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SARP Research Proceedings

ORYZA simulation modules for potential and nitrogen limited rice production

H. Drenth, H.F.M. ten Berge & J.J.M. Riethoven (Editors)

SARP Research Proceedings - December 1994

DLO-Research Institute for Agrobiology and Soil Fertility, Wageningen
WAU-Department of Theoretical Production Ecology, Wageningen
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Preface

This issue describes a number of modules or subroutines, that can be combined to yield whole models. The modules have been derived by splitting up models that had earlier been developed as entities: the ORYZA_N and ORYZA_0 models. There is an overlap between the material presented here and the ORYZA_1 model documented earlier in this SARP Research Proceedings series.

Modules are defined as modelled subgroups of processes that can be seen as largely independent 'units'. The purpose of this attempt to provide a modular framework is twofold. First, to establish a basis for structured and coordinated model development in a context with many researchers working simultaneously on related topics. Second, to facilitate comparison between different formulations of subprocesses, e.g. dry matter production, nitrogen allocation, etc. A modular structure ensures that the complementary model elements, which are supposed to be identical among the compared models, are indeed exactly identical and do not generate 'noise' which would otherwise be attributed to the conciously imposed model differences. Only further modelling practice will show whether this attempt to enhance structured development is indeed successful. For the moment, this line of work is viewed as a parallel, not a replacement, of ongoing modelling activities.

The material presented here focusses on the role of nitrogen in rice growth: distribution of nitrogen in the crop, utilization of leaf nitrogen to produce dry matter, and translocation of nitrogen between crop organs. During the last phases of preparing this issue, data sets from many more SARP sites across the whole region have become available. These will be presented in 1995 and will probably lead to revision of some modules and parameter values.

Based on these new sets, a thorough comparison between simple (light use efficiency based) and complex (canopy photosynthesis based) models will be made with the help of these ORYZA modules, across the wide range of environments covered in the network.

Wageningen
December, 1994

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Contents

1 Introduction

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We present in this issue a set of simulation modules which can be combined into different sets, to form complete simulation models. The two sets presented here are referred to as ORYZA_N and ORYZA_0. The modules are 'building blocks' for simulating rice production in different environments and under different constraints. The sets presented here are viewed as a starting point only. Many of the modules can be further polished, and new modules describing other processes (e.g. aspects of water limited production) will be added in the near future. Thus a library of modules, each describing a component (group of subprocesses)., may gradually be developed.
Teams from several national research centres participating in SARP have worked on evaluation and development of these modules. They also have collected data sets for model improvement and validation. Based on these results of detailed studies on rice-nitrogen relations, a number processes relevant to yield formation under limited N supply can now be described quantitatively.
The ORYZA_N modules describe the potential as well as the nitrogen limited growth of rice. These modules have evolved from models, such as the potential production module MACROS-L1D (Penning de Vries et al., 1989), the model SUCROS (Goudriaan & van Laar, 1994) and the model L3C. The main difference between ORYZA1 and the current ORYZA_N version is that the latter includes nitrogen uptake and allocation to crop organs. ORYZA_N was originally written in PCSMP. In 1993 it was translated into FORTRAN77, which allowed running the model within the FORTRAN Simulation Environment (FSE) (van Kraalingen, 1991) and within the SARP-SHELL (Riethoven, 1994).
ORYZA_0 simulates biomass accumulation in rice as limited by nitrogen uptake and daily total global radiation. The equations used in describing both the soil and the crop component of the model are stripped down to the bare basics. ORYZA_0 can, therefore, be regarded as a summary model of N limited rice growth. The complexity found in the more detailed crop growth and development models, such as ORYZA_1 and ORYZA_N, is avoided here: explicit formulations of phenological development, leaf area development, light interception, assimilation, respiration, conversion of glucose into dry matter, partitioning of dry matter, remobilization of carbohydrates, and the formation of sink size are all omitted. The net results of all these processes are expressed in a few coefficients.
Contrary to the other ORYZA models, ORYZA_0 includes a soil component to describe N

uptake. In accordance, the crop component of the model gives more attention than previous ORYZA models to crop N demand, as a factor which might limit N uptake.
ORYZA_0 uses coefficients which can be derived directly from field observations of biomass and N contents. Some of the empirical coefficients are not fully understood but can nevertheless be used in fertilizer optimization (ten Berge et al., 1994a), once they have been determined.
Both models can be run under the SARP-shell, which provides a user-friendly interface and facilitates the choice of modules, model sections and the use of forcing functions.
Chapter 2 describes each of the ORYZA_N modules. ORYZA_0 modules are described in Chapter 3. The aim of this manual is not to provide complete explanation of processes involved, but to give an overview of currently existing modules with a brief explanation of statements. Results of validation of both models at different SARP locations are given in Chapter 4. The listings of the modules are given in Appendices 8 and 9.

General structure of the ORYZA_N and ORYZA_0 models

The submodels are written as FORTRAN77 subroutines according to the format of the FORTRAN Simulation Environment (FSE). FSE is an environment for continuous simulation of crop growth and is entirely written in FORTRAN77 (van Kraalingen, 1991). It consists of a main model, named MAIN, and a general model subroutine, named MODELS. MAIN provides the control structure for reruns, weather data and time, and a collection of utilities that perform specific tasks. The subroutine MODELS is the interface routine between the FSE driver (MAIN) and the simulation model. It is used to specify the call to a particular model, i.e. set of modules, in this case ORYZA_N or ORYZA_0.
The WEATHER system (van Kraalingen et al., 1991) is used to read weather data from weather data files. The TTUTIL (Rappoldt & van Kraalingen, 1990) and COME_ON (Riethoven, 1994) libraries are used to perform specific tasks such as parameter and data input from files and model output.
Data files needed for FSE are: CONTROL.DAT, a timer file, weather data file(s), data files used by the model, and optionally, rerun file(s). The CONTROL.DAT contains the names of input files, like the timer, data and the rerun files. The timer file contains time variable (year, time, step etc.) and information on the weather data file(s) to be used. The data file(s) contain in this case plant parameters, initial values of state variables and measured plant data. The rerun files contain timer data and plant data or parameters used in the reruns.
FSE distinguishes four different tasks, that control the order of calculation in the crop growth model: initialization (ITASK = 1), rate calculation (ITASK = 2), integration (ITASK = 3) and terminal calculation (ITASK = 4). The FSE driver calls the subroutine MODELS, and consequently the core subroutine (ORYZAN) of the ORYZA_N model or (ORYZA0) of the ORYZA_0 model is called, at each new task at each time step. For more detailed information on FSE see Appendix 7.

Figure 1.1 shows the structure of the whole set of subroutines. The two alternative sets are accessed via two main subroutine, ORYZAN and ORYZA0, respectively. The subroutine ORYZAN consists of only calls to lower level subroutines. These are TIMENV, DEVELP, LFAREA containing the computation of general variables, and the specific crop growth subroutine BIOMS1. BIOMS1 calls a specific set of subroutines, defining crop growth. In the subroutine ORYZA0 the subroutines TIMENV and BIOMS2 are called. BIOMS2 calls the specific crop growth subroutines.
The ORYZA_N model requires that the user set a number of switches, which define the model. By choosing a particular set of switch values, some parts of the model are activated, others are skipped. This approach provides the researcher with a toolbox for analyzing experimental data or for developing new model sections. Table 1.1 gives an overview of the various switches available. A more detailed explanation will be given in the Chapter 2. ORYZA_0 uses either the measured or simulated amount of nitrogen in the leaves, again via a switch (SWINLV).

Table 1.1 The switches, the associated processes and the choices that have to be in made in ORYZA_N by the user.

Switch	Processes involved	Choices
SWINUP	Leaf N uptake N supply to grains N allocation and removal	Potential or N-limited production
SWILAI	Leaf area development	5 ways to calculate leaf area
SWINPH	Daily gross CO_2 assimilation	Measured or simulated N in leaves, used in photosynthesis calculation
SWINPR	Daily gross CO_2 assimilation	N profile in canopy or uniform N distribution
SWISIN	Tiller and grain formation	Sink limitation or no sink limitation
SWISAI	Leaf & stem area development	Include or exclude stem area in leaf area

About the layout of this volume

The subroutines are described in the following chapters. The FORTRAN code lines are printed in a Courier letter type before the explanatory text, as shown in the following example:

```
SAI  = SSGA * WSTS
IF (SWISAI.EQ.1) THEN
   LAI = LAI + 0.5*SAI
END IF
```

The parameters and data associated with a set of program statements are printed after the set, in italics. These parameters or tables are inputs specified in the plant data file. In the cases where experimental case-specific values are presented (as opposed to standard values), this will be referred to as 'Example of user input'.

SSGATB = 0.,0.0003, 0.9,0.0003, 2.1,0.

Example of user input:

DVRV = 0.000784

DVRR = 0.001674

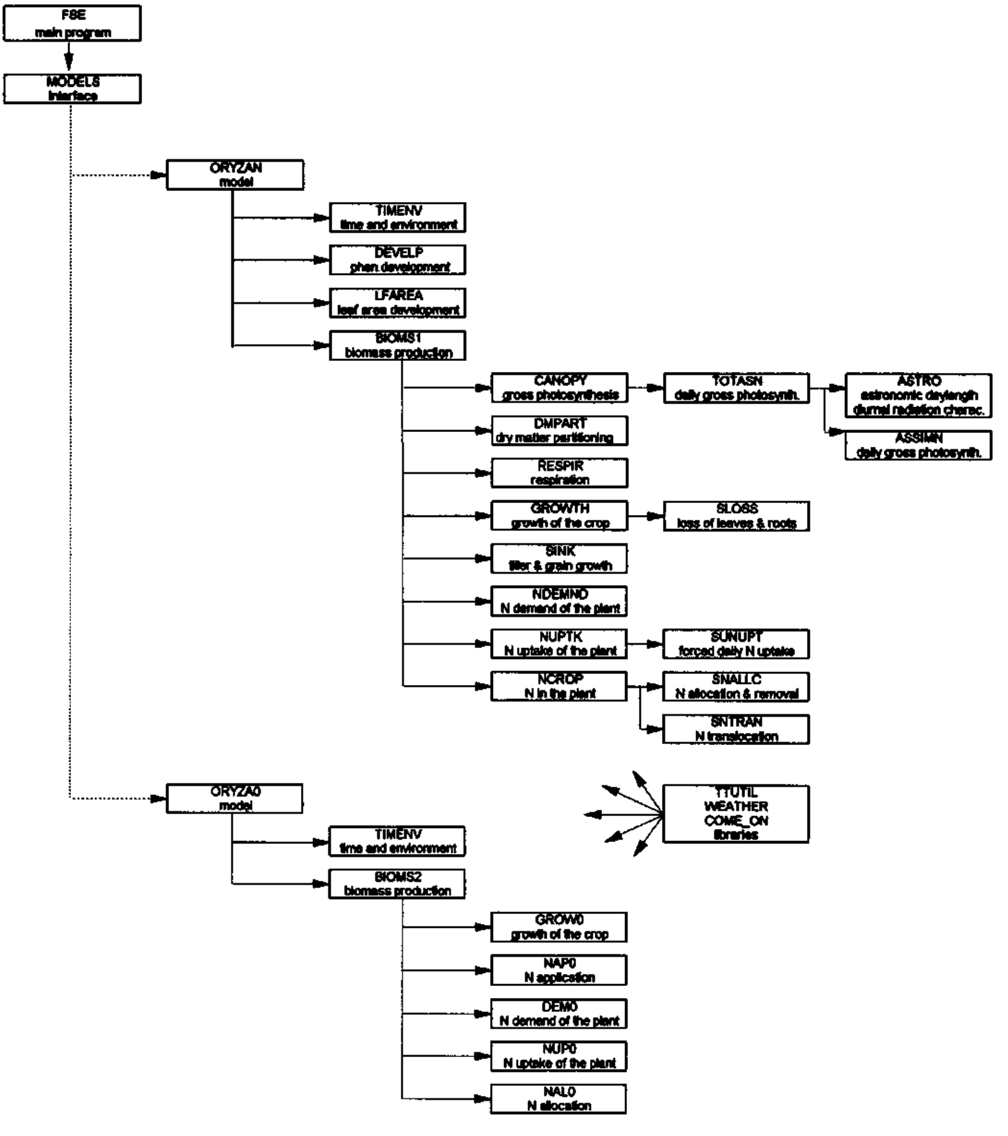

Figure 1.1 Structure of the subroutines sets ORYZA_N and ORYZA_0.

2 Description of the ORYZA_N modules (version 2.0)

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The subroutine ORYZAN calls the subroutines TIMENV, DEVELP, LFAREA and BIOMS1. In the following sections these will be described.

2.1 Time and environment (TIMENV)

The module TIMENV computes general time and environmental variables.

```
DAT = TIME - STTIME
```

The number of days after transplanting (DAT) is calculated as the difference between TIME and STTIME, the starting time of simulation. The simulation starts always at transplanting.

```
TAV    = 0.5*(TMX + TMN)
TAVD   = 0.5*(TAV + TMX)
```

The average temperature over 24 hours (TAV, °C) is calculated from the daily maximum temperature (TMX, °C) and minimum temperature (TMN, °C). These temperatures are inputs for this module. The average temperature in daytime (TAVD, °C) is the average of the 24 hours average temperature (TAV, °C) and the maximum temperature (TMX, °C).

```
HU     = MIN(30.-TBD, (MAX (0., TAV-TBD)))
HULV   = MIN(26.-TBLV, (MAX (0., TAV-TBLV)))

TBD    =   8.0 ; TBLV =  8.0
```

The effective daily temperature for the development of a plant is expressed in the heat units (HU, (K d) d^{-1}). Below the base temperature (TBD, °C), of 8 °C the phenological development of rice stops. The maximum average temperature for the development of a rice plant is set to 30 °C. The effective temperature for development is the difference between the daily 24 hours temperature (TAV, °C) and the base temperature (TBD, °C), as long as this difference will not exceed the maximum possible value which is determined by the base and the maximum average temperature for development.

A similar procedure is followed for leaf area where the effective daily heat unit is named HULV (K) and the base temperature is named TBLV (°C) and is also 8 °C. The maximum temperature here is set to 26 °C. Heat unit (HU, K) is used in the calculation of the development rate of a plant (see Section 2.2). The heat unit of the leaves is used in the leaf area calculation (see Section 2.3).

```
TS   = INTGR2 (TS  , HU   , DELT,  'TS', FILEI1)
TSLV = INTGR2 (TSLV, HULV , DELT,'TSLV', FILEI1)
```

The total accumulation of heat units is computed by the integration over time, giving the temperature sum for plant development (TS, K d) and the temperature sum for leaf development (TSLV, K d). Both TS and TSLV are initialized at zero.

2.2 Phenological development (DEVELP)

Many physiological and morphological processes, like i.e. the partitioning of dry matter over the various plant organs, depend directly on the phenological development stage of the plant. This development stage is expressed in a dimensionless variable (DVS), with the value of 0 at seedling emergence, 1 at flowering and 2 at maturity (van Keulen, 1982).
Two important periods of phenological development are distinguished: the vegetative growth phase (from seedling emergence to flowering) and the reproductive growth phase (from flowering to maturity). The main difference between these periods finds expression in the dry matter and nitrogen allocation pattern to the plant organs. The development rate is calculated separately for each period; development rate in the vegetative stage is named DVR (d^{-1}), development rate in the reproductive stage is named DRR (d^{-1}). Phenological development is a function of temperature. A development rate coefficient for both periods is expressed in $(K\ d)^{-1}$. DVRV is the coefficient for the vegetative growth phase and DVRR for the reproductive growth phase. These coefficients change with variety, nitrogen nutrition and under drought stress. The development rate is calculated by multiplying the development rate coefficients with the daily heat units, HU (K).

```
IF (DVS.LT.1.) THEN

   TSHCKD = SHCKD * TSTR

   IF ((TS+TSI).LT.(TSTR+TSHCKD)) THEN
      DVR = 0.
   ELSE
      DVR = DVRV * HU
   END IF

   DRR = 0.
```

```
ELSE
   DVR = DVRR * HU
   DRR = DVR
END IF
SHCKD  = 0.4
```

Example of user input:

```
DVRV = 0.000784
DVRR = 0.001674
```

The transplanting of rice causes a delay in the phenological development. The delay is a function of the age of the transplanted seedlings, expressed in degree days (TSTR, K d) (Kropff et al., 1994). TSTR is set equal to the initial temperature sum. The model starts simulating at transplanting day, the initial temperature sum is the temperature sum over the period from emergence to transplanting. The degree delay per unit seedling age is expressed in the parameter SHCKD (K d), and set to 0.4. The delay is computed in the variable TSHCKD (K d), by multiplying the seedling age expressed in degree days by the degree delay per unit seedling age. The development rate will remain zero until the total temperature sum (TS + TSI) is greater than the temperature sum at transplanting added with the delay in degree days due to the transplanting shock.

```
DVS  = INTGR2 (DVS , DVR, DELT, 'DVS ', FILEI1)
```

The development stage is determined by integrating development rate. Because the model is not starting simulation at emergence an initial development stage (DVSI) is needed as input.

2.3 Leaf area (LFAREA)

Simulation of leaf area can be done in several different ways. Through the switch SWILAI the user can choose from 5 options to calculate or impose the leaf area. Two options are listed in the following segment:

```
IF (SWILAI.EQ.1) THEN
   SLA = SLAC*LINT(SLAFAC, ILSLAF, DVS)
   IF (TSLV.LT.TSLVC) THEN
      LAI = LAII
   ELSE
      LAI = WLVG*SLA
   END IF
```

```
ELSE IF (SWILAI.EQ.4) THEN
   SLA = SLAC*LINT(SLAFAC, ILSLAF, DVS)
   IF (TSLV.LT.TSLVC) THEN
      LAI = LAII
   ELSE
      LAI = XXWLVG*SLA
   END IF
TSLVC  = 89.7
SLAC   = 0.0020
SLAFAC = 0.00,1.72,0.21,1.72,0.24,1.72,0.33,1.32,0.70,1.20,
         1.01,1.00,2.00,0.75,2.10,0.75
```

When SWILAI is 1 or 4 the leaf area is calculated from the weight of the leaves and the specific leaf area (SLA, ha kg^{-1}). Option 1 uses simulated weight of the leaves (WLVG, kg ha^{-1}), option 4 uses measured weight of the leaves (XXWLVG, kg ha^{-1}), read from a function table in the input file with plant data.
Leaves formed in an early stage of the growth period of the plant are thinner than leaves formed later (Penning de Vries et al., 1989). The specific leaf area defined in this module is determined by a specific leaf area constant (SLAC, ha kg^{-1}), and a dimensionless factor that corrects for the development stage of the plant (SLAFAC) using the reference value of 1.0 at DVS=1, by definition. The value of SLAC is the specific leaf area at the moment of flowering. The SLAFAC is the ratio of specific leaf area at any moment to SLAC. For an explanation of the determination of SLAC and SLAFAC see Appendix 3. The average SLAC appears to be about 0.002 ha kg^{-1}. Although differences exist for varieties, locations and growth conditions (e.g. N supply) (Table 2.1). As a first approximation, leaf area development is ignored after transplanting until a temperature sum (TSLV) of 89.7 K d (TSLVC) is reached. Later, more refined formulations were proposed by Kropff et al. (1994).

```
ELSE IF (SWILAI.EQ.2) THEN
   LAI = MAX (LAII,EXP(LINT (LAILNT, ILLAIN, TSLV)))
LAILNT = 0.,-1.61,89.15,-1.61,157.0,-1.01,303.,-0.31, 451., 0.45,
         589., 1.07, 734., 1.34, 882., 1.46,1020., 1.37,
         1171., 1.24,1324., 1.13,1483., 1.04
```

Option 2 formulates the leaf area index on the basis of tabulated values of ln(LAI) vs. TSLV (LAILNT). This approach presumes that temperature is the only factor affecting leaf area development, and is only valid when no constraints exists to nitrogen and water uptake.

```
      ELSE IF (SWILAI.EQ.3) THEN
         IF(DVS.LT.0.3.AND.LAIOLD.LT.1.5) THEN
            WLVEXP = WLVG
            LAIEXP = LAII*MAX(1.,EXP(RGRL*(TSLV-TSLVC)))
            LAI    = LAIEXP+0.5*WSTS*SSA
         ELSE
            SLA    = SLAC*LINT(SLAFAC, ILSLAF, DVS)
            LAI    = MAX(0.,LAIEXP)+0.5*WSTS*SSA+
     $                 (WLVG-MAX(0.,WLVEXP))*SLA
         END IF
         LAIOLD = LAI
      RGRL   = 0.0085
      SSA    = 0.001
```

Option 3 distinguishes two growth phases of leaves: an exponential phase followed by a linear growth phase. In the exponential growth phase the RGRL is the relative growth rate of leaf area expressed per degree day ($(K\ d)^{-1}$). The linear growth is defined identical to the calculation under option 1 and 4, with the exception that the stem area is included.

Table 2.1 SLAC derived from data from experiments carried out at IRRI, the Philippines, in three different seasons, with three varieties and different levels of nitrogen application.

Season	Treatment	SLAC	
	($kg\ ha^{-1}$)	IR72	LINE
1991 wet season	0	0.0019	0.0016
	80	0.0023	0.0019
	110	0.0021	0.0020
1992 dry season	0	0.0013	0.0016
	180	0.0019	0.0018
	225	0.0019	0.0020
		IR50 plot 1	IR50 plot 5
1990-1991 wet season	130	0.0027	0.0027

```
      ELSE IF (SWILAI.EQ.5) THEN
        LAI = XXLAI
      END IF
```

Option 5 allows the use of straight observed LAI values as a forcing function.

```
SSGA = LINT(SSGATB, ILSAI, DVS)
SAI  = SSGA * WSTS
IF (SWISAI.EQ.1) THEN
   LAI = LAI + 0.5*SAI
END IF

SSGATB = 0.,0.0003, 0.9,0.0003, 2.1,0.
```

In both option 3 and 5 half of the stem area is included in the leaf area and thus contribute to the total photosynthetically active area. The factor 0.5 is used to reduce the photosynthetically active stem area. This is a rather arbitrary value and no good quantitative assessment is available to underpin this value.
In option 3 the specific stem area (SSA, ha kg^{-1}) is used to calculate the stem area.
In option 5 stem area (SAI) is determined by multiplying the weight of the stems (WSTS, kg ha^{-1}) by the specific green stem area (SSGA, ha kg^{-1}). The specific green stem area is a function of the development stage (SSGATB). After flowering the specific green stem area approaches zero, because of death of sheath tissue (Kropff et al., 1994). In option 5 the switch SWISAI is used to in- or exclude the stem area in the leaf area.

2.4 Biomass of the crop (BIOMS1)

The subroutine BIOMS1 only consists of calls to the subroutines needed to compute crop biomass accumulation. These subroutines are described in the following sections.

2.4.1 Daily gross CO_2 assimilation (CANOPY, TOTASN, ASTRO, ASSIMN)

The subroutine CANOPY and the underlying subroutines TOTASN, ASSIMN and ASTRO are fully based on the theory developed by Goudriaan to describe daily gross crop CO_2 assimilation (DTGA, kg CO_2 ha^{-1} d^{-1}) from incident photosynthetically active radiation (PAR, J m^{-2} s^{-1}) and photosynthesis characteristics of individual leaves. The algorithms and basic theory are largely identical with those described by Goudriaan & van Laar (1994) and are not repeated here. The procedure includes numerical (Gaussian) integration over time, over leaf layers (depth in the canopy), and over leaf angle classes.
This report only describes the slight adaptations made, which were also proposed by Goudriaan, and the required input parameters. The adaptations are all related to the introduction of two relations: (1) the linear dependency of light saturated leaf photosynthesis (AMAX, kg CO_2 ha^{-1} leaf h^{-1}) on leaf nitrogen content; and (2) a relation between AMAX and depth in the canopy, which results from redistribution of nitrogen within a crop canopy: top leaves have higher nitrogen contents than lower leaves. Both relations will be described a little further in this section.

```
EFF    = LINT (EFFTB,  ILEFF,  TAVD)
EFFTB  = 10.,0.54, 40.,0.36
```
(CANOPY)

The CO_2 assimilation - light response of individual leaves is characterised by an initial slope, the initial light use efficiency (EFF, kg CO_2 ha^{-1} leaf h^{-1} (= J m^{-2}leaf s^{-1})) and an asymptote level, AMAXT (kg CO_2 ha^{-1} leaf h^{-1}). The initial light use efficiency shows a linear relation with temperature (TAVD, °C). The actual values used here were obtained by calibration (Kropff et al., 1994).

```
REDFT  = LINT (REDFTT, ILREDF, TAVD)
REDFTT = -10.0,0., 10.,0., 20.,1. , 37.,1., 43.,0.0
```
(CANOPY)

The light saturated rate of leaf CO_2 assimilation (AMAXT, kg CO_2 ha^{-1} leaf h^{-1}) depends on temperature and leaf nitrogen concentration. The dimensionless factor REDFT accounts for the effect of temperature on AMAXT. The REDFT values given here were proposed by Penning de Vries et al. (1989).

```
IF (LAI.LT.1.5.AND. DVS.LT.1.) KDF =  0.4
IF (LAI.GE.1.5) KDF = 0.6
```
(CANOPY)

Photosynthesis of the leaves depends on the distribution of light and nitrogen in the crop. The distribution of light is expressed by the extinction coefficient for diffuse light (KDF), and related to the leaf area index. For rice a value of 0.4 is used until the canopy closes and 0.6 for a closed canopy. KDF is lower in the early stages of canopy development, because leaves are clustered, especially in transplanted rice (Kropff et al., 1994).

```
NB     = 0.15
ALPHAN = 33.
```

Of the two 'nitrogen relations' introduced into the standard TOTASS-ASSIM routines, the first applies to the relation between leaf nitrogen content and AMAXT. The relation is linear and is expressed in two parameters: NB and ALPHAN. NB is the value of nitrogen content (g m^{-2} leaf) where AMAXT equals zero, and has a value of 0.15 g m^{-2}. ALPHAN is the slope of AMAXT vs. nitrogen content and is set at 33.0 (kg CO_2 ha^{-1} h^{-1})/(gN m^{-2} leaf). This relation can be expressed in symbols as follows:

$$A_x = \alpha_N \cdot (n - n_b) \tag{2.1}$$

where

A_x is the light saturated rate of leaf CO_2 assimilation (kg CO_2 ha^{-1}leaf h^{-1})

α_N is the slope of A_x versus nitrogen content (kg CO_2 ha^{-1} h^{-1})

n is the amount of nitrogen in the leaves per unit leaf area (g m^{-2} leaf)
n_b is the value of nitrogen content where A_x equals zero (g m^{-2} leaf)

It can be shown that the most efficient distribution of leaf nitrogen over the canopy is one that corresponds to an attenuation of AMAX with depth (expressed in leaf area index units LAI') identical with the attenuation of light. Since the distribution of light vs. LAI' is expressed in the form of an exponential relation with extinction coefficient KDF, the same form is chosen for the AMAX vs. LAI' relation. The corresponding extinction coefficient is named KDIFN:

```
AMAX = AMAXT * EXP(-KDIFN*LAIC)
```
(ASSIMN)

Where AMAXT is the temperature corrected value of A_{x0} (AMAX01) defined below. In the following, the temperature correction will be ignored for simplicity.

$$A_x = A_{x0} \cdot e^{-k_N L'} \tag{2.2}$$

where
A_x is the light saturated rate of leaf CO_2 assimilation at depth L' (AMAX, kg CO_2 ha^{-1} leaf h^{-1})
A_{x0} is maximum leaf photosynthesis rate at the top of the canopy (AMAX01, kg CO_2 ha^{-1} leaf h^{-1})
k_N extinction coefficient to express the profile of nitrogen in the canopy (KDIFN)
L' is the dimensionless depth co-ordinate LAI' (LAIC)

The dimensionless depth co-ordinate LAI' has a value of zero at the top of the canopy and increases downward to LAI (L).

```
KDIFN  = SWINPR*KDIFNP
KDIFNP = 0.2
```
(CANOPY)

The nitrogen content is higher in the top leaves. The vertical distribution of nitrogen in the canopy is expressed with the help of the above mentioned extinction coefficient KDIFN. The value of 0.2 is derived from experiments by Bastiaans (personal communication). Through the switch SWINPR the user can define either a uniform distribution of nitrogen in the canopy (SWINPR = 0) or a nitrogen profile with extinction coefficient KDIFN (SWINPR = 1).
AMAX01 varies strongly with the total amount of nitrogen in the (bulk) leaves (NT, g m^{-2} ground), leaf area index LAI, and the shape of the nitrogen profile, i.e. .KDIFN. This coefficient is therefore not an independent input parameter, as AMAX was in the original

TOTASS routine, but is calculated from the above state variables and coefficients as follows.

Combining Eqn 2.1 and 2.2 gives in symbols:

$$\alpha_N(n - n_b) = A_{x0} \cdot e^{-k_N L'} \tag{2.3}$$

Integration of Eqn 2.3 over depth L' gives the total amount of leaf nitrogen NT (g N m^{-2} ground surface; in symbols N_T) as an explicit expression:

$$N_T = \frac{A_{x0}}{\alpha_N} \int_0^L e^{-k_N L'} dL' + n_b L \tag{2.4}$$

$$= \frac{A_{x0}}{\alpha_N \cdot k_N}\left(1 - e^{-k_N L}\right) + n_b L \tag{2.5}$$

and results in the desired expression for A_{x0}:

$$A_{x0} = (N_T - n_b L) \cdot \alpha_N \cdot k_N / \left(1 - e^{-k_N L}\right) \tag{2.6.a}$$

which simplifies to:

$$A_{x0} = \alpha_N \cdot (N_T / L - n_b) \tag{2.6.b}$$

Eqn 2.6.b is used in the subroutine TOTASN to derive AMAX01.

(TOTASN)

```
IF (KDIFN.GT.0.)THEN
   AMAX01=ALPHAN*KDIFN*(NT-NB*LAI)/(1.-EXP(-KDIFN*LAI))
ELSE
   AMAX01=ALPHAN*(NT/LAI-NB)
ENDIF

AMAXT=LIMIT(1., 70., REDFT * AMAX01)
```

The light saturated rate of leaf CO_2 assimilation (AMAXT, kg CO_2 ha^{-1} leaf h^{-1}) is equal to AMAX01, corrected for temperature with the factor REDFT. An absolute upper limit of 70 kg CO_2 ha^{-1} leaf h^{-1} is imposed, based on experimental values.

AMAXT is subsequently introduced into the subroutine ASSIM to calculate the light saturated leaf photosynthesis rate at three selected (fixed Gauss coefficients) depths LAI' in the canopy, according to Eqn 2.2.

```
IF (SWINPH.EQ.1) THEN                                  (CANOPY)
   ANLVPH = ANLV
ELSE
   ANLVPH = XXNLV
END IF
```

The amount of nitrogen in the leaves which is input (ANLVPH, kg ha^{-1}) to the subroutine TOTASN is either equal to the measured or the simulated amount of nitrogen in the leaves (XXNLV, ANLV respectively, kg ha^{-1}). Through the switch SWINPH the user can make a choice.

```
PCGT  = INTGR2(PCGT, DTGA, DELT,'PCGT', FILEI1)        (CANOPY)
```

The instantaneous assimilation rate of the whole canopy (FGROS, kg CO_2 ha^{-1} h^{-1}) is calculated in ASSIMN, which in return is used in TOTASN to calculate the daily total gross assimilation (DTGA, kg CO_2 ha^{-1} d^{-1}). Integration of DTGA over time gives the total photosynthesis since start of simulation (PCGT, kg ha^{-1}). PCGT is initialized at zero.

2.4.2 Dry matter partitioning (DMPART)

```
FSH = LINT (FSHTB, ILFSH, DVS)
FLV = LINT (FLVTB, ILFLV, DVS)
FST = LINT (FSTTB, ILFST, DVS)
FSO = LINT (FSOTB, ILFSO, DVS)
FRT = 1.-FSH
```

Example of user input:

```
FSTTB  = 0.00,0.53,
         0.48,0.53,0.62,0.52,0.69,0.55,0.77,0.59,
         0.84,0.68,0.92,0.79,1.00,0.16,1.38,0.00,
         1.82,0.00,2.10,0.00
FLVTB  = 0.00,0.47,
         0.48,0.47,0.62,0.48,0.69,0.45,0.77,0.41,
         0.84,0.32,0.92,0.21,1.00,0.12,1.38,0.00,
         1.82,0.00,2.10,0.00
FSHTB  = 0.00,0.70,
         0.48,0.70,0.62,0.88,0.69,0.89,0.77,0.87,
```

```
              0.84,0.89,0.92,0.90,1.00,0.92,1.38,1.00,
              1.82,1.00,2.10,0.00
FSOTB       = 0.00,0.00,
              0.48,0.00,0.62,0.00,0.69,0.00,0.77,0.00,
              0.84,0.00,0.92,0.00,1.00,0.72,1.38,1.00,
              1.82,1.00,2.10,1.00
```

The daily dry matter increment (GCR, kg ha^{-1} d^{-1}) is partitioned over leaves, roots, stems and later on to the storage organs. This partitioning is described by dimensionless factors (FSH, FRT, FLV, FST, FSO) as a function of development stage (DVS). First a separation is made between the roots (FRT) and the shoots (FSH). Then the shoot fraction is partitioned over the leaves (FLV), stems (FST), and the storage organs (FSO). For rice the largest share of dry matter is initially attributed to the leaves and the roots, then to the stems and at the end of the growing period to the storage organs (Figure 2.1). Partitioning tables (FSHTB, FLVTB, FSTTB, FSOTB) are derived from data sampled at periodic harvests. Appendix 3 gives more information about the determination of the partitioning tables.

2.4.3 Maintenance and growth respiration (RESPIR)

Within total respiration of a crop two subprocesses are distinguished: maintenance respiration and growth respiration. Maintenance respiration provides the energy for

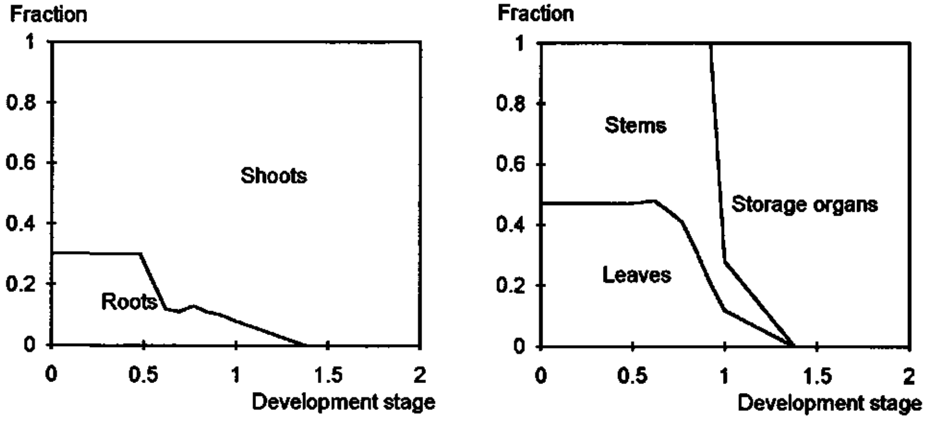

Figure 2.1 Cumulative dry matter partitioning to roots and shoots as a function of development stage (A) and cumulative dry matter partitioning to leaves, stems and storage organs as a function of development stage (B). Data derived from the 300 kg treatment of the experiment carried at TNAU-TNRRI, India, wet season 1988-1989.

maintaining existing biomass. Growth respiration is the energy requirement for production of new dry matter.
The following calculations are involved in the calculation of the maintenance respiration:

```
FNLV   = ANLV/(WLVG+TINY)
FNST   = ANST/(WSTS+TINY)
FNRT   = ANRT/(WRTL+TINY)
ACTLV  = (FNLV-RFNLV)/(NMAXLX-RFNLV)
ACTST  = (FNST-RFNST)/(NMAXSX-RFNST)
ACTRT  = (FNRT-RFNRT)/(NMAXRX-RFNRT)
TEFF   = Q10**((TAV-TREF)/10.)
```

```
RFNLV  = 0.005; RFNST  = 0.002; RFNRT  = 0.002
NMAXLX = 0.06 ; NMAXSX = 0.03 ; NMAXRX = 0.034
TREF   = 25.0 ; Q10    = 2.0
```

The maintenance respiration consists of three components: maintenance of concentration differences across membranes, maintenance of proteins and metabolic activity (Penning de Vries et al., 1989). The first two components are expressed in the maintenance respiration rates of the plant organs. These rates are determined by the weights of the organs, temperature, the maintenance respiration coefficients, and the activity of the organs. In general, the more active tissue and the higher the nitrogen concentration, the higher the rate of maintenance respiration (Penning de Vries et al., 1989). In the model the nitrogen concentration determines the activity of the tissue. The activity coefficients are based on the protein content of the organs (FNLV, FNST, FNRT). These fractions are the ratio of total amount of nitrogen in the plant organ (ANLV, ANST, ANRT, kg ha^{-1}) to the weight of the plant organ (WLVG, WSTS, WRTL, kg ha^{-1}). TINY is a very small value (0.0001), included to prevent division by zero. The 'active' fraction of nitrogen is equal to the difference between the actual fraction (FNLV, FNST, FNRT) and the residual fraction of nitrogen (RFNLV, RFNST, RFNRT) in the plant organ. The activity coefficient (ACTLV, ACTST, ACTRT) is the ratio of this 'active' fraction to the potential nitrogen fraction (NMAXLX, NMAXSX, NMAXRX) in the plant organ, corrected again for residual nitrogen. For an activity coefficient of 1.0, the potential respiration rate is reached.
Maintenance respiration will increase with a rising temperature. This effect of temperature on the maintenance respiration rate is named TEFF and is characterised by a Q_{10} value of 2 (Penning de Vries et al., 1989). The maintenance respiration rate is doubled when the temperature rises 10 K. The reference temperature (TREF, °C) for the relative temperature effect is set at 25 °C.

```
RMLV   = WLVG*MAINLV*(1.+ACTLV)/2.*TEFF
RMST   = WSTS*MAINST*(1.+ACTST)/2.*TEFF
RMRT   = WRTL*MAINRT*(1.+ACTRT)/2.*TEFF
```

```
RMSO   = WSO *MAINSO*TEFF
RMCR   = RMLV+RMST+RMSO+RMRT
RMCO2 = 44./30.*RMCR

MAINLV = 0.02 ; MAINST = 0.015; MAINSO = 0.003; MAINRT = 0.01
```

Maintenance requirements differ per plant organ and are proportional to the weights of the plant organs. These requirements are expressed in the maintenance coefficients (MAINLV, MAINST, MAINRT, MAINSO, kg CH_2O kg^{-1} dry matter d^{-1}). The maintenance coefficients used are specific for rice and represent the potential requirements. The maintenance respiration rates (RMLV, RMST, RMRT, kg CH_2O ha^{-1} d^{-1}) are calculated from the weights of the organs (WLVG, WSTS, WRTL, kg ha^{-1} d^{-1}), the maintenance coefficients (MAINLV, MAINST, MAINRT), the activity coefficients (ACTLV, ACTST, ACTRT) and the temperature effect TEFF. To keep the maintenance respiration rates at at least half of the potential maintenance respiration in situations with low nitrogen contents a division by 2 is introduced. For the calculation of the RMSO (kg CH_2O ha^{-1} d^{-1}) no activity coefficient is included. This rate is only dependent on the temperature and the requirements of the tissue.
The total maintenance respiration rate (RMCR, kg CH_2O ha^{-1} d^{-1}) of the crop is the sum of the individual respiration rates of the plant organs. Expressed in kg CO_2 ha^{-1} d^{-1}, the total respiration rate is named RMCCO2, and is equal to the RMCR converted with the factor 44./30..

