'}$ .

III.21 The subscripts of  $\Theta$  should not be 1 and 2, but  $b$  and  $e$ :

$$(\Theta_b - \Theta_e)D + J_{in} - J_{out, \Theta_e} - W_{act, \Theta_e} = 0$$

III.24  $ARDEP$  should be called  $F_{dep}$  to be consistent with Equation III.131.

III.27 Below this equation  $RILISP$  is defined. This must be  $RILSP$ .

III.33  $f$  should have an index:  $f_t$ .

III.64  $J_{out}/\Theta \cdot D \cdot SSOL_{i,b}$  should be  $\frac{J_{out}}{\Theta \cdot D} \cdot SSOL_{i,b}$

III.105  $LEAFC_i - A_i/B_i$  should be  $\frac{LEAFC_i - A_i}{B_i}$

III.106 an = sign should be inserted:

$$f_{LAI} = q_l \cdot \frac{(LAI - LAI_{cr})}{LAI_{cr}}$$

III.128 one parenthesis must be deleted:

$$SLA = 0.5 \cdot (q + r \cdot LEAFC_N + s + t \cdot LEAFC_P)$$

III.132 The calculation order should be corrected to:

$$F_{out} = J_{out} \cdot \frac{SSOL_{i,b} + SSOL_{i,e}}{D \cdot (\Theta_b + \Theta_e)}$$

III.133 The calculation order should be corrected to:

$$SSOL_{i,e} = \frac{SSOL_{i,e} \cdot (K_d + 1 - a) + \Sigma in_i - UP_{act,i}}{K_d + a + 1}$$

III.135 The indexes  $b$  and  $e$  should be added:

$$POOL_{k,i,e} = POOL_{k,i,b} + \Sigma in_{k,i} - \Sigma out_{k,i}$$