Growth respiration rate is calculated as follows:

```
CO2RT  = 44./12. * (CRGRT *12./30. - FCRT)
CO2LV  = 44./12. * (CRGLV *12./30. - FCLV)
CO2ST  = 44./12. * (CRGST *12./30. - FCST)
CO2STR = 44./12. * (CRGSTR*12./30. - FCSTR)
CO2SO  = 44./12. * (CRGSO *12./30. - FCSO)

RGCR   = GRT*CO2RT + GLV*CO2LV + GSTS*CO2ST + GSO*CO2SO +
$          GSTR*CO2STR

CRGLV  = 1.326; CRGST  = 1.326; CRGRT  = 1.326
CRGSO  = 1.462; CRGSTR = 1.111
FCLV   = 0.419; FCST   = 0.444; FCSO   = 0.487
FCRT   = 0.431; FCSTR  = 0.444
```

Some of the carbohydrates required for dry matter growth disappear via growth respiration in the form of CO_2. The rest is converted into structural dry material. The fraction carbon, named FC(LV, ST, RT, STR, SO), express the amount of carbon remaining in the dry mass of plant organs. The parameters CRG(LV, ST, RT, STR, SO, kg CH_2O

(kg dry matter)$^{-1}$) represent the carbohydrate requirements of the plant organs for dry matter growth. The values of the carbohydrate requirements depend on the chemical composition of the tissue. The values used here are specific for rice (Penning de Vries et al., 1989). The growth respiration of a plant organ (CO2LV, CO2RT, CO2ST, CO2SO, CO2STR, kg CO_2 (kg dry matter)$^{-1}$) is calculated as the difference between the carbon requirement and the remaining carbon in the structural material. Because the requirements are expressed kg carbohydrates (CH_2O) per kg dry matter a conversion to carbon is needed, using the factor 12./30.(molecular weights). Growth respiration of the plant organs is expressed in kg CO_2 per kg dry matter and therefore a second conversion from carbon to CO_2 is needed (multiplication with the molecular weights: 44./12.). The growth respiration rate of the crop (RGCR, kg CO_2 ha^{-1} d^{-1}) is the sum of the growth respiration of the plant organs multiplied by the growth rate of the individual plant organs (GLV, GSTS, GRT, GSO, GSTR, kg dry matter ha^{-1} d^{-1}).

```
RCRT = INTGR2 (RCRT , RMCCO2 + RGCR, DELT,'RCRT', FILEI1)
```

Integration over time of the maintenance respiration and the growth respiration gives the total respiration (RCRT) expressed in kg CO_2 ha^{-1}.

```
 FCCR   = FSH* (FLV*FCLV + FST*(1.-FSTR)*FCST + FSO*FCSO +
$           FCSTR*FST*FSTR) + FRT*FCRT
```

The fraction carbon of total dry mass in the crop is the weighted average of the fractions of carbon in the plant organs with the dry matter allocation over the organs.

2.4.4 Growth of the crop (GROWTH)

```
 CRGCR = FSH*(CRGLV*FLV  + CRGST*FST*(1.-FSTR) +
&        CRGSTR*FSTR*FST + CRGSO*FSO) + CRGRT*FRT
```

The carbohydrate requirement for crop growth (CRGCR, kg CH_2O (kg dry matter)$^{-1}$), depends on the chemical composition of the newly produced dry matter. CRGCR is therefore obtained by weighing the carbohydrate requirements of the individual plant organs (CRG(LV, ST, RT, STR, SO), kg CH_2O (kg dry matter)$^{-1}$) with the partitioning factors, which define the allocation of dry matter to the plant organs.

```
IF (FST.LT.0.01) THEN
   LSTR = WSTR/TCLSTR
ELSE
   LSTR = 0.
END IF
```

```
GCR    = ((DTGA*30./44.)-RMCR+(LSTR*FCSTR*30./12.))/CRGCR
TCLSTR = 10.
FCSTR  = 0.444
```

The growth rate of the crop (GCR, kg dry matter ha^{-1} d^{-1}) is calculated from the total amount of carbohydrates available for growth, and the carbohydrate requirement CRGCR. Two sources contribute to the pool of available carbohydrates: (a) daily gross photosynthesis (DTGA, kg CO_2 ha^{-1} d^{-1}), after correction for maintenance respiration (RMCR, kg CH_2O ha^{-1} d^{-1}) and (b) amount of translocatable stem reserves, expressed in the mobilisation rate of stem reserves (LSTR, kg ha^{-1} d^{-1}). Since the growth rate is expressed in kg CH_2O the gross photosynthesis is converted from kg CO_2 to kg CH_2O by multiplying with the ratio of molecular weights (30./44.). The amount of carbohydrates released by remobilisation is calculated from the amount of carbon (LSTR * FCSTR) and the conversion factor 30./12. (carbon to carbohydrates).
The carbohydrate reserves (WSTR, kg ha^{-1}) are stored in the stems. The reserves become available for translocation to the grains when the partitioning to the stems (FST) ceases. This will usually coincide with the time of flowering. The loss rate of stem reserves is calculated by dividing the weights of the stem reserves with a time coefficient (TCLSTR, d^{-1}), which is set at 10 days.

```
NMINL = LINT (NMINLT, ILNMNL, DVS)
NMINLT = 0.,0.025 ,  1.0,0.012 ,  2.1,0.007
CALL SLLOSS(DVSG2,DVS,FNLV,NMINL,RDR,LAI,LAIREF,
&           WLVG,WRTL,LLV,LRT)
```

The loss of leaves and roots depends on the fraction of nitrogen in the leaves. The loss rates of leaves and roots (LLV, LRT, kg ha^{-1} d^{-1}) are computed in the subroutine SLOSS (described later in this section).

```
GRT  = GCR * FRT
GLV  = GCR * FSH * FLV
GSTS = GCR * FSH * FST * (1.-FSTR)
GSH  = GCR * FSH
GSO  = MIN ((GCR * FSH * FSO), GSOM)
IF ((FSO*GSH).LT.GSOM) THEN
   GSTREX = 0.
ELSE
   GSTREX = (FSO*GSH)-GSOM
END IF
GSTR = GCR * FSH * FST * FSTR + GSTREX
```

The growth rates of the plant organs (GRT, GLV, GSTS, GSH, GSO, GSRT, kg ha^{-1} d^{-1}) are calculated from the daily total growth rate of the crop (GCR, kg ha^{-1} d^{-1}) and the dry matter partitioning coefficients (FSH, FRT, FST, FLV, FSTR, FSO). First the daily growth is partitioned over the root and the shoot. The dry matter which is allocated to the shoot is partitioned over the leaves, stems and the storage organs. The growth rate of the stem (GSTS) does not include the dry matter which is stored in the form of stem reserves, FSTR. The input variable FSTR represents the fraction of the dry matter allocated to the stems, which is stored as reserves in normal (no sink limitations) situations. This fraction can be calculated from the difference between the maximum measured weight of stems and the weight of the stems at harvest divided by the maximum measured weight of the stems (see also Appendix 3). If such 'normal' FSTR value is used to simulate cases where the maximum growth rate of the storage organs (GSOM, kg ha^{-1} d^{-1}) limits the storage of carbohydrates in grains, an extra term GSTREX (kg ha^{-1} d^{-1}) is introduced to define the growth of stem reserves. The growth rate of the reserves is named GSTR (kg ha^{-1} d^{-1}). GSTR represents the dry matter stored directly in stems, and the dry matter stored additionally in stems as a result of limited sink size, GSOM.

```
WLVG = INTGR2 (WLVG, GLV - LLV,   DELT, 'WLVG', FILEI1)
WLVD = INTGR2 (WLVD, LLV  ,       DELT, 'WLVD', FILEI1)
WSTS = INTGR2 (WSTS, GSTS,        DELT, 'WSTS', FILEI1)
WSTR = INTGR2 (WSTR, GSTR - LSTR, DELT, 'WSTR', FILEI1)
WSO  = INTGR2 (WSO,  GSO  ,       DELT, 'WSO ', FILEI1)
WRTL = INTGR2 (WRTL, GRT-LRT  ,   DELT, 'WRTL', FILEI1)
WRTD = INTGR2 (WRTD, LRT,         DELT, 'WRTD', FILEI1)
```

The weights of the plant organs (WLVG, WLVD, WSTS, WSTR, WSO, WRTL, WRTD, kg ha^{-1}) are updated daily by integration of the growth and loss rates over time. Weights of the green leaves (WLVG), stems (WSTS) and live roots (WRTL) are initialized as non-zero input values. The other integrations are initialized at zero.

```
WSTT = WSTS + WSTR
WSHG = WLVG + WSTS  + WSO  + WSTR
WSHT = WLVG + WSTS  + WSO  + WSTR + WLVD
WCR  = WSHG + WRTL
WRR  = WSO * GPR / GMC
HI   = WSO * GPR / WCR

GPR  = 0.90
GMC  = 0.86
```

Other variables are calculated from the weights, such as total weight of the shoot (WSHG (green shoot), WSHT (total)), total weight of the crop (WCR, kg ha^{-1}) total weight of the stems (WSTT, kg ha^{-1}), including the stem reserves. The weight of the rough rice (WRR, kg ha^{-1}) is the weight of the storage organs corrected for the fraction of grain biomass in the total storage organs (0.90) and the grain moisture content (14%). The harvest index (HI) is the weight of grain dry matter (WRR) divided by the total crop weight (WCR).

Loss of leaves and roots (SLOSS)

```
IF (FNLV.LT.1.1*NMINL) THEN
   RDRL = RDR * 5.
ELSE IF (FNLV.GT.1.5*NMINL) THEN
   RDRL = RDR
ELSE
   RDRL = (5.-(FNLV-1.1*NMINL)/(0.4*NMINL)*4.)*RDR
END IF
RLRLV   = (LAI/LAIREF)*RDRL
RLRRT   = RLRLV

RDR    = 0.01
LAIREF = 5.
```

The relative loss rates of leaves (RLRLV, d^{-1}) and roots (RLRRT, d^{-1}) depend on the nitrogen fraction in the leaves. When the nitrogen fraction in the leaves is very low, between the minimum fraction (NMINL) and 1.1 times this fraction, the relative death rate (intermediate variable RDRL, d^{-1}) increases to 5 times the current relative death rate (RDR, d^{-1}). At fractions of more than one and a half times the minimum nitrogen fraction the current relative death rate of 0.01 d^{-1} is applied. A linear decrease of RDRL with increasing nitrogen fraction is applied where FNLV has a value between 1.1 and 1.5 times NMINL.

The intermediate variable RDRL is the relative death rate at a reference leaf area index of 5. The relative loss of leaves (RLRLV) for the actual LAI is derived by multiplying with the ratio of the actual LAI to the reference leaf area index (LAIREF) to account for higher leaf loss rates in dense canopies. The relative loss rate of roots (RLRRT) is set equal to the relative loss rate of leaves (RLRLV). The values of all these coefficients require refinement based on field observations.

```
IF (DVS.LT.DVSG2) THEN
   LLV  = 0.
   LRT  = 0.
ELSE
   LLV  = WLVG*RLRLV
   LRT  = WRTL*RLRRT
END IF

DVSG2   = 1.15
```

Loss of leaves and roots occurs only after flowering, when the DVS is greater than 1.15 (DVSG2). The loss rates (LLV, LRT, kg ha^{-1} d^{-1}) are derived by multiplying the weight of the plant organ (WLVG, WSTS, kg ha^{-1}) with the relative death rate of that organ (RLRLV, RLRRT, d^{-1}).

2.4.5 Tiller and grain formation (SINK)

Within this module the user can choose for production with or without sink limitation. The storage capacity of panicles is determined by the number of grains per unit surface and the maximum growth rate of the grains. Through the switch SWISIN, sink limitation is activated.

```
IF (SWISIN.EQ.1) THEN
   GSOM  = 1000.
```

If SWISIN is set to 1.0, simulation will not take into account a limitation of sink size. The maximum growth rate of the storage organs (GSOM, kg ha^{-1} d^{-1}) is arbitrarily set at a high value of 1000 kg ha^{-1} d^{-1}.
When SWISIN is set to zero, sink limitation is defined as follows:

```
ELSE
   IF (DVS.GE.DVSG1.AND.DVS.LE.DVSG2) THEN
      DVSGR = 1.
   ELSE
      DVSGR = 0.
   END IF
```

The grain formation is starting at the development stage 0.95 (DVSG1) and ends at the development stage 1.15 (DVSG2). This period is indicated by the switch DVSGR, which has the value 1.0 during the grain filling period and is zero otherwise.

```
TEFG   = LINT (GGRT, ILGRT, TAV)
GFP    = 1./(1.33 * NOTNUL(DRR))
GGRMN  = WGRMX/GFP
GGRMX  = GGRMN*2.
GSOM   = NGR * GGRMX * TEFG

GGRT   = 10.,0.,15.,0.,18.,0.75,23.,1.0,27.,0.9,40.,0.0
WGRMX  = 23.5E-6
```

The maximum growth rate of the storage organs (GSOM, kg ha^{-1} d^{-1}) is determined by the maximum growth rate of one grain (GGRMX, kg d^{-1}) and the number of grains (NGR, ha^{-1}). A temperature dependence is accounted for in the factor TEFG. This factor is a function (GGRT) of the average temperature (TAV). The maximum growth rate of one grain (GGRMX) is twice the minimum growth rate of a grain (GGRMN, kg d^{-1}). This minimum growth rate is calculated from the average weight of a grain (WGRMX, kg) and a mean grain filling duration (GFP, d). This period is calculated from the development rate in the reproductive phase (DRR, d^{-1}).

```
NGRP  = GCR * CRGCR/GGRMN
NGRMX = NTI * 100.
GNGR  = DVSGR * MAX(0.,MIN(NGRP-NGR, NGRMX-NGR)/TCFG)
WGR   = WSO/(MAX(1.*NGR,1000.))

TCFG  = 3.
DVSG1 = 0.95
DVSG2 = 1.15
```

In the above lines the determination of the number of grains in a sink limited production system is described (SWISIN=0.). The potential number of grains (NGRP, ha^{-1}) is determined by the amount of carbohydrate available per day and the minimum growth rate of one grain (GGRMN, kg d^{-1}). The available amount of carbohydrates is derived by multiplying the daily growth rate (GCR, kg ha^{-1} d^{-1}) with the carbohydrate requirement of the crop for dry matter growth (CRGCR, kg kg^{-1}). The maximum number of grains in one tiller is set at 100. The total maximum number of grains (NGRMX, ha^{-1}) is therefore equal to the number of tillers (NTI, ha^{-1}) multiplied by 100. The daily growth of the grain number per hectare (GNGR, ha^{-1} d^{-1}) is the number of grains, which still can be formed, divided by the time coefficient TCFG. The number of grains to be formed are determined by the difference between the maximum (NGRMX) and actual number of grains (NGR), as long as this does not exceed the difference between the potential (NGRP) and actual number of grains (NGR). The weight of the grains is now determined by dividing the weight of the storage organs (WSO, kg ha^{-1}) by the number of grains, with a minimum value of 1000 and a maximum of NGR.

Tiller formation in sink limited production:

```
IF (DVS.GE.DVST1.AND.DVS.LE.DVST2) THEN
   DVSTF = 1.
ELSE
   DVSTF = 0.
END IF

CNTI  = LINT (CNTIT, ILCNTI, DVS)
TIL   = TILMX *  LINT (RTILT, ILRTIL, FNLV)
NTIP  = MIN (GCR*CRGCR/CNTI, PLNUM*TIL)
```

```
GNTI   = DVSTF * MAX (0.,(NTIP-NTI)/TCFT)

DVST1  = 0.30; DVST2 = 0.75
TCFT   = 15.
TILMX  = 50.
PLNUM  = 500000.
CNTIT  = 0.,5.E-6, .3,5.E-6, .75,25.E-6, 1.0,75.E-6, 2.1,75.E-6
RTILT  = 0.,0., .02,.2, .04,.6, .05,.8, .06,1., .08,1.
```

DVSTF is a switch, which 'activates' the tillering period, starting at a development stage of 0.3 (DVST1) until a development stage of 0.75 (DVST2). During this period the production rate of new tillers (GNTI, kg ha^{-1} d^{-1}) is calculated from the number of tillers that still can be formed, according the potential number of tillers (NTIP), and a the time coefficient TCFT (d). The potential number of tillers (NTIP, ha^{-1}) is limited by the amount of available carbohydrates (GCR*CRGCR). NTIP is determined by the number of tillers of a plant (TIL) multiplied by the number of plants (PLNUM), as long as this does not exceed the number of tillers that can be produced with the available amount of carbohydrates. The amount of carbohydrates required to initiate and maintain a tiller (CNTI, kg ha^{-1} d^{-1}) is a function of the development stage, and read from the function table named CNTIT. The function shows that the older the plants the more carbohydrates are required to initiate and maintain a tiller. Older plants have a larger initial tiller size, and more carbohydrates are required to maintain these tillers (Penning de Vries et al., 1989). The number of tillers per plants depends on the fraction of nitrogen in the leaf. The maximum number of tillers per plant (TILMX) is therefore corrected with a factor, which is a function (RTILT) of FNLV. The higher the fraction of nitrogen in the leaves (FNLV) the more tillers are formed. The maximum number is reached when the leaves have a nitrogen content of 6%.

```
IF (DVS.GE.DVST1.AND.DVS.LE.(DVST2+0.15)) THEN
   DVSTD = 1.
ELSE
   DVSTD = 0.
END IF

LNTI   = DVSTD * MAX (0.,(NTI-NTIP)/TCDT)

TCDT = 10.0
```

The loss rate of tillers is calculated during the tillering period and 0.15 DVS beyond the end of the tillering period. DVSTD is the switch used to activate the calculation in this period. It has always a value of zero, except during this loss period, where it has a value of 1. When NTI > NTIP, the loss rate (LNTI, ha^{-1} d^{-1}) is proportional to the difference between NTIP (ha^{-1}) and NTI (d^{-1}). A time coefficient for loss of tillers, named TCDT (d), is used.

```
NTI  = INTGR2 (PLNUM, GNTI-LNTI  , DELT,'NTI ', FILEI1)
NGR  = INTGR2 (NGR  , GNGR       , DELT,'NGR ', FILEI1)
```

The accumulated number of tillers (NTI, ha^{-1}) and grains (NGR, ha^{-1}) is derived by integration of the growth rates of the tillers (GNTI, LNTI, ha^{-1} d^{-1}) and grains (GNGR, ha^{-1} d^{-1}) over time. The initial number of tillers is equal to the number of plants (PLNUM).

2.4.6 Crop nitrogen demand (NDEMND)

The module NDEMND computes the nitrogen demand of the plant organs. The nitrogen demands of the leaves, stems and roots (NDEML, NDEMS, NDEMR, respectively) are calculated from the difference between the potential and actual amount of nitrogen in the existing and new biomass of the plant organs.

```
NMAXL = LINT(NMAXLT, ILNMXL, DVS)
NMAXS = LSNR * NMAXL
NMAXR = LRNR * NMAXL

NMAXLT = 0.00, 0.06, 0.40,0.05, 0.70,0.04, 1.00,0.03,
         1.50,0.025, 2.00,0.02, 2.10,0.02
LSNR = 0.50, LRNR = 0.37
```

The potential amount of nitrogen in the plant organs is determined by the maximum fraction of nitrogen in the plant organs (NMAXL, NMAXS, NMAXR, kg kg^{-1}). The maximum as well as the minimum nitrogen fraction in the leaves changes with the development stage (Figure 2.2). The highest value is found at the beginning of the growing period. Experimental data from different locations, covering various varieties and nitrogen treatments, show a relationship between the maximum nitrogen fractions in stems and roots and the maximum nitrogen fraction in the leaves (Figure 2.3 and 2.4).

```
IF (SWIFLO.EQ.0.AND.DVS.GT.1.0) THEN
   SWIFLO = 1
   ANCRF  = ANCR
END IF

NMINSO = LINT (NMNSOT, ILNNSO, ANCRF)

NMNSOT = 0.0,0.0075, 50.0,0.0075, 150.0,0.015, 250.0,0.015
```

The minimum fraction of nitrogen in the storage organs is determined by the amount of nitrogen in the crop at the moment of flowering (ANCRF, kg ha^{-1}). After flowering part of this nitrogen is reallocated from the leaves, stems and roots to the storage organs.

Figure 2.5 shows the relationship between the nitrogen fraction in the storage organs at harvest and ANCRF. These data include only experiments and treatments where no post-flowering nitrogen uptake occurred. The function NMNSOT is based on this relationship and dictates a minimum nitrogen content of the panicles. Post-flowering nitrogen uptake may augment this base value, up to a maximum of 0.0175 (NMAXSO).

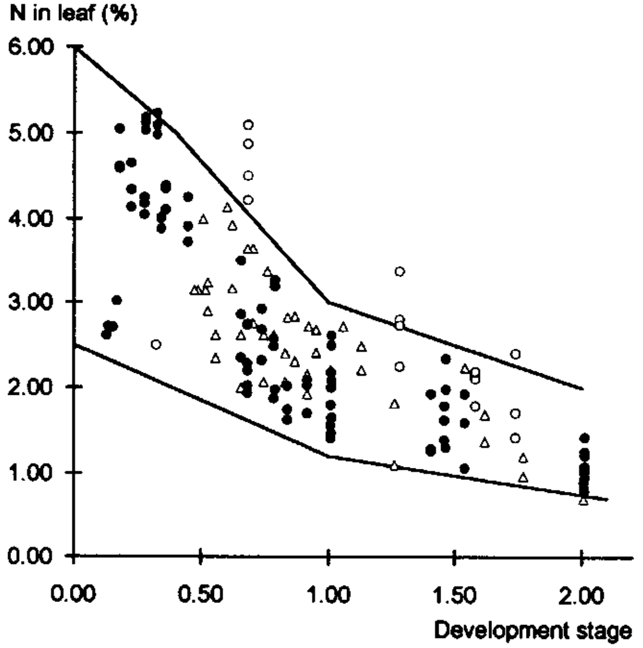

Figure 2.2 Mass fraction (%) of nitrogen in leaves as a function of development stage. Data derived from experiments carried out at IRRI (Philippines, wet season 1991 & dry season 1992, ●), CRRI (India, dry season 1990, ○) and at TNAU-TNRRI (India, wet season 1988-1989, Δ). Data include several nitrogen treatments. The solid lines represent the minimum and maximum nitrogen content of the leaves as defined in the tables NMINLT and NMAXLT.

```
NDEML  = (NMAXL*(WLVG + GLV) - ANLV)/TCNA
NDEMS  = (NMAXS*(WSTS + GSTS)- ANST)/TCNA
NDEMR  = (NMAXR*(WRTL + GRT) - ANRT)/TCNA

TCNA = 1.
```

The nitrogen demands of the plant organs (NDEML, NDEMS, NDEMR, kg ha^{-1} d^{-1}) are calculated from the difference between the potential and actual amount of nitrogen in the plant organ, divided by the time coefficient for nitrogen acquisition (TCNA, d). The potential amount of nitrogen consists of the maximal possible amount of nitrogen (NMAXL, NMAXS, NMAXR, kg kg^{-1}) in existing (WLVG, WSTS, WRTL, kg ha^{-1}) and new produced biomass (GLV, GSTS, GRT, kg ha^{-1} d^{-1}). It is assumed that the time coefficient TCNA is 1 day. Further work should provide more insight in the range of possible values for TCNA.

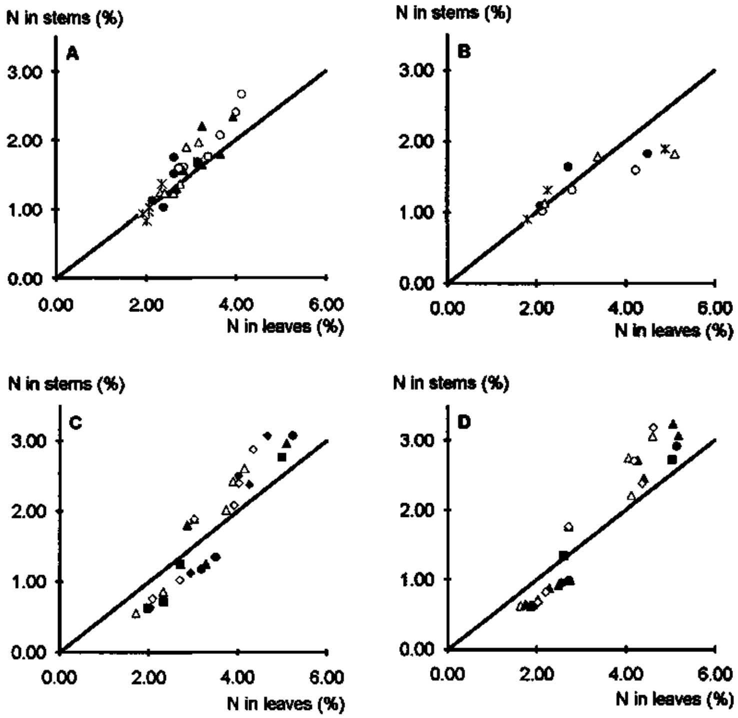

Figure 2.3 Mass fraction (%) of nitrogen in stems as a function of the nitrogen fractions in the leaves (%). Data derived from experiments carried out at: (A) TNAU-TNRRI, India, wet season 1988-1989; (B) CRRI, India, dry season 1990; (C) & (D) IRRI, Philippines, wet season 1991 & dry season 1992. The symbols imply different nitrogen treatments. The solid lines represent the relation (LSNR = 0.50) used in the simulation, see Section 4.2.

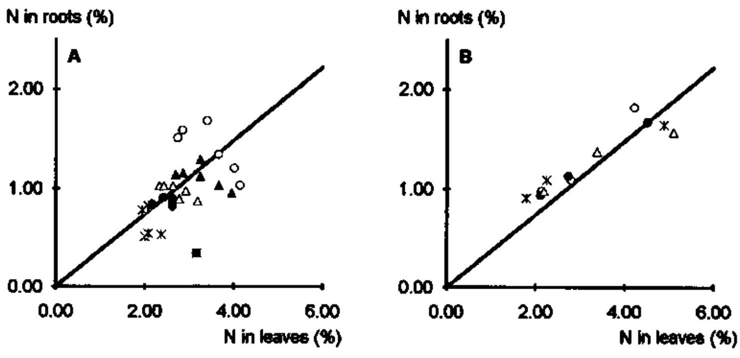

Figure 2.4 Mass fraction (%) of nitrogen in roots as a function of the nitrogen fractions in the leaves (%). Data derived from experiments carried out at: (A) TNAU-TNRRI, India, wet season 1988-1989; (B) CRRI, India, dry season 1990. The symbols imply different nitrogen treatments. The solid lines represent the relation (LRNR = 0.37) used in the simulation, see Section 4.2.

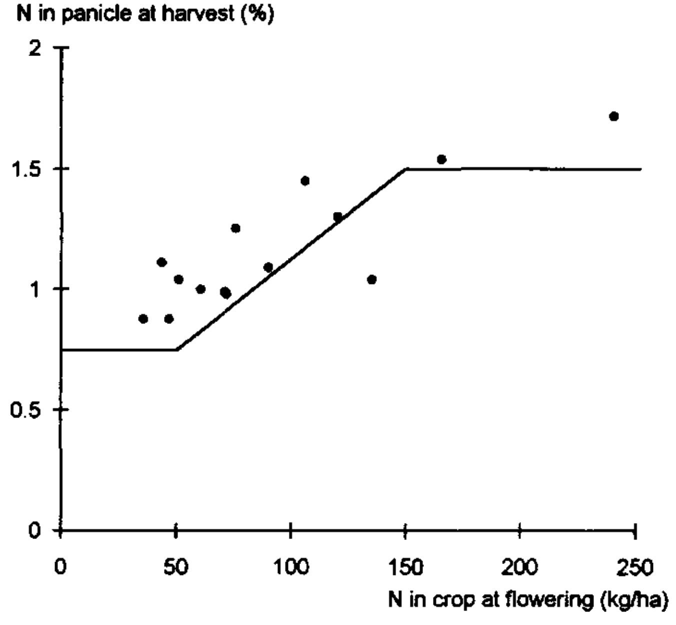

Figure 2.5 Nitrogen in the panicle (%) at harvest as function of the amount of nitrogen in the crop (kg ha^{-1}) at flowering. The dots (●) represent data from experiments carried out at IRRI (Philippines, wet season 1991), CRRI (India, dry season 1990) and at TNAU-TNRRI (India, wet season 1988-1989). Data include several nitrogen treatments. The solid lines represent the relation (NMSOT) used in the simulation, see Section 4.2.

```
IF(WSO.LT.10.) THEN
   NDEMG = 0.
   NDEMGX= 0.
ELSE
   NDEMG = NMINSO*GSO
   NDEMGX= NMAXSO*GSO
ENDIF
NMAXSO = 0.0175
```

The minimum demand of the storage organs (NDEMG, kg ha^{-1} d^{-1}) is determined by the minimum fraction of nitrogen in the storage organs (NMINSO, kg kg^{-1}) and the growth rate of the storage organs (GSO, kg $ha^{-1}d^{-1}$). The maximum demand (NDEMGX, kg ha^{-1} d^{-1}) is found by multiplying the maximum fraction of nitrogen in the storage organs (NMAXSO, kg kg^{-1}) with the growth rate.

```
NDEMV  = NDEML + NDEMS + NDEMR
NDEMT  = NDEMV + NDEMG
```

The total demand (NDEMT, kg ha^{-1} d^{-1}) is the sum of the separate demands of the various plant organs.

2.4.7 Nitrogen uptake (NUPTK)

```
NMAXL = LINT(NMAXLT, ILNMXL, DVS)
NMAXS = LSNR * NMAXL
NMAXR = LRNR * NMAXL

IF (SWINUP.EQ.1) THEN
   CALL SUNUPT(TIME,DOYS,ANLCR,NS,NA,NTOTMT,DNOST,
$               DNAPT,CRDN,F1,NUPT,DNAP,DNOS,NTOTM)
ELSE IF (SWINUP.EQ.2) THEN
   NUPT = NDEMV + GLV*NMAXL + GSTS*NMAXS + GRT*NMAXR
ENDIF

LSNR = 0.50, LRNR = 0.37
NMAXLT = 0., 0.06, 0.4,0.05,  0.7,0.040, 1.0,0.030,
         1.50,0.025, 2.0,0.020, 2.1,0.020
```

The nitrogen uptake rate (NUPT, kg ha^{-1} d^{-1}) is either obtained from interpolation between measured values of total crop nitrogen uptake (nitrogen limited production), or is taken equal to crop nitrogen demand (potential production). The choice between these two options is made through the switch SWINUP. For nitrogen limited production (SWINUP = 1) the daily nitrogen uptake is calculated by non linear interpolation from the amounts of nitrogen in the crop, which are observed in live biomass at sampling dates. This interpolation is performed by the subroutine SUNUPT. For potential production the switch option (SWINUP = 2) is used. In this case a maximum nitrogen concentration in the plant organs is maintained, corresponding to development stage. The nitrogen uptake rate (NUPT) is the sum of the nitrogen demand of existing biomass (NDEMV, kg ha^{-1} d^{-1}) and the demand associated with the new growth of the leaves, stems and roots. This demand of new biomass is calculated from the growth rate of the plant organ (GLV, GSTS, GRT, kg ha^{-1} d^{-1}) and the maximum nitrogen fraction in that organ (NMAXL, NMAXS, NMAXR, kg kg^{-1}).

```
NUPTOT = INTGR2 (NUPTOT,NUPT      ,    DELT,'NUPTOT', FILEI1)
ANTOT  = INTGR2 (ANTOT ,NUPT      ,    DELT,'ANTOT' , FILEI1)
NUPNEG = INTGR2 (NUPNEG,MIN(0.,NUPT), DELT,'NUPNEG', FILEI1)
```

The total nitrogen uptake accumulated since the start of the simulation (NUPTOT, kg ha^{-1}) is obtained by integration of NUPT. The total amount of nitrogen in the crop (live and dead material, ANTOT, kg ha^{-1}) is larger by an amount ANTOTI, which is the initial value of nitrogen (kg ha^{-1}) contained in the initial crop biomass.

NUPNEG (kg ha^{-1}) is an integral variable used to keep track of 'negative uptake'. It represents, of course, no real physiological process, but is a numerical 'counter' that can be used to see whether losses through leaf and root dying are properly parameterized. NUPNEG is equal to zero or smaller than zero. Non-zero values of NUPNEG imply that in reality losses were higher than simulated. This signal function is useful when measured N uptake is used as a forced function.

Daily nitrogen uptake according to a forcing function (SUNUPT)

The subroutine SUNUPT calculates, by non-linear interpolation, the daily nitrogen uptake from amounts of nitrogen in live biomass observed at sampling dates.

Example of user input:

```
NS     = 11
DNOST  = 344.,362.,369.,376.,383.,390.,397.,
         407.,425.,433.,441.
NTOTMT= 2.18,13.90,16.98,28.14,37.87,41.69,
         43.51,41.78,52.48,54.87,54.87
```

The observed amounts of nitrogen are tabulated input, named NTOTMT (kg ha^{-1}). This table contains measured cumulative uptake, at the sampling days. The sampling days are specified in the table DNOST. The parameter NS represents the number of sampling days, and is used as a counter. The target amount of nitrogen in the crop (NTOTM) and the target sampling day (DNOS) are defined in the subroutine. An explanation for defining the input tables and parameters is given in Appendix 3.

The procedure to calculate daily nitrogen uptake includes two steps: (1) identification of the nearest next sampling date ('target' date), and identification of crop nitrogen content on that nearest sampling date ('target' sampling); (2) determination of the daily uptake from the time lapse separating the 'current simulation date' from that target date, and the amount of nitrogen still to be taken up before reaching the target date and corresponding target uptake.

Step (1):

```
      DATEX=TIME
      DO 10 I=1,NS
         IF(DATEX.GT.DNOST(I)) THEN
            CONTINUE
         ELSE
            NTOTM  = NTOTMT(I)
            NTOTMN = NTOTMT(I+1)
            DNOS   = DNOST(I)
            DNOSN  = DNOST(I+1)
            GOTO 20
         ENDIF
10    CONTINUE
20    CONTINUE
```

This procedure assigns for every 'simulation day' (DATEX) the proper target values of NTOTM and DNOS, tabulated in NTOTMT and DNOST, respectively.

First part of step (2):

```
      DO 30 I=1,NA
         IF(ABS(DATEX-DOYS).LT.0.1) THEN
            DNAP=DOYS
            DSLA=1.
            GOTO 40
         ELSEIF(DATEX.GT.DNAPT(I)) THEN
            CONTINUE
         ELSE
            DNAP=DNAPT(I-1)
            DSLA=DATEX-DNAP
            GOTO 40
         ENDIF
30    CONTINUE
40    CONTINUE
      IF(DSLA.LE.CRDN) THEN
         F1 = 1.* SQRT(CRDN/MAX(1.,DSLA))
      ELSE
         F1 = 1.
      ENDIF
      CRDN=5.
```

Example of user input:

```
      NA    = 6
      DNAPT = 306.,344.,370.,392.,406.,600.
```

The nitrogen uptake rate often shows a sharp increase just after nitrogen application. To account for this effect in simulation, the number of days passed since the last nitrogen application should be known. The nitrogen application dates are therefore needed as input. These dates are tabulated input, named DNAPT (d). The number of split nitrogen applications is given as the parameter NA. In the DO-loop the most recent nitrogen application day, which is passed already, is defined (DNAP). DSLA is the variable representing the number of days passed since this application day. During a critical period of CRDN days (here arbitrarily set at 5 days) after application the nitrogen uptake rate is higher than the average uptake rate between two sampling dates. Thereafter, uptake drops below the average rate (Figure 2.6 and 2.7). This is simulated with the help of the shape factor F1. As long as DSLA is less than CRDN, F1 is calculated as the square root of the ratio of CRDN to DSLA. The more days are passed since the application, F1 approaches the value of 1. If the critical number of 5 days is passed F1 is set to 1.

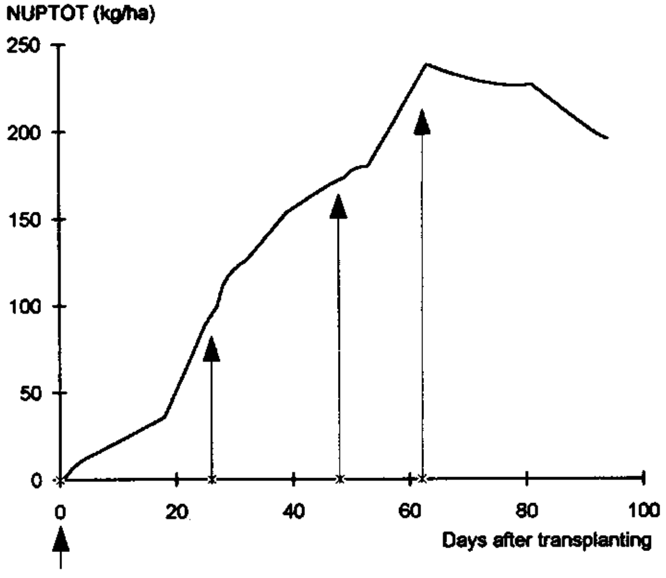

Figure 2.6 Cumulative nitrogen uptake (NUPTOT, kg ha^{-1}) calculated from observations via non-linear interpolation by the routine with CRDN = 5 days. Data from TNAU-TNRRI (India, wet season 1988-1989) the 300 kg N treatment. The arrows indicate the N application dates.

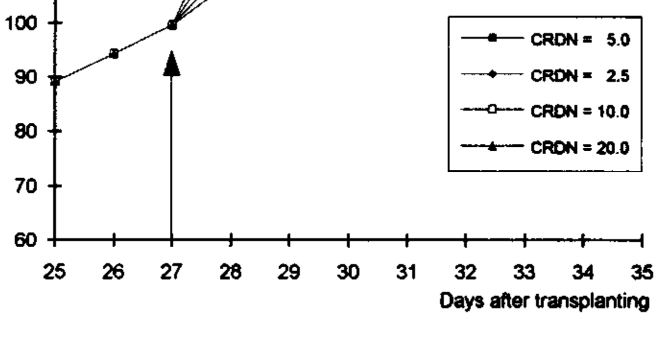

Figure 2.7 Cumulative nitrogen uptake (NUPTOT, kg ha^{-1}) as function of days after transplanting, interpolated with different values of CRDN, for TNAU-TNRRI (India, wet season 1988-1989) the 300 kg treatment. The arrow indicates the application date.

The procedure then continues as follows:

```
      IF(DATEX.GE.DNOST(NS)) THEN
         NUPT=0.
      ELSE
         IF (NINT(DATEX).EQ.NINT(DNOS)) THEN
            IF (NTOTMN.GT.ANLCR)  THEN
               NUPT=MIN(NTOTMN-ANLCR,
     $         F1*(NTOTMN-ANLCR)/NOTNUL(DNOSN-DATEX))
            ELSE
               NUPT=MAX(NTOTMN-ANLCR,
     $          (NTOTMN-ANLCR)/NOTNUL(DNOSN-DATEX))
            ENDIF
         ELSE
            IF (NTOTM.GT.ANLCR) THEN
               NUPT=MIN(NTOTM-ANLCR,
     $         F1*(NTOTM-ANLCR)/NOTNUL(DNOS-DATEX))
            ELSE
               NUPT=MAX(NTOTM-ANLCR,
     $          (NTOTM-ANLCR)/NOTNUL(DNOSN-DATEX))
            ENDIF
         ENDIF
      ENDIF
```

The nitrogen uptake rate is calculated as the difference between the current simulated amount of nitrogen in the live crop (ANLCR, kg ha^{-1}) and the target amount of nitrogen measured (NTOTM, kg ha^{-1}) on the nearest future sampling date, divided by the period between the current simulation day (DATEX) and the target sampling day (DNOS). Some variations are applied.

In the situation where NTOTM is greater than ANLCR, the uptake rate is positive and the coefficient F1 determines the uptake pattern between sampling dates. NUPT can, obviously, not exceed the difference between NTOTM and ANLCR. When NTOTM is less than ANLCR a linear decrease of nitrogen in the crop is imposed. The shape factor (F1) has no meaning during time intervals when the total amount of crop nitrogen is decreasing and is therefore not used. On the target sampling day itself the NUPT will be calculated in the same way for the above described situations, however using already the next target amounts of nitrogen (NTOTMN) and target sampling day (DNOSN).

To prevent division by zero the function NOTNUL is introduced. If the difference between DATEX and DNOS is less than or equal to zero, NOTNUL will attain the value 1. Otherwise it will have the value of zero. On the last sampling day (DNOS(NS)), which coincides with the harvest day, NUPT will be zero.

2.4.8 Nitrogen in the crop (NCROP)

In this module the partitioning and translocation of nitrogen to and from the plant organs are defined. In addition, some extra variables are determined:

```
NMAXL  = LINT(NMAXLT, ILNMXL, DVS)
NMAXS  = LSNR * NMAXL
NMAXR  = LRNR * NMAXL

NMINL  = LINT(NMINLT, ILNMNL, DVS)
NMINS  = LSNR * NMINL
NMINR  = LRNR * NMINL

FNLV   = ANLV/(WLVG+TINY)
FNST   = ANST/(WSTS+TINY)
FNRT   = ANRT/(WRTL+TINY)
FNSO   = ANSO/(WSO+TINY)

LSNR   = 0.50, LRNR = 0.37
NMAXLT = 0., 0.06, 0.4,0.05,  0.7,0.040, 1.0,0.030,
         1.50,0.025, 2.0,0.020, 2.1,0.020
NMINLT = 0.,0.025 ,  1.0,0.012 ,  2.1,0.007
```

The maximum and minimum mass fractions of nitrogen in the leaves (NMAXL, NMINL) are defined as a function of the development stage (NMAXLT, NMINLT). The maximum and minimum possible nitrogen fractions in the roots (NMAXR, NMINR) and the stems (NMAXS, NMINR) are expressed as a function of the nitrogen fraction in the leaves (see also Section 2.4.6). The actual fraction of nitrogen in the plant organs is defined as the ratio of the amount of nitrogen in the organs (ANLV, ANST, ANRT, kg ha^{-1}) to the mass of the organs (WLVG, WSTS, WRTL, WSO, kg ha^{-1}). TINY is introduced to prevent division by zero.

```
NLDLV = LLV * MAX(RFNLV,0.5*FNLV)
NLDRT = LRT * RFNRT
RFNLV  = 0.005; RFNRT  = 0.002
```

The nitrogen loss due to death of roots and leaves is related to the leaf and root loss rates (LLV, LRT, kg ha^{-1} d^{-1}). The dead root biomass has a residual nitrogen fraction in the tissue (RFNRT), which is not translocatable to other organs. Multiplication of the root loss rates with this fraction gives the nitrogen loss due to death of roots (NLDRT, kg ha^{-1} d^{-1}). For the leaves, the loss rate (LLV, kg ha^{-1} d^{-1}) is multiplied with half of the nitrogen fraction in the leaves (FNLV), as long as this is greater than the residual fraction of nitrogen in the leaves (RFNLV).

```
      CALL SNALLC(SWINUP,ANLV,ANST,ANRT,GLV,GSTS,GRT,
     $              NDEML,NDEMS,NDEMR,NUPT,NMAXL,NMAXS,NMAXR,
     $              NALV,NAST,NART,EXCESS,ANRTRE,ANSTRE,ANLVRE,AVAIL)

      CALL SNTRAN(SWINUP,ANLV,ANST,ANRT,WLVG,WSTS,WRTL,WSO,
     $              RFNLV,RFNST,RFNRT,TCNT,TEFG,NDEMG,NDEMGX,
     $              NALV,NAST,NART,EXCESS,ANRTRE,ANSTRE,ANLVRE,
     $              NTLV,NTST,NTRT,NSUPG,EXCTOG,EXCPOL)
```

The model simulates removal of nitrogen from an organ under three different conditions. (1) the total observed amount of crop nitrogen (NTOTMT) is exceeded by the current simulated value; (2) the current simulated concentration in an organ exceeds the physiological maximum at that development stage; (3) grain nitrogen demand is not fully covered by new uptake. Nitrogen translocation based on the first criterion is regarded as a nitrogen loss from the crop depending on the demand of the grains. Translocation arising from the conditions (1) and (2) is computed in the subroutine SNALLC. The translocation based on condition (3) is computed in the subroutine SNTRAN.

```
      ANSO  = INTGR2(ANSO, NSUPG, DELT,'ANSO', FILEI1)
      ANLV  = INTGR2(ANLV, NALV-ANLVRE-NTLV-NLDLV+EXCPOL, DELT,
     $                                        'ANLV', FILEI1)
      ANLD  = INTGR2(ANLD, NLDLV, DELT,'ANLD', FILEI1)
      ANST  = INTGR2(ANST, NAST-ANSTRE-NTST, DELT,'ANST', FILEI1)
      ANRT  = INTGR2(ANRT, NART-ANRTRE-NTRT-NLDRT, DELT,'ANRT', FILEI1)
      ANRD  = INTGR2(ANRD, NLDRT, DELT,'ANRD', FILEI1)

      ANCR  = ANSO+ANLV+ANLD+ANST+ANRT+ANRD
      ANLCR = ANCR-ANLD-ANRD
```

The amounts of nitrogen in the plant organs are calculated by integration of the allocation, loss and translocation rates of nitrogen to and from the organs. A more detailed description of the various rate variables follows.
The total amount of nitrogen in the living crop tissue (ANLCR, kg ha^{-1}) is the sum of the amounts of nitrogen in the plant organs. Where the nitrogen in the dead leaves and roots is included, the variable is named ANCR (kg ha^{-1}).

Nitrogen allocation to and removal from plant organs (SNALLC)

In the calculation of nitrogen allocation and removal, two options are distinguished: (1) potential production and (2) nitrogen limited production. Again the switch SWINUP is used to make a choice, which implies a calculation of rates, specific for that option. If SWINUP is equal to 1 the model simulates nitrogen limited production. Potential production is simulated if the switch is set to zero. First the allocation of nitrogen for nitrogen limited production is described.

```
POSDEM = (MAX(0.,NDEML)+MAX(0.,NDEMR)+MAX(0.,NDEMS))
NEGDEM =-(MIN(0.,NDEML)+MIN(0.,NDEMR)+MIN(0.,NDEMS))
AVAIL  = NEGDEM+NUPT
```

The allocation or removal of nitrogen to/from plant organs depends on the availability of nitrogen and the demands of the other plant organs. The variables POSDEM (kg ha^{-1} d^{-1}) and NEGDEM (kg ha^{-1} d^{-1}) represent the sum of the positive nitrogen demand (POSDEM) and nitrogen excesses (NEGDEM) in the organs. If an organ does not contain the maximum possible amount of nitrogen, the demand is considered to be positive. NEGDEM is defined as the amount of nitrogen present per organ in excess of the maximum possible amount of nitrogen at the actual development stage. This redundant nitrogen is numerically treated as a 'negative demand' and becomes available for translocation. The sum of all 'negative demands' (NEGDEM, kg ha^{-1} d^{-1}) constitutes, together with new uptake (NUPT, kg ha^{-1}), the daily pool of nitrogen available for allocation to plant organs (AVAIL, kg ha^{-1}). AVAIL can be either positive or negative. Negative values are always associated -by definition- with a net loss of total crop nitrogen (according to the imposed forcing function NTOTMT).

```
IF(AVAIL.GT.0.) THEN
   IF(NDEMR.GT.0.) NART=MIN(NDEMR,AVAIL*(NDEMR/(POSDEM+TINY)))
   IF(NDEMR.LE.0.) NART= 0.
   IF(NDEMS.GT.0.) NAST=MIN(NDEMS,AVAIL*(NDEMS/(POSDEM+TINY)))
   IF(NDEMS.LE.0.) NAST= 0.
   IF(NDEML.GT.0.) NALV=MIN(NDEML,AVAIL*(NDEML/(POSDEM+TINY)))
   IF(NDEML.LE.0.) NALV= 0.
   EXCESS = AVAIL - NART - NAST -NALV
   ANRTRX = 0.
   ANSTRX = 0.
   ANLVRX = 0.
ELSE
   NART   = 0.
   NAST   = 0.
   NALV   = 0.
   EXCESS = 0.
   ANRTRX = (ANRT/(ANLV+ANST+ANRT)) * AVAIL
   ANSTRX = (ANST/(ANLV+ANST+ANRT)) * AVAIL
   ANLVRX = (ANLV/(ANLV+ANST+ANRT)) * AVAIL
ENDIF
```

For AVAIL > 0, the nitrogen available in the pool is allocated to the plant organs with a positive demand. The rates of nitrogen allocation to each organ (NALV, NAST, NART, kg ha^{-1} d^{-1}) are proportional to the respective organ demands. The proportional demand is the organ demand (NDEML, NDEMS, NDEMR, kg ha^{-1} d^{-1}) relative to the sum of all positive demands (POSDEM, kg ha^{-1} d^{-1}). TINY is a very small value, introduced to prevent division by zero. A plant organ cannot receive more of nitrogen than allowed by its demand. What remains of the pool AVAIL after allocation is named EXCESS (kg ha^{-1} d^{-1}).

A negative value of NUPT means that the net amount of nitrogen in the crop (as prescribed by the observed forcing function NTOTMT) is decreasing. This loss is numerically expressed as a 'negative nitrogen uptake rate'. If the absolute value of NUPT is, in this case, larger than NEGDEM, the amount available for allocation (AVAIL) becomes negative. All organs, therefore, loose an extra amount of nitrogen. This is in proportion to their total nitrogen content. This removal of nitrogen in excess of NEGDEM is defined in the variables ANRTRX, ANSTRX and ANLVRX (kg ha^{-1} d^{-1}). The proportionality factors are derived by dividing the amount of nitrogen in an organ (ANLV, ANRT, ANST, kg ha^{-1}) by the sum of the amounts of nitrogen in the organs. The nitrogen allocation rates (NART, NAST, NALV) are then set to zero. When AVAIL is positive, an eventual loss of nitrogen ('negative nitrogen uptake', NUPT) from the crop is covered by the redundant nitrogen in the organs (NEGDEM). Under these conditions the variables ANRTRX, ANSTRX and ANLVRX remain zero.

```
      ANRTRE = -(MIN(0.,NDEMR) + ANRTRX)
      ANSTRE = -(MIN(0.,NDEMS) + ANSTRX)
      ANLVRE = -(MIN(0.,NDEML) + ANLVRX)
```

The total amount of nitrogen removed from the plant organs (ANRTRE, ANSTRE, ANLVRE, kg ha^{-1} d^{-1}) thus consists of the redundant nitrogen in an organ and the extra removal to realise the imposed negative value of NUPT. The redundant nitrogen is the amount of nitrogen present per organ in excess of the maximum possible amount of nitrogen at the actual development stage and expressed numerically as a 'negative demand' (NDEMR, NDEML, NDEMS, kg ha^{-1} d^{-1}).

```
      ELSEIF(SWINUP.EQ.2) THEN
         NALV   = NDEML+ GLV  * NMAXL
         NART   = NDEMR+ GRT  * NMAXR
         NAST   = NDEMS+ GSTS * NMAXS
         EXCESS = 0.
         ANRTRE = 0.
         ANSTRE = 0.
         ANLVRE = 0.
      ENDIF
```

For potential production where no nitrogen uptake is externally imposed (from observations), nitrogen allocation rate (NALV, NAST, NART, kg ha^{-1} d^{-1}) equals nitrogen demand (kg ha^{-1} d^{-1}), which includes for this purpose also the nitrogen associated with nitrogen saturated new growth. The latter is calculated by multiplying new growth (GLV, GSTS, GRT, kg ha^{-1} d^{-1}) with the maximum fraction of nitrogen at the actual development stage (NMAXL, NMAXS, NMAXR).

Nitrogen supply to the grains by translocation (SNTRAN)

This section describes the translocation of nitrogen solely as a result of the demand of the grains, referred to as condition (3) in this section.

```
ATNLV  = MAX(0.,(ANLV - ANLVRE + NALV - WLVG*RFNLV)/TCNT)
ATNST  = MAX(0.,(ANST - ANSTRE + NAST - WSTS*RFNST)/TCNT)
ATNRT  = MAX(0.,(ANRT - ANRTRE + NART - WRTL*RFNRT)/TCNT)
ATN    = ATNLV+ATNST+ATNRT
TCNT   = 10.
```

All the nitrogen allocated to the storage organs is supplied by translocation from leaves, stems and roots. The potential 'translocatable' amounts of nitrogen are determined per organ (ATNLV, ATNST, ATNRT (kg ha^{-1} d^{-1}) from the available amount of nitrogen in the organ. A time coefficient (TCNT, d) is used and has a value of 10 days. To derive the amount of nitrogen available for translocation from an organ, the daily rates for allocation (NALV, NAST, NART, kg ha^{-1} d^{-1}), removal of nitrogen consisting of the redundant nitrogen in an organ and the extra removal to realise the imposed negative value of NUPT (ANLVRE, ANSTRE, ANRTRE, kg ha^{-1} d^{-1}) and the residual fraction of nitrogen in the tissue are first taken into account. This residual amount is calculated from the weight of the plant organ (WLVG, WSTS, WRTL, kg ha^{-1}) and the residual nitrogen fraction (RFNLV, RFNST, RFNRT). The sum of the potential translocation rates gives the total potential amount of 'translocatable' nitrogen (ATN, kg ha^{-1} d^{-1}).

Part 1:

```
*-----Actual N supply rates by plant organs, in kg /ha/d
      IF (WSO.LT.10.) THEN
         NTLV=0.
         NTST=0.
         NTRT=0.
*-----Excess nitrogen in plant in nitrogen pool
         EXCPOL = EXCESS
         EXCTOG = 0.
```

Part 2:

```
      ELSEIF (NDEMG-EXCESS.GE.0.) THEN
```

Part 2.A:

```
         IF(ATN.GE.(NDEMG-EXCESS)) THEN
*-----Conversion potential to actual translocation
            NTLV  = MAX(0.,(NDEMG-EXCESS))*ATNLV/ATN
            NTST  = MAX(0.,(NDEMG-EXCESS))*ATNST/ATN
            NTRT  = MAX(0.,(NDEMG-EXCESS))*ATNRT/ATN
```

Part 2.B:

```
         ELSE
            NTLV  = ATNLV
            NTST  = ATNST
            NTRT  = ATNRT
         ENDIF
*-----All excess nitrogen in plant translocated to grains
         EXCTOG = EXCESS
         EXCPOL = 0.
```

Part 3:

```
      ELSE
         NTLV = 0.
         NTST = 0.
         NTRT = 0.
*-----Excess nitrogen in plant translocated to grains up to maximum
*     demand of the grains
         EXCTOG = MIN(NDEMGX, EXCESS)
         EXCPOL = EXCESS - EXCTOG
      ENDIF
```

Actual translocation starts only at the onset of the grain filling phase (WSO > 10 kg ha^{-1}) (Part 1 in program lines). The actual translocation rates (NTLV, NTST, NTRT, kg ha^{-1} d^{-1}) remain zero before this phase is reached. During this phase all excess nitrogen (EXCESS, kg ha^{-1} d^{-1}) that becomes available during this period adds up to a fictive pool named EXCPOL. The only purpose of this 'pool' is to provide a numerical signal that some part of the system is not modelled properly when EXCPOL is not equal to zero.

After flowering in the grain filling period nitrogen from EXCESS and from the plant organs can be translocated to the grains depending on the demand of the grains. When the nitrogen demand of the grains (NDEMG, kg ha^{-1} d^{-1}) is greater then EXCESS (Part 2.B in program lines), all the EXCESS will go to the grains. This is expressed in the fictive variable EXCTOG, which is defined as the amount of nitrogen from EXCESS translocated to the grains. Translocation from the plant organs (NTLV, NTST, NTRT) will cover the 'remaining' of the nitrogen demand (NDEMG-EXCESS). If the potential amount of translocatable nitrogen (ATN, kg ha^{-1} d^{-1}) can cover this 'remaining' demand (ATN > (NDEMG-EXCESS)), the plant organs will contribute in proportion to their respective amounts of available nitrogen (ATNLV, ATNST, ATNRT) (Part 2.A in program lines). When ATN is too small to cover the 'remaining demand' (ATN < (NDEMG-EXCESS)), all the available nitrogen from the organs will be translocated to the grains (Part 2.B in program lines).

If the NDEMG is smaller than the EXCESS (Part 3 in program lines), EXCESS will be the only source of nitrogen supply to the grains. The nitrogen translocation rates from the plant organs (NTLV, NTST, NTRT) remain zero.

```
*-----Actual N supply to grains by translocation

      IF (SWINUP.EQ.1) THEN
         NSUPG = NTLV+NTST+NTRT+EXCTOG

      ELSEIF (SWINUP.EQ.2) THEN
         NSUPG = NDEMG

      ENDIF
```

The actual nitrogen supply to the grains (NSUPG, kg ha^{-1} d^{-1}) is in a nitrogen limited situation (SWINUP = 1) equal to the sum of the nitrogen translocation rates from the various plant organs (as contributed on the basis of the various reallocation criteria listed earlier) and the amount of excess nitrogen in the plant organs, expressed in EXTOG. For potential production (SWINUP = 2) the NSUPG is equal to the demand of the grains.

3 Description of the ORYZA_0 modules (version 2.0)

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The subroutine ORYZA0 calls the subroutines TIMENV and BIOMS2. In the following sections these will be described (see Figure 1.1).

3.1 Time and environment (TIMENV)

In the module TIMENV the following statements are used:

```
DAT    = TIME - STTIME
DATEH  = STTIME + DATH


RDM    = RDD * 1.E-06
RADTOT = INTGR2 (RADTOT, RDM, DELT, 'RADTOT', FILEI1)
DATH   = 90.
```

DATEH is the calendar date of harvest, calculated from the starting time (STTIME) and the length of the period between transplanting and harvest, DATH.
The starting date (STTIME) is the calendar date corresponding to transplanting; duration from transplanting to first flowering (DATFF, see Section 3.2.5) and DATH are specified as parameters (inputs). For the purpose of zonation studies, where the dates corresponding to phenological stages are often sought as model outputs, ORYZA_0 can easily be extended by including one of the ORYZA-modules for phenological development which then calculates flowering and maturity dates based on planting date and weather variables.
Radiation is converted from J m^{-2} d^{-1} (RDD) to MJ m^{-2} d^{-1} (RDM). Cumulative radiation (RADTOT, MJ m^{-2}) is derived by integration of RDM over time.

3.2 Biomass accumulation by the crop (BIOMS2)

The subroutine BIOMS2 consists of only calls to the subroutines needed to compute crop biomass accumulation . These subroutines are described in the following sections.

3.2.1 Dry matter accumulation (GROW0)

```
      FSV   = INSW(DAT-DATFSV, FSV1, FSV2)

      RNEFF = FSV * ((P/(RDD * 1.E-06))*(1.-EXP(-EPSIL*(RDD * 1.E-06)/
     &        (P*NL+TINY))))
      GCR   = 10.* RNEFF * (RDD * 1.E-06) * NL
      WCR   = INTGR2 (WCR, GCR, DELT, 'WCR', FILEI1)

      IF (INQOBS(FILEI1, 'WCR')) XXWCR = GETOBS(FILEI1,'WCR')
      WRR   = HI*WCR

      P     = 10.
      EPSIL = 2.5
```

Example of user input:

```
      FSV1  = 0.87
      FSV2  = 0.70
      WCRI  = 16.0
      DATFSV= 70.
      HI    = 0.5
```

The crop growth rate G (g m^{-2} d^{-1}) is calculated from daily incident global radiation R (RDD, J m^{-2} d^{-1}), converted to MJ m^{-2} d^{-1}, and the amount of N contained in the leaf canopy, N_L, which is expressed in g leaf nitrogen per m^2 ground (!) surface area:

$$G = p N_L \left[1 - e^{-\varepsilon R / (p N_L)} \right] \quad (3.1)$$

where p is the initial leaf nitrogen use coefficient (P, g dry matter g^{-1} leaf N d^{-1}), ε is the initial global radiation use coefficient (EPSIL, g dry matter MJ^{-1} incident global radiation). The variable N_L is the 'production capital' available to the crop for converting radiation into dry matter. It replaces two other variables used separately in most other crop growth models: leaf area index (LAI) and leaf nitrogen concentration (usually per unit leaf surface area). ORYZA_0 thus does not distinguish between the two processes of light interception and its subsequent utilization. As a consequence, the parameter p represents the overall efficiency by which leaf nitrogen is used in producing dry matter. The adjective 'initial' in the definition of p serves to indicate that the overall crop leaf nitrogen utilization coefficient $LNUC \equiv G/N_L$ indeed approaches the value of p at low levels of N_L. Likewise, the overall global radiation use coefficient $GRUC \equiv G/R$ approaches, for low radiation levels, the initial global radiation use coefficient ε. These implications of Eqn 3.1 on the overall radiation and nitrogen use coefficients are depicted in Figures 3.1 - 3.4.

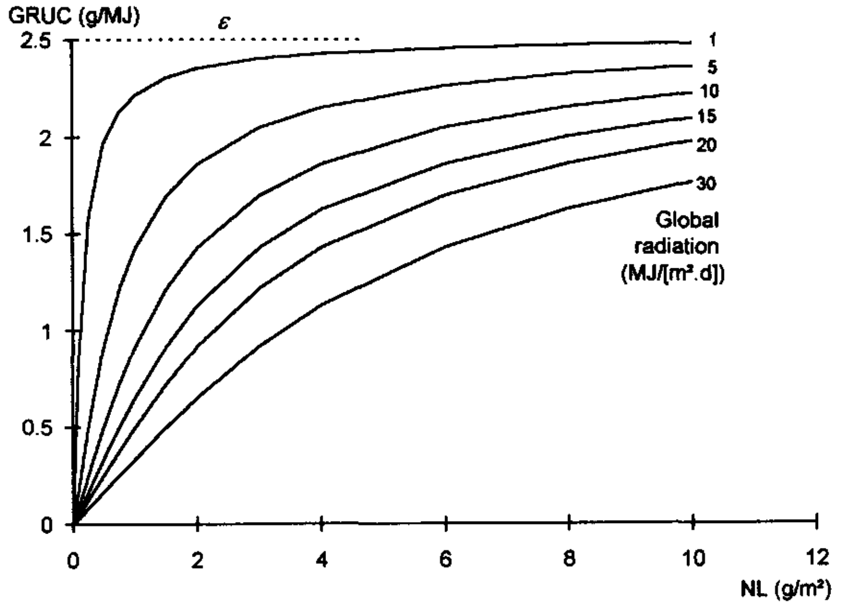

Figure 3.1 Overall global radiation use coefficient (GRUC, g dry matter MJ^{-1} incident global radiation) as a function of amount of leaf nitrogen (NL, g N m^{-2} ground surface area), for selected levels of global radiation (MJ m^{-2} d^{-1}).

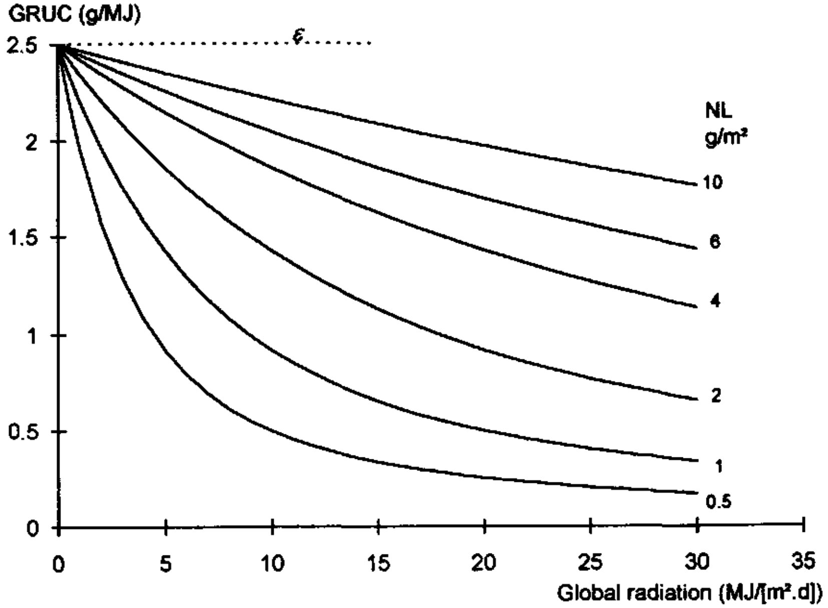

Figure 3.2. Overall global radiation use coefficient (GRUC, g dry matter MJ^{-1} incident global radiation) as a function of incident global radiation level (MJ m^{-2} d^{-1}), for selected levels of leaf nitrogen N_L (g N m^{-2} ground surface area).

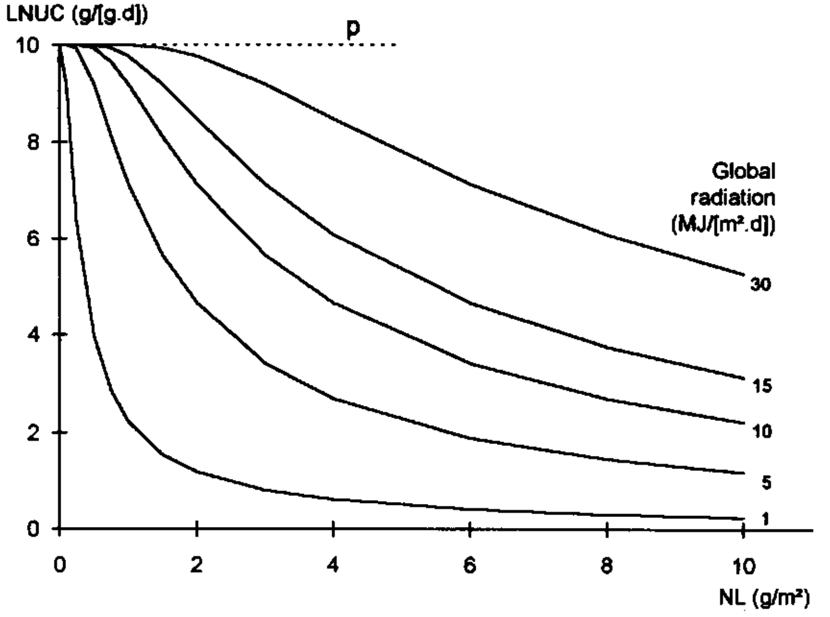

Figure 3.3. Overall leaf nitrogen use coefficient (LNUC, g dry matter g^{-1} leaf nitrogen d^{-1}) as a function of the amount of leaf nitrogen (N_L, g N m^{-2} ground surface area), for selected levels of global radiation (MJ m^{-2} d^{-1}).

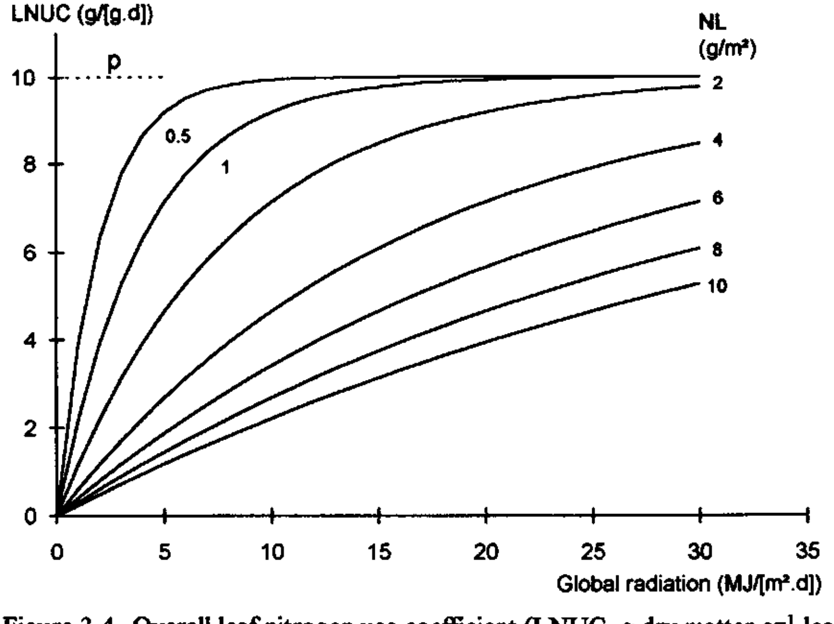

Figure 3.4. Overall leaf nitrogen use coefficient (LNUC, g dry matter g^{-1} leaf nitrogen d^{-1}) as a function of incident global radiation (MJ m^{-2} d^{-1}), for selected levels of leaf nitrogen (N_L, g m^{-2} ground area).

The values of p and ε can be obtained by fitting Eqn 3.1 to real data time curves of biomass, using measured time series of R and N_L. Since there is a strong interaction, however, between p and ε values, we propose here that the two parameters are not obtained by calibration of growth curves. Instead, we propose the use of mean values for ε and p as found across a range of data sets: $\varepsilon = 2.5$ g MJ^{-1} and p = 10.0 g g^{-1}d^{-1}. The effects of local conditions (site-variety interactions) are then merged into one single match factor f_{SV}, which is then used in combination with these fixed p and ε values:

$$G = f_{SV} \cdot p \cdot N_L \left[1 - e^{-\varepsilon R / (p N_L)}\right] \quad (3.2)$$

In the algorithm, the crop growth rate (GCR) is expressed in kg ha^{-1} (hence multiplication by factor 10) and one-day time steps are used to convert, by rectangular integration over time, the growth rate into the crop biomass. A harvest index specified as the parameter HI (g g–1) converts total crop biomass (i.e. including root biomass) into grain yield (WRR, kg ha^{-1}).

The measured (XXWCR) as well as the simulated (WCR) weights of the crop, the grain yield (WRR) and the amount of N in the leaves (ANLV) are all expressed in kg ha^{-1} within the model.

```
NL1  = MAX(0., ANLV/10.)
IF (INQOBS(FILEI1, 'FNLV')) FNLV = GETOBS(FILEI1, 'FNLV')/100.
IF (INQOBS(FILEI1, 'WLV' )) WLV  = GETOBS(FILEI1, 'WLV ')
NL2  = MAX(0., FNLV*WLV/10.)
NL   = INSW (0.5-SWINLV, NL2, NL1)
```

Through the switch SWINLV the user can either choose to use the measured amount of N in the leaves or the simulated amount of N in the leaves. These program lines are included in the subroutine BIOMS2.

```
LNUC = RNEFF*RDM
GRUC = RNEFF*NL
```

The overall nitrogen use efficiency (LNUC, g g^{-1} d^{-1}) and overall radiation use efficiency (GRUC, g MJ^{-1}) are calculated as output variables only.

It appears that in many cases a sudden shift in the value of f_{SV} occurs around the flowering stage. To take into account this behaviour for the purpose of fertilizer optimization under such conditions, the model accepts pre- and post-flowering values of f_{SV}. These are specified as the parameters FSV1 (pre-flowering) and FSV2 (post-flowering). The date at which f_{SV} shifts from the first to the second value is specified as DATFSV (in days after transplanting).

In initialization section:

```
IF (RTINCL.EQ.1) THEN
   WCR    = WCRI
   WSHT   = -99.0
ELSE
   WSHT   = WCRI
   RELTME = (DOY-STTIME)/DATEF
   RSR    = LINT(RSRT, ILRSRT, RELTME)
   WRT    = RSR * WSHT
   WCR    = WSHT + WRT
ENDIF

RTINCL = 0
WCRI   = 16.0
RSRT   = 0., 0.4, 1.1, 0.15
```

By choosing a value of 1 or 0 for the variable RTINCL, the user indicates whether root biomass is in- or excluded (resp.) in the data on the weight of the crop. To be able to initialise the weight of the crop when root biomass is not measured, a root weight is calculated with the help of a root:shoot ratio (RSR). This ratio is a function of the days after transplanting related to the time of flowering, expressed in days after transplanting. The sum of the weight of the shoot (WSHT, kg ha^{-1}) and of the root (WRT, kg ha^{-1}) provides the initial weight of the crop. When root biomass is included in the weight of the crop (RTINCL = 1) the weight of the shoot (WSHT) is set to -99.0.

In integration section:

```
IF (RTINCL.EQ.1) THEN
   WSHT = -99.0
ELSE
   IF (DOY.LT.(DATEF+STTIME)) THEN
       RELTME = (DOY-STTIME)/DATEF
       RSR    = LINT(RSRT, ILRSRT, RELTME)
       WSHT   = WCR/(1.+RSR)
   ELSE
       WSHT = WCR/(1.+0.15)
   END IF
END IF
```

When root biomass was not measured the simulated weight of the shoot (WSHT, kg ha^{-1}) is calculated with the help of the root:shoot ratio (RSR), after integration of the weight of the crop (WCR, kg ha^{-1}). Before flowering the RSR is changing in time. After flowering a fixed ratio of 0.15 is used. In this case the measured weight of the crop (XXWCR, kg ha^{-1}) should be compared with the simulated weight of the shoot (WSHT, kg ha^{-1}).

3.2.2 N uptake: the fertilizer application curve, recovery and soil N supply (NAP0)

```
X       = EXP(-B*(DAT-M))
APSLOP  = MIN(FERTMX-APCUM, B*C*X*(1.+ A*X)**(-1.-1./A))
APCUM   = INTGR2 (APCUM, APSLOP, DELT, 'APCUM', FILEI1)
```

In terminal section:

```
NAPPLD  = APCUM
```

Example of user input:

```
A       = 1.
B       = 0.1
C       = 300.
M       = 30.
FERTMX  = 200.
```

The N application curve $A(t)$ describes the cumulative amount of N applied up to time t, for a hypothetical continuous N application scheme. The slope dA/dt of this curve would thus represent the amount applied daily (APSLOP, kg N ha^{-1} d^{-1}), if it were possible to give a small fertilizer dressing every day. Although such a continuous application curve cannot be followed in real crop management, we chose to take this approach because it facilitates numerical optimization. The $A(t)$ curve is a member of the family of generalized logistic functions:

$$A(t) = c \cdot \left[1 + a \cdot e^{-b \cdot (t-m)}\right]^{-1/a} \tag{3.3}$$

and its slope is given as the derivative

$$\frac{dA}{dt} = \left[b \cdot c\left(e^{-b \cdot (t-m)}\right)\left(1 + a \cdot e^{-b \cdot (t-m)}\right)\right]^{-1-1/a} \tag{3.4}$$

where a and b are constants defining the shape of the curve, m the relative position of the curve with respect to the time axis, and c is the scale factor which defines the asymptote level approached at large t. The amount of N available for uptake from fertilizer equals

$\rho_N(t)[dA/dt]$. The fraction not recovered, $(1-\rho_N)$, is not conserved for later uptake. $A(t)$ may remain well below the asymptote level c during the whole season because the curve may be truncated: when $A(t)$ reaches the user-prescribed total amount of fertilizer input, A_{tot} (FERTMX, kg N ha^{-1}), the remainder of the logistic application curve is ignored. The cumulative application is, in ORYZA_0, not expressed directly as $A(t)$ (APCUM, kg ha^{-1}) according to Eqn 3.3, but is obtained via integration of Eqn 3.4. This is necessary because the function value $A(t)$ is always non-zero, even at $t = 0$, while the cumulative application curve should start with an initial value of 0 kg ha^{-1} at $t = 0$.

N uptake: soil N supply and fertilizer N recovery

```
RECOV  = LINT(RECT,ILRECT,DAT)
NAVAIL = RECOV*APSLOP + SOLSUP
```

Example of user input:

```
SOLSUP = 0.6
RECT   =  0.,0.0, 60.,0.8, 65.,0.4, 70.,0.0, 150.,0.
```

The availability of N for uptake by the crop (NAVAIL, kg ha^{-1} d^{-1}) is determined by 'native' soil N supply, S_N (SOLSUP, kg ha^{-1} d^{-1}), applied amounts of N from mineral and/or organic fertlizer sources (APSLOP, kg ha^{-1} d^{-1}), and $\rho_N(t)$ (RECOV, g g^{-1}), the time course of apparent recovery of applied fertilizer-N. S_N represents the rate at which N released from mineralisation is taken up by the crop. Its value is estimated from N uptake in non-fertilized plots by dividing the full season's total N uptake by the number of field days. The resulting value ranges between 0.2 and 0.8 kg ha^{-1} d^{-1}, but for an average good rice soil S_N amounts to 0.5-0.6 kg ha^{-1} d^{-1}.

Fertilizer-N recovery reflects the competition for N between loss processes and uptake by roots. Because the size of the root system - and thus its competitive strength vs. loss processes - increases rapidly during the vegetative stage, ρ_N first increases to reach a maximum around panicle initiation (PI) stage or later (up to flowering). Depending on environmental conditions and possibly also crop characteristics, the maximum ρ_N is sustained for a while and then usually declines soon after flowering. At some locations, e.g. at Sukamandi and Bogor, West Java, SARP teams have observed a steep decline of ρ_N already around the PI stage. This is currently attributed to soil conditions but certainly deserves further investigation. Whatever the explanation may be, the observed location specific $\rho_N(t)$ can be taken as a fact and must be taken into account in optimizing fertilizer management. It is, therefore, an input to the ORYZA_0 model. The table RECT (g g^{-1}) can be obtained from field trials by evaluating the effects of N split applications given at different times.

The model uses $\rho_N(t)$ as the best attainable recovery fraction, which thus defines the unavoidable fertilizer loss fraction. In reality, as in model calculations, the actual fertilizer-N recovery may be considerably lower than $\rho_N(t)$ if other uptake limitations exist. Hence, $\rho_N(t)$ can only be interpreted as a soil-cum-crop system characteristic when it is based on observations made under reasonable levels of N application. Fertilizer-N recovery observed under excessive N application has no significance as a system property. In ORYZA_0, $\rho_N(t)$ is applied on a day-to-day basis to convert, for a given day, a hypothetical amount of applied fertilizer to an amount potentially available for uptake. A first approximation of $\rho_N(t)$ for good rice soils shows a linear increase from 0.0 at transplanting to 0.4-0.7 at PI stage, sometimes increasing to 0.8-1.0 around FF stage, then again decreasing linearly to 0.0-0.2 over a time span of 3 weeks after FF.

3.2.3 Nitrogen uptake: demand (DEM0)

```
SWIEXP = 0.
IF(MAXNCR-ANCR.GT.0.0.AND.MAXDAT-DAT.GT.0.0) SWIEXP = 1.

MAXUP0 = RUR*ANCR
MAXUP2 = NUPCO * GCR

FNMAX  = LINT(FNMAXT,ILFNMA,DAT)
MAXUP3 = ((WCR+GCR*DELT)*FNMAX - ANCR)/DELT

IF (ANLVMX-ANLV.LT.0.0) THEN
    MAXUP4 = 0.
ELSE
    MAXUP4 = LARGE
ENDIF

IF (DATH-DAT-7.0.LT.0.) THEN
   MAXUP5 = 0.
ELSE
   MAXUP5 = LARGE
END IF

M12345 = MIN(MAXUP1,MAXUP2,MAXUP3,MAXUP4,MAXUP5)

IF((0.5-SWIEXP).LT.0.) THEN
   DEMAND = MAXUP0
ELSE
   DEMAND = M12345
END IF
```

Example of user input:

```
RUR    = 0.2
NUPCO  = 0.03
ANLVMX = 100.
```

```
DATH    = 94.
MAXUP1  = 5.
FNMAXT  = 0.,0.03, 40.,0.017, 60.,0.015, 80.,0.01, 130.,0.07
```

N uptake by the crop is determined by N availability in the root zone, and the crop N demand. Demand is not a well defined concept, and includes subprocesses of various nature. We will nevertheless use it as a lumped variable which expresses all the different limitations to N uptake arising from the current state and growth rate of the crop, i.e. those limitations not directly resulting from low N availability in the bulk root zone.

During the first 20 days after transplanting (DAT), demand is exclusively governed by the relative uptake coefficient, r_N (RUR, d^{-1}). The exponential uptake phase ends before completing the 20 days period if total crop uptake N_c (ANCR, kg ha^{-1}) reaches 35.0 kg ha^{-1}:

$$\frac{dN_c}{dt} = r_N \cdot N_c \qquad \text{for } N_c < 35.0 \text{ and } t < 20\text{DAT} \qquad (3.5)$$

The critical N_c value of 35.0 kg ha^{-1} d^{-1} corresponds roughly to LAI = 2 for an average young rice canopy, i.e. with a specific leaf area of 0.03 m^2 g^{-1}, leaf N content of 0.03 g g^{-1}, and f_{NL}= 0.6 g g^{-1}.

The value of r_N was found to be roughly 0.20 d^{-1}, which corresponds closely with the relative growth rate of LAI used in other models. This numerical correspondence comes as no surprise, since specific leaf area and leaf N concentration are usually fairly constant during the first weeks of rice growth. This coefficient may be a varietal characteristic and will depend on temperature (as does leaf area development). The latter is not taken into account here. For each particular case (location, variety) the value of this coefficient can be determined directly from the observed N uptake vs. time, under conditions of surplus N supply (high basal application, incorporated into the soil).

After the exponential phase, other limitations to uptake exist:

(1) Uptake rate cannot exceed a given absolute maximum value, u_N (MAXUP1, kg ha^{-1} d^{-1}).
(2) The ratio of daily N uptake to daily biomass production cannot exceed a maximum value, q_N (NUPCO, kg kg^{-1}).
(3) The maximum overall concentration of N in the total crop biomass, c_{max} (FNMAX, kg kg^{-1}), follows a pattern prescribed by the crop development stage; daily uptake cannot exceed the difference between c_{max} and the current ratio $N_c/(W_c+G \cdot \Delta t)$.
(4) Uptake ceases when the size of the leaf nitrogen pool N_L reaches $N_{L,max}$ (ANLVMX, kg ha^{-1}).
(5) No N is taken up during the last week before maturity.

These parameters, u_N, q_N, c_{max}, and $N_{L,max}$ will be called 'N-demand' parameters. At the moment, we do not know to what extent they vary among cultivars, soil types, and weather conditions. More insight will be attained soon, because these parameters can be determined from field observations of uptake and crop growth vs. time, under non-limiting N supply; the many detailed experiments conducted by SARP teams allow such analyses. Soil effects on the values of some of these parameter should not be ruled out, even though we designated them as demand- (not: supply-) limiting factors; soil factors other than those directly affecting bulk root zone N availability might limit the N uptake ability of the root system and would thus affect N demand, according to the proposed definition of demand. At a later stage it may appear that some of the N-demand parameters are redundant.

The maximum N uptake rate u_N (MAXUP1, kg ha^{-1} d^{-1}) can reach values up to 8.0 kg ha^{-1} d^{-1}, as was observed in a young rice crop under very high (400 kg N ha^{-1}) N application at Aduthurai, India (Thiyagarajan et al., 1991; ten Berge et al., 1994b). This, however, is regarded as exceptional. At other locations, e.g. IRRI, in Los Baños, Philippines, u_N remained below 5.0 kg ha^{-1} d^{-1}. It seems that, at least at IRRI, its value is lower for wet season than for dry season conditions. In any case, the value of u_N crucially affects biomass production according to model calculations.

A first estimate for q_N (NUPCO, g g^{-1}) based on a number of experiments conducted within the framework of SARP is 0.035 g g^{-1}. Possibly, both u_N and q_N can reach higher values when the crop is highly deficient in nitrogen and is suddenly exposed to a large N supply. To determine u_N and q_N under such conditions, the crop must be sampled at short time intervals (e.g. 2 d).

The maximum overall (including roots) crop N content c_{max} (FNMAX, g g^{-1}) usually starts at 0.04 kg kg^{-1} for very young plants, decreases then linearly to about 0.02 at flowering and 0.015 when the crop approaches maturity. These rather high values are typical of modern short duration varieties, and may be considerably lower in other rice types.

The remaining N-demand coefficient, $N_{L,max}$ (ANLVMX), may reach values up to 100 kg N ha^{-1} g per m^2 ground surface area, as observed at IRRI during 1993 dry season in rice cvar IR72.

At any stage after exponential uptake, the minimum of potential uptake rates allowed by the limitations (1) - (5) is used in ORYZA_0 as the governing demand limitation.

3.2.4 Actual nitrogen uptake (NUP0)

```
NUPT   = MAX(0., MIN(DEMAND , NAVAIL))
ANCR   = INTGR2 (ANCR, NUPT, DELT, 'ANCR', FILEI1)
```

in terminal section:

```
NHRVST  = ANCR
```

The actual uptake rate (NUPT, kg ha^{-1} d^{-1}) on a given day is calculated as the minimum of nitrogen availability and crop nitrogen demand. Total crop N uptake (ANCR, kg ha^{-1}) is the integral of uptake rate over time.

3.2.5 Allocation and redistribution of nitrogen (NAL0)

```
ANLVI   = FNCLV * ANCRI
ANSOCH  = INSW(DAT-DATFF,0.,GCR*FNSO)
ANLVCH  = INSW(DAT-DATFF,NUPT*FNCLV,(NUPT-ANSOCH)*FNCLV)
ANLV    = INTGR2 (ANLV  ,ANLVCH  ,DELT, 'ANLV', FILEI1)
```

Example of user input:

```
ANCRI = 0.4
DATFF = 60.
FNSO  = 0.01
FNCLV = 0.50
```

Of the total amount of N taken up every day, only a fraction is allocated to the leaves. This fraction, f_{NL} (FNCLV, g g^{-1}), is usually stable during crop development up to 'first flowering' (FF) stage. The FF stage is reached when 10% of the rice hills carry at least one flowering panicle. This is usually a week before full flowering (i.e. the stage when 90% of the hills carry at least one flowering panicle; the 'full flowering' stage plays no role in ORYZA_0). The date corresponding to the FF stage, t_{FF}, marks a shift in nitrogen allocation pattern and triggers the redistribution of leaf nitrogen.
It thus relates N_{L} (ANLV, kg ha^{-1}) to total crop N uptake, N_{c} (ANCR, kg ha^{-1}) and can easily be estimated from field observations at any time during this period:

$$f_{\mathrm{NL}} = \frac{N_{\mathrm{L}}}{N_{\mathrm{c}}} \qquad (3.6)$$

Considerable variation in f_{NL} has been observed among rice varieties. Results collected by SARP teams have shown a range of 0.40 (cvar CR1009) to 0.55 (cvar IR64). This parameter may well be the most discriminative varietal property with respect to the so-called 'N-responsiveness'. The rate of N allocation (ANLVCH, kg ha^{-1} d^{-1}) to the N_{L} pool follows as:

$$\frac{\mathrm{d}N_{\mathrm{L}}}{\mathrm{d}t} = f_{\mathrm{NL}} \frac{\mathrm{d}N_{\mathrm{c}}}{\mathrm{d}t} \qquad (3.7)$$

From the onset of flowering, the growth of panicles (including grains) represents a strong sink for nitrogen. Since virtually all crop growth after FF stage is invested in panicles, the panicle N demand, dN_P/dt (ANSOCH, kg ha^{-1} d^{-1}), is the product of total crop growth rate and the fraction of N in panicles, n_p (FNSO, g g^{-1}):

$$\frac{dN_P}{dt} = n_p \cdot G \tag{3.8}$$

where N_P is the total amount of nitrogen contained in panicles (kg ha^{-1}). The nitrogen required for allocation to panicles may be derived from the leaves, if the demand cannot be covered by direct N uptake. The rate of N extraction from leaves is supplemented with N reallocated from stems, leaf sheaths and roots. The ratio of N supply rates from these two contributing sources - leaf and non-leaf vegetative tissues, respectively - to panicles is assumed to be equal to the original partitioning coefficient, f_{NL}. The rate of N translocation from leaves is therefore:

$$\frac{dN_L}{dt} = f_{NL} \cdot \left(\frac{dN_c}{dt} - \frac{dN_P}{dt}\right) \quad \text{for } t > t_{FF} \tag{3.9}$$

Translocation implies that the difference term in brackets is negative, which is usually the case after t_{FF} the time of first flowering. Possibly, post-flowering N uptake rate could exceed panicle N demand, which would render the difference term positive.

When post-flowering N uptake is so large that the leaf N pool exceeds the value that had previously been attained at FF stage, additional N taken up is likely to be stored in the leaf mass only, because the capacity of roots and stems to store excess N is limited. Likewise, extraction of N from vegetative tissues for panicle growth would be from leaves only at such extreme N_L levels:

$$\frac{dN_L}{dt} = \frac{dN_c}{dt} - \frac{dN_P}{dt} \qquad \text{for } t > t_{FF} \text{ and } N_L > N_L \text{ at } t_{FF} \tag{3.10}$$

This refinement (Eqn 3.10) is not included in the current NAL0 module, but a formulation of this type is likely to be added when more data become available to support this hypothesis. It is known that n_p increases under conditions of high post-flowering N uptake, especially when the sink size (number of spikelets per m^2) is limited. This combination of conditions will not occur under normal N management and weather conditions, but can be encountered by a crop recovering after a stress phase. Values of n_p ranging from 0.007 g g^{-1} (CR1009, Thanjavur, Tamil Nadu, India) to 0.015 and higher (IR72, IRRI dry season) have been observed by SARP scientists. These values apply to whole panicles, not just grains, and are always lower than the grain N values.

4 Validation

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4.1 General

Validation of the ORYZA_N and ORYZA_0 models composed from the modules presented in the previous chapters was carried out with seven data sets. The data sets vary in location, season, variety and nitrogen treatment (Table 4.1). For the complete sets of data and more information on the experiments, as used for validation, see Appendix 10.

Table 4.1 Basic information on the data sets used for validation of the ORYZA_N modules.

Location		Institute	Year	Season	Variety	Treatment (kg nitrogen per ha)
India	Aduthurai	TNRRI-TNAU	1988/1989	wet	ADT 39	0, 100, 200, 300, 400
India	Cuttack	CRRI	1990	dry	IR 36	0, 50, 100, 150
Philippines	Los Baños	IRRI	1990/1991	wet	IR 64	130
Philippines	Los Baños	IRRI	1991	wet	IR72	0, 80, 110
Philippines	Los Baños	IRRI	1991	wet	LINE	0, 80, 110
Philippines	Los Baños	IRRI	1992	dry	IR72	0, 180, 225
Philippines	Los Baños	IRRI	1992	dry	LINE	0, 180, 225

4.2 Results of validation of ORYZA_N

For each of the data sets presented in Table 4.1, the ORYZA_N model was run for two options, (1) nitrogen limited production using measured nitrogen contents in leaves to calculate daily gross assimilation, and (2) using simulated nitrogen contents in leaves (all green leaves averaged) to calculate daily gross assimilation. In the latter case, measured total nitrogen uptake was used as forcing function, and leaf nitrogen content was derived from it by the simulation model (Table 4.2). The switch settings corresponding to these three groups of simulation runs are listed in Table 4.3.

Table 4.2 Explanation of the ORYZA_N model definition by switches for the two options.

Nitrogen limited production	
Measured nitrogen content	Simulated nitrogen content
measured leaf weight and SLA for LAI calculation	measured leaf weight and SLA for LAI calculation
simulated leaf N content as input for photosynthesis	measured leaf N content as input for photosynthesis
N uptake forcing function	N uptake forcing function

Table 4.3 Switch settings used for the validation runs with the ORYZA_N model.

Switches	Nitrogen limited production	
	Measured N content	Simulated N content
SWILAI	4	4
SWINPH	0	1
SWINUP	1	1
SWINPR	1	1
SWISAI	0	0
SWISIN	1	1

Weights of the crop

The weights of the crop were well simulated when using measured as well as simulated leaf nitrogen in the calculation of daily gross assimilation (Figure 4.1). Looking into the results of the separate data sets the 300 and 400 kg N per ha treatment of the Aduthurai set (TNAU-TNRRI) show a slight overestimation at the end of the season. Overestimation also occurs for the highest nitrogen application treatments (100 and 150 kg N ha^{-1}) of the Cuttack (CRRI) data set, using the measured as well as using the simulated amount of nitrogen in the leaves. The use of the simulated amount of nitrogen in the leaves leads to an overestimation of biomass for all treatments of the Cuttack data set. This is because the amount of leaf nitrogen is overestimated by the model.

Weights of the storage organs

Apart from the Aduthurai data set there is a slight tendency to underestimate the weights of the storage organs (Figure 4.2). The use of simulated nitrogen in the leaves for photosynthesis calculation reduces this underestimation. Since the weights of the crops are well simulated, the underestimation of the weights of the storage organs must be due to inaccuracies in partitioning and redistribution of the carbohydrates in the plant. Perhaps the remobilisation of the shielded reserves from the stems to the storage organs is too low and remobilisation from the leaves cannot be ignored.

Amounts of nitrogen in the plant organs

Figures 4.3 and 4.4 show the simulated amounts of nitrogen in the plant organs plotted against the observed values. The total amount of nitrogen uptake is used as a forcing function and therefore equal to the observed values. These figures give information about the partitioning of nitrogen to the plant organs.

The amounts of nitrogen in the roots show much scatter. This may be due to errors easily made with the root sampling. However, absolute amounts of root nitrogen are small compared to total crop nitrogen uptake. Large relative deviations in root nitrogen therefore have little impact on biomass production. Amounts of nitrogen in the stems are underestimated, especially at higher levels of nitrogen. Increasing of the maximum nitrogen fraction of the stems (NMAXS) increases the nitrogen demand of stems, which decreases the gap between simulated and measured values.

The amount of nitrogen in the storage organs seems to be overestimated at higher levels of nitrogen. The overestimated values, however belong to one data set (TNAU-TNRRI, Aduthurai).

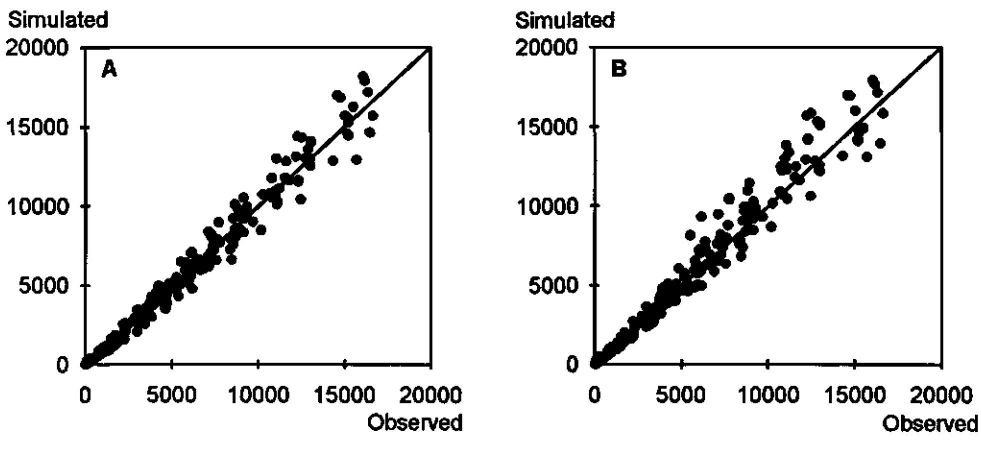

Figure 4.1 Weight of the crop (kg ha^{-1}) simulated versus observed for all data sets (●) at sampling dates. The simulated values were obtained from simulation runs of ORYZAN, using measured leaf nitrogen (A) or simulated leaf nitrogen (B) as input to the modules that calculate daily gross assimilation.

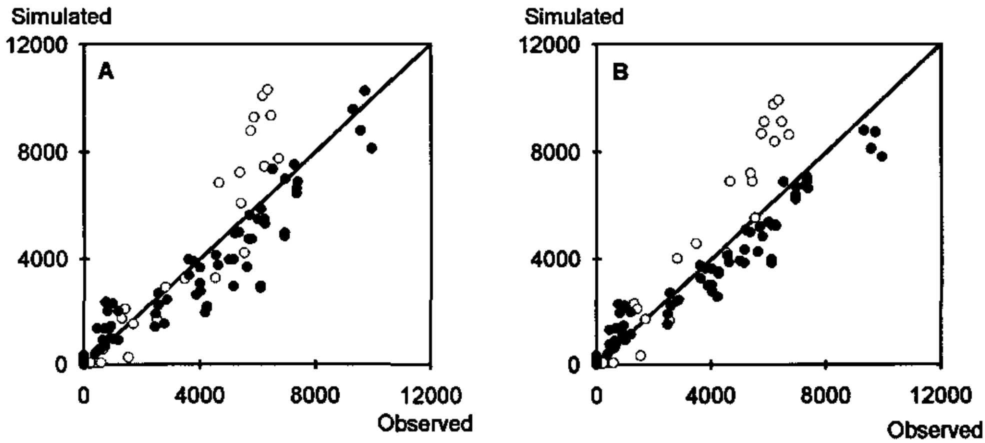

Figure 4.2 Weight of the storage organs (kg ha^{-1}) simulated versus observed for the data set TNAU-TNRRI (India, wet season 1988-1989, ○) and the other data sets (●), at sampling dates. The simulated values were obtained from simulation runs of ORYZAN, using measured leaf nitrogen (A) or simulated leaf nitrogen (B) as input to the modules that calculate daily gross assimilation.

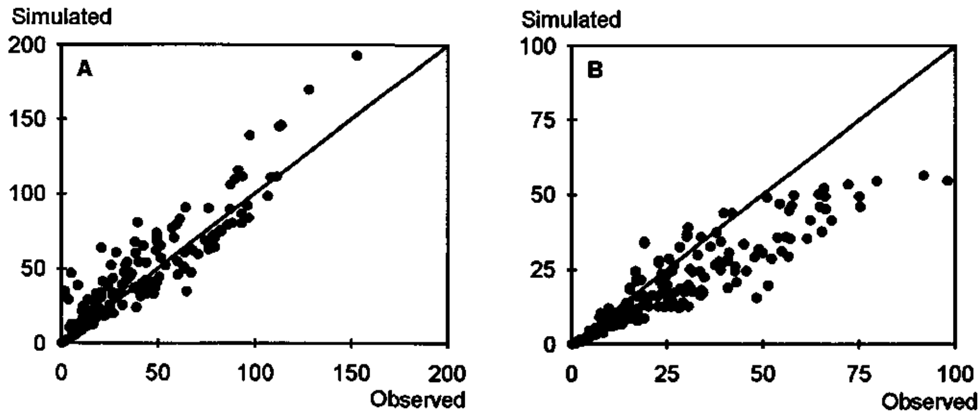

Figure 4.3 Amount of nitrogen (kg ha^{-1}) in the leaves (A) and in the stems (B) simulated versus observed for all data sets (●) at sampling dates. The simulated values were obtained from simulation runs of ORYZAN, using simulated leaf nitrogen as input to the modules that calculate daily gross assimilation.

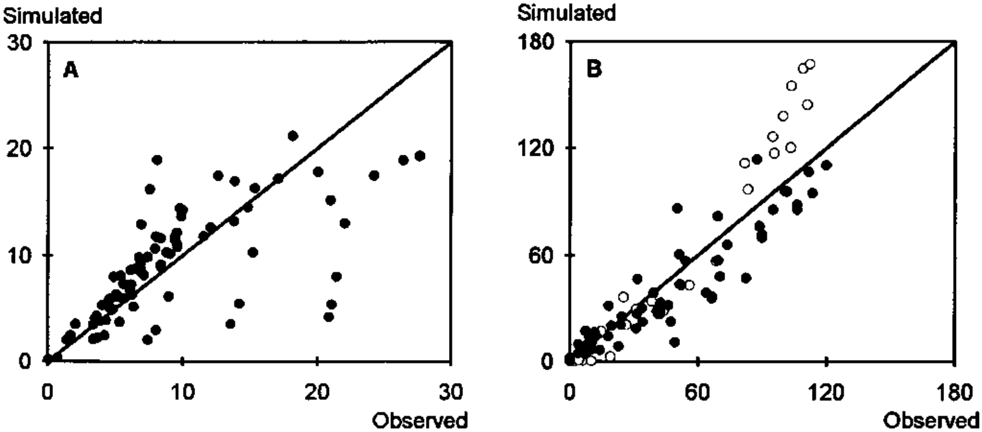

Figure 4.4 Amount of nitrogen (kg ha^{-1}) in the roots (A) and the storage organs (B) simulated versus observed at sampling dates. Data for the roots were derived from experiments carried out at CRRI (India, dry season 1990, ●) and TNAU-TNRRI (India, wet season 1988-1989, ●). Data for the storage organs were derived from experiments carried out at TNAU-TNRRI (India, wet season 1988-1989, O) and at the other locations (●). The simulated values were obtained from simulation runs ORYZAN, using simulated leaf nitrogen as input to the modules that calculate daily gross assimilation.

4.3 Results of validation of ORYZA_0

ORYZA_0 was run for all data set listed in Table 4.1, except for the wet season 1990/1991 Los Baños, Philippines. We tested here only the growth component of the model, by using time series of measured amount of leaf nitrogen (N_L) to predict the time series of crop biomass with the help of Eqn 3.2, using measured daily global radiation. In the cases of Aduthurai (TNRRI-TNAU) and Cuttack (CRRI) (both in India) the original radiation data in sunshine hours were converted in the WEATHR system to J m^{-2} d^{-1} units with the help of the Ångström formula. In the data sets obtained from IRRI, no root mass data were available. We estimated root mass from above ground biomass with the help of a tabulated function as explained in Section 3.2.1.

Whereas the ORYZA_0 model makes use of a matching factor (f_{SV}) when applied to fertilizer use optimization and also when used as a diagnostic tool, we have chosen not to vary this factor in the present validation study. We used a value of 0.87 for f_{SV} in all data sets (= both pre- and post-flowering), which is an average obtained from a range of other experiments (The full range of f_{SV} found across many experiments is 0.7 - 1.15). The reference values of 10 g g^{-1} d^{-1} and 2.5 g MJ^{-1} were maintained for p and ε, respectively, as proposed in Section 3.2.1

Figure 4.5 shows the measured and simulated time curves of total crop biomass. Generally, a slight overestimation by the model is found, in other words, the f_{SV} value was lower in the experiments under study, especially at the higher N levels. In the four IRRI cases (Figure 4.5 A to D), the shape of the growth curves is generally acceptable, and also the relative differences between treatments are predicted well by the model.

In the Cuttack (CRRI) data set, the deviation is more. This is consistent with other experiments from this site, where f_{SV} values of 0.6 seem to be normal under wet season conditions. In the Aduthurai (TNRRI-TNAU) case, growth curves are described well by the model until the flowering stage. From then onward, net growth virtually ceased in reality, whereas the predictions based on measured leaf N and radiation indicate that roughly 10 t ha^{-1} extra biomass could have been produced after flowering, in the high N treatments. Although this clear discrepancy between observed and simulated growth curves points at the weakness of the model to describe such cases properly, these Aduthurai (TNRRI-TNAU) findings are important in a diagnostic sense, because the case obviously deviates from the behaviour at other sites. We conclude that limitations other than source capacity determined the grain filling at Aduthurai (TNRRI-TNAU).

(From other sets collected in Tamil Nadu - not presented here - it appears that a decrease in f_{SV} by 20-50% after flowering is quite normal in this region, although not to the extent documented here. Growth curves at many other sites indicate that f_{sv} can be maintained at the pre-flowering value, and hence that such productivity collapse is not inherent to rice. These findings are relevant for N management: if the source capacity is not used to the full extent, the investment in fertilizer nitrogen is partially wasted. As long as the other, yet unknown, limitations to post-flowering production are not resolved, we should take this low N productivity into account in designing N management strategies. Research efforts should first be focused on resolving the real constraints. Inspection of sink size, spikelet viability, and possible effects of diseases seem to be the logical first steps.)

The above observations are also reflected in Figure 4.6, where observed and simulated biomass values corresponding to all sampling dates are plotted. Again, good absolute and relative (both across treatments and vs. time) predictions are found for the IRRI cases, whereas the gross overestimation at Aduthurai (TNRRI-TNAU) is apparent.

Comparison of the above results with those presented in Section 4.2 shows that the performance of the ORYZA_0 model with fixed f_{sv} (as used here) is comparable to that of more physiology-based models, such as ORYZA_N (Chapter 2) and ORYZA_1, which uses the same photosynthesis routines as ORYZA_N. These models seem to have the same limitations when production constraints other than leaf nitrogen and radiation are relevant.

Another observation is that growth curves obtained at IRRI may not be representative for irrigated rice in general, although a wider analysis of more data sets is required to substantiate this statement. Such a broad ecoregional analysis is currently under way and will be reported in one of the upcoming SARP Research Proceedings issues.

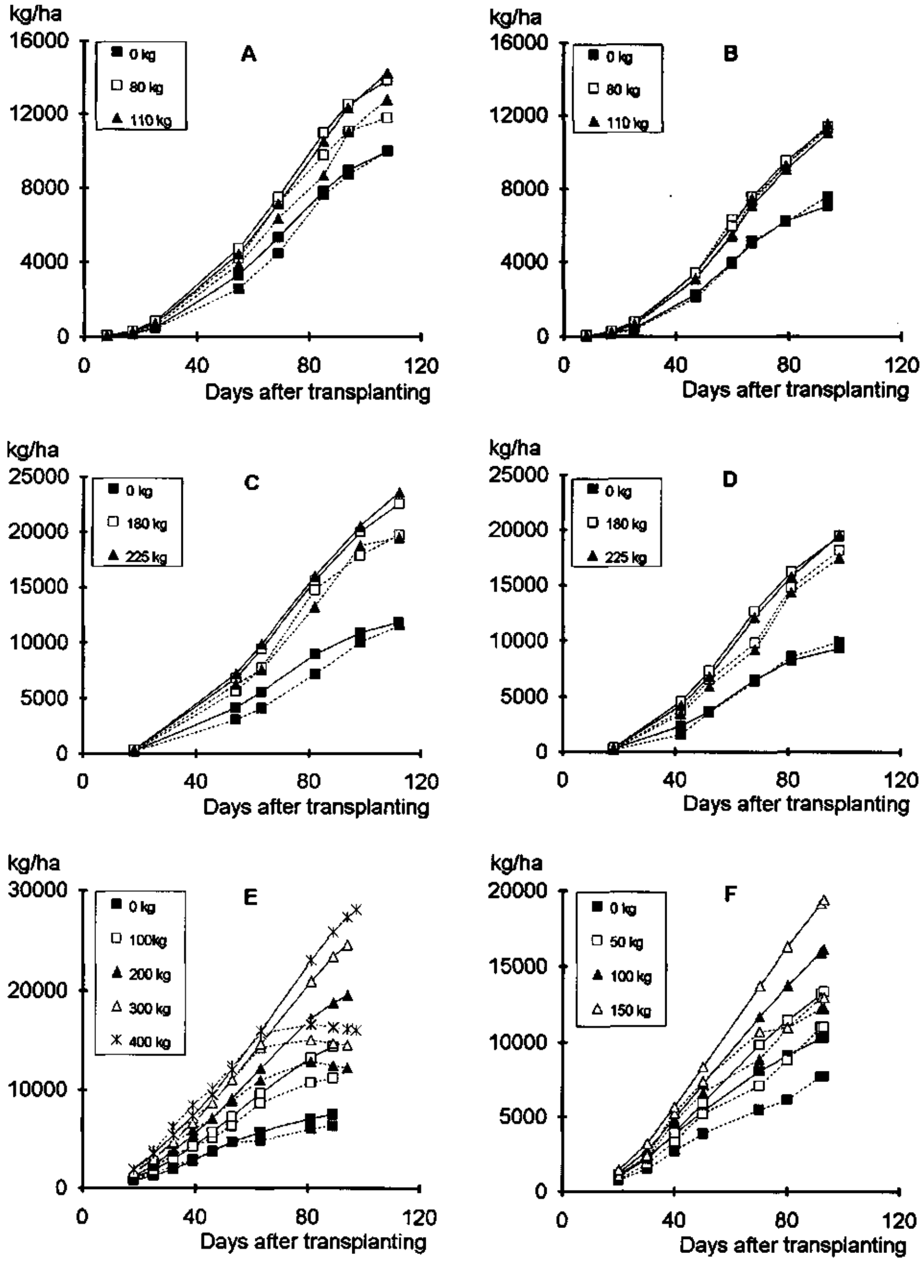

Figure 4.5 Measured (broken line) and simulated (solid line) time curves of total crop biomass (kg ha^{-1}). Data sets presented here: IRRI, Philippines, wet season 1991, varieties LINE (A) and IR72 (B); IRRI, dry season 1992, varieties LINE (C) and IR72 (D); TNRRI-TNAU, India, wet season 1988-1989, variety ADT 39 (E); CRRI, India, dry season 1990, variety IR36 (F).

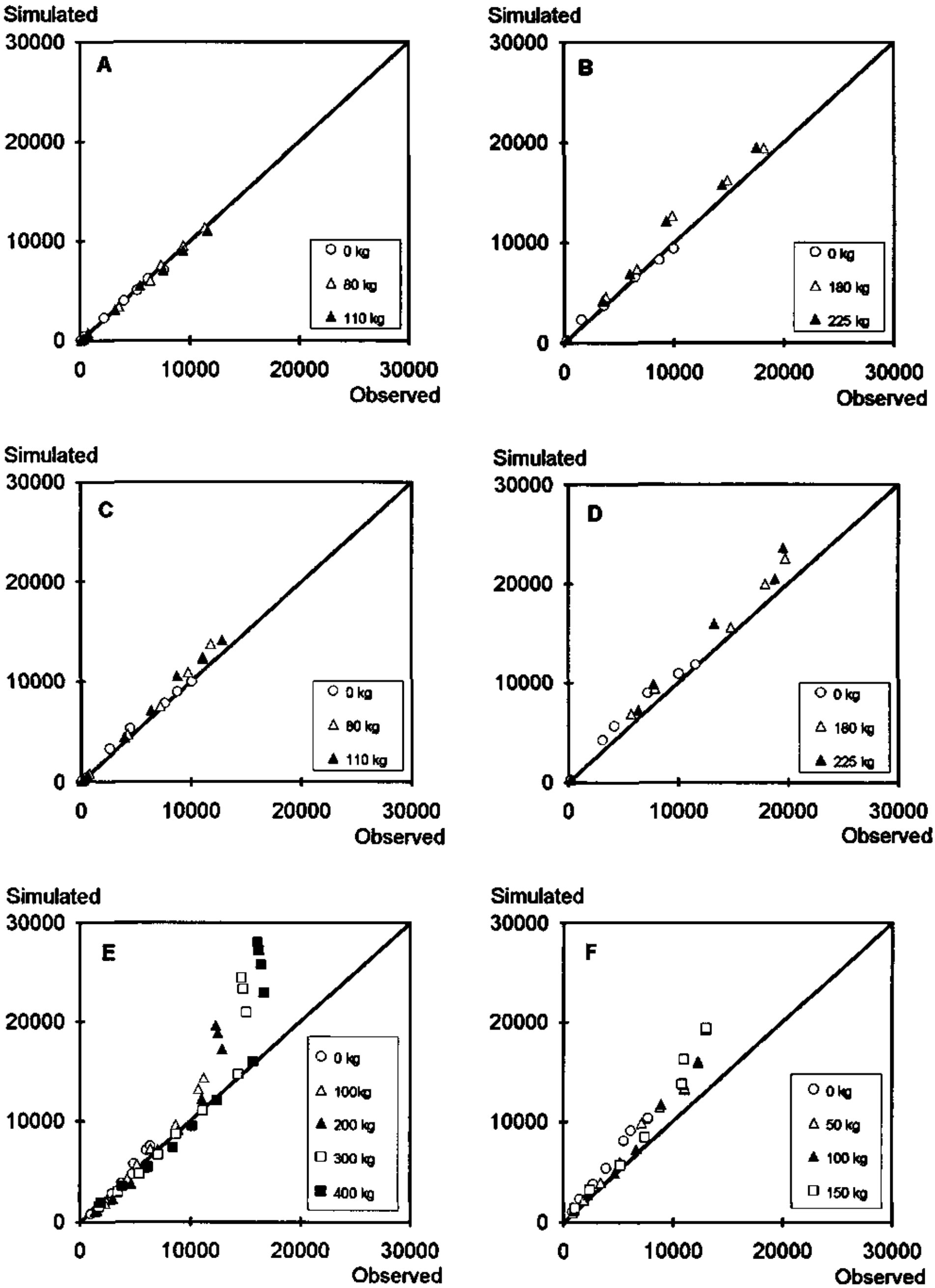

Figure 4.6 Total crop biomass (kg ha^{-1}), simulated versus observed at sampling dates. Data sets presented here: IRRI, Philippines, wet season 1991, varieties IR72 (A) and LINE (C); IRRI, dry season 1992, varieties IR72 (B) and LINE (D); TNRRI-TNAU, India, wet season 1988-1989, variety ADT 39 (E); CRRI, India, dry season 1990, variety IR36 (F).

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Appendix 1 Acronyms used in the ORYZA modules

Acronym	Explanation	unit
A	symmetry parameter of cumulative application curve	-
ACTLV	activity coefficient of leaves based on N content	-
ACTRT	activity coefficient of roots based on N content	-
ACTST	activity coefficient of stems based on N content	-
ALPHAN	slope of AMAX versus NPA	kg CO_2 ha^{-1} hr^{-1} (gN $m^{-2})^{-1}$
AMAXT	maximum rate of photosynthesis of single leaves (CO_2) at top of canopy	kg $ha^{-1}h^{-1}$
AN(LV,RT,ST)RE	total amount of N removed from leaves (LV), stems (ST) and roots (RT) due to negative AVAIL	kg ha^{-1} d^{-1}
ANCR(I)	amount of N in the crop (live and dead material) (initial)	kg ha^{-1}
ANCRF	amount of N in crop at flowering	kg ha^{-1}
ANLCR	amount of N in the crop (live material)	kg ha^{-1}
ANLD	amount of N in the dead leaves	kg ha^{-1}
ANLV(I)	amount of N in the leaves (initial)	kg ha^{-1}
ANLVCH	rate of N allocation to the leaves	kg ha^{-1} d^{-1}
ANLVMX	maximum amount of N in leaves	kg ha^{-1}
ANLVPH	amount of N in the leaves (measured or simulated) used for calculation of the photosynthesis in SUNPHO	kg ha^{-1}
ANRD	amount of N in the dead roots	kg ha^{-1}
ANRT(I)	amount of N in the roots (initial)	kg ha^{-1}
ANSO	amount of N in the storage organs	kg ha^{-1}
ANSOCH	rate of N allocation to grains	kg ha^{-1} d^{-1}
ANST(I)	amount of N in the stems (initial)	kg ha^{-1}
ANTOT(I)	total amount of N in the crop (live and dead material) (initial)	kg ha^{-1}
APCUM(I)	cumulative N application curve (initial)	kg ha^{-1}
APSLOP	daily fertilizer N application	kg ha^{-1} d^{-1}
AVAIL	net pool of N available for allocation on each day	kg ha^{-1} d^{-1}
B	slope parameter of cumulative N application curve	d^{-1}
C	asymptote level of cumulative N application curve	kg ha^{-1}
CBCHK	function for carbon balance check	-
CKCFL	sum of integrated carbon fluxes into and out of the crop	kg ha^{-1}
CKCIN	carbon in the crop accumulated since simulation started	kg ha^{-1}
CKNFL	sum of integrated N fluxes into and out of the crop	kg ha^{-1}
CKNIN	N in crop accumulated since simulation started	kg ha^{-1}
CNTI	carbohydrates needed to initiate and maintain 1 tiller	kg $ha^{-1}d^{-1}$
CNTIT	relation of CNTI to DVS	-
CO2LV	growth respiration of leaves	kg CO_2 kg^{-1}DM
CO2RT	growth respiration of roots	kg CO_2 kg^{-1}DM
CO2SO	growth respiration of storage organs	kg CO_2 kg^{-1}DM
CO2ST	growth respiration of stems	kg CO_2 kg^{-1}DM
CO2STR	growth respiration of shielded reserves	kg CO_2 kg^{-1}DM
CRDN	critical day number which affects the rate at which N uptake declines after fertilizer N-application	-

Acronym	Explanation	unit
CRG(LV,RT,SO,ST,STR,CR)	weight of carbohydrates required for dry matter growth of leaves (LV), roots (RT), storage organs (SO), stems (STS), shielded reserves (STR), crop (CR)	$kg\ kg^{-1}$
DAT	days after transplanting	d
DATEF	time of flowering in days after transplanting	-
DATEH	harvest date in days of year (DOY)	-
DATEX	dummy for printing	d
DATH	harvest date in days after transplanting	-
DATFF	date of first flowering in days after transplanting	-
DATFSV	date at which FSV shifts from FSV1 to FSV2	-
DELT	CSMP time period for integration	d
DEMAND	total crop demand of N	$kg\ ha^{-1}\ d^{-1}$
DNAP	day number of N applications	d
DNAPT	table of N application dates	-
DNOS	day number of crop sampling for N	-
DNOST	table of day numbers (DOY) at which NTOTMT was measured	-
DOY(S)	day of year=Julian date (at beginning of simulation)	d
DRR	development rate crop in reproductive (R) phase	d^{-1}
DTGA	photosynthesis canopy, gross, in current weather and physiological state, in CO_2	$kg\ CO_2\ ha^{-1}d^{-1}$
DTRP	number of days between sowing and transplanting	d
DVR	development rate crop in vegetative (V) phase	d^{-1}
DVRR	development rate crop in reproductive (R) phase	$(Kd)^{-1}$
DVRV	development rate crop in vegetative (V) phase	$(Kd)^{-1}$
DVS(I)	phenological development stage crop (initial)	-
DVSG1,2	DVS when grain formation starts (1), ends (2)	-
DVSGR	variable with value 1.0 during grain formation, else 0.0	-
DVST(1,2)	DVS when tiller formation starts (1), ends (2)	-
DVSTD	switch active during tiller formation, and 0.15 DVS units beyond	-
DVSTF	switch active during tiller formation	-
EFF	initial light use efficiency for individual leaves	$kg\ CO_2\ ha^{-1}\ h^{-1}$
EFFTB	table of EFF as a function of temperature	-
EPSIL	initial radiation use coefficient	$g\ MJ^{-1}$
EXCESS	excess of N in the crop (after allocation)	$kg\ ha^{-1}\ d^{-1}$
EXCPOL	pool of excess N	$kg\ ha^{-1}\ d^{-1}$
EXCTOG	amount of N from EXCESS translocated to the grains	$kg\ ha^{-1}\ d^{-1}$
F1	coefficient determining the N uptake rate after N application	-
FC(CR,LV,RT,SO,ST,STR)	fraction carbon of total dry mass in the crop (CR), leaves (LV), roots (RT), storage organs (SO) and stems (ST), shielded reserves (STR)	$kg\ kg^{-1}$
FERTMX	total fertilizer N input	$kg\ ha^{-1}$
FGHDAY	first sampling day of storage organs, expressed in days after transplanting	d
FLV	fraction of daily shoot dry matter increment allocated to leaves	-
FLVTB	tabulated FLV as function of DVS or DAT	-
FNCLV	fraction of total crop N present in leaves (preflowering)	$g\ g^{-1}$

Acronym	Explanation	unit
FNLV(I)	fraction of N in leaves (initial)	-
FNMAX	maximum overall fraction of N in total existing biomass	$g\ g^{-1}$
FNMAXT	tabulated FNMAX as function of DAT	$g\ g^{-1}$
FNRT(I)	fraction of N in roots (initial)	-
FNSO	fraction of N in storage organs	-
FNST(I)	fraction of N in stems (initial)	-
FRT	fraction of daily dry matter increment allocated to roots	-
FSH	fraction of daily dry matter increment allocated to shoots	-
FSHTB	tabulated FSH as function of DVS or DAT	-
FSO	fraction of daily shoot dry matter increment allocated to storage organs	-
FSOTB	tabulated FSO as function of DVS or DAT	-
FST	fraction of daily shoot dry matter increment allocated to stems including leaf sheaths	-
FSTR	fraction of stem weight at flowering that is remobilizable (shielded reserves)	$kg\ kg^{-1}$
FSTTB	tabulated FST as function of DVS or DAT	-
FSV	site-variety match factor	-
FSV1	site-variety match factor before flowering	-
FSV2	site-variety match factor after flowering	-
G(CR,LV,RT,SO,STR,STS,SH)	growth rate (dry matter) of the whole crop (CR), leaves (LV), roots (RT), storage organs (SO), shielded reserves (STR, starch), stems (STS) and shoot (SH)	$kg\ ha^{-1}d^{-1}$
GFP	grain filling period	d
GGRMN	minimal growth rate of one grain	$kg\ d^{-1}$
GGRMX	maximal growth rate of one grain	$kg\ d^{-1}$
GGRT	tabulated TEFG as function of TPAV	-
GMC	grain moisture content	-
GN(GR,TI)	growth of number of grains, tillers	$ha^{-1}d^{-1}$
GRUC	growth per unit incident radiation	$g\ MJ^{-1}$
GPR	grain:panicle biomass ratio	-
GSOM	maximum growth rate storage organs	$kg\ ha^{-1}d^{-1}$
GSTREX	extra growth rate shielded reserves (STR, starch) from excess of carbohydrates, which can not go to the grains	$kg\ ha^{-1}\ d^{-1}$
HI	harvest index (based on total biomass, including roots)	$kg\ kg^{-1}$
HU	daily heat unit for plant development	$(K\ d)\ d^{-1}$
HULV	daily heat unit for leaf development	$(K\ d)\ d^{-1}$
IDOY	integer value of DOY	d
ITRP	actual transplanting time	d
KDF	extinction coefficient for diffuse light	-
KDIFN	extinction coefficient for N in canopy	-
KDIFNP	dummy for KDIFN	-
KDIFT	tabulated KDIF as function of ALV	-
LAI(I)	leaf area index (initial)	-
LAIEXP	ALV in exponential growth phase	-
LAILNT	tabulated ln(LAI) vs. TSLV	-

Acronym	Explanation	unit
LAIOLD	leaf area at previous time step	-
LAIREF	Leaf area index reference	-
LARGE	dummy variable	-
LAT	latitude (south of equator negative values)	degree
LLV	rate of loss of leaf weight (dry matter)	kg $ha^{-1}d^{-1}$
LNTI	loss of number of tillers	$ha^{-1}d^{-1}$
LNUC	growth per day per unit leaf N	g g^{-1} d^{-1}
LRT	rate of loss of root weight (dry matter)	kg $ha^{-1}d^{-1}$
LSNR	leaf:stem nitrogen ratio	-
LSTR	loss rate of stem reserves (starch)	kg $ha^{-1}d^{-1}$
LRNR	leaf:root nitrogen ratio	-
M	time shift parameter of cumulative application curve	d
M12345	actual demand, equals the minimum value of all limitations	kg ha^{-1} d^{-1}
MAINLV	maintenance respiration coefficient of leaves	kg CH_2O kg^{-1} DM d^{-1}
MAINRT	maintenance respiration coefficient of roots	kg CH_2O kg^{-1} DM d^{-1}
MAINSO	maintenance respiration coefficient of storage organs	kg CH_2O kg^{-1} DM d^{-1}
MAINST	maintenance respiration coefficient of stems	kg CH_2O kg^{-1} DM d^{-1}
MAXDAT	number of days in exponential N uptake phase (DAT)	-
MAXNCR	maximum amount of N in crop during exponential N uptake phase	kg ha^{-1} d
MAXUP0	maximum N uptake rate during exponential growth phase	kg ha^{-1} d^{-1}
MAXUP1	maximum daily N uptake	kg ha^{-1} d^{-1}
MAXUP2	N uptake rate as limited by the maximum N fraction per unit new dry matter	kg ha^{-1} d^{-1}
MAXUP3	N uptake rate as limited by maximum overall fraction of N in total existing biomass	kg ha^{-1} d^{-1}
MAXUP4	N uptake rate as limited by the maximum bulk amount leaf N reached	kg ha^{-1} d^{-1}
MAXUP5	N uptake rate as limited by nearing maturity stage	kg ha^{-1} d^{-1}
MF1	initial leaf nitrogen use coefficient before flowering	g d^{-1} g^{-1}
MF2	initial leaf nitrogen use coefficient after flowering	g d^{-1} g^{-1}
NA	number of N application dates	-
NA(LV,RT,ST)	N acquisition by leaves (LV), roots (RT), stem (ST)	kg ha^{-1} d^{-1}
NAPPLD	total amount of N applied	kg ha^{-1}
NAVAIL	total N availability (soil and fertilizer)	kg ha^{-1} d^{-1}
NB	min N concentration leaf at AMAX=0	g m^{-2}
NDEM(G,L,R,S)	N demand of grains (G), leaves (LV)	kg ha^{-1} d^{-1}
NDEMGX	maximum N demand of the storage organs	kg ha-1 d-1
NDEMT	total N demand of crop	kg ha^{-1} d^{-1}
NDEMV	N demand of leaves plus stems and roots	kg ha^{-1} d^{-1}
NGR(MX,P)	number of grains (maximum, potential)	ha^{-1}
NHRVST	total N uptake at harvest	kg ha^{-1}
NL	leaf N, as ANLV, but expressed in g m^{-2}	g m^{-2}
NL1	simulated amount of N in the leaves (NL)	g m^{-2}
NL2	measured amount of N in the leaves (NL)	g m^{-2}
NLD(LV,RT)	N loss rate due to death of leaves(LV) and roots(RT)	kg $ha^{-1}d^{-1}$
NLSINT	N loss due to death of leaves and roots	kg ha^{-1}

Acronym	Explanation	unit
NMAX(L,R,S,SO)	maximum N fraction in leaves (L), roots (RT), stems (S), storage organs (SO) at given DVS	kg kg^{-1}
NMAX(LX,RX,SX)	absolute maximum of NMAX(LT,RT,ST) over whole season	kg kg^{-1}
NMAXLT	relation of NMAXL to DVS	kg kg^{-1}
NMIN(L,R,S,SO)	minimum N concentration in leaves (L), roots (R), stems (S), storage organs (SO) at given DVS	kg kg^{-1}
NMINLT	relation of NMINL to DVS	-
NMNSOT	table of NMINSO as function of amount of N in the crop at flowering (ANCRF)	kg kg^{-1}
NS	number of sampling dates for total N in the crop	-
NSUPG	rate of N supply to grains	kg ha^{-1} d^{-1}
NT(LV,RT,ST)	N translocated from leaves (LV), roots (RT) and stems (ST)	kg ha^{-1} d^{-1}
NTI	number of tillers, including number of main stems (NTII)	ha^{-1}
NTIP	potential number of tillers (limited by carbohydrates)	ha^{-1}
NTOTM	total N in crop measured (cumulative uptake), forcing function	kg ha^{-1}
NTOTMT	tabulated NTOTM	kg ha^{-1}
NUPCO	maximum ratio of daily N uptake to growth	g g^{-1}
NUPNEG	'negative N uptake' counter	kg ha^{-1} d^{-1}
NUPT	N uptake rate	kg ha^{-1} d^{-1}
NUPT	N uptake rate by crop	kg ha^{-1} d^{-1}
NUPTOT	total N uptake, cumulative since initial	kg ha^{-1}
NUPTP	potential N uptake	kg ha-1 d-1
P	initial leaf nitrogen use coefficient	g g^{-1} d^{-1}
PCGT	DTGA totalled since start of simulation	kg ha^{-1}
PLNUM	number of plants	ha^{-1}
Q10	Q10 of maintenance respiration sensitivity to temperature	-
RADTOI	initial cumulative radiation (= 0)	MJ m^{-2} d^{-1}
RADTOT	cumulative radiation	MJ m^{-2}
RCRT	respiration crop, totalled (in CO_2)	kg ha^{-1}
RDD	radiation, daily total global, measured	J m^{-2} d^{-1}
RDM	radiation, daily total global, measured	MJ m^{-2} d^{-1}
RDR	relative death rate root and leaf	d^{-1}
RDT	radiation, daily total global, measured	J $m^{-2}d^{-1}$
RECOV	best attainable recovery	g g^{-1}
RECT	tabulated RECOV as function of DAT	g g^{-1}
REDFT	factor accounting for effect of temperature on AMAX	-
REDFTT	table of REDFT as function of temperature	-
RELTME	days after transplanting relative to time of flowering as expressed in days after transplanting	-
RFNLV	residual N fraction of leaves	kg kg^{-1}
RFNRT	residual N fraction of roots	kg kg^{-1}
RFNST	residual N fraction of stems	kg kg^{-1}
RGCR	respiration (in CO_2) due to growth of the whole crop (CR)	kg $ha^{-1}d^{-1}$
RGRL	relative growth rate of leaf area per degree day	$(K\ d)^{-1}$
RLRLV	relative loss of leaf weight (dry matter)	d^{-1}
RLRRT	relative loss of root weight (dry matter)	d^{-1}

Acronym	Explanation	unit
RM(CR,LV,RT,SO,ST)	maintenance respiration (CH_2O) of whole crop(CR), leaves (LV), roots (RT), storage organs (SO), stems (ST)	kg $ha^{-1}d^{-1}$
RMCCO2	maintenance respiration (CO_2) of whole crop	kg $ha^{-1}d^{-1}$
RMMA	maintenance respiration due to metabolic activity (CH_2O)	kg $ha^{-1}d^{-1}$
RNEFF	growth per unit radiation and unit leaf N	g g^{-1} (MJ $m^{-2})^{-1}$
RSR	root:shoot ratio	-
RSRT	tabulated RSR as a function of DAT related to DATEF	-
RTINCL	setting to indicate whether root biomass is measured (ORYZA-0)	-
RTILT	relation of relative tillering capacity to N content of leaves	
RUR	relative nitrogen uptake rate	d^{-1}
SAI	stem area index	ha ha^{-1}
SCP	scattering coefficient of leaves for PAR	J m^{-2} s^{-1}
SHCKD	degree day delay per unit of seedling age	K d
SLA	specific leaf area	ha kg^{-1}
SLAC	specific leaf area constant	ha kg^{-1}
SLAFAC	tabulated relation of SLA to DVS	-
SOLSUP	native soil N supply	kg ha^{-1} d^{-1}
SSA	specific stem area	ha kg^{-1}
SSGA	specific green stem area	ha kg^{-1}
SSGATB	table of SSGA as function of DVS	-
STTIME	starting time of simulation (day of year)	d
SWIEXP	switch to define the end of exponential uptake phase	-
SWIFLO	dummy switch, used to determine the time of flowering	-
SWILAI	switch for choosing calculation of leaf area	-
SWINLV	switch for choosing measured or simulated amount of N in the leaves (in ORYZA_0)	-
SWINPH	switch for choosing measured or simulated amount of N in the leaves for calculation of photosynthesis	-
SWINPR	switch for choosing N profile in canopy	-
SWINUP	switch for choosing N input option	-
SWISAI	switch to include or exclude stem area in leaf area	-
SWISIN	switch for choosing sink limitation	-
TAV(D)	actual air temperature at each DTIME (A), in daytime (D) and 24h average (V)	°C
TBD	base temperature for plant development	°C
TBLV	base temperature for leaf development	°C
TCDT	time coefficient for loss of tillers	d
TCFG	time coefficient for formation of grains	d
TCFT	time coefficient for formation of tillers	d
TCLSTR	time coefficient for loss of stem reserves	d^{-1}
TCNA	time coefficient for N acquisition	d
TCNT	time coefficient for N translocation	d
TEFF	temperature effect on maintenance respiration	-
TEFG	relation of temperature to growth rate of grains	-
TIL	maximum number of tillers per plant at given leaf N content	-
TILMX	maximum number of tillers per plant	-

Acronym	Explanation	unit
TMN	minimum night temperature	°C
TMX	maximum day temperature	°C
TREATM	character string send to the output file, containing the title of the experiment	-
TREF	reference temperature for maintenance respiration	°C
TS(I)	temperature sum for plant development(initial)	K d
TSHCKD	transplanting shock for phenological development	K d
TSLV(C)	temperature sum for leaf development (constant)	K d
TSTR	temperature sum for phenological development at transplanting	K d
WCR (I)	weight crop (shoot plus storage organs, roots) (initial)	kg ha^{-1}
WGR(MX)	average weight of a grain, filled plus unfilled (maximum)	kg
WLV	weight of the leaves	kg ha^{-1}
WLVD	weight dead leaves	kg ha^{-1}
WLVEXP	WLV during exponential phase of leaf area development	kg ha^{-1}
WLVG(I)	weight green leaves (initial)	kg ha^{-1}
WRR	weight rough rice	kg ha^{-1}
WRT	weight of the roots (live and dead)	kg ha^{-1}
WRTD	weight dead roots	kg ha^{-1}
WRTL(I)	weight live roots (initial)	kg ha^{-1}
WSHG	sum of WLVG, WSTS, WSTR and WSO (live shoot)	kg ha^{-1}
WSHT	sum of WLVG, WLVD, WST, WSTR and WSO (total shoot)	kg ha^{-1}
WSO	weight storage organs	kg ha^{-1}
WSTR	weight of shielded reserves (starch) in stem	kg ha^{-1}
WSTS(I)	weight stems (initial) minus WSTR contained in it	kg ha^{-1}
WSTT	weight stem plus shielded reserves	kg ha^{-1}
XXLAI	measured LAI	ha ha^{-1}
XXNCR	measured N content in crop	kg ha^{-1}
XXNLCR	measured N content in live plant organs	kg ha^{-1}
XXNLD	measured N content in dead leaves	kg ha-1
XXNLV	measured N content in the leaves	kg ha^{-1}
XXNRT	measured N content in the roots	kg ha^{-1}
XXNSO	measured N content in the storage organs	kg ha^{-1}
XXNST	measured N content in the stems	kg ha^{-1}
XXWCR	measured weight of crop	kg ha^{-1}
XXWLVD	measured weight of dead leaves	kg ha^{-1}
XXWLVG	measured weight of leaves	kg ha^{-1}
XXWRTL	measured weight of roots	kg ha^{-1}
XXWSO	measured weight of storage organs	kg ha^{-1}
XXWSTS	measured weight of stems	kg ha^{-1}

Appendix 2 Input required for the ORYZA_N modules

Three separate data files are needed to run the ORYZA_N modules: a WEATHER, TIMER and CROP data file. This section gives a list of the parameters and data needed as input in these files. An example of these files is given in Appendix 6.

Acronym	Explanation	unit
Weather data file		
latitude		degree
altitude		m
maximum day temperatures during a year		°C
minimum night temperatures during a year		°C
daily total global radiation during year		sunshine h or kJ m^{-2} d^{-1}
Crop data files		
FGHDAY	first sampling day of storage organs, expressed in days after transplanting (DAT, real value)	d
DTRP	time between seeding and transplanting	d
DATH	harvest date in days after transplanting	-
RADTOI	initial cumulative radiation (= 0)	MJ m^{-2} d^{-1}
WLVGI	initial weight of green leaves	kg ha^{-1}
WRTLI	initial weight of roots	kg ha^{-1}
WSTSI	initial weight of stems	kg ha^{-1}
FNLVI	initial fraction of N in leaves (mass basis)	-
FNRTI	initial fraction of N in roots (mass basis)	-
FNSTI	initial fraction of N in stems (mass basis)	-
DVSI	initial phenological development stage	-
TSI	initial temperature sum for plant development, starting from seeding onwards	K d
FSTR	fraction of stem weight at flowering that is remobilizable	kg kg^{-1}
DVRV	development rate crop in the vegetative stage	$(K\ d)^{-1}$
DVRR	development rate crop in the reproductive stage	$(K\ d)^{-1}$
SLAC	specific leaf area constant (if LAI is available)	ha kg^{-1}
SLAFAC	tabulated relation of SLA/SLAC ratio to DVS (if LAI is available)	-
LAI	leaf area index	-
NS	number of sampling dates for total N in the crop	-
DNOST	table of day numbers (DOY) at which NTOTMT was measured	-
NTOTMT	total amount of N measured in crop biomass (including roots) (cumulative uptake)	kg ha^{-1}
NA	the number of nitrogen application dates	-
DNAPT	day number of nitrogen applications	d
WLVG	tabulated measured weight of the leaves	kg ha^{-1}
WLVD	tabulated measured weight of the dead leaves	kg ha^{-1}

Acronym	Explanation	unit
WRTL	tabulated measured weight of the roots	kg ha^{-1}
WSO	tabulated measured weight of the storage organs	kg ha^{-1}
WSTS	tabulated measured weight of the stems	kg ha^{-1}
ANLV	tabulated measured N content in leaves	kg ha^{-1}
ANLD	tabulated measured N content in dead leaves	kg ha^{-1}
ANRT	tabulated measured N content in roots	kg ha^{-1}
ANSO	tabulated measured N content in storage organs	kg ha^{-1}
ANST	tabulated measured N content in stems	kg ha^{-1}
FLVTB	tabulated FLV as function of DVS or DAT	-
FSHTB	tabulated FSH as function of DVS or DAT	-
FSTTB	tabulated FST as function of DVS or DAT	-
FSOTB	tabulated FSO as function of DVS or DAT	-
Timer file		
STTIME	Start time of simulation in day of year (DOY)	d
FINTIM	Finish time	d
IOBSD	List of harvest data for which output is required	d
PRSEL	Definition of a selective output of a part of the variables.	-
SWILAI	switch for choosing calculation of leaf area	-
SWINPH	switch for choosing measured or simulated amount of N in the leaves for calculation of photosynthesis	-
SWINPR	switch for choosing N profile in canopy	-
SWINUP	switch for choosing N input option	-
SWISAI	switch to include or exclude stem area in leaf area	-
SWISIN	switch for choosing sink limitation	-

Appendix 3 Determination of parameters, functions and tables used in ORYZA_N

This appendix illustrates how the various parameters, functions and tables can be derived and specified in the proper format.

Weather data file

The weather data should be in the WEATHER format, suitable for the FSE programs. The WEATHER format was developed jointly at the Research Institute for Agrobiology and Soil Fertility (AB-DLO) and the department of Theoretical Production Ecology of the Wageningen Agricultural University (van Kraalingen et al., 1991).

Timer file

Type a timer file like the example in Appendix 6, including:

STTIME
Give the day of transplanting as the starting time as Day of Year

DTRP
Give the number of days between sowing and transplanting (in days)

IOSBD
Give the year and the days on which you sampled and from which you like to have output. The format for this is: YEAR, DOY, YEAR, DOY, YEAR, DOY etc. See also example in Appendix 6.

FINTIM
Give a finish time for the simulation.

PRSEL
With the PRSEL parameter you can define a selective output of a part of the variables. If you do not use the PRSEL parameter, all the variables will be in the output file. PRSEL gives you the possibility to only send a selection of the variables to the output file. See also Appendix 6.

SWILAI	= 1:	use of simulated leaf mass and SLA
	= 2:	use of tabulated (measured) ln(LAI) vs. temperature sum
	= 3:	use of relative growth rate for leaf area, RGRL, during exponential stage, and SLA afterwards
	= 4:	use of measured leaf mass and SLA

	= 5:	use of measured LAI
SWINPH	= 0:	use of measured amount of nitrogen in leaves for photosynthesis calculation
	= 1:	use of simulated amount of nitrogen in leaves for photosynthesis calculation
SWINPR	= 0:	no nitrogen profile in canopy; uniform distribution
	= 1:	nitrogen profile in canopy; with extinction coefficient KDIFN
SWINUP	= 1:	nitrogen limited production; N uptake as forcing function
	= 2:	potential production; N uptake equals demand
SWISAI	= 0:	stem area is NOT included in leaf area
	= 1:	stem area is included in leaf area
SWISIN	= 1:	no sink limitation; no GSOM
	= 2:	sink limitation; GSOM is calculated from tiller and grain number

Crop data file

FGHDAY

FGHDAY is the first day on which storage organs are sampled. It is expressed in days after transplanting (DAT)

DVSI & TSI

If simulation starts at transplanting date the DVSI and TSI are needed. Both can be calculated with the program DRATES in FORTRAN (Kropff et al., 1994), which is available at the SARP project.

FSTR

The fraction of stem weight at flowering, that is remobilizable, can be calculated as follows:

$$\mathrm{FSTR} = \frac{(\text{maximum measured weight of the stems - weight of the stems at harvest})}{\text{maximum measured weight of the stems}}$$

Example:

DAT	WSTS
40	3000
50	4000
60	5000
70	4500
80	3500

FSTR =(5000 - 3500) / 5000 = 0.3

DVRV & DVRR

The development rates in the vegetative and reproductive stages can be calculated with the program DRATES in FORTRAN (Kropff et al., 1994), available at the SARP project.

SLAC & SLAFAC

If leaf area is measured the SLAC and SLAFAC can be calculated. Otherwise the standard SLAC and SLAFAC is used.

SLAC

Specific leaf area constant is the specific leaf area at flowering, calculated as follows:

$$SLAC = \frac{\text{measured LAI at flowering}}{\text{measured WLVG at flowering}}$$

SLAFAC

The relation of the specific leaf area to development stage is expressed in the SLAFAC. The SLAFAC is the SLA at time t divided by the SLA at flowering.

$$SLAFAC = \frac{(LAI_t / WLVG_t)}{SLAC_{flowering}}$$

Write the values of SLAFAC in relation to DVS in a table :
SLAFAC = (0.0, 1.72), (0.30, 1.60),............,(2.0,0.75)

NOTE: include a dummy value at DVS = 0 and DVS = 2.1

NS

The number of sampling dates for total N in the crop (NTOTMT).

DNOST

Table of day numbers (DOY) at which NTOTMT was measured. The last figure in the table should be the harvest date or just after. For seasons across January 1st , day numbers proceed as 365., 366., 367., 368. etc. until the end of the season.

NTOTMT

The total N in crop measured (cumulative uptake), at the days specified in DNOST. The last figure of the table NTOTMT should be the total amount of N in the crop at harvest.

NA

The number of nitrogen application dates, includes basal dressing at planting/seeding, and a dummy date after harvest.

DNAPT

The day numbers (DOY) of nitrogen application are specified in table DNAPT. The first figure in the table is equal to DOYS; also in absence of basal dressing. The last figure should be any date after harvest! For seasons across January 1st , day numbers proceed as 365., 366., 367., 368. etc. until the end of the season. NOTE: if you have no nitrogen application you still have to give two dates: DOYS and any date after harvest. In this case do not forget to give two for the number of applications (NA)

Partitioning: FLVTB, FSTTB, FSOTB, FSHTB

A procedure to calculate the partitioning tables (see also ORYZA1, Kropff et al., 1994):

1. Calculate DVS for sampling dates with the program DRATES in FORTRAN (Kropff et al., 1994) (available at the SARP project).

2. Make a table including sampling date, development stage (DVS), weight of leaves (WLVG), stems (WSTS), storage organs (WSO), totals and the difference in weight between two harvests (see for example Table A3.1).

Table A3.1 Example of partitioning calculation.

sampling date (d)	DVS	*mean* DVS	WLVG (kg ha^{-1})	*ΔWLVG*	WSTS (kg ha^{-1})	*ΔWSTS*	WSO (kg ha^{-1})	*ΔWSO*	WSHG (kg ha^{-1})	*ΔWSHG*
100	0.8		2000		4000		0		6000	
		0.9		*500*		*2000*		*0*		*3500*
120	1.0		2500		6000		1000		9500	
		1.1		*0*		*0*		*2000*		*2000*
140	1.2		2500		6000		3000		11500	
		1.3	(1800)	*0*	(5000)	*0*		*2000*		*2000*
160	1.4		2500		6000		5000		13500	
			(1000)		(4000)					

In this example, after flowering (DVS=1) there is no increase in leaves and stems.

3. Calculate the mean DVS for the period between two harvests and divide the individual increase in weight per organ by the total increase in weight (WSHG).

DVS	FLV	FST	FSO
0.9	500/3500 = 0.14	2000/3500 = 0.57	1000/3500 = 0.29
1.1	0/2000 = 0.00	0/2000 = 0.00	2000/1000 = 1.00
1.3	0/2000 = 0.00	0/2000 = 0.00	2000/1000 = 1.00

4. Write these fractions in the partitioning tables, as a function of DVS:

   FLVTB = 0.90,0.11 , 1.10,0.00 ,..............., 2.10,0.00
   FSTTB = 0.90,0.59 , 1.10,0.00 ,..............., 2.10,0.00
   FSOTB = 0.90,0.00 , 1.10,1.00 ,..............., 2.10,1.00

5 If root mass is measured, FSH can be calculated:
   - Include in Table A3.1 a column with the weights of the roots.
   - Calculate the total weight of dry mass (including the root mass) WCR.
   - Calculate the increase in weight of the total dry mass (WCR).
   - Divide the increase in shoot weight (WSHG = WSTS + WLVG + WSO) by the increase in weight of total dry mass (WCR).

6 Grain filling starts at 10 days before flowering, therefore the FSO remains zero until 10 days before flowering. For this a dummy value is included in the FSO at 10 days before flowering.

7 NOTE: include dummy values at DVS = 0. and DVS = 2.1, to prevent extrapolation.

WLVG, WLVD, WSTS, WRTL, WSO
Write the weights of the plant organs in tables in relation to the year, and day of year (DOY). See for the format the example file in Appendix 6.

ANLV, ANLD, ANST, ANRT, ANSO
Write the weights of the amount of nitrogen in plant organs in a table related to the year and the day of the year (DOY). See for the format the example file in Appendix 4.

WSO
Approximately 10 to 15 days before flowering the panicle initiation starts. To establish this within the interpolation of the measured weights of the storage organs a dummy value of zero at 10 days before flowering should be included in WSO.

Appendix 4 Input required for the ORYZA_0 modules

Three separate data files are required to run the ORYZA_0 modules: a weather, crop data and timer file. This section gives a list of the parameters and data needed as input in these files. An example of these files is given in Appendix 6.

Acronym	Explanation	unit
Weather data file		
latitude		degree
altitude		m
daily total global radiation during year		sunshine h or kJ m^{-2} d^{-1}
Crop data files		
A	symmetry parameter of cumulative application curve	-
ANCRI	initial amount of N in the crop	kg ha^{-1}
ANLVMX	maximum amount of N in leaves	kg ha^{-1}
APCUMI	initial cumulative application (= 0)	kg ha^{-1}
B	slope parameter of cumulative N application curve	d^{-1}
C	asymptote level of cumulative N application curve	kg ha^{-1}
DATEF	time of flowering in days after transplanting	-
DATFF	date of first flowering in days after transplanting	-
DATFSV	date at which FSV shifts from FSV1 to FSV2	-
DATH	harvest date in days after transplanting	-
FERTMX	total fertilizer N input	kg ha^{-1}
FNCLV	fraction of total crop N present in leaves (preflowering)	g g^{-1}
FNLV	fraction of N in leaves	-
FNMAXT	tabulated FNMAX as function of DAT	g g^{-1}
FNSO	fraction of N in storage organs	-
FSV1	site-variety match factor before flowering	-
FSV2	site-variety match factor after flowering	-
HI	harvest index (based on total biomass, including roots)	kg kg^{-1}
M	time shift parameter of cumulative application curve	d
MAXUP1	maximum absolute N uptake rate	kg ha^{-1} d^{-1}
NUPCO	maximum ratio of daily N uptake to growth	g g^{-1}
RADTOI	initial cumulative radiation (= 0)	MJ m^{-2} d^{-1}
RECT	tabulated RECOV as function of DAT	g g^{-1}
RSRT	tabulated RSR as a function of DAT related to DATEF	-
RTINCL	setting to indicate whether root biomass is measured	-
RUR	relative nitrogen uptake rate	d^{-1}
SOLSUP	native soil N supply	kg ha^{-1} d^{-1}
WCR	weight crop (shoot plus storage organs, roots)	kg ha^{-1}
WCRI	initial weight of the crop	kg ha^{-1}
WLV	weight of the leaves	kg ha^{-1}
Timer file		
STTIME	Start time of simulation in day of year (DOY)	d
FINTIM	Finish time	d
IOBSD	List of harvest data for which output is required	d
PRSEL	Definition of a selective output of a part of the variables.	-
SWINLV	switch for choosing measured or simulated amount of N in the leaves (in ORYZA_0)	-

Appendix 5 Determination of parameters and tables used in ORYZA_0

1 Weather variables

The model uses only one daily weather variable, R:

symbol	acronym	description	unit
R	RDT	the incident daily global radiation	MJ m^{-2} d^{-1}

Radiation is the main driving variable for dry matter production. Daily global radiation data are contained in the standard WEATHR data files and are inserted into the model with the help of the WEATHR system. Within the model the unit is converted from kJ m^{-2} d^{-1} to MJ m^{-2} d^{-1}. (If no measured global radiation data are available, daily sunshine duration (h) can be used. WEATHR takes care of the conversion to kJ m^{-2} d^{-1} when the values of the radiation conversion parameters a and b). For more details on the WEATHR system, the reader is referred to van Kraalingen et al. (1991).

2 System parameters

Note: The units of input parameters in the model description (Chapter 3) may be different from those in model input files. This is to avoid conversion factors in presenting the theory. In the actual algorithm, the conversion from g m^{-2} to kg ha^{-1}, and vice versa, is necessary. This is the consequence of combining two conventions: growth, N uptake and N application are usually expressed in kg ha^{-1} d^{-1}. Radiation is expressed in MJ m^{-2} d^{-1}.

2.1 Parameters denoting key dates

symbol	acronym	description	unit
t_{TP}	STTIME	calendar day of planting	d
t_{FF}	DATFF	time of first flowering in days after transplanting	d
t_H	DATH	time of harvest in days after transplanting	d

(unit = as used in algorithm)

STTIME is the date of transplanting and also the starting date for a simulation run. Initial state values used in the model refer to this date. DATFF is important because the remobilization of nitrogen from leaves to panicle occurs from DATFF onward up to harvest. DATFF therefore marks a transition in leaf N allocation (from Eqn 3.7 to Eqn 3.9 - 3.10). The simulation stops when DATH is passed.

2.2 Crop and soil parameters

symbol	acronym	description	unit
ε	EPSIL	initial global radiation use coefficient	g MJ^{-1}
p	P	initial leaf nitrogen use coefficient	g g^{-1} d^{-1}
f_{SV}	FSV1	site-variety match factor (before flowering)	-
	FSV2	site-variety match factor (after flowering)	-
n_p	FNSO	fraction nitrogen in grain (incl. panicle)	-
f_N	FNCLV	fraction of total crop nitrogen present in leaves (pre-flowering)	g g^{-1}
$N_{L,max}$	ANLVMX	maximum amount of nitrogen in leaves	kg ha^{-1}
u_N	MAXUP1	maximum daily nitrogen uptake	kg ha^{-1} d^{-1}
q_N	NUPCO	maximum ratio of daily N uptake to growth	g g^{-1}
r_N	RUR	relative nitrogen uptake rate	d^{-1}
$c_{max}(t)$	FNMAXT	maximum N concentration (in mean crop biomass) table vs. time	g g^{-1}
I_H	HI	harvest index, grain yield divided by total crop biomass (incl. roots; grain 0% moisture)	kg kg^{-1}
S_N	SOLSUP	native soil N supply	kg ha^{-1} d^{-1}
$\rho(t)$	RECT	fertilizer N recovery table vs. time	g g^{-1}

(unit = as used in algorithm)

At the moment we do not know which of the above parameters have universal values, i.e. are constant for all sites, weather conditions and varieties. Likewise, in some cases it is not clear whether a coefficient is a crop or soil characteristic, or a result of interactions between these two. That, however, should be no discouragement. More will be discovered about the nature of these coefficients by determining their values for many data sets. Meanwhile, the ORYZA_0 model can actually be applied using these empirical coefficients as inputs, to optimize fertilizer use.

This section describes each input parameter, its derivation from observations, and its variability to the extent now acknowledged. It is hoped that soon more insights in most of these parameters will be obtained, based upon analysis of existing data sets collected at the SARP sites.

ε, p and f_{SV} (EPSIL, P, FSV1, FSV2)

The parameters ε and p are taken to be constants. Values of 2.5 g MJ^{-1} for ε and 10.0 g g^{-1} d^{-1} for p were found as averages over 8 experiments at 3 sites covering a total of 70 treatments. Taking the parameters ε and p as constant, the site-variety factor f_{SV} serves as a matching factor to account for local conditions, and is obtained by calibration (see Section 2.3 of this appendix). In some cases, the value of f_{SV} before flowering is different from f_{SV} after flowering. The pre-flowering value is named FSV1, the post-flowering value FSV2.

n_P (FNSO)
This parameter is directly found by analyzing panicle plus grains for nitrogen. The nitrogen content gradually decreases, however, during grain filling. Another complication is that n_P often depends on fertilizer application level. It certainly varies also among varieties. It is therefore important that a realistic mean value, for the variety under consideration, is used in the optimization calculations. If no information is available, a default value of 0.012 can be used as approximation. It should be noted that n_P applies to the whole panicle and is therefore always lower than the grain N concentration.

f_N (FNCLV)
To determine this parameter, all pre-flowering observations of total leaf nitrogen (kg N ha^{-1}ground surface; Y-axis) are plotted versus total crop nitrogen uptake N_c (kg N ha^{-1}ground surface; along X-axis). The average slope of the ensuing relation is f_N. It is important to exclude post-flowering data, because the relation leaf N: crop N vanishes after flowering.

$N_{L,max}$ (ANLVMX)
The total amount of leaf N is probably bound to a maximum. The highest values found so far are roughly 100 kg N ha^{-1}. Determine the value by multiplying leaf dry matter with leaf N content. Obviously, this should only be done for the higher N application levels. Best is to take two or three treatments: sometimes the maximum N treatment suffers from diseases or other problems.

u_N (MAXUP1)
The maximum daily nitrogen uptake u_N is determined by calculating, again for a few of the highest N application levels, the rate of uptake over time intervals. This is done by dividing ΔN_c (the total crop N increment between two sampling dates, in kg N ha^{-1}) by the duration of the sampling interval, i.e. the time Δt between the two sampling dates. (The symbol Δ denotes a difference between two values). This is repeated for all sampling intervals. This can be done for both pre- and post-flowering cases. The resulting u_N values are plotted vs. time, using the centre of each sampling interval as the mean time corresponding to that interval. The maximum value is used as u_N. (Of course, u_N has a meaning only if ample N was available for uptake).
Climate and soil may have a strong influence on u_N, although relations have not yet been established. Values as high as 8 kg N ha^{-1} d^{-1} are rarely found. Values of 3 - 5 kg N ha^{-1} d^{-1} are found more commonly. The ORYZA_0 simulation studies made on the

basis of experimentally determined coefficients indicate that u_N is, in many cases, the most important limitation to N uptake during a major part of the growth cycle.

q_N (NUPCO)

This maximum ratio of daily N uptake to growth is calculated again as a mean value over a sampling interval Δt. It is found by dividing the corresponding increment of crop N uptake, ΔN_c, by the crop biomass (incl. roots!) increment ΔW. This parameter has a physiological background: the crop cannot absorb N at infinite rate, even in cases of severe N stress, because N is assimilated into structures requiring carbon. So the rate of carbon assimilation is very likely to limit the potential N uptake rate. We have, so far, found q_N values up to 0.035 kg N kg^{-1} dry matter, but more information from different sites and varieties is needed. This coefficient is to be derived for treatments with high N application; and both to high-N and low-N antecedent crop status.

r_N (RUR)

The relative nitrogen uptake rate is determined by plotting the natural logarithm of total crop N uptake, $\ln(N_c)$, vs. time. The first part of this relation, covering 2-3 weeks, is usually a straight line. The slope of this linear section is r_N. This is done only for treatments where the crop had ample nitrogen available from transplanting onward. Values up to 0.2 d^{-1} have been found so far.

$c_{max}(t)$ (FNMAXT)

The maximum N concentration (in the mean crop biomass) is calculated as total crop nitrogen uptake N_c (kg N ha^{-1}) divided by total crop biomass (incl. roots) W (kg ha^{-1}). (Not as the mean value of the distinguished organ tissue concentrations!), and is plotted vs. time. c_{max} is a function of time and is defined in the model as a table, where the first value of each pair is time, the second is c_{max}:

```
FNMAXT= 0.,0.030, 70.,0.020, 100.,0.015, 130.,0.010
```

The model obtains the daily values of c_{max} by linear interpolation between these values with the help of the LINT function. Probably, this variable differs among varieties. Note: Since values are tabulated vs. time - not developing stage - these tables are certainly different for varieties of different growth duration.

I_H (HI)

The harvest index is here defined as grain yield (0% moisture) divided by total crop biomass (incl. roots). The results obtained in SARP so far have shown that I_H is always close to 0.50 except under very extreme N application schemes. Also, deviations may be expected if the mean radiation level increases or decreases gradually during the growing season. This happens at the transitions from wet to dry season and vv. I_H can be analyzed easily for each experiment and this should be done as a standard practice. This will provide information on seasonal dependence. Also, if problems occur during grain filling (cold, pests low spikelet viability, low spikelet numbers), the occurrence of a low I_H serves as a first signal.

S_N (SOLSUP)

The supply of N by the soil without fertilizer is assessed from plots which received no fertilizer N.

As a first approximation, we suggest to take total crop N uptake N_c (kg N ha^{-1}) divided by the number of field days. This gives the mean daily N supply rate. In reality, supply rates fluctuates over time but we have little information about this, and patterns will probably be not general. In ORYZA_0 this aspect is ignored because of lack of experimental data.

$\rho(t)$ (RECT)

Fertilizer-N recovery is a complex variable to predict, because it is affected by many crop and soil processes. It is, on the other hand, easy to determine. It is the fraction of applied fertilizer which is absorbed by the crop. We correct for soil-N supply by subtracting from total crop uptake, N_c, the amount of N taken up by an unfertilized crop.

The seasonal overall recovery is easily determined. Unfortunately, we need to know its course over time, $\rho(t)$. Excluding here the experimental use of N^{15} because no SARP data are available, a first approximation of $\rho(t)$ can be obtained from particular experiments. Several examples of such experiments are now available in SARP. A requirement is that the experiment include two treatments differing only in one of the split dose applications. All other applications should be identical for the two treatments. For example, in treatment T1, fertilizer is given at times t1, t2 and t3. In T2, the same amounts at t1 and t2 are given as in T1, but at t3 a different amount is given, for example zero, or any other amount different from what was applied at t3 in T1. At the end of the season, total uptake N_c is determined for both T1 and T2. The extra uptake in the treatment which received most N (applied) is then divided by the extra amount applied in that treatment. The resulting ratio is the apparent recovery corresponding to t3. The best information is obtained when the application levels are not too high (see Section 3.2.2). Excessive N application obviously leads to low recovery, which then has no meaning at more reasonable input levels.

Another way of recovery analysis is also possible: if treatments differ in more than one split dose application, but are identical up to a given time t_x, the difference in N uptake resulting from a treatment difference imposed at t_x may be assessed from sampling shortly after t_x, i.e. still before the second different treatment event is imposed. This is only a reliable procedure if the amount applied at t_x is not excessive, and enough time is allowed after t_x to take up most of the 'recoverable' N from that application event, before sampling.

As explained in Section 3.2.2, ORYZA_0 interprets 'recovery' in a special way: it does not 'convert' a fraction $\rho(t_x)$ of N applied at t_x into uptake directly. Instead, a fraction $(1-\rho(t_x))$ is considered as unavoidable loss. So, $\rho(t)$ is a potential recovery. Some part of potentially recoverable N may be lost if the crop cannot absorb the whole fraction $\rho(t)$ at the time of application.

The information obtained in the manner described above is then combined into a table:

```
FUNCTION RECT= 0.,0.0, 40.,0.7, 70.,0.8, 75.,0.8, 85.,0.01, 135.,0.
```

This table is linearly interpolated with the help of the LINT function. A good default is to start with a value of 0 at transplanting (on the first day, no applied N would be taken up); then have a linear increase up to PI stage where a peak value is reached (e.g. a fraction $\rho = 0.7$ is potentially absorbed from a small amount of N applied at PI stage, provided the crop is not N saturated). Then, depending on soil and climate, ρ may be maintained at this high level for a while, e.g. upto flowering, and then quickly decrease to zero again after 10-20 days after flowering.

It must be noted that this $\rho(t)$ curve determines to a large extent the outcome of the optimization procedure. Erroneous assumptions in $\rho(t)$ definitely lead to erroneous recommendations. This is unpleasant, but unavoidable: $\rho(t)$ varies in reality and has a strong effect on N uptake. Ignoring this would defeat the purpose of fine-tuning fertilizer recommendation.

The most important feature of $\rho(t)$ is the time when the peak value is reached, and the length of the period during which a high ρ level is maintained. These features are more relevant to optimizing fertilizer timing than the absolute level of $\rho(t)$.

In composing the table, note that a tabulated value is reached ('during the simulation') only when the corresponding time is reached. For example, if in reality no N can be taken up after flowering, the table should include a value 0.0 right after flowering, not two weeks later. Recovery would otherwise decrease gradually during the two weeks following flowering, and the (simulated) crop would (erroneously) absorb a considerable amount of 'extra' N in that period. Much can be said against this approach of defining and utilizing $\rho(t)$ in calculations for fertilizer optimization. At the moment, however, this seems to be the most appropriate way. Its main advantage being that its empirical nature allows taking into account site peculiarities.

2.3 Determination of the site-variety match factor f_{SV}

(In the following, read FSV1 and FSV2 for f_{SV}. FSV1 is the pre-flowering value, FSV2 the post-flowering value. In many, but not all, cases these values are identical. The model uses the two as separate parameters, to allow for differentiation where necessary).

The site-variety match factor f_{SV} cannot be derived directly from observations. It is, instead, obtained by calibration with the help of the ORYZA_0 model. While the full model describes the whole sequence of N application, N uptake, N distribution, and N utilization for dry matter production, the model also allows for a 'shortcut'. When the parameter SWINLV is set to 1., measured instead of calculated values of leaf N concentration (FNLV, kg kg^{-1}) and leaf mass (WLVG, kg ha^{-1}) are used by the model to calculate crop growth. Another required input is observed biomass (WCR, kg ha^{-1}) vs. time (DAT, d) as explained below.

To determine f_{SV}, run the ORYZA_0 model after setting the SWINLV value to 1. (in timer file) and introducing the observed values of FNLV and WCR as input. Each treatment is one rerun set. Do not mix different experiments in a series of reruns. Each rerun should only represent a nitrogen treatment. All treatments should stem from the same trial (i.e. identical site, time, hence weather). Provide the proper values of observed global radiation. Plot, after completing a set of reruns, the observed vs. simulated biomass, so XWCR vs. WCR, for all sampling dates and treatments. Most probably, the points will not be on a 1:1 line. Now adjust the value of f_{SV} by trial and error until the data points join roughly on a 1:1 line (this is called 'calibration'). When the best f_{SV} value has been found (best attainable fit), it must be checked by plotting both WCR and XWCR vs. time, for this f_{SV} value. The two time curves should be roughly identical, although some deviation will always remain. The value of the parameter f_{SV} is noted and introduced in the data file for optimization purposes.

This calibration procedure may seem cumbersome, but is in fact easy. For the time being, we use this 'visual' procedure (i.e. just looking at the graph and judging when best fit is reached) instead of numerical methods. It would be easy to follow a numerical procedure (as done for optimizing the fertilizer application parameters) but this is avoided: the 'visual' method forces us to check how well the basic growth equation (Eqn 3.2) describes the particular experiment under study. If this foundation is not solid, the model-based fertilizer recommendation also lacks solid ground.

2.4 Fertilizer application parameters

Four parameters define the fertilizer application curve $A(t)$ as expressed in Eqn 3.3 in Section 3.2.2.. A fifth parameter determines the absolute N input level which may cut off the $A(t)$ curve. Together, these parameters express N fertilizer management in the form of a continuous application curve.

symbol	acronym	description	unit
a	A	affects symmetry of logistic function	-
b	B	affects slope at inflection point	d^{-1}
c	C	asymptote level of logistic function	kg N ha^{-1}
m	M	affects t at inflection point	d
A_{tot}	FERTMX	absolute total N input level	kg N ha^{-1}

(unit = as used in algorithm)

2.5 Optimization

The application of the ORYZA_0 model in optimizing the fertilizer application strategy is not discussed in this volume. A separate manual (ten Berge et al., 1994a) is available, which describes how the ORYZA_0 model is continued with a numerical optimization procedure, to determine optimal values for the fertilizer management parameters *a*, *b*, *c*, *m* and FERTMX. These optimal values define a recommended fertilizer application strategy for a given set of soil, crop and environment specifications, as defined in this appendix.

Appendix 6 Examples of input files required for the ORYZA_N and ORYZA_0 modules

Example of a CONTROL.DAT:

```
FILEON='C:\USR\RESULTS.OUT'
FILEIR='RERUNS.DAT'
FILEIT='C:\USR\TIMER.DAT'
FILEI1='C:\USR\PLANT.DAT'
FILEI2='DUMMY.DAT'
FILEOL='RESULTS.LOG'
```

Example of a weather data file (van Kraalingen et al., 1991):

```
*-----------------------------------------------------------
*  Station Name: IRWE0001
*  Author      : Climate Unit           -99.000: nil value
*  Source      : CLICOM database
*
*  Comments    : This file is extracted from CLICOM database
*  Longitude:  121 15 E   Latitude: 14 11 N    Altitude:  21m
*
*  Column     Daily Value
*     1       Station number
*     2       Year
*     3       Day
*     4       Irradiation          KJ m-2 d-1
*     5       min temperature          oC
*     6       max temperature          oC
*     7       early morning vp        kPa
*     8       mean wind speed         m s-1
*     9       precipitation          mm d-1
*-----------------------------------------------------------
121.25 14.18   21 0.00 0.00
1  1990  1  17500.0     18.5     29.5     2.41     1.1    0
1  1990  2  18200.0     20       29.6     2.26     1.2    0
1  1990  3  9900.0      22.2     27.8     2.66     2.3    0
1  1990  4  13300.0     23       27.6     2.49     2.1    0
1  1990  5  17500.0     19.9     28.6     2.42     2.3    0
1  1990  6  9000.0      22.5     27.6     2.61     2.0    0
1  1990  7  14600.0     19.5     28.3     2.39     2.3    0
1  1990  8  14200.0     22.4     28.6     2.70     2.4    0
1  1990  9  10800.0     20.6     29       2.69     1.3    0.6
ETC.
```

Example of a timer file for ORYZA_N:

```
 * required TIMER variables
 * ------------------------
STTIME = 306.
DTRP   = 38.
FINTIM = 601.

SWILAI = 4           ! 1 = tabulated (measured) SLA/SLAC ratio vs DVS used
                     ! 2 = tabulated (measured) ln(LAI) vs temperature sum
                     ! 3 = use of param (measured) relative growth rate
                     !     for leaf area, RGRL for sink lim (=exp) stage,
                     !     and measured SLA for source limited stage
                     ! 4 = use of measured leaf mass and calculated SLA
                     ! 5 = use measured LAI
SWINUP = 1           ! 1 = N limited production; uptake forcing function
                     ! 2 = potential production; uptake equals demand
SWISIN = 1           ! 1 = no sink limitation; no GSOM
                     ! 2 = sink limitation; use of GSOM, calculated from
                     !     tiller and grain number
SWINPH = 1           ! 0 = use measured amount of nitrogen in leaves for
                     !     photosynthesis calculation
```

```
               z   ! 1 = use simulated  amount of nitrogen in leaves for
                   !     photosynthesis calculation
SWINPR = 1         ! 0 = no nitrogen profile in canopy;
                   !     homogenous distribution
                   ! 1 = with nitrogen profile in canopy;
                   !     with extinction coefficient
SWISAI = 0         ! 0 = stem area NOT included in LAI
                   ! 1 = stem area included in LAI

DELT   = 1.0      ! time step (for Runge-Kutta first guess)
PRDEL  = 10.0     ! output time step
IPFORM = 5        ! code for output table format:
                  ! 4 = spaces between columns
                  ! 5 = TAB's between columns (spreadsheet output)
                  ! 6 = two column output
COPINF = 'N'      ! Switch variable whether to copy the input files
                  ! to the output file ('N' = do not copy,
                  ! 'Y' = copy)
DELTMP = 'N'      ! Switch variable what should be done with the
                  ! temporary output file ('N' = do not delete,
                  ! 'Y' = delete)
                  ! List of harvest data for which output is
                  ! required, if the variable is commented out
                  ! no extra output is done.
IFLAG  = 1100     ! Flag what should be done with warnings and
                  ! errors from the weather system. (See manual)

PRSEL= 'DOY','DAT','WSHG','WCR','XXWCR','WSO','XXWSO','<TABLE>',
 'DOY','DAT','WLVG','XXWLVG','WSTS','XXWSTS','WRTL','XXWRTL','<TABLE>',
 'DOY','DAT','NTOTM','ANLCR','ANCR','XXNCR','ANLV','XXNLV','<TABLE>',
 'DOY','DAT','ANST','XXNST','ANRT','XXNRT','ANSO','XXNSO','<TABLE>',
 'DOY','DAT','ANLD','ANRD','<TABLE>'

IOBSD = 1988,344,1988,362,1989, 3,1989,10,1989,17,1989,24,1989,31,
        1989, 41,1989, 59,1989,67,1989,72,1989,75

* WEATHER variables
* -----------------
WTRDIR = 'c:\sys\weather\'
CNTR   = 'ADUT'             ! Country code
ISTN   = 1                  ! Station code
IYEAR  = 1988               ! Year
```

Example of a timer file for ORYZA_0:

```
 * required TIMER variables
 * ------------------------
STTIME = 306.
DTRP   = 38.
FINTIM = 601.

SWINLV = 1        ! 0 = use simulated amount of nitrogen in the leaves
                  ! 1 = use measured amount of nitrogen in the leaves

DELT   = 1.0      ! time step (for Runge-Kutta first guess)
PRDEL  = 10.0     ! output time step
IPFORM = 5        ! code for output table format:
                  ! 4 = spaces between columns
                  ! 5 = TAB's between columns (spreadsheet output)
                  ! 6 = two column output
COPINF = 'N'      ! Switch variable whether to copy the input files
                  ! to the output file ('N' = do not copy,
                  ! 'Y' = copy)
DELTMP = 'N'      ! Switch variable what should be done with the
                  ! temporary output file ('N' = do not delete,
                  ! 'Y' = delete)
                  ! List of harvest data for which output is
                  ! required, if the variable is commented out
                  ! no extra output is done.
IFLAG  = 1100     ! Flag what should be done with warnings and
                  ! errors from the weather system. (See manual)

PRSEL = 'TIME', 'DAT', 'WCR', 'XXWCR'
```

```
IOBSD = 1988,344,1988,362,1989, 3,1989,10,1989,17,1989,24,1989,31,
        1989, 41,1989, 59,1989,67,1989,72,1989,75

* WEATHER variables
* -----------------
WTRDIR = 'c:\sys\weather\'
CNTR   = 'ADUT'                    ! Country code
ISTN   = 1                         ! Station code
IYEAR  = 1988                      ! Year
```

Example of a crop data file of ORYZA_N:

```
*********************************************************************
* PARAMETERS, FUNCTIONS, TABLES, ALL VALUES COMMON TO ALL EXPERIMENTS
*********************************************************************
*----- Time and environmental variables
TBD    =   8.0 ; TBLV =  8.0
*********************************************************************
*----- Phenological development
SHCKD  = 0.4
*********************************************************************
*----- Leaf area development
RGRL   = 0.0085
SLAC   = 0.002; SSA = 0.001
SLAFAC = 0.00,1.72,0.21,1.72,0.24,1.72,0.33,1.32,0.70,1.20,
         1.01,1.00,2.00,0.75,2.10,0.75
LAILNT = 0.,-1.61,89.15,-1.61,157.0,-1.01,303.,-0.31, 451., 0.45,
         589., 1.07,734., 1.34, 882., 1.46,1020., 1.37,
         1171., 1.24,1324., 1.13,1483., 1.04
SSGATB = 0.,0.0003, 0.9,0.0003, 2.1,0.
*********************************************************************
*----- Daily gross canopy CO2 assimilation
ALPHAN = 33.
KDF    = 0.6
KDIFNP = 0.2
NB     = 0.15
SCP    = 0.2
EFFTB  = 10.,0.54, 40.,0.36
REDFTT = -10.0,0., 10.,0., 20.,1. , 37.,1., 43.,0.0
*********************************************************************
*----- Maintenance and growth respiration
FCLV   = 0.419; FCST   = 0.444; FCSO = 0.487
FCRT   = 0.431; FCSTR  = 0.444
MAINLV = 0.02 ; MAINST = 0.015; MAINSO = 0.003; MAINRT = 0.01
NMAXLX = 0.06 ; NMAXSX = 0.030; NMAXRX = 0.034
RFNLV  = 0.005; RFNST  = 0.002; RFNRT  = 0.002
TREF   = 25.0 ; Q10    = 2.0
*********************************************************************
*----- Growth of the crop
CRGLV  = 1.326; CRGST  = 1.326; CRGRT  = 1.326
CRGSO  = 1.462; CRGSTR = 1.111
LAIREF = 5.
RDR    = 0.01
TCLSTR = 10.
*********************************************************************
*----- Tiller and grain formation
DVST1  = 0.30; DVSG1 = 0.95
DVST2  = 0.75; DVSG2 = 1.15
PLNUM  = 500000.
TCFT   = 15.; TCDT = 10.0; TCFG=3.
TILMX  =50.
WGRMX  = 23.5E-6
CNTIT  = 0.,5.E-6, .3,5.E-6, .75,25.E-6, 1.0,75.E-6, 2.1,75.E-6
GGRT   = 10.,0.,15.,0.,18.,0.75,23.,1.0,27.,0.9,40.,0.0
RTILT  = 0.,0., .02,.2, .04,.6, .05,.8, .06,1., .08,1.
*********************************************************************
*----- Nitrogen in the crop
CRDN=5.
TCNT   = 10.; TCNA = 1.
LSNR   = 0.50 ; LRNR  = 0.37
NMAXSO = 0.0175
NMAXLT = 0., 0.06, 0.4,0.05,  0.7,0.040, 1.0,0.030,
         1.50,0.025, 2.0,0.020, 2.1,0.020
```

```
*NMAXST = 0.,.025, .4,.03,  .7,.030, 1.,.02,
*         1.5,.015, 2.,.01, 2.1,.01
*NMAXRT = 0.,.034, .4,.013,  .6,0.017,.85,.017,
*         1.1,.014, 2.,.011, 2.1,.01
NMINLT = 0.,0.025 ,  1.0,0.012 ,  2.1,0.007
NMNSOT = 0.0,0.0075, 50.0,0.0075, 150.0,0.015, 250.0,0.015
NMINSO = 0.010
*****************************************************************
*******************************************************
* Thiyagarajan, Tamil Nadu, India
* 1988-1989
* variety:   ADT 39
* treatment: 300 kg N/ha
*******************************************************
TREATM ='THIYAGARAJAN, 1989, ADT39, 300 kg/ha N'

* dummy initialisation
RADTOI = 0.

DTRP   = 38.
DATH   = 90.
FGHDAY = 63.0
WLVGI  = 47.0
WSTSI  = 38.0
WRTLI  = 19.0
FNSTI  = 0.0168
FNLVI  = 0.0315
FNRTI  = 0.0034
DVSI   = 0.501
TSI    = 676.9
FSTR   = 0.37
DVRV   = 0.000740
DVRR   = 0.001606
NS     = 11
DNOST  = 344.,362.,369.,376.,383.,390.,397.,407.,425.,438.,441.
NTOTMT = 2.18,38.24,91.48,128.14,155.89,171.09,182.60,240.41,217.71,
         181.80,181.80
NA     = 6
DNAPT  = 306.,344.,370.,392.,406.,600.

WSTS_OBS =
1988., 344.,  38.,
1988., 362., 640.,
1989.,   3.,1438.,
1989.,  10.,2385.,
1989.,  17.,3257.,
1989.,  24.,4221.,
1989.,  31.,5500.,
1989.,  41.,6073.,
1989.,  59.,5136.,
1989.,  72.,3828.
WSTS_TRG = 1900.,1.,0.,
           2000.,1.,0.
WSTS_FRC = 0

WLVG_OBS =
1988., 344.,  47.,
1988., 362., 571.,
1989.,   3.,1300.,
1989.,  10.,2080.,
1989.,  17.,2695.,
1989.,  24.,3150.,
1989.,  31.,3486.,
1989.,  41.,3899.,
1989.,  59.,3761.,
1989.,  72.,2808.
WLVG_TRG = 1900.,1.,0.,
           2000.,1.,0.
WLVG_FRC = 0

* Dummy values or WLVD
WLVD_OBS = 1900.,1.,0.,
           2000.,1.,0.
WLVD_TRG = 1900.,1.,0.,
           2000.,1.,0.
WLVD_FRC = 0

WRTL_OBS =
```

```
1988., 344.,  19.,
1988., 362., 500.,
1989.,   3., 710.,
1989.,  10., 925.,
1989.,  17.,1150.,
1989.,  24.,1324.,
1989.,  31.,1502.,
1989.,  41.,1790.,
1989.,  59.,1507.,
1989.,  72.,1507.
WRTL_TRG = 1900.,1.,0.,
           2000.,1.,0.
WRTL_FRC = 0

WSO_OBS  =
1988., 344.,   0.,
1989.,  28.,   0.,
1989.,  41.,2542.,
1989.,  60.,4763.,
1989.,  72.,6450.
WSO_TRG = 1900.,1.,0.,
          1989.,30.,2.,
          1989.,50.,2.,
          2000.,1.,0.
WSO_FRC = 0

ANST_OBS   =
1988., 344.,0.64,
1988., 362.,14.14,
1989.,   3.,33.65,
1989.,  10.,42.69,
1989.,  17.,53.74,
1989.,  24.,66.27,
1989.,  31.,72.05,
1989.,  41.,79.56,
1989.,  59.,57.01,
1989.,  72.,30.62
ANST_TRG = 1900.,1.,0.,
           2000.,1.,0.
ANST_FRC = 0

ANLV_OBS   =
1988., 344., 1.48,
1988., 362.,18.50,
1989.,   3.,51.09,
1989.,  10.,75.92,
1989.,  17.,87.32,
1989.,  24.,89.46,
1989.,  31.,93.42,
1989.,  41.,97.09,
1989.,  59.,63.56,
1989.,  72.,26.68
ANLV_TRG = 1900.,1.,0.,
           2000.,1.,0.
ANLV_FRC = 0

ANRT_OBS   =
1988., 344., 0.06,
1988., 362., 5.60,
1989.,   3., 6.75,
1989.,  10., 9.53,
1989.,  17.,14.84,
1989.,  24.,15.36,
1989.,  31.,17.12,
1989.,  41.,20.05,
1989.,  59.,15.22,
1989.,  72.,13.56
ANRT_TRG = 1900.,1.,0.,
           2000.,1.,0.
ANRT_FRC = 0

ANSO_OBS   =
1988., 344.,  0.00,
1989.,  28.,  0.00,
1989.,  41., 43.72,
1989.,  59., 81.92,
1989.,  72.,110.94
ANSO_TRG = 1900.,1.,0.,
```

```
          2000.,1.,0.
ANSO_FRC = 0

* Dummy values or ANLD
ANLD_OBS = 1900.,1.,0.,
          2000.,1.,0.
ANLD_TRG = 1900.,1.,0.,
          2000.,1.,0.
ANLD_FRC = 0

* Dummy values or LAI
LAI_OBS = 1900.,1.,0.,
          2000.,1.,0.
LAI_TRG = 1900.,1.,0.,
          2000.,1.,0.
LAI_FRC = 0

* NOTE the first values of the functions are dummy's
*      the values at 2.1 are dummy's
FSTTB  = 0.00,0.53,
         0.48,0.53,0.62,0.52,0.69,0.55,0.77,0.59,
         0.84,0.68,0.92,0.79,1.00,0.16,1.38,0.00,
         1.82,0.00,2.10,0.00
FLVTB  = 0.00,0.47,
         0.48,0.47,0.62,0.48,0.69,0.45,0.77,0.41,
         0.84,0.32,0.92,0.21,1.00,0.12,1.38,0.00,
         1.82,0.00,2.10,0.00
FSHTB  = 0.00,0.70,
         0.48,0.70,0.62,0.88,0.69,0.89,0.77,0.87,
         0.84,0.89,0.92,0.90,1.00,0.92,1.38,1.00,
         1.82,1.00,2.10,0.00
FSOTB  = 0.00,0.00,
         0.48,0.00,0.62,0.00,0.69,0.00,0.77,0.00,
         0.84,0.00,0.92,0.00,1.00,0.72,1.38,1.00,
         1.82,1.00,2.10,1.00
```

Example of a crop data file of ORYZA_0:

```
**********************************************************
* Thiyagarajan, Tamil Nadu, India
* 1988-1989
* variety:   ADT 39
* treatment: 0 KG/HA
**********************************************************
TREATM='THIYAGARAJAN, 1989, ADT39, 0 kg/ha N'

* dummy variables
DVSI   = 0.
TBD  = 0.
TBLV = 0.

* Initial constants
* ------------------
WCRI   = 104.0
ANCRI  = 2.18
RADTOI = 0.
APCUMI = 0.

* Model parameters
* -----------------
RTINCL = 0
DATFSV = 53.
DATEF  = 53.
*Flowering is at 53 DAT, DATFF is 53-7
DATFF  = 46.
DATH   = 89.
FSV1   = 0.87
FSV2   = 0.87
FNSO   = 0.01
FNCLV  = 0.50
ANLVMX = 100.
MAXUP1 = 5.
RUR    = 0.2
NUPCO  = 0.03
```

```
HI     = 0.5
SOLSUP = 0.6
FERTMX = 200.
A      = 1.
B      = 0.1
C      = 300.
M      = 30.
LARGE  = 100.
TINY   = 0.001

* AFGEN functions
* ---------------
FNMAXT =
   0., 0.03,
   40., 0.017,
   60., 0.015,
   80., 0.01,
   130., 0.07
RECT   =
   0., 0.0,
   60., 0.8,
   65., 0.4,
   70., 0.0,
   150., 0.
RSRT =
   0., 0.4,
   1.1, 0.15

* Observed values
* ---------------
WLVG_OBS   =
1988., 344.,  47.0,
1988., 362., 286.0,
1989.,   3., 469.0,
1989.,  10., 715.0,
1989.,  17., 828.0,
1989.,  24., 943.0,
1989.,  31., 936.0,
1989.,  41., 840.0,
1989.,  59., 792.0,
1989.,  67., 767.0

WCR_OBS =
1988., 344.0,   104.0,
1988., 362.0,   966.0,
1989.,   3.0,  1510.0,
1989.,  10.0,  2250.0,
1989.,  17.0,  2922.0,
1989.,  24.0,  3718.6,
1989.,  31.0,  4706.5,
1989.,  41.0,  4840.0,
1989.,  59.0,  6008.0,
1989.,  67.0,  6368.0

FNLV_OBS =
1988., 344.0, 3.15,
1988., 362.0, 2.35,
1989.,   3.0, 2.00,
1989.,  10.0, 2.07,
1989.,  17.0, 2.07,
1989.,  24.0, 1.93,
1989.,  31.0, 1.45,
1989.,  41.0, 1.10,
1989.,  59.0, 0.97,
1989.,  67.0, 0.70
```

Appendix 7 The FORTRAN Simulation Environment (FSE)

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Introduction

The models ORYZA_N and ORYZA_0 presented in this book are programmed in FORTRAN 77, using a crop growth simulation driver called FSE (FORTRAN Simulation Environment; van Kraalingen, 1991). The simulation environment consists of a main model that contains the control structure for rerun facilities, reading of weather data and the dynamic loop (integration, rate calculation and time update), a framework for the major process related routines and a collection of utility routines that perform specific tasks such as reading of parameter values from data files and for generating model output.
The utility routines used are part of the FORTRAN 77 library TTUTIL (Rappoldt & van Kraalingen, 1990). The reports by van Kraalingen (1991) and Rappoldt & van Kraalingen (1990) can be obtained from the Institute for Agrobiological and Soil Fertility Research (AB-DLO), PO Box 14, 6700 AA Wageningen, The Netherlands.

Integration and time loop

The integration method used in the FSE program is the Euler or rectangular integration method. The order in which calculations are executed and how reruns are implemented is shown in Figure A7.1. At the point where output is generated, values of state variables and rate variables refer to the same time. In the design of FSE, state and rate calculations are implemented in separate sections in the major subroutines for plant and soil processes. The main program controls which section is activated through the concept of *task-controlled execution*. This is illustrated in Figure A7.2. The program lines of the plant and soil water subprocesses are separated into rate and state sections and only one of these sections is executed during a single call from the main program. Four different task are distinguished: *initialization* (ITASK=1), *integration* (ITASK=3), *rate calculation* (ITASK=2) and *terminal calculation* (ITASK=4).
After each time step a decision is made if another time step is required or if the simulation should proceed to the terminal section (Figure A7.1). One of the criteria to stop the simulation is that the pre-defined finish time (FINTIM) has been exceeded. In crop growth models, however, simulation has to be terminated when the crop is mature or if some other criterion has been met. It is thus necessary that the simulation loop can be terminated from within each of the submodels. This is implemented using a variable called TERMNL of the

type LOGICAL, which indicates if the simulation loop should be terminated. The simulation loop continues as long as TERMNL=.FALSE. and the criterion is programmed as an emulated DO-WHILE loop (FORTRAN 77 has no DO-WHILE control structure).
The subroutine TIMER2 (in TTUTIL library) controls the time variables in the model. The basic actions of the subroutine TIMER2 are: (*i*) (ITASK=1) check the values of FINTIM, DELT (time step of integration), TIME, etc. and copy these to variables local to the subroutine,

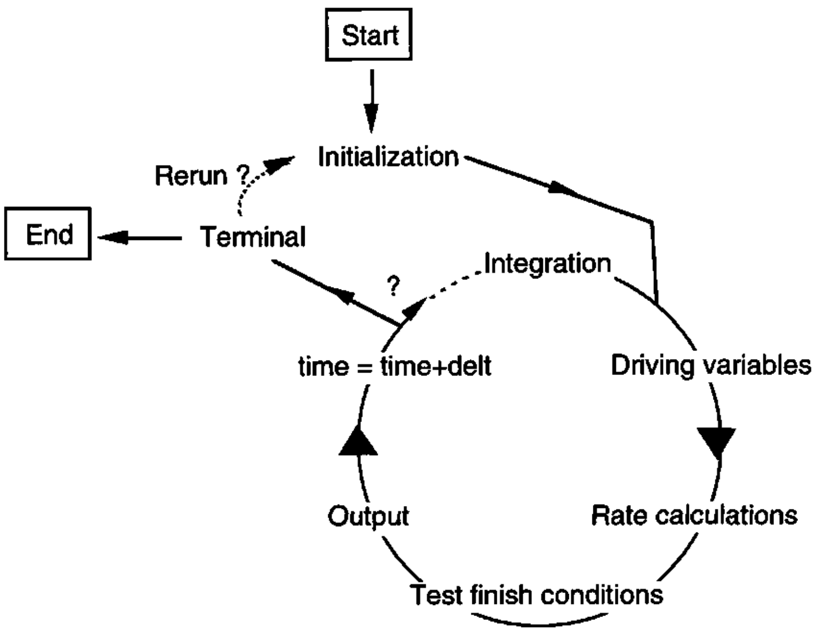

Figure A7.1 The order in which calculations are executed when simulating continuous systems using the Euler integration, illustrating where to enter and to leave the circle and how reruns are implemented.

switch on the output flag at the start of the simulation when TIME is a multiple of PRDEL (time interval for printed output) and when the simulation terminates, (*ii*) (ITASK=2) check whether the local time variables have the same value as the global time variables, add DELT to TIME, calculate the day number (DOY), flag if TIME is a multiple of PRDEL using the variable OUTPUT, flag if TIME has exceeded FINTIM using the variable TERMNL.
The TIMER routine which is used in the FSE program has some extra features: The year of simulation is automatically incremented and leap years are also recognized (DAY runs until 366), and the day number is available as an integer and as a real value (IDOY and DOY, respectively).

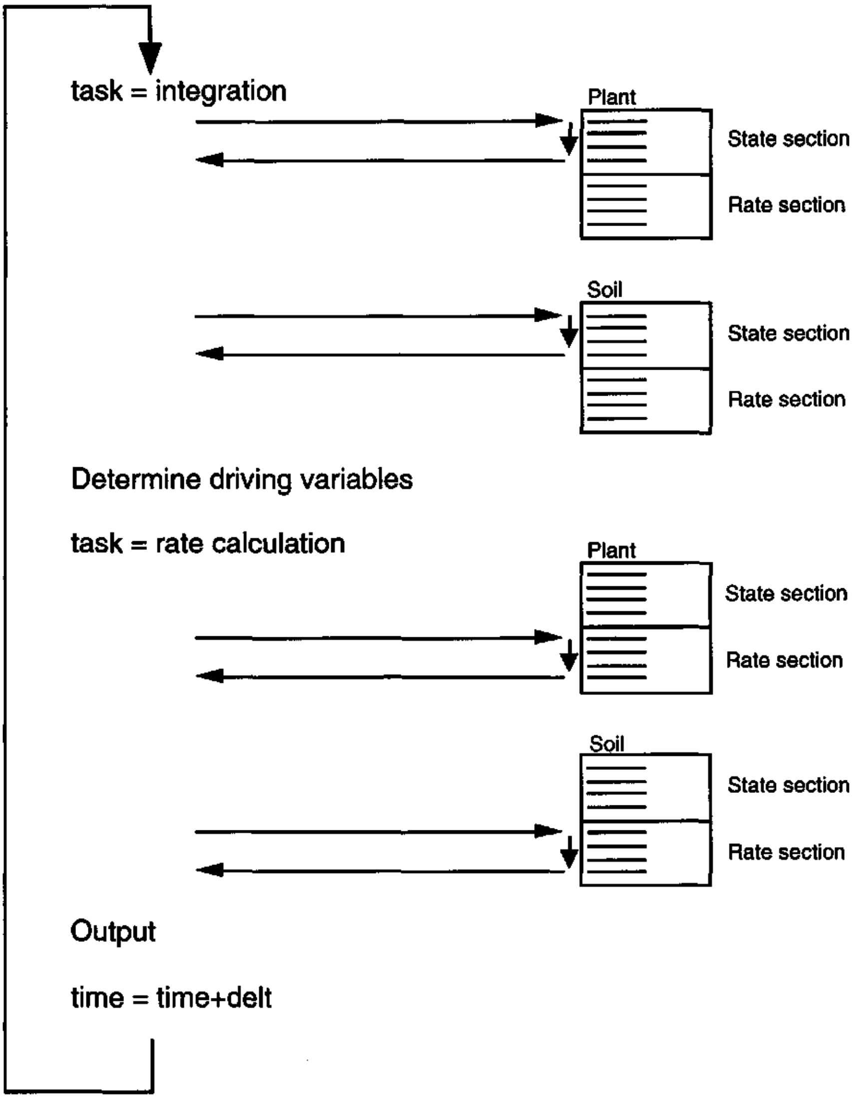

Figure A7.2 General structure for incorporating several subprocesses into a single simulation model. The plant growth and soil water rectangles represent *one* subprocess description containing integration and rate calculations but called from different places in the main model with different task parameters.

Initialization of the states and parameters from external data files

All state variables in the model have to be initialized in the process subroutines. The rate variables do not have to be initialized, because the model starts with the rate calculations after the initialization. Integration is only performed if previously a rate calculation has been carried out.

The input data files: reading data

Most of the parameters and initial values of the state variables of the various subprocesses are read from data files. The data files CONTROL.DAT and TIMER.DAT, the files with species characteristics (see listings in Appendix 6) and if available a SOIL.DAT have identical formats, and each variable in them may appear only once. The weather data files will be discussed separately. The values for the initial state variables and parameters are read from the data files using a set of TTUTIL subroutines whose names all begin with RD (e.g. RDSREA means 'read a single real value'). With these routines the user can request the value by supplying the name of the requested variable (after having defined which data file to use). The statement:

```
CALL RDSREA ('WLVGI', WLVGI)
```

requests the subroutine RDSREA to extract the value of WLVGI from the data file and assigns it to the variable WLVGI. It does so by searching for the line: WLVGI = <value> in the data file. The data file is selected by the following statement:

```
CALL RDINIT (IUNITP, IUNITO, FILEP)
```

which calls the routine that

- opens the file with variable name FILEP using unit=IUNITP+1 (FILEP is a character string that has been assigned to the string PLANT.DAT in the calling program, then
- analyses the data file,
- creates a temporary file from the data file using unit=IUNITP,
- closes the data file (leaving IUNITP used !!), and
- sends all error messages that have been created to a log file (with unit=IUNITO; this log file has been opened previously!).

After this call, the plant subroutine can acquire the numerical values (including arrays) or character strings through the different RD routines, RDSREA (read single real), RDSINT (read single integer), RDAREA (read array of reals), and RDSCHA (read single character string (in TIMER.DAT)). The CLOSE statement deletes the temporary file that is created by the RD routines. A corresponding data file PLANT.DAT could be as follows:

```
WLVGI  = 0.; AMAXM = 40.
AMDVST = 0.,1., 1300., 2200.,0.
KDF    = 0.69
```

The following syntax rules applies to these input files:

- The file consists of names and numerical values of variables, separated by an '=' sign, e.g. `AMAX = 40.;`
- The name of a variable may not exceed six characters;
- For array variables, more than one numerical value may follow the equal sign, separated by commas;
- Identical numerical array values can be given as n*<numerical value> (e.g. 10*5.4);
- Variables may appear in the file in any order;
- Comment lines start with '*' in the first column, or '!' in any column (the rest of the line is ignored);
- Continuation character is ',' on preceding line (applies to arrays only);
- Names of variables and numerical values can be given on the same line if separated by a single semicolon ';' ;
- Only the first 80 characters of each record of the data file are read;
- No tabs or other control and extended ASCII characters are allowed in the file.

The CONTROL.DAT file

The CONTROL.DAT file (Listing A7.1) contains the file names that are used during the execution of an FSE model. This file was not present in the FSE 1.0 version of FSE which made it impossible to do reruns on the names of input files. In FSE 2.0 reruns can now be done on the names of all *input* files specified in the CONTROL.DAT except the name of the reruns file itself and the names of the output file. In this file a distinction is made between names of input files (beginning with `FILEI`) and names of output files (beginning with `FILEO`).

Listing A7.1 Example of the contents of the CONTROL.DAT.

```
**********************************************************************
FILEON='C:\USR\RESULTS.OUT'
FILEIR='RERUNS.DAT'
FILEIT='C:\USR\TIMER.DAT'
FILEI1='C:\USR\PLANT.DAT'
FILEI2='DUMMY.DAT'
FILEOL='RESULTS.LOG'
**********************************************************************
```

The `FILEON` and `FILEOL` variables are assigned the names of 1) the normal output file (containing the output table) and 2) the log file respectively. Both `FILEON` and `FILEOL` may be set to the same file name.

The `FILEIT` and `FILEIR` variables are assigned the names of the timer file and the reruns file respectively. The above mentioned file names are used by the FSE-driver. The file names that can be used by the model(s) are specified through the FILEI1, FILEI2, FILEI3, FILEI4, FILEI5 variable names. These names are optional and can be specified only when they are needed.

The timer file

The timer file (e.g. TIMER.DAT) (Listing A7.2) specifies the value of the time variables such as time step of integration, time between different outputs to file, etc.; the directory in which the weather data are stored, the country code, station number and year; and some miscellaneous control variables. If many weather data files are used, it may be convenient to store these data in a separate directory. By assigning a directory name to the variable WTRDIR, the weather system is directed to read weather data from that directory, e.g.:

```
WTRDIR = 'C:\WEATHER\'
The country code:
CNTR = 'NL'
```

For a list of available weather data files, their corresponding country codes and station numbers, see van Kraalingen et al. (1991), e.g.

NL	<- country code for the Netherlands
PHIL	<- country code for the Philippines

These two character strings are read through the RDSCHA routine (in TTUTIL library) in the MAIN program.

The variables ISTN and IYEAR refer to the weather data and indicate the station number and year from a country. For example, when the country code is NL (The Netherlands), ISTN=1 and IYEAR=1984, the weather data from Wageningen 1984 will be used by the model. During execution, the weather system will try to open a file by the name of NL1.984 on the given directory given (WTRDIR).

The variables STTIME, FINTIM, PRDEL and DELT represent the time parameters of the model. STTIME is the start day of the whole program; its value should be between 1 and 365. FINTIM is the finish time of the simulation, counted from the start of simulation. For example, when STTIME=93., and FINTIM=10., the simulation will continue until DAY=103. The variable PRDEL indicates the time between consecutive outputs to the output file (e.g. RESULTS.OUT). For example, when PRDEL=5., output is given each time that TIME is a multiple of PRDEL (TIME=5.,10.,15. etc.). Irrespective of the value of PRDEL, output is always given at the start of the simulation (TIME=0) and when the simulation is terminated (either FINTIM=TIME or some other finish criterion). By giving PRDEL a high value (e.g. 1000), intermediate outputs are suppressed. The value of DELT, the time step of integration, is one day. This value cannot be changed, because of the procedures used in the CO_2 assimilation subroutines, that calculate daily rates using the Gaussian integration method.

Listing A7.2 Example of the contents of a timer file. For explanation of abbreviations see Appendix 1.

```
*********************************************************************
* Defining the simulation run                                       *
*********************************************************************
WTRDIR = 'C:\WEATHER\'
CNTR   = 'NL'
ISTN   = 1          ! Station number of weather data
IYEAR  = 1985       ! Year of weather data
IFLAG  = 1101       ! Indicates where weather error and warnings
                    ! go (1101 means errors and warnings to log
                    ! file, errors to screen, see FSE manual)
*
* Time variables and output file options
STTIME = 121.       ! Start day of simulation
FINTIM = 148.       ! Finish time of simulation
PRDEL  = 5.         ! Time between consecutive outputs to file
DELT   = 1.         ! Time step of integration

IPFORM = 4          ! Format of output file
                    ! (0 = no output table, 4 = normal table,
                    !  5 = Tab-delimited (for Excel), 6=TTPLOT format)
DELTMP = 'N'        ! Switch variable what should be done with
                    ! the temporary output file:
                    !   'N' = do not delete,
                    !   'Y' = delete
COPINF = 'N'        ! Switch variable what should be done with
                    ! the inputfiles:
                    !   'N' = do not copy inputfiles into
                    !         outputfile,
                    !   'Y' = copy inputfiles into outputfile

IOBSD  = 1985,182, 1985,194
                    ! List of observation data for which output
                    ! is required.0 = no harvest data.
                    ! The list should consist of
                    ! pairs of <year>,<day> combinations.

PRSEL= 'DOY','DAT','WSHG','WCR','XXWCR','WSO','XXWSO','<TABLE>',
       'WLVG','XXWLVG','WSTS','XXWSTS','WRTL','XXWRTL','<TABLE>'
*********************************************************************
```

The variable IPFORM defines if an output table is required (no output table: IPFORM=0) and if so, what the format should be. A multiple column table (IPFORM=4) is sufficient for normal printing and viewing. Using IPFORM=5, a tab-delimited multiple column table, which is easily imported in spreadsheet programs such as EXCEL, is generated. A two-column format is generated using IPFORM=6.

The variable DELTMP defines whether the file of temporary output data (RES.BIN) should be deleted at termination of the simulation (DELTMP ='N', do not delete, DELTMP ='Y', delete). This file is created during the dynamic phase of the simulation and is read during the terminal phase of the simulation to generate the output file RESULTS.OUT.

The variable COPINF defines whether the inputfiles should be copied to the output file. When COPINF='Y', all inputfiles are appended to the outputfile. When COPINF='N', nothing is done with the inputfiles.
The variable IFLAG defines where errors and warnings from the weather system should be sent to (screen or file). For full documentation on the possible IFLAG values see van Kraalingen et al. (1991).
The variable IOBSD can be used to force output at day numbers for which harvest data from the field are available. In many cases these harvest data will not coincide with output intervals in the model unless PRDEL is set to unity (which may cause large output files to be generated). A maximum of 50 day numbers can be defined here. A single value of zero indicates that no forced output is required, e.g.:

```
IOBSD = 0.                          <- No forced output
IOBSD = 1985,11                     <- Output is forced on day 11 in 1985
```

The variable PRSEL can be used to select a subset of the normal output variables without having to change the model. With PRSEL, e.g. several tables can be generated below each other. For example:

```
PRSEL = 'WSO','XXWSO','<TABLE>','DVS','<TABLE>'
```

generates a table with WSO and XXWSO after which a separate table with DVS is printed.

The plant data files

With the FSE crop growth model, plant data files are supplied containing parameters and initial state values. These parameters and initial state variables are discussed at length in this book and will not be discussed here further. The general syntax rules for data files as discussed above apply to these files as well. Examples of plant data files for ORYZA_N and ORYZA_0 are listed in Appendix 6.

Weather data

The weather data used in the model are read from external files. The weather data file definition, however, is different from those for the RD routines. The weather data system used, has been developed jointly by the Centre for Agrobiological Research and the Department of Theoretical Production Ecology of the Wageningen Agricultural University. It is especially designed for use in crop growth simulation models and has been documented in a separate report (van Kraalingen et al., 1991; available on request).
The weather data system basically consists of two parts: the weather data files and a reading program to retrieve data from those files. A single data file can contain, at the

most, the daily weather data from one meteorological station for one particular year. The country name (abbreviated), station number and year to which the data refer are reflected in the name of the data file (Listing A7.3).

Listing A7.3 Example of the contents of a WEATHER file (NL1.985).

```
*-----------------------------------------------------------------------------*
* Station name: Wageningen (Haarweg), Netherlands
* Year: 1985
* Author: Peter Uithol                          -99.000: NIL VALUE
* Source: Natuur- en Weerkunde via Nel van Keulen
* Longitude: 5 40 E, latitude: 51 58 N, altitude: 7 m.
*
* Column  Daily value
* 1       station number
* 2       year
* 3       day
* 4       irradiation                    (kJ m-2 d-1)
* 5       minimum temperature            (degrees Celsius)
* 6       maximum temperature            (degrees Celsius)
* 7       early morning vapour pressure  (kPa)
* 8       mean wind speed (height: 2 m)  (m s-1)
* 9       precipitation                  (mm d-1)
*-----------------------------------------------------------------------------*
   5.67  51.97     7. 0.00 0.00
   1 1985   1   660.   0.2   5.7   0.670   5.4   6.8
   1 1985   2  2200.  -2.9   0.7   0.490   2.2   0.1
   1 1985   3  2280.  -5.5   0.2   0.520   1.6   0.0
   1 1985   4  3310. -18.4  -5.2   0.230   0.7   0.4
   1 1985   5  4220. -19.5  -7.8   0.210   0.6   0.0
   1 1985   6  1940. -13.8  -6.2   0.310   3.9   1.7
   1 1985   7  4040. -21.4  -9.7   0.200   3.3   0.0
   1 1985   8  2710. -21.3  -6.2   0.240   2.2   0.0
   1 1985   9   930.  -7.8  -3.8   0.380   4.1   0.1
   1 1985  10  1540. -11.6  -3.6   0.390   2.1   0.6
<continued>

   1 1985 362   940.  -6.2  -3.0   0.430   1.1   0.0
   1 1985 363  2000.  -3.7  -1.2   0.460   1.7   0.0
   1 1985 364   900.  -5.3  -2.4   0.450   2.9   0.0
   1 1985 365  3410.  -6.2  -3.0   0.660   5.4   0.0
*-----------------------------------------------------------------------------*
```

The reading program consists of a set of subroutines and functions, only two of which are intended to be called by the main program (STINFO and WEATHR). The others are internal to the reading program.

A call to the first subroutine (STINFO) defines the country (CNTR), station code (ISTN), year number (IYEAR) and the name of the directory containing the weather data (WTRDIR), this information is first read from the data file TIMER.DAT. A control parameter (IFLAG) is also supplied to indicate where possible messages of the system should be directed (screen and/or log file), and a name must be given to the log file if that name should differ from the default name WEATHER.LOG. The subroutine STINFO returns the location parameters (longitude LONG, latitude LAT, and altitude ELEV) of the selected meteorological station and, if the radiation is calculated from sunshine hours by the weather system, two

coefficients of the Ångström formula (*a* and *b*) pertaining to the selected station. The value of a status variable (ISTAT) indicates a possible error or warning (e.g. the data file requested does not exist). The location parameters can later be used to calculate day length (from the latitude) or average air pressure (from the altitude).
After this initialization procedure, weather data for specific days can be obtained by calls to the second subroutine (WEATHR) with day number starting from January 1^{st} as 1, as input parameter. The output of WEATHR consists of six weather variables for that day and the value of the status variable ISTAT indicating a possible error or warning (e.g. missing data, data obtained by interpolation, requested day is out of range, etc.). The six weather variables are daily incoming total global radiation (RDD), minimum and maximum air temperature (TMMN and TMMX), vapour pressure (VP), wind speed (WN) and rainfall (RAIN).
The subroutine STINFO can be called again at any time during program execution to change any of its input parameters. A call to STINFO with identical input parameters is also permitted (in fact this is done regularly in the FSE main program). Similarly, the subroutine WEATHR can be called repeatedly with any day number between 1 and 365 (or 366 in the case of a leap year).

Implementing reruns

The FSE program includes a rerun facility. The general idea behind the rerun facility is that the data files remain identical and that the changes in data are specified in a separate file called e.g. RERUNS.DAT (Listing A7.4) which may contain the names and values of variables from any of the 'standard' data files that are read by the program. Thus, the file RERUNS.DAT may contain parameters from SOIL, PLANT and TIMER data files. In the first run, the values from the standard data files will be used. In subsequent runs those values are then automatically replaced by the values from the rerun file. Execution will continue until all the rerun sets from RERUNS.DAT have been used. Before a rerun is started, the model checks if all the variables of the preceding set were used. If this is not the case, it is assumed that there is a typing error in the data files and the simulation is halted. The output of the different runs is merged in one output file. If the file RERUNS.DAT is absent or empty, the model will execute one single run, using the data from the standard data files. It is shown in Figure A7.1 that the control structure for the reruns is programmed as a loop around the actual model.
The format of the rerun files is identical to that of the other data files, except that the names of variables may appear in the file more than once. Arrays can also be redefined in a rerun file. The order and number of the variables should be the same in each set. A new set starts when the first variable is repeated. This is shown in the following example, where the variables STTIME and NPL from file TIMER.DAT are redefined:

```
STTIME =  90;  NPL = 11., 5.                         <- 1st rerun set
STTIME = 110;  NPL = 11., 5.                         <- 2nd rerun set
```

Important:
Each variable of which the value is changed somewhere in the rerun file should be assigned a value in each set, even if that value is identical to the value in the previous set.

Listing A7.4 Example of the contents of a RERUNS.DAT file.

```
**********************************************************************
* RERUNS.DAT file                                                    *
*                                                                    *
* When a value for an input variable is changed in a rerun,          *
* that value must be changed accordingly in each set, even           *
* if that value is identical in all sets.                            *
* Lines with an asterisk (*) in the first column are comment lines   *
* Input variables can be separated by a semi-column (;)              *
*                                                                    *
**********************************************************************
SWINLV = 1      ! use measured amount of nitrogen in the leaves
FSV1   = 0.87   ! site variety factor before flowering

SWINLV = 0      ! use simulated amount of nitrogen in the leaves
FSV1   = 0.90   ! site variety factor before flowering
**********************************************************************
```

Output of simulation results

Output is organized from each major subroutine separately. This avoids large argument lists to communicate output variables to the main program and limits the number of changes in the main program when, for instance, another plant routine with different output variables is used.
All subroutines write their output to the same output file (of which the name is defined in the FSE main program). By using a set of special routines (the OUT routines), output can be written in the form of tables. It is also possible to add print plots of selected variables to that output file (see for details Rappoldt & van Kraalingen, 1990). The use of the OUT routines considerably simplifies the generation of output files. The available routines are OUTDAT for output of single variables and OUTARR for arrays.
The OUTDAT routine also has a task parameter as input (the first argument in the call statement), similar to the subprocess descriptions. The first call (with ITASK=1) to OUTDAT (CALL OUTDAT(1,20,'X',0.)) specifies that X will be the independent variable and that unit 20 and 21 can be used for the output file. Subsequent calls with ITASK=2 (CALL OUTDAT(2,0,'X',X)) instruct OUTDAT to store the incoming names and numerical values in a temporary file (with the units from the ITASK=1 call). The number of combinations of name and value that can be stored depends solely on free disk space and not on RAM memory. The first call to OUTDAT below the DO-loop (with ITASK=4, CALL OUTDAT(4, 0,'X',0.)) instructs the routine to create an output table using the information stored in the temporary file. Different output formats may be chosen, dependent on the value of the task variable. Tab-delimited format (e.g. for the EXCEL spreadsheet) can be generated by

defining IPFORM in the TIMER.DAT file IPFORM=5, two-column format with ITASK=6. With any of these ITASK values, the string between quotes is written above the output.
The OUTARR call is actually an 'interface' call to OUTDAT. What the routine does internally is that it generates names (like A(1) and A(2)) and calls OUTDAT repeatedly for each of these name-value combinations. The range of array subscripts that should be generated by OUTARR is specified by the third and the fourth (last) subroutine arguments. This procedure can be repeated several times. The final call to OUTDAT (with 99) deletes the temporary file (CALL OUTDAT(99,0,' ',0.)).

Operation of the model

The model does not require interactive input during execution. The runs have been specified completely in the data files. During execution, the model will display run number, year number and day number on the screen. During execution, errors and warnings may occur from the weather system and/or from the other modules of the model. They, generally, consist of one line of text. If simulation is terminated by an error during the dynamic section of the run, the outputs generated before the error in that particular run occurred, are written to the temporary file but are not yet written to the output file (RESULTS.OUT) until the terminal section of the model. Data can be recovered from the temporary file, using the OUTREC program (OUTput RECovery, see next Section on Error Recovery).

Errors and warnings from the FSE program

Several checks are performed by the model. All errors terminate the model execution and a message to that effect is displayed on the screen. In some cases the error is also written to the output file (RESULTS.OUT). Warnings are displayed on the screen and are sometimes also written to the output file.
The weather system can also generate errors and warnings. Unlike errors from other sections of the model, the weather system itself never terminates the execution of the model. It is the FSE MAIN program that subsequently terminates the simulation run. Errors from the weather system are written to the screen and the log file WEATHER.LOG, warnings are written to the log file only.
If a run is terminated by some error from the model, the output file RESULTS.OUT will not contain the results of that specific run. But the results up till the error occurred are written to the temporary file RES.BIN. This file can be converted into an output table by running the output recovery program OUTREC. This program requests an integer number from the user. A standard output table is generated by a '4' (the default), '5' generates a tab-delimited table (meant to be imported in EXCEL), '6' generates an output of only two columns at a time. The output table will be written to the file OUTREC.OUT so that any existing RESULTS.OUT file is not deleted.

Appendix 8 Listing of the ORYZA_N modules

```
*----------------------------------------------------------------------*
*                                                                      *
*                                                                      *
*            FORTRAN Simulation Environment (FSE 2.0b)                 *
*                        September, 1994                               *
*                                                                      *
*                                                                      *
*     FSE 2.0 is a simulation environment suited for simulation of     *
*     biological processes in time, such as crop and vegetation growth,*
*     insect population development etc.                               *
*                                                                      *
*     The MAIN program, subroutine FSE and subroutine MODELS are       *
*     programmed by D.W.G. van Kraalingen, DLO Centre for              *
*     Agrobiological Research, PO Box 14, 6700 AA, Wageningen, The     *
*     Netherlands (e-mail: d.w.g.van.kraalingen@cabo.agro.nl).         *
*                                                                      *
*     A manual of FSE 2.0 is in preparation.                           *
*                                                                      *
*     Version 1.0 of FSE is described in:                              *
*     Kraalingen, D.W.G. van 1991. The FSE system for crop simulation, *
*     Simulation Report CABO-TT No.23, Centre for Agrobiological       *
*     Research, Dept. of Theoretical Production Ecology, 77 pp.        *
*                                                                      *
*     Data files needed for FSE 2.0:                                   *
*          (excluding data files used by models called from MODELS):  *
*        - CONTROL.DAT (contains file names to be used),               *
*        - timer file whose name is specified in CONTROL.DAT,          *
*        - optionally, a rerun file whose name is specified in         *
*          CONTROL.DAT,                                                *
*        - weather data files as specified in timer file               *
*     Object libraries needed for FSE 2.0:                             *
*        - TTUTIL (at least version 3.2)                               *
*        - WEATHER (at least version from 17-Jan-1990)                 *
*----------------------------------------------------------------------*

      PROGRAM MAIN

      CALL FSE

      END

      SUBROUTINE FSE

      IMPLICIT REAL (A-Z)

*-----Standard declarations for simulation and output control

      INTEGER   ITASK  , INSETS, ISET  , IPFORM, IL, ILEN
      LOGICAL   OUTPUT , TERMNL, RDINQR, STRUNF, ENDRNF
      CHARACTER COPINF*1, DELTMP*1
      INTEGER   INPRS  , STRUN , ENDRUN

      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 weather system
      INTEGER   IFLAG   , ISTAT1, ISTAT2 , ISTN
      REAL      ANGA    , ANGB  , ELEV   , LAT , LONG, RDD
      REAL      TMMN    , TMMX  , VP     , WN  , RAIN
      LOGICAL   WTRMES  , WTRTER
      CHARACTER WTRDIR*80, CNTR*7, WSTAT*6, DUMMY*1

*-----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

*-----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

*-----Unit numbers for control file (C), data files (D),
*     output file (O), log file (L) and rerun file (R). File name for
*     control file and empty strings for input files 1-5.
*     WTRMES flags any messages from the weather system

      DATA IUNITC /10/, IUNITO /30/
      DATA IUNITR /50/
      DATA FILEIC /'CONTROL.DAT'/
      DATA FILEI1 /' '/, FILEI2 /' '/, FILEI3 /' '/
      DATA FILEI4 /' '/, FILEI5 /' '/
      DATA WTRMES /.FALSE./

      DATA STRUNF /.FALSE./, ENDRNF /.FALSE./

*-----Adaptions for FSECM1 common block
      IUNITD = 20
      IUNITL = 40

*-----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)
      IF (RDINQR('STRUN'))  THEN
         CALL RDSINT ('STRUN',STRUN)
         STRUNF = .TRUE.
```

```
      END IF
      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

*-----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
         ENDRUN = INSETS
      ELSE
         ENDRUN = MAX (ENDRUN, 0)
         ENDRUN = MIN (ENDRUN, INSETS)
      END IF

      IF (.NOT.STRUNF) THEN
         STRUN = 0
      ELSE
         STRUN = MAX (STRUN, 0)
         STRUN = MIN (STRUN, ENDRUN)
      END IF

      DO 10 ISET=STRUN,ENDRUN

      WRITE (*,'(A)') '   FSE 2.0b: Initialize model'

*-----Select data set
      CALL RDFROM (ISET, .FALSE.)

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

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

*-----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)

*-----Read time, control and weather variables from timer file
      CALL RDINIT (IUNITD  , IUNITL, FILEIT)
      CALL RDSREA ('STTIME', STTIME)
      CALL RDSREA ('FINTIM', FINTIM)
      CALL RDSREA ('PRDEL' , PRDEL )
      CALL RDSREA ('DELT'  , DELT  )
      CALL RDSINT ('IYEAR' , IYEAR )
      CALL RDSINT ('ISTN'  , ISTN  )
      CALL RDSINT ('IPFORM', IPFORM)
      CALL RDSCHA ('COPINF', COPINF)
      CALL RDSCHA ('DELTMP', DELTMP )
      CALL RDSCHA ('WTRDIR', WTRDIR)
      CALL RDSCHA ('CNTR'  , CNTR)
      CALL RDSINT ('IFLAG' , IFLAG)

*-----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)

      CLOSE (IUNITD)

*-----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)

*-----Open weather file and read station information and return
*     weather data for start day of simulation.
*     Check status of weather system, WTRMES flags if warnings or errors
*     have occurred during the whole simulation. WTRTER flags if the run
*     should be terminated because of missing weather
```

```
      CALL STINFO (IFLAG , WTRDIR, ' ', CNTR, ISTN, IYEAR,
     &             ISTAT1, LONG  , LAT, ELEV, ANGA, ANGB)
      CALL WEATHR (IDOY  , ISTAT2, RDD, TMMN, TMMX, VP, WN, RAIN)
      IF (ISTAT1.NE.0.OR.ISTAT2.NE.0) WTRMES = .TRUE.
      WSTAT  = '444444'
      IF (ABS (ISTAT2).GE.111111) THEN
         WRITE (WSTAT,'(I6)') ABS (ISTAT2)
      ELSE IF (ISTAT2.EQ.0) THEN
         WSTAT = '111111'
      END IF

*-----initialize OBSSYS routine
      IF (ITASK.EQ.1) CALL OBSINI

*-----Conversion of total daily radiation from kJ/m2/d to J/m2/d
      RDD = RDD*1000.

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


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

      WRITE (*,'(A)') '   FSE 2.0b: 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,
     &                FILEI1, FILEI2, FILEI3, FILEI4, FILEI5,
     &                FILEIT, OUTPUT, TERMNL,
     &                DOY   , IDOY  , YEAR  , IYEAR ,
     &                TIME  , STTIME, FINTIM, DELT  ,
     &                LAT   , 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)
      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 STINFO (IFLAG , WTRDIR, ' ', CNTR, ISTN, IYEAR,
     &             ISTAT1, LONG  , LAT, ELEV, ANGA, ANGB)
      CALL WEATHR (IDOY, ISTAT2, RDD, TMMN, TMMX, VP, WN, RAIN)
      IF (ISTAT1.NE.0.OR.ISTAT2.NE.0) WTRMES = .TRUE.
      WSTAT  = '444444'
      IF (ABS (ISTAT2).GE.111111) THEN
         WRITE (WSTAT,'(I6)') ABS (ISTAT2)
      ELSE IF (ISTAT2.EQ.0) THEN
         WSTAT = '111111'
      END IF

*-----Conversion of total daily radiation from kJ/m2/d to J/m2/d
      RDD = RDD*1000.

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

*-----Call routine that handles the different models
      CALL MODELS (ITASK , IUNITD, IUNITO, IUNITL,
     &             FILEI1, FILEI2, FILEI3, FILEI4, FILEI5,
     &             FILEIT, OUTPUT, TERMNL,
     &             DOY   , IDOY  , YEAR  , IYEAR ,
     &             TIME  , STTIME, FINTIM, DELT  ,
     &             LAT   , 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 MODELS (ITASK , IUNITD, IUNITO, IUNITL,
     &                FILEI1, FILEI2, FILEI3, FILEI4, FILEI5,
     &                FILEIT, OUTPUT, TERMNL,
     &                DOY   , IDOY  , YEAR  , IYEAR ,
     &                TIME  , STTIME, FINTIM, DELT  ,
     &                LAT   , 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

*======================================================================*
*                                                                      *
*                           Terminal section                           *
*                                                                      *
*======================================================================*

      ITASK = 4

      WRITE (*,'(A)') '   FSE 2.0b: Terminate model'

*-----Call routine that handles the different models
      CALL MODELS (ITASK , IUNITD, IUNITO, IUNITL,
     &             FILEI1, FILEI2, FILEI3, FILEI4, FILEI5,
     &             FILEIT, OUTPUT, TERMNL,
     &             DOY   , IDOY  , YEAR  , IYEAR ,
     &             TIME  , STTIME, FINTIM, DELT  ,
     &             LAT   , WSTAT , WTRTER,
```

```
     &             RDD   , TMMN  , TMMX  , VP    , WN, RAIN)

*-----Generate output file dependent on option from timer file
      IF (IPFORM.GE.4) THEN
         IF (INPRS.EQ.0) THEN
            CALL OUTDAT (IPFORM, 0, 'Simulation results',0.)
         ELSE
*           Selection of output variables was in timer file
*           write tables according to output selection array PRSEL
            CALL OUTSEL (PRSEL,IMNPRS,INPRS,IPFORM,'Simulation results')
         END IF
      END IF

      IF (WTRTER) THEN
         WRITE (*,'(/,A,/,/,/)')
     &     ' The run was terminated due to missing weather'
         WRITE (IUNITO,'(/,A,/,/,/)')
     &     ' The run was terminated due to missing weather'
         IF (IUNITO.NE.IUNITL) WRITE (IUNITL,'(/,A,/,/,/)')
     &     ' The run was terminated due to missing weather'
      END IF

*-----Delete temporary output file dependent on switch from timer file
      IF (DELTMP.EQ.'Y'.OR.DELTMP.EQ.'y') CALL OUTDAT (99, 0, ' ', 0.)

10    CONTINUE

      IF (INSETS.GT.0) CLOSE (IUNITR)

*-----If input files should be copied to the output file,
*     copy rerun file (if present) and timer file and if there, input
*     files 1-5

      IF (COPINF.EQ.'Y'.OR.COPINF.EQ.'y') THEN
         IF (INSETS.GT.0) CALL COPFL2 (IUNITR, FILEIR, IUNITO, .TRUE.)
         CALL COPFL2 (IUNITD, FILEIT, IUNITO, .TRUE.)
         IF (FILEI1.NE.' ') CALL COPFL2 (IUNITD, FILEI1, IUNITO, .TRUE.)
         IF (FILEI2.NE.' ') CALL COPFL2 (IUNITD, FILEI2, IUNITO, .TRUE.)
         IF (FILEI3.NE.' ') CALL COPFL2 (IUNITD, FILEI3, IUNITO, .TRUE.)
         IF (FILEI4.NE.' ') CALL COPFL2 (IUNITD, FILEI4, IUNITO, .TRUE.)
         IF (FILEI5.NE.' ') CALL COPFL2 (IUNITD, FILEI5, IUNITO, .TRUE.)
      END IF

*-----Delete all .TMP files that were created by the RD* routines
*     during simulation
      CALL RDDTMP (IUNITD)

*-----Write to screen which files contain what
      IL = ILEN (FILEON)
      WRITE (*,'(/,3A)') ' File: ',FILEON(1:IL),
     &  ' contains simulation results'
      WRITE (*,'(2A)') ' File: WEATHER.LOG',
     &  ' contains messages from the weather system'
      IL = ILEN (FILEOL)
```

```
      WRITE (*,'(3A,/)') ' File: ',FILEOL(1:IL),
     &  ' contains messages from the rest of the model'

*-----Write message to screen and output file if warnings and/or errors
*     have occurred from the weather system, pause and wait for return
*     from user to make sure he has seen this message

      IF (WTRMES) THEN

         WRITE (*,'(/,A,/,A,/,A)') ' WARNING from FSE:',
     &     ' There have been errors and/or warnings from',
     &     ' the weather system, check file WEATHER.LOG'
         WRITE (IUNITO,'(A,/,A,/,A)') ' WARNING from FSE:',
     &     ' There have been errors and/or warnings from',
     &     ' the weather system, check file WEATHER.LOG'

         WRITE (*,'(A)') ' Press <Enter>'
         READ  (*,'(A)') DUMMY

      END IF

*-----Close output file and temporary file of OUTDAT
      CLOSE (IUNITO)
      CLOSE (IUNITO+1)

*-----Close log file (if used)
      IF (FILEOL.NE.FILEON) CLOSE (IUNITL)

*-----Close log file of weather system
      CLOSE (91)

      RETURN
      END

*----------------------------------------------------------------------*
* SUBROUTINE MODELS                                                    *
* Authors: Daniel van Kraalingen                                       *
* Date   : 5-Jul-1993                                                  *
* Purpose: This subroutine is the interface routine between the FSE-   *
*          driver and the simulation models. This routine is called    *
*          by the FSE-driver at each new task at each time step. It    *
*          can be used by the user to specify calls to the different   *
*          models that have to be simulated                            *
*                                                                      *
* FORMAL PARAMETERS:  (I=input,O=output,C=control,IN=init,T=time)      *
* name   type meaning                                    units  class *
* ----   ---- -------                                    -----  ----- *
* 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 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  *
* 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  *
* LAT     R4  Latitude of site                       dec.degr.     I  *
* WSTAT   C7  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              degrees C     I  *
* TMMX    R4  Daily maximum temperature              degrees 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  *
*                                                                      *
* Fatal error checks: none                                             *
* Warnings          : none                                             *
* Subprograms called: models as specified by the user                  *
* File usage        : none                                             *
*----------------------------------------------------------------------*

      SUBROUTINE MODELS (ITASK , IUNITD, IUNITO, IUNITL,
     &                   FILEI1, FILEI2, FILEI3, FILEI4, FILEI5,
     &                   FILEIT, OUTPUT, TERMNL,
     &                   DOY   , IDOY  , YEAR  , IYEAR,
     &                   TIME  , STTIME, FINTIM, DELT ,
     &                   LAT   , WSTAT , WTRTER,
     &                   RDD   , TMMN  , TMMX  , VP   , WN, RAIN)
      IMPLICIT REAL (A-Z)

*     Formal parameters
      INTEGER   ITASK, IUNITD, IUNITO, IUNITL, IDOY, IYEAR
      CHARACTER FILEI1*(*), FILEI2*(*), FILEI3*(*)
      CHARACTER FILEI4*(*), FILEI5*(*), FILEIT*(*)
      LOGICAL   OUTPUT, TERMNL, WTRTER
      CHARACTER WSTAT*7

      SAVE

      CALL       ORYZAN (ITASK , IUNITD, IUNITO, IUNITL,
     &                   FILEI1, FILEI2, FILEI3, FILEI4, FILEI5,
     &                   FILEIT, OUTPUT, TERMNL,
     &                   DOY   , TIME  , STTIME, FINTIM, DELT ,
     &                   LAT   , WSTAT , WTRTER,
     &                   RDD   , TMMN  , TMMX )

      RETURN
      END
```

```
*----------------------------------------------------------------------*
*                                                                      *
*                              ORYZAN                                  *
*                                                                      *
*                               SARP                                   *
*                            March 1994                                *
*                           Version: 1.1                               *
*                                                                      *
*                                                                      *
* Research Institute for Agrobiology and Soil Fertility (AB-DLO),      *
* P.O.Box 14, 6700 AA Wageningen, The Netherlands                      *
*                                                                      *
* International Rice Research Institute, P.O. Box 933,                 *
* 1099 Manila, The Philippines and                                     *
*                                                                      *
* Department of Theoretical Production Ecology, P.O. Box 430,          *
* 6700 AK Wageningen, The Netherlands.                                 *
*                                                                      *
*                                                                      *
* Purpose: Module for nitrogen limited and potential                   *
*          rice production                                             *
*                                                                      *
* History:                                                             *
* The model contains components derived from:                          *
* - MACROS-L1D by Penning de Vries F.W.T. et al., 1989. Simulation of  *
*                 ecophysiological processes of growth in several      *
*                 annual crops. Simulation Monographs 29, Pudoc,       *
*                 Wageningen and IRRI, Los Banos, 271 pp.              *
* - SUCROS     by Laar, H.H. van, J. Goudriaan & H. van Keulen, 1992.  *
*                 Simulation of crop growth for potential and water-   *
*                 limited production situations. Simulation Reports 27,*
*                 CABO-TPE, Wageningen, The Netherlands, 72 pp.        *
* - ORYZA1     by Kropff, M.J.K., H.H. van Laar & H.F.M. ten Berge,    *
*                 1993. ORYZA1. Abic model for irrigated lowland rice  *
*                 production. Draft report, 88 pp.                     *
*                                                                      *
*                                                                      *
*  FORMAL PARAMETERS:  (I=input,O=output,C=control,IN=init,T=time)     *
*  name   type meaning                                    units  class *
*  ----   ---- -------                                    -----  ----- *
* 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 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  *
* FILEIT  *C  Name of the timerfile                          -     IC  *
* OUTPUT  L4  Flag to indicate if output should be done      -      I  *
* TERMNL  L4  Flag to indicate if simulation is to stop      -    I/O  *
* DOY     R4  Day number within year of simulation (REAL)    d      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  *
* LAT     R4  Latitude of site                         dec.degr.    I  *
* WSTAT   C7  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  *
* TMN     R4  Daily minimum temperature                 degrees C   I  *
* TMX     R4  Daily maximum temperature                 degrees C   I  *
*                                                                      *
* Fatal error checks: If one of the characters of WSTAT = '4'          *
*                     indicates missing weather                        *
* Warnings          : none                                             *
* Subprograms called: TIMENV, DEVELP, LFAREA, BIOMS1                   *
* File usage        : IUNITD, IUNITO, IUNITL, FILEIT,FILEI1, FILEI2,   *
*                     FILEI3, FILEI4, FILEI5                           *
* Libraries used    : TTUTIL, COME_ON                                  *
*                                                                      *
*----------------------------------------------------------------------*
      SUBROUTINE ORYZAN (ITASK , IUNITD, IUNITO, IUNITL,
     &                   FILEI1, FILEI2, FILEI3, FILEI4, FILEI5,
     &                   FILEIT, OUTPUT, TERMNL,
     &                   DOY   , TIME  , STTIME, FINTIM, DELT ,
     &                   LAT   , WSTAT , WTRTER,
     &                   RDD   , TMN   , TMX )


      IMPLICIT REAL (A-Z)

*     Formal parameters
      INTEGER  ITASK , IUNITD, IUNITO, IUNITL
      LOGICAL  OUTPUT, TERMNL, WTRTER
      CHARACTER FILEI1*(*), FILEI2*(*),FILEI3*(*),FILEI4*(*)
      CHARACTER FILEI5*(*), FILEIT*(*), WSTAT*(*)
      REAL DOY, LAT, TMN, TMX, FINTIM, DELT

*     Standard local declarations
      INTEGER ITOLD, IWVAR
      INTEGER SWILAI, SWINUP, SWISIN, SWINPH
      INTEGER SWINPR, SWISAI
      CHARACTER WUSED*6

*     Other local declarations:
      CHARACTER*80  TREATM

      SAVE

*     initial value of previous task
      DATA ITOLD /4/

      IF (DELT.LT.1.0) CALL ERROR
     &   ('ORYZAN','DELT too small for ORYZAN')
```

```
*     code for the use of RDD, TMMN, TMMX, VP, WN, RAIN  (in that order)
*     a letter 'U' indicates that the variable is Used in calculations
      DATA WUSED/'UUU---'/

*     Check weather data availability
      IF (ITASK.EQ.1.OR.ITASK.EQ.2.OR.ITASK.EQ.4) THEN
         DO 10 IWVAR=1,6
*           is there an error in the IWVAR-th weather variable ?
            IF (WUSED(IWVAR:IWVAR).EQ.'U' .AND.
     &          WSTAT(IWVAR:IWVAR).EQ.'4') THEN
               WTRTER = .TRUE.
               TERMNL = .TRUE.
               ITOLD  = ITASK
               RETURN
            END IF
10       CONTINUE
      END IF


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

      IF (ITASK.EQ.1) THEN

*--------Message send to output file
         CALL OUTCOM ('FSE-ORYZAN: Rice Production related to N supply')

*--------Read switches that are used to control the active modules
*        and processes of the model. Switches are supposed to be
*        situated within the timerfile.

         CALL RDINIT (IUNITD  , IUNITL, FILEIT)

         CALL RDSINT ('SWILAI', SWILAI)
         CALL RDSINT ('SWINUP', SWINUP)
         CALL RDSINT ('SWISIN', SWISIN)
         CALL RDSINT ('SWINPH', SWINPH)
         CALL RDSINT ('SWINPR', SWINPR)
         CALL RDSINT ('SWISAI', SWISAI)

         CLOSE (IUNITD)

         CALL RDINIT (IUNITD  , IUNITL, FILEI1)

*--------Dataset used printed in output file
         CALL RDSCHA ('TREATM',TREATM)
         CALL OUTCOM (TREATM)

         CLOSE (IUNITD)

      ELSE IF (ITASK.EQ.2) THEN

*----------------------------------------------------------------------*
*                        Rate calculation section                      *
*----------------------------------------------------------------------*

         CONTINUE

      ELSE IF (ITASK.EQ.3) THEN

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

         CONTINUE

      ELSE IF (ITASK.EQ.4) THEN

*----------------------------------------------------------------------*
*                        Terminal section                              *
*----------------------------------------------------------------------*

         CONTINUE

      END IF

       CALL TIMENV (ITASK, IUNITD, IUNITL, FILEI1,
     &                    OUTPUT, TERMNL, WSTAT, WTRTER,
     &                    TIME, STTIME, DOY, YEAR, DELT,
     &                    RDD, TMN, TMX,
     &                    DAT, DATEH, HU, HULV, TAV, TAVD, TS, TSLV)

       CALL DEVELP (ITASK, IUNITD, IUNITL, FILEI1,
     &                    OUTPUT, DELT,
     &                    HU, TS,
     &                    DVS, DVR, DRR)

       CALL LFAREA (ITASK, IUNITD, IUNITL, FILEI1,
     &                    OUTPUT, DELT,
     &                    SWILAI, SWISAI,
     &                    DVS, TSLV, WLVG, WSTS,
     &                    LAI, SAI, XXLAI)

       CALL BIOMS1 (ITASK, IUNITD, IUNITL, FILEI1,
     &                    OUTPUT, TERMNL, WSTAT, WTRTER,
     &                    TIME, STTIME, DOY, DELT,
     &                    LAT, RDD,
     &                    SWINPR, SWINPH, SWINUP, SWISIN,
     &                    DAT, TAV, TAVD, DVS, DRR, LAI,
     &                    WLVG, WSTS)

      RETURN
      END

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

```
*  SUBROUTINE TIMENV                                                   *
*                                                                      *
*  Author : SARP                                                       *
*  Date   : December 1994                                              *
*  Version: 2.0                                                        *
*                                                                      *
*  Research Institute for Agrobiology and Soil Fertility (AB-DLO),     *
*  P.O.Box 14, 6700 AA Wageningen, The Netherlands                     *
*                                                                      *
*  International Rice Research Institute, P.O. Box 933,                *
*  1099 Manila, The Philippines and                                    *
*                                                                      *
*  Department of Theoretical Production Ecology, P.O. Box 430,         *
*  6700 AK Wageningen, The Netherlands.                                *
*                                                                      *
*                                                                      *
*  Purpose: Compute the time and environmental variables.              *
*                                                                      *
*  FORMAL PARAMETERS:(I=input,O=output,C=control,IN=init,T=time)       *
*  name   type meaning                                   units  class *
*  ----   ---- -------                                   -----  ----- *
* 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 input file no. 1                      -      I *
* OUTPUT  L4  Flag to indicate if output should be done     -      I *
* TERMNL  L4  Flag to indicate if simulation is to stop     -    I/O*
* WSTAT   C7  Status code from weather system               -      I *
* WTRTER  L4  Flag whether weather can be used by model     -      I *
* TIME    R4  Time of simulation                            d      I *
* STTIME  R4  Start time of simulation                      d      I *
* DOY     R4  Julian day of year                            d      I *
* YEAR    R4  Year                                          y      I *
* DELT    R4  Time step of integration                      d      I *
* RDD     R4  Radiation                                 J/m2/d     I *
* TMN     R4  Minimum night temperature                  deg C     I *
* TMX     R4  Maximum day temperature                    deg C     I *
* DAT     R4  Day after transplanting                       d      O *
* DATEH   R4  Harvest date in days after transplanting      -      O *
* HU      R4  Daily heat unit plant development             K      O *
* HULV    R4  Daily heat unit for leaf development          K      O *
* TAV     R4  24h average of actual air temperature      deg C     O *
* TAVD    R4  actual average air temp. at daytime        deg C     O *
* TS      R4  Temperature sum for plant development        K d     O *
* TSLV    R4  Temperature sum of leaf development          K d     O *
*                                                                      *
* Fatal error checks: if one of the characters of WSTAT = '4',         *
*                     indicates missing weather                        *
* Warnings          : none                                             *
* Subprograms called: none                                             *
* File usage        : IUNITD,IUNITD+1, IUNITL                          *
* Libraries used    : TTUTIL                                           *
*                                                                      *
*----------------------------------------------------------------------*
      SUBROUTINE TIMENV (ITASK , IUNITD, IUNITL, FILEI1,
     &                   OUTPUT, TERMNL, WSTAT , WTRTER,
     &                   TIME  , STTIME, DOY   , YEAR  , DELT  ,
     &                   RDD   , TMN   , TMX   ,
     &                   DAT   , DATEH , HU    , HULV  , TAV   ,
     &                   TAVD  , TS    , TSLV)

      IMPLICIT REAL (A-Z)

*     Formal parameters
      INTEGER   ITASK,  IUNITD, IUNITL
      LOGICAL   OUTPUT, TERMNL, WTRTER
      CHARACTER*(*) FILEI1, WSTAT

*     Standard local declarations
      INTEGER IWVAR,ITOLD
      CHARACTER WUSED*6

*     Function declarations
      REAL INTGR2

*     State variables, initial values and rates
      REAL RADTOT, RADTOI, RDM
      REAL TS, HU
      REAL TSLV, HULV

*     Model parameters
      REAL DATH

*     Auxiliary variables
      REAL DAT, DATEH, TAV, TAVD


      SAVE

      DATA ITOLD /4/

*     code for the use of RDD, TMMN, TMMX, VP, WN, RAIN  (in that order)
*     a letter 'U' indicates that the variable is Used in calculations
      DATA WUSED/'UUU---'/

*     Check weather data availability
      IF (ITASK.EQ.1.OR.ITASK.EQ.2.OR.ITASK.EQ.4) THEN
         DO 10 IWVAR=1,6
*           is there an error in the IWVAR-th weather variable ?
            IF (WUSED(IWVAR:IWVAR).EQ.'U' .AND.
     &          WSTAT(IWVAR:IWVAR).EQ.'4') THEN
               WTRTER = .TRUE.
               TERMNL = .TRUE.
               ITOLD  = ITASK
               RETURN
            END IF
10       CONTINUE
      END IF
```

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

*----------------------------------------------------------------------*
*                         Initialization                               *
*----------------------------------------------------------------------*
*-----Message
      IF (DELT.LT.1.0) CALL ERROR
     &      ('TIMENV','DELT too small for TIMENV')

      CALL RDINIT (IUNITD, IUNITL, FILEI1)

*-----Read initial states
      CALL RDSREA ('RADTOI', RADTOI)

*-----Environmental Variables
      CALL RDSREA ('TBD'   , TBD   )
      CALL RDSREA ('TBLV'  , TBLV  )
      CALL RDSREA ('DATH'  , DATH  )

      CLOSE (IUNITD)

*-----Initialization of states
      TS     = 0.
      TSLV   = 0.
      RADTOT = RADTOI

      ELSE IF (ITASK.EQ.2) THEN

*----------------------------------------------------------------------*
*                         Rate calculation section                     *
*----------------------------------------------------------------------*

*-----Time variables

*-----Days after Transplanting (DAT)

         DAT    = TIME - STTIME
         DATEH  = STTIME + DATH

************************************************************************
*-----Environmental variables


*-----Actual air temperature in daytime and 24h average
      TAV    = 0.5*(TMX + TMN)
      TAVD   = 0.5*(TAV + TMX)

*-----Heat unit for plant and leaf development
      HU     = MIN(30.-TBD, (MAX (0., TAV-TBD)))
      HULV   = MIN(26.-TBLV,(MAX (0., TAV-TBLV)))

*-----Radiation in MJ m-2 d-1
      RDM = RDD * 1.E-06

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

```
*-----Output section

      IF (OUTPUT) THEN

         CALL OUTDAT (2, 0, 'TIME',      TIME)
         CALL OUTDAT (2, 0, 'DOY',        DOY)
         CALL OUTDAT (2, 0, 'YEAR',      YEAR)
         CALL OUTDAT (2, 0, 'DAT',        DAT)
         CALL OUTDAT (2, 0, 'DATEH',    DATEH)
         CALL OUTDAT (2, 0, 'HU',          HU)
         CALL OUTDAT (2, 0, 'HULV',      HULV)
         CALL OUTDAT (2, 0, 'RADTOT',  RADTOT)
         CALL OUTDAT (2, 0, 'RDM',        RDM)
         CALL OUTDAT (2, 0, 'TAV',        TAV)
         CALL OUTDAT (2, 0, 'TAVD',      TAVD)
         CALL OUTDAT (2, 0, 'TS',          TS)
         CALL OUTDAT (2, 0, 'TSLV',      TSLV)

      END IF
************************************************************************

      ELSE IF (ITASK.EQ.3) THEN

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

*-----Environmental variables

*-----Temperature sum for plant and leaf development
      TS   = INTGR2 (TS  , HU   ,        DELT, FILEI1,  'TS')
      TSLV = INTGR2 (TSLV, HULV ,        DELT, FILEI1, 'TSLV')

*-----Radiation in MJ m-2 d-1
      RADTOT = INTGR2 (RADTOT, RDM, DELT, FILEI1, 'RADTOT')

************************************************************************
*-----Finish conditions

*-----Finish condition of ORYZA_N in subroutine BIOMS1
*-----Finish condition of ORYZA_0 in subroutine BIOMS2

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

      ELSE IF (ITASK.EQ.4) THEN
*----------------------------------------------------------------------*
*                         Terminal section                             *
*----------------------------------------------------------------------*
         CONTINUE

      END IF

      RETURN
      END
```

```
*----------------------------------------------------------------------*
*  SUBROUTINE DEVELP                                                   *
*                                                                      *
*  Authors: SARP                                                       *
*  Date   : December 1994                                              *
*  Version: 2.0                                                        *
*                                                                      *
* Research Institute for Agrobiology and Soil Fertility (AB-DLO),      *
* P.O.Box 14, 6700 AA Wageningen, The Netherlands                      *
*                                                                      *
* International Rice Research Institute, P.O. Box 933,                 *
* 1099 Manila, The Philippines and                                     *
*                                                                      *
* Department of Theoretical Production Ecology, P.O. Box 430,          *
* 6700 AK Wageningen, The Netherlands.                                 *
*                                                                      *
*                                                                      *
*  Purpose: Computes development stage                                 *
*                                                                      *
*  FORMAL PARAMETERS:(I=input,O=output,C=control,IN=init,T=time)       *
*  name   type meaning                                  units  class *
*  ----   ---- -------                                  -----  ----- *
* 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 input file no. 1                   -       I   *
* OUTPUT  L4   Flag to indicate if output should be done  -       I   *
* TERMNL  L4   Flag to indicate if simulation is to stop  -      I/O  *
* WSTAT   C7   Status code from weather system            -       I   *
* WTRTER  L4   Flag whether weather can be used by model  -       I   *
* DELT    R4   Time step of integration                   d       I   *
* HU      R4   Daily heat unit plant development          K       I   *
* TS      R4   Temperature sum for plant development     K d      I   *
* DVS     R4   Phenelogical development stage crop        -       O   *
* DVR     R4   Development rate crop in vegetative phase  1/d     O   *
* DRR     R4   Development rate crop in reproductive phase 1/d    O   *
*                                                                      *
* Fatal error checks: If one of the characters of WSTAT = '4'          *
*                     indicates missing weather                        *
* Warnings          : none                                             *
* Subprograms called: none                                             *
* File usage        : IUNITD, IUNITO, IUNITL, FILEI1                   *
* Libraries used    : TTUTIL, COME_ON                                  *
*                                                                      *
*----------------------------------------------------------------------*
      SUBROUTINE DEVELP (ITASK, IUNITD, IUNITL, FILEI1,
     &                   OUTPUT, DELT,
     &                   HU, TS,
     &                   DVS, DVR, DRR)

      IMPLICIT REAL (A-Z)
```

```
*-----Formal parameters
      INTEGER   ITASK,  IUNITD, IUNITL
      LOGICAL   OUTPUT
      CHARACTER*(*) FILEI1
      REAL DVS, DRR, HU, TS, TSI

      SAVE

      IF (ITASK.EQ.1) THEN

*======================================================================*
*                          Initialization                              *
*======================================================================*

*-----Message
      IF (DELT.LT.1.0) CALL ERROR
     &      ('DEVELP','DELT too small for DEVELP')

      CALL RDINIT (IUNITD, IUNITL, FILEI1)

*-----Phenological development
      CALL RDSREA ('SHCKD' , SHCKD )
      CALL RDSREA ('DVRV'  , DVRV  )
      CALL RDSREA ('DVRR'  , DVRR  )
      CALL RDSREA ('DVSI'  , DVSI  )
      CALL RDSREA ('TSI'   , TSI   )

      CLOSE (IUNITD)

*-----Initialization of states/rates
      DVS    = DVSI
      TSTR   = TSI
      DRR    = 0.

      ELSE IF (ITASK.EQ.2) THEN

*======================================================================*
*                       Rate calculation section                       *
*======================================================================*

*-----Development rates

      IF (DVS.LT.1.) THEN

         TSHCKD = SHCKD * TSTR

         IF ((TS+TSI).LT.(TSTR+TSHCKD)) THEN
            DVR = 0.
         ELSE
            DVR    = DVRV * HU
         ENDIF

         DRR = 0.

      ELSE
```

```
         DVR = DVRR * HU
         DRR = DVR

      END IF

************************************************************************
*-----Output section

      IF (OUTPUT) THEN

         CALL OUTDAT (2, 0, 'DRR',         DRR)
         CALL OUTDAT (2, 0, 'DVR',         DVR)
         CALL OUTDAT (2, 0, 'DVS',         DVS)
         CALL OUTDAT (2, 0, 'TSHCKD',   TSHCKD)

      END IF
************************************************************************

      ELSE IF (ITASK.EQ.3) THEN

*======================================================================*
*                        Integration section                           *
*======================================================================*

*-----Phenological development stage

      DVS  = INTGR2 (DVS , DVR,         DELT, FILEI1, 'DVS')

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

      ELSE IF (ITASK.EQ.4) THEN
*======================================================================*
*                        Terminal section                              *
*======================================================================*

         CONTINUE

      END IF

      ITOLD = ITASK

      RETURN
      END


*----------------------------------------------------------------------*
*  SUBROUTINE LFAREA                                                   *
*                                                                      *
*  Authors: SARP                                                       *
*  Date   : December 1994                                              *
*  Version: 2.0                                                        *
*                                                                      *
*  Research Institute for Agrobiology and Soil Fertility (AB-DLO),     *
*  P.O.Box 14, 6700 AA Wageningen, The Netherlands                     *
*                                                                      *
*  International Rice Research Institute, P.O. Box 933,                *
*  1099 Manila, The Philippines and                                    *
*                                                                      *
*  Department of Theoretical Production Ecology, P.O. Box 430,         *
*  6700 AK Wageningen, The Netherlands.                                *
*                                                                      *
*                                                                      *
*  Purpose: Computes leaf and stem area development                    *
*                                                                      *
*  FORMAL PARAMETERS:(I=input,O=output,C=control,IN=init,T=time)       *
*  name    type meaning                                    units  class *
*  ----    ---- -------                                    -----  ----- *
* 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 input file no. 1                     -      I  *
* OUTPUT   L4   Flag to indicate if output should be done    -      I  *
* DELT     R4   Time step of integration                     d      I  *
* SWILAI   I4   Switch for choosing LAI algorithm            -     IC  *
*               (1 = simulated leaf mass and SLA,                      *
*                2 = tabulated ln(LAI) vs Temperature sum              *
*                3 = use RGRL in exponential growth phase,             *
*                    and SLA afterwards                                *
*                4 = measured leaf mass and SLA                        *
*                5 = measured LAI)                                     *
* SWISAI   I4   Switch to incl/excl stem area into LAI       -     IC  *
*               (0 = SAI not included, 1 = SAI included)               *
* DVS      R4   Phenological development stage crop          -      I  *
* TSLV     R4   Temperature sum of leaf development         K d     I  *
* WLVG     R4   Weight of green leaves                     kg/ha    I  *
* WSTS     R4   Weight of stems minus WSTR                 kg/ha    I  *
* LAI      R4   Leaf area index                              -      O  *
* SAI      R4   Stem area index                              -      O  *
* XXLAI    R4   Measured LAI                                 -      O  *
*                                                                      *
* Fatal error checks: If one of the characters of WSTAT = '4'          *
*                     indicates missing weather                        *
* Warnings          : none                                             *
* Subprograms called: none                                             *
* File usage        : IUNITD, IUNITL, FILEI1                           *
* Libraries used    : TTUTIL, COME_ON                                  *
*                                                                      *
*----------------------------------------------------------------------*
      SUBROUTINE LFAREA (ITASK, IUNITD, IUNITL, FILEI1,
     &                   OUTPUT, DELT,
     &                   SWILAI, SWISAI,
     &                   DVS, TSLV, WLVG, WSTS,
     &                   LAI, SAI, XXLAI)


      IMPLICIT REAL (A-Z)

*-----Formal parameters
```

```
      INTEGER   ITASK,  IUNITD, IUNITL
      LOGICAL   OUTPUT
      CHARACTER*(*) FILEI1
      INTEGER SWILAI,SWISAI

*-----Standard local declarations
      INTEGER IMNP
      PARAMETER (IMNP=100)

*-----Function declarations
      LOGICAL INQOBS

*-----Leaf area development
      INTEGER ILSLAF, ILLAIN, ILSAI
      REAL    SLAFAC(IMNP), LAILNT(IMNP), SSGATB(IMNP)
      PARAMETER (TSLVC = 89.7)

      SAVE

      IF (ITASK.EQ.1) THEN

*======================================================================*
*                         Initialization                               *
*======================================================================*

*-----Message
      IF (DELT.LT.1.0) CALL ERROR
     &      ('LFAREA','DELT too small for LFAREA')

*-----Message send to outputfile
      IF (SWILAI.EQ.1) THEN
         CALL OUTCOM ('SWILAI=1 ; measured SLA/SLAC vs DVS')
      ELSE IF (SWILAI.EQ.2) THEN
         CALL OUTCOM ('SWILAI=2 ; measured ln(LAI) vs TS')
      ELSE IF (SWILAI.EQ.3) THEN
         CALL OUTCOM ('SWILAI=3 ; incl. transpl.shock??')
      ELSE IF (SWILAI.EQ.4) THEN
         CALL OUTCOM ('SWILAI=4 ; meas.leaf mass, calculated SLA')
      ELSE IF (SWILAI.EQ.5) THEN
         CALL OUTCOM ('SWILAI=5 ; measured LAI')
      ELSE
         CALL ERROR ('LFAREA','illegal value used for switch SWILAI')
      END IF

      IF (SWISAI.EQ.0) THEN
         CALL OUTCOM ('SWISAI=0 ; stem area not included in LAI')
      ELSE IF (SWISAI.EQ.1) THEN
         CALL OUTCOM ('SWISAI=1 ; stem area included in LAI')
      ELSE
         CALL ERROR ('LFAREA','illegal value used for switch SWISAI')
      END IF

      CALL RDINIT (IUNITD, IUNITL, FILEI1)

*-----Initital states
      CALL RDSREA ('WLVGI' , WLVGI )
      CALL RDSREA ('WSTSI' , WSTSI )

*-----Leaf area development
      CALL RDSREA ('SLAC'   , SLAC   )
      CALL RDSREA ('SSA'    , SSA    )
      CALL RDAREA ('SLAFAC', SLAFAC, IMNP, ILSLAF)
      CALL RDAREA ('SSGATB', SSGATB, IMNP, ILSAI)
      CALL RDAREA ('LAILNT', LAILNT, IMNP, ILLAIN)
      CALL RDSREA ('RGRL'   , RGRL   )

      CLOSE (IUNITD)

*-----Initialization of states/rates
      LAI    = 0.

      WLVG   = WLVGI
      WSTS   = WSTSI

      SAI    = 0.
      LAIEXP = 0.
      WLVEXP = 0.

*-----Initialise to -99 in case of missnig observed values.
      XXLAI  = -99.
      XXWLVG = -99.

      SLA    = SLAC*LINT(SLAFAC, ILSLAF, DVS)
      LAII   = WLVGI *SLA
      LAIOLD = LAII


      ELSE IF (ITASK.EQ.2) THEN

*======================================================================*
*                      Rate calculation section                        *
*======================================================================*

*-----Reading of Measured Data

      IF (INQOBS(FILEI1,  'LAI')) XXLAI  = GETOBS(FILEI1, 'LAI')
      IF (INQOBS(FILEI1, 'WLVG')) XXWLVG = GETOBS(FILEI1, 'WLVG')

************************************************************************
*-----Leaf area development

      IF (SWILAI.EQ.1) THEN

         SLA = SLAC*LINT(SLAFAC, ILSLAF, DVS)
         IF (TSLV.LT.TSLVC) THEN
            LAI = LAII
         ELSE
            LAI = WLVG*SLA
         END IF
```

```
      ELSE IF (SWILAI.EQ.2) THEN

         LAI = MAX (LAII,EXP(LINT (LAILNT, ILLAIN, TSLV)))

      ELSE IF (SWILAI.EQ.3) THEN

         IF(DVS.LT.0.3.AND.LAIOLD.LT.1.5) THEN
            WLVEXP = WLVG
            LAIEXP = LAII*MAX(1.,EXP(RGRL*(TSLV-TSLVC)))
            LAI    = LAIEXP+0.5*WSTS*SSA
         ELSE
            SLA    = SLAC*LINT(SLAFAC, ILSLAF, DVS)
            LAI    = MAX(0.,LAIEXP)+0.5*WSTS*SSA+
     $                (WLVG-MAX(0.,WLVEXP))*SLA
         END IF
         LAIOLD = LAI

      ELSE IF (SWILAI.EQ.4) THEN

         SLA = SLAC*LINT(SLAFAC, ILSLAF, DVS)
         IF (TSLV.LT.TSLVC) THEN
            LAI = LAII
         ELSE
            LAI = XXWLVG*SLA
         END IF

      ELSE IF (SWILAI.EQ.5) THEN
        LAI = XXLAI
      END IF

*-----Stem area
      SSGA = LINT(SSGATB, ILSAI, DVS)
      SAI  = SSGA * WSTS
      IF (SWISAI.EQ.1) THEN
         LAI = LAI + 0.5*SAI
      END IF

************************************************************************
*-----Output section

      IF (OUTPUT) THEN

         CALL OUTDAT (2, 0, 'LAI',       LAI)
         CALL OUTDAT (2, 0, 'LAIEXP',  LAIEXP)
         CALL OUTDAT (2, 0, 'LAIOLD',  LAIOLD)
         CALL OUTDAT (2, 0, 'SAI',       SAI)
         CALL OUTDAT (2, 0, 'SLA',       SLA)
         CALL OUTDAT (2, 0, 'SLAC',     SLAC)
         CALL OUTDAT (2, 0, 'SSGA',     SSGA)
         CALL OUTDAT (2, 0, 'WLVEXP',  WLVEXP)
         CALL OUTDAT (2, 0, 'XXLAI',    XXLAI)

      END IF

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

      ELSE IF (ITASK.EQ.3) THEN

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

*     No integration here for LFAREA

         CONTINUE

      ELSE IF (ITASK.EQ.4) THEN

*======================================================================*
*                          Terminal section                            *
*======================================================================*

         CONTINUE

      END IF

      RETURN
      END


*---------------------------------------------------------------------*
*  SUBROUTINE BIOMS1                                                  *
*                                                                     *
*  Author : SARP                                                      *
*  Date   : December 1994                                             *
*  Version: 2.0                                                       *
*                                                                     *
*  Research Institute for Agrobiology and Soil Fertility (AB-DLO),    *
*  P.O.Box 14, 6700 AA Wageningen, The Netherlands                    *
*                                                                     *
*  International Rice Research Institute, P.O. Box 933,               *
*  1099 Manila, The Philippines and                                   *
*                                                                     *
*  Department of Theoretical Production Ecology, P.O. Box 430,        *
*  6700 AK Wageningen, The Netherlands.                               *
*                                                                     *
*                                                                     *
*  Purpose: Computes the biomass of the crop                          *
*                                                                     *
*  FORMAL PARAMETERS:(I=input,O=output,C=control,IN=init,T=time)      *
*  name    type meaning                                 units  class  *
*  ----    ---- -------                                 -----  -----  *
* 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 input file no. 1                  -       I   *
* OUTPUT   L4   Flag to indicate if output should be done -       I   *
* TERMNL   L4   Flag to indicate if simulation is to stop -     I/O   *
```

```
* WSTAT    C7  Status code from weather system                -        I  *
* WTRTER   L4  Flag whether weather can be used by model      -        I  *
* TIME     R4  Time of simulation                             d        I  *
* STTIME   R4  Start time of simulation                       d        I  *
* DOY      R4  Day number within year of simulation (REAL)    d        I  *
* DELT     R4  Time step of integration                       d        I  *
* LAT      R4  Latitude of site                         dec.degr.      I  *
* RDD      R4  Daily shortwave radiation                  J/m2/d       I  *
* SWINPR   I4  Switch to include N profile in canopy                      *
*              (0 = no N profile, 1 = N profile)              -        I  *
* SWINPH   I4  Switch to select sim.or force of ANLV                      *
*              (0 = measured ANLV, 1 = simulated ANLV         -        I  *
* SWINUP   I4  Switch for choosing nitrogen input option                  *
*              (1 = N uptake as forcing function,                         *
*               2 = potential production)                     -        IC *
* SWISIN   I4  Switch for sink limitation                                 *
*              (1 = no sink limitation, 2 = sink limitation)  -        IC *
* DAT      R4  Day after transplanting                        d        I  *
* TAV      R4  24h average of actual air temperature        deg C      I  *
* TAVD     R4  actual average air temp. at daytime          deg C      I  *
* DVS      R4  Phenelogical development stage crop            -        I  *
* DRR      R4  Development rate crop in reproductive phase   1/d       I  *
* LAI      R4  Leaf area index                                -        I  *
* WLVG     R4  Weight green leaves                          kg/ha      O  *
* WSTS     R4  Weight stems minus WSTR                      kg/ha      O  *
*                                                                         *
* Warnings          : none                                                *
* Subprograms called: CANOPY, DMPART, RESPIR, GROWTH, SINK, NDEMND,      *
*                     NUPTK , NCROP                                       *
* File usage        : IUNITD, IUNITL                                      *
* Libraries used    : TTUTIL                                              *
*                                                                         *
*-------------------------------------------------------------------------*
      SUBROUTINE BIOMS1 (ITASK , IUNITD, IUNITL, FILEI1,
     &                   OUTPUT, TERMNL, WSTAT , WTRTER,
     &                   TIME  , STTIME, DOY   , DELT  ,
     &                   LAT   , RDD   ,
     &                   SWINPR, SWINPH, SWINUP, SWISIN,
     &                   DAT   , TAV   , TAVD  , DVS   , DRR   , LAI,
     &                   WLVG  , WSTS)

      IMPLICIT REAL (A-Z)

*-----Formal parameters
      INTEGER   ITASK,  IUNITD, IUNITL
      LOGICAL   OUTPUT, TERMNL, WTRTER
      CHARACTER*(*) FILEI1
      CHARACTER*(*) WSTAT
      INTEGER SWINPR, SWINPH, SWINUP, SWISIN

      SAVE

      IF (ITASK.EQ.1) THEN

*=========================================================================*
*                          Initialization section                         *
*=========================================================================*
*-----Message
      IF (DELT.LT.1.0) CALL ERROR
     &      ('BIOMS1','DELT too small for BIOMS1')

      ELSE IF (ITASK.EQ.2) THEN

*=========================================================================*
*                          Rate calculation section                       *
*=========================================================================*
         CONTINUE

      ELSE IF (ITASK.EQ.3) THEN

*=========================================================================*
*                           Integration section                           *
*=========================================================================*
*-----Finish conditions

      IF (DVS.GE.2.0)    TERMNL = .TRUE.

      ELSE IF (ITASK.EQ.4) THEN

*=========================================================================*
*                            Terminal section                             *
*=========================================================================*

         CONTINUE

      END IF

        CALL CANOPY     (ITASK , IUNITD, IUNITL, FILEI1,
     &                   OUTPUT, TERMNL, WSTAT , WTRTER,
     &                   DOY   , DELT  ,
     &                   LAT   , RDD   ,
     &                   SWINPR, SWINPH,
     &                   DVS   , TAVD  , LAI   , ANLV,
     &                   DTGA  , PCGT)

        CALL DMPART     (ITASK , IUNITD, IUNITL, FILEI1,
     &                   OUTPUT, DELT  ,
     &                   DVS   ,
     &                   FLV   , FRT   , FSH   , FSO   , FST)

        CALL RESPIR     (ITASK , IUNITD, IUNITL, FILEI1,
     &                   OUTPUT, DELT  ,
     &                   TAV   ,
     &                   ANLV  , ANRT  , ANST  ,
     &                   FLV   , FRT   , FSH   , FSO   , FST,
     &                   WLVG  , WRTL  , WSO   , WSTS  ,
     &                   GLV   , GSTS  , GSTR  , GRT   , GSO,
     &                   RMCR  , RGCR  , RCRT)
```

```
      CALL GROWTH      (ITASK , IUNITD, IUNITL, FILEI1,
     &                  OUTPUT, DELT  ,
     &                  DVS   , LAI   , DTGA  , RMCR  , FNLV  , GSOM,
     &                  FLV   , FRT   , FSH   , FSO   , FST,
     &                  LLV   , LRT   , LSTR  , CRGCR ,
     &                  GCR   , GRT   , GLV   , GSTS  , GSTR  ,GSO,GSH,
     &                  WLVG  , WLVD  , WSTS  , WSTR  , WSO   , WRTL  ,
     &                  WRTD  , WCR   , WSHG)

      CALL SINK        (ITASK , IUNITD, IUNITL, FILEI1,
     &                  OUTPUT, DELT  ,
     &                  SWISIN,
     &                  DVS   , DRR   , TAV   , WSO   , FNLV  ,
     &                  GCR   , CRGCR ,
     &                  GSOM  , NTI   , NGR)

      CALL NDEMND      (ITASK , IUNITD, IUNITL, FILEI1,
     &                  OUTPUT, DELT  ,
     &                  DVS   , GSO   , GLV   , GSTS  , GRT,
     &                  ANLV  , ANST  , ANRT  , ANCR  ,
     &                  WLVG  , WSTS  , WRTL  , WSO   ,
     &                  NDEML , NDEMS , NDEMR , NDEMG , NDEMV , NDEMT,
     &                  NDEMGX)

      CALL NUPTK       (ITASK , IUNITD, IUNITL, FILEI1,
     &                  OUTPUT, TIME  , STTIME, DELT  ,
     &                  SWINUP,
     &                  ANLCR , NDEMV , DVS   , GLV   , GSTS  , GRT,
     &                  NUPT  , NUPTOT, ANTOT , NUPNEG, NTOTM)

      CALL NCROP       (ITASK , IUNITD, IUNITL, FILEI1,
     &                  OUTPUT, DELT  ,
     &                  SWINUP,
     &                  DVS   , DAT   ,
     &                  WLVG  , WSTS  , WRTL  , WSO   ,
     &                  LLV   , LRT   , GLV   , GSTS  , GRT,
     &                  NDEMG , NDEMGX, NDEML , NDEMS , NDEMR , NUPT,
     &                  FNLV  , FNRT  , FNST  , FNSO  ,
     &                  ANLV  , ANST  , ANRT  , ANSO  , ANLCR , ANCR)

      RETURN
      END

*----------------------------------------------------------------------*
* SUBROUTINE CANOPY                                                    *
*                                                                      *
* Authors: SARP                                                        *
* Date   : December 1994                                               *
* Version: 2.0                                                         *
*                                                                      *
* Purpose: This subroutine computes the daily gross canopy             *
*          CO2 assimilation. It makes use of the subroutine TOTASN     *
*          which is equal to the subroutine TOTASS                     *
*          with an adaptation for the amount of Nitrogen in the        *
*          leaves. Through the switch SWINPH either measured or        *
*          simulated N in leaves is used within TOTASN. SWINPR is      *
*          a switch for choosing a nitrogen profile in the crop        *
*          or not.                                                     *
*                                                                      *
* FORMAL PARAMETERS:(I=input,O=output,C=control,IN=init,T=time)        *
* name   type meaning                                    units  class *
* ----   ---- -------                                    -----  ----- *
* 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 input file no. 1                     -       I  *
* OUTPUT  L4  Flag to indicate if output should be done    -       I  *
* TERMNL  L4  Flag to indicate if simulation is to stop    -      I/O *
* WSTAT   C7  Status code from weather system              -       I  *
* WTRTER  L4  Flag whether weather can be used by model    -       I  *
* DOY     R4  Day number within year of simulation (REAL)  d       I  *
* DELT    R4  Time step of integration                     d       I  *
* LAT     R4  Latitude of site                         dec.degr.   I  *
* RDD     R4  Daily shortwave radiation                  J/m2/d    I  *
* SWINPR  I4  Switch to include N profile in canopy                   *
*              (0 = no N profile, 1 = N profile)           -       I  *
* SWINPH  I4  Switch to select sim.or force of ANLV                   *
*              (0 = measured ANLV, 1 = simulated ANLV      -       I  *
* DVS     R4  Phenelogical development stage crop          -       I  *
* TAVD    R4  actual average air temp. at daytime        deg C     I  *
* LAI     R4  Leaf area index                              -       I  *
* ANLV    R4  Amount of N in the leaves                  kg/ha     I  *
* DTGA    R4  Gross canopy assimilation                  kg/ha/d   O  *
* PCGT    R4  DTGA totaled since start of simulation     kg/ha     O  *
*                                                                      *
* Fatal error checks: If one of the characters of WSTAT = '4'         *
*                     indicates missing weather                        *
* Warnings          : none                                             *
* Subprograms called: none                                             *
* File usage        : IUNITD, IUNITL, FILEI                            *
* Libraries used    : TTUTIL, COME_ON                                  *
*                                                                      *
*----------------------------------------------------------------------*
      SUBROUTINE CANOPY  (ITASK, IUNITD, IUNITL, FILEI1,
     &                    OUTPUT, TERMNL, WSTAT, WTRTER,
     &                    DOY, DELT,
     &                    LAT, RDD,
     &                    SWINPR, SWINPH,
     &                    DVS, TAVD, LAI, ANLV,
     &                    DTGA, PCGT)

      IMPLICIT REAL (A-Z)

*-----Formal parameters
      INTEGER   ITASK,  IUNITD, IUNITL
      LOGICAL   OUTPUT, TERMNL, WTRTER
      CHARACTER*(*) FILEI1
```

```
      CHARACTER*(*) WSTAT
      INTEGER SWINPR, SWINPH

*-----Standard local declarations
      INTEGER IWVAR,IMNP
      PARAMETER (IMNP=100)
      CHARACTER WUSED*6

*-----Function declarations
      LOGICAL INQOBS

*-----Daily gross canopy CO2 assimilation
      INTEGER ILEFF, ILREDF
      REAL EFFTB(IMNP), REDFTT(IMNP)

      SAVE

*     code for the use of RDD, TMMN, TMMX, VP, WN, RAIN  (in that order)
*     a letter 'U' indicates that the variable is Used in calculations
      DATA WUSED/'UUU---'/

*     Check weather data availability
      IF (ITASK.EQ.1.OR.ITASK.EQ.2.OR.ITASK.EQ.4) THEN
         DO 10 IWVAR=1,6
*           is there an error in the IWVAR-th weather variable ?
            IF (WUSED(IWVAR:IWVAR).EQ.'U' .AND.
     &           WSTAT(IWVAR:IWVAR).EQ.'4') THEN
               WTRTER = .TRUE.
               TERMNL = .TRUE.
               ITOLD  = ITASK
               RETURN
            END IF
10       CONTINUE
      END IF


      IF (ITASK.EQ.1) THEN

*=====================================================================*
*                          Initialization                             *
*=====================================================================*
*-----Message
      IF (DELT.LT.1.0) CALL ERROR
     &      ('CANOPY','DELT too small for CANOPY')

*-----Message send to output file
      IF (SWINPH.EQ.0) THEN
         CALL OUTCOM ('SWINPH=0 ; XNLV (measured) in Photosynthesis')
      ELSE IF (SWINPH.EQ.1) THEN
         CALL OUTCOM ('SWINPH=1 ; NLV (simulated) in Photosynthesis')
      ELSE
         CALL ERROR ('CANOPY','illegal value used for switch SWINPH')
      END IF

      IF (SWINPR.EQ.0) THEN
         CALL OUTCOM ('SWINPR=0 ; no N profile in canopy')
      ELSE IF (SWINPR.EQ.1) THEN
         CALL OUTCOM ('SWINPR=1 ; N profile in canopy')
      ELSE
         CALL ERROR ('CANOPY','illegal value used for switch SWINPR')
      END IF


      CALL RDINIT (IUNITD, IUNITL, FILEI1)

*-----Daily gross canopy CO2 assimilation
      CALL RDSREA ('KDF'   , KDF   )
      CALL RDSREA ('NB'    , NB    )
      CALL RDSREA ('ALPHAN', ALPHAN)
      CALL RDSREA ('KDIFNP', KDIFNP)
      CALL RDSREA ('SCP'   , SCP   )
      CALL RDAREA ('REDFTT', REDFTT, IMNP, ILREDF)
      CALL RDAREA ('EFFTB' , EFFTB , IMNP, ILEFF)

      CLOSE (IUNITD)

*-----Initialization of states/rates
      DTGA   = 0.
      AMAXT  = 0.
      PCGT   = 0.
      XXNLV  = -99.


      ELSE IF (ITASK.EQ.2) THEN

*=====================================================================*
*                     Rate calculation section                        *
*=====================================================================*

*-----Reading of measured data

      IF (INQOBS(FILEI1, 'ANLV')) XXNLV = GETOBS(FILEI1,'ANLV')

***********************************************************************
*-----Daily gross canopy CO2 assimilation

      EFF    = LINT (EFFTB,  ILEFF,  TAVD)
      REDFT  = LINT (REDFTT, ILREDF, TAVD)

      IF (SWINPH.EQ.1) THEN
         ANLVPH = ANLV
      ELSE
         ANLVPH = XXNLV
      END IF

      IF (LAI.LT.1.5.AND. DVS.LT.1.) KDF =  0.4
      IF (LAI.GE.1.5) KDF = 0.6
      KDIFN = SWINPR*KDIFNP

      CALL TOTASN(DOY, LAT, RDD, SCP, EFF, KDF, LAI, KDIFN, ANLVPH,
```

```
     &          ALPHAN, NB, REDFT, AMAXT, DTGA)

***********************************************************************
*-----Output section

      IF (OUTPUT) THEN
         CALL OUTDAT (2, 0, 'ALPHAN',   ALPHAN)
         CALL OUTDAT (2, 0, 'ANLVPH',   ANLVPH)
         CALL OUTDAT (2, 0, 'DTGA',       DTGA)
         CALL OUTDAT (2, 0, 'EFF',         EFF)
         CALL OUTDAT (2, 0, 'KDF',         KDF)
         CALL OUTDAT (2, 0, 'KDIFN',     KDIFN)
         CALL OUTDAT (2, 0, 'PCGT',       PCGT)
         CALL OUTDAT (2, 0, 'REDFT',     REDFT)
      END IF

      ELSE IF (ITASK.EQ.3) THEN

*=====================================================================*
*                        Integration section                          *
*=====================================================================*
*-----Total daily gross canopy CO2 assimilation

      PCGT  = INTGR2(PCGT, DTGA,        DELT,FILEI1,'PCGT')

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

      ELSE IF (ITASK.EQ.4) THEN

*=====================================================================*
*                         Terminal section                            *
*=====================================================================*

         CONTINUE

      END IF

      RETURN
      END


*---------------------------------------------------------------------*
*  SUBROUTINE DMPART                                                  *
*                                                                     *
* Authors: SARP                                                       *
* Date   : December 1994                                              *
* Version: 2.0                                                        *
*                                                                     *
* Research Institute for Agrobiology and Soil Fertility (AB-DLO),     *
* P.O.Box 14, 6700 AA Wageningen, The Netherlands                     *
*                                                                     *
* International Rice Research Institute, P.O. Box 933,                *
* 1099 Manila, The Philippines and                                    *
*                                                                     *
* Department of Theoretical Production Ecology, P.O. Box 430,         *
* 6700 AK Wageningen, The Netherlands.                                *
*                                                                     *
*                                                                     *
* Purpose: This subroutine computes the dry matter partitioning       *
*                                                                     *
* FORMAL PARAMETERS:(I=input,O=output,C=control,IN=init,T=time)       *
* name   type meaning                                    units  class *
* ----   ---- -------                                    -----  ----- *
* 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 input file no. 1                     -      I   *
* OUTPUT  L4  Flag to indicate if output should be done    -      I   *
* TERMNL  L4  Flag to indicate if simulation is to stop    -     I/O  *
* WSTAT   C*  Status code from weather system              -      I   *
* WTRTER  L4  Flag whether weather can be used by model    -      I   *
* DELT    R4  Time step of integration                     d      I   *
* DVS     R4  Phenological development stage crop          -      I   *
* FLV     R4  Fraction of daily dry matter increment                  *
*             allocated to leaves                          -      O   *
* FRT     R4  Fraction of daily dry matter increment                  *
*             allocated to roots                           -      O   *
* FSH     R4  Fraction of daily dry matter increment                  *
*             allocated to shoots                          -      O   *
* FSO     R4  Fraction of daily dry matter increment                  *
*             allocated to storage organs                  -      O   *
* FST     R4  Fraction of daily dry matter increment                  *
*             allocated to stems including leaf sheaths    -      O   *
*                                                                     *
* Fatal error checks: If one of the characters of WSTAT = '4'         *
*                     indicates missing weather                       *
* Warnings          : none                                            *
* Subprograms called: none                                            *
* File usage        : IUNITD, IUNITO, IUNITL, FILEI1                  *
* Libraries used    : TTUTIL                                          *
*                                                                     *
*---------------------------------------------------------------------*
      SUBROUTINE DMPART (ITASK, IUNITD, IUNITL, FILEI1,
     &                   OUTPUT, DELT,
     &                   DVS,
     &                   FLV, FRT, FSH, FSO, FST)


      IMPLICIT REAL (A-Z)

*-----Formal parameters
      INTEGER   ITASK,  IUNITD, IUNITL
      LOGICAL   OUTPUT
      CHARACTER*(*) FILEI1

*-----Standard local declarations
      INTEGER IMNP
      PARAMETER (IMNP=40)
```

```
*-----Fraction of daily dry matter increment allocated to plant organs
      INTEGER ILFSH, ILFLV, ILFST, ILFSO
      REAL FSHTB(IMNP), FLVTB(IMNP), FSTTB(IMNP), FSOTB(IMNP)

      SAVE

      IF (ITASK.EQ.1) THEN

*=====================================================================*
*                         Initialization                              *
*=====================================================================*
*-----Message
      IF (DELT.LT.1.0) CALL ERROR
     &      ('DMPART','DELT too small for DMPART')

      CALL RDINIT (IUNITD, IUNITL, FILEI1)

*-----Fraction of daily dry matter increment allocated to plant organs
      CALL RDAREA ('FSHTB' , FSHTB , IMNP, ILFSH)
      CALL RDAREA ('FLVTB' , FLVTB , IMNP, ILFLV)
      CALL RDAREA ('FSTTB' , FSTTB , IMNP, ILFST)
      CALL RDAREA ('FSOTB' , FSOTB , IMNP, ILFSO)

      CLOSE (IUNITD)

      ELSE IF (ITASK.EQ.2) THEN

*=====================================================================*
*                         Rate calculation section                    *
*=====================================================================*

*-----Fraction of daily dry matter increment allocated to plant organs

      FSH = LINT (FSHTB, ILFSH, DVS)
      FLV = LINT (FLVTB, ILFLV, DVS)
      FST = LINT (FSTTB, ILFST, DVS)
      FSO = LINT (FSOTB, ILFSO, DVS)

      FRT = 1.-FSH
      IF (FRT.LT.-1.E-03) CALL ERROR
     &   ('DMPART', 'partitioning to shoot (FSH) > 1.00; check!')

***********************************************************************
*-----Output section

      IF (OUTPUT) THEN

         CALL OUTDAT (2, 0, 'FLV',         FLV)
         CALL OUTDAT (2, 0, 'FRT',         FRT)
         CALL OUTDAT (2, 0, 'FSH',         FSH)
         CALL OUTDAT (2, 0, 'FSO',         FSO)
         CALL OUTDAT (2, 0, 'FST',         FST)

      END IF

*=====================================================================*
*                         Integration section                         *
*=====================================================================*

      ELSE IF (ITASK.EQ.3) THEN

*     No integration here for DMPART

*=====================================================================*
*                         Terminal section                            *
*=====================================================================*

      ELSE IF (ITASK.EQ.4) THEN
      END IF

      ITOLD = ITASK

      RETURN
      END

*---------------------------------------------------------------------*
*  SUBROUTINE RESPIR                                                  *
*                                                                     *
* Authors: SARP                                                       *
* Date   : December 1994                                              *
* Version: 2.0                                                        *
*                                                                     *
* Research Institute for Agrobiology and Soil Fertility (AB-DLO),     *
* P.O.Box 14, 6700 AA Wageningen, The Netherlands                     *
*                                                                     *
* International Rice Research Institute, P.O. Box 933,                *
* 1099 Manila, The Philippines and                                    *
*                                                                     *
* Department of Theoretical Production Ecology, P.O. Box 430,         *
* 6700 AK Wageningen, The Netherlands.                                *
*                                                                     *
*                                                                     *
* Purpose: This subroutine computes the maintenance respiration       *
*          and growth respiration.                                    *
*                                                                     *
* FORMAL PARAMETERS:(I=input,O=output,C=control,IN=init,T=time)       *
* name   type meaning                                   units  class *
* ----   ---- -------                                   -----  ----- *
* 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 input file no. 1                     -      I  *
* OUTPUT  L4  Flag to indicate if output should be done    -      I  *
* DELT    R4  Time step of integration                     d      I  *
* TAV     R4  24h verage of actual air temperature       deg C    I  *
* ANLV    R4  Amount of N in leaves                      kg/ha    I  *
```

```
* ANRT     R4  Amount of N in roots                        kg/ha     I  *
* ANST     R4  Amount of N in stems                        kg/ha     I  *
* FLV      R4  Fraction of daily dry matter increment                   *
*              allocated to leaves                          -        I  *
* FRT      R4  Fraction of daily dry matter increment                   *
*              allocated to roots                           -        I  *
* FSH      R4  Fraction of daily dry matter increment                   *
*              allocated to shoots                          -        I  *
* FSO      R4  Fraction of daily dry matter increment                   *
*              allocated to storage organs                  -        I  *
* FST      R4  Fraction of daily dry matter increment                   *
*              allocated to stems including leaf sheaths    -        I  *
* WLVG     R4  Weight of green leaves                      kg/ha     I  *
* WRTL     R4  Weight of living roots                      kg/ha     I  *
* WSO      R4  Weight of storage organs                    kg/ha     I  *
* WSTS     R4  Weight of stems minus WSTR in it            kg/ha     I  *
* GLV      R4  Growth rate of leaves                       kg/ha/d   I  *
* GSTS     R4  Growth rate of stems                        kg/ha/d   I  *
* GSTR     R4  Growth rate of shielded reserves            kg/ha/d   I  *
* GRT      R4  Growth rate of roots                        kg/ha/d   I  *
* GSO      R4  Growth rate of storage organs               kg/ha/d   I  *
* RMCR     R4  Maintenance respiration of whole crop       kg/ha/d   O  *
* RGCR     R4  respiration(in CO2) due to growth crop      kg/ha/d   O  *
* RCRT     R4  respiration crop, totaled (in CO2)          kg/ha     O  *
*                                                                       *
* Fatal error checks: If one of the characters of WSTAT = '4'           *
*                     indicates missing weather                         *
* Warnings          : none                                              *
* Subprograms called: none                                              *
* File usage        : IUNITD, IUNITL, FILEI1                            *
* Libraries used    : TTUTIL, COME_ON                                   *
*                                                                       *
*-----------------------------------------------------------------------*
      SUBROUTINE RESPIR (ITASK, IUNITD, IUNITL, FILEI1,
     &                   OUTPUT, DELT,
     &                   TAV,
     &                   ANLV, ANRT, ANST,
     &                   FLV, FRT, FSH, FSO, FST,
     &                   WLVG, WRTL, WSO, WSTS,
     &                   GLV, GSTS, GSTR, GRT, GSO,
     &                   RMCR, RGCR, RCRT)

      IMPLICIT REAL (A-Z)

*-----Formal parameters
      INTEGER   ITASK,  IUNITD, IUNITL
      LOGICAL   OUTPUT
      CHARACTER*(*) FILEI1

      SAVE

      DATA TINY /1.E-4/

      IF (ITASK.EQ.1) THEN

*=======================================================================*
*                             Initialization                            *
*=======================================================================*

*-----Message
         IF (DELT.LT.1.0) CALL ERROR
     &         ('RESPIR','DELT too small for RESPIR')

         CALL RDINIT (IUNITD, IUNITL, FILEI1)

*-----Reference temperature for maintenance respiration
         CALL RDSREA ('TREF'  , TREF  )

*-----Q10 of maintenance respiration sensitivity to temperature
         CALL RDSREA ('Q10'   , Q10   )

*-----Maintenance respiration coefficients
         CALL RDSREA ('MAINLV', MAINLV)
         CALL RDSREA ('MAINST', MAINST)
         CALL RDSREA ('MAINSO', MAINSO)
         CALL RDSREA ('MAINRT', MAINRT)

*-----Absolute maximum N fraction over whole season
         CALL RDSREA ('NMAXLX', NMAXLX)
         CALL RDSREA ('NMAXSX', NMAXSX)
         CALL RDSREA ('NMAXRX', NMAXRX)

*-----Weight of carbohydrates required for dry matter growth
         CALL RDSREA ('CRGLV' , CRGLV )
         CALL RDSREA ('CRGST' , CRGST )
         CALL RDSREA ('CRGRT' , CRGRT )
         CALL RDSREA ('CRGSO' , CRGSO )
         CALL RDSREA ('CRGSTR', CRGSTR)

*-----Residual fraction N
         CALL RDSREA ('RFNLV' , RFNLV )
         CALL RDSREA ('RFNST' , RFNST )
         CALL RDSREA ('RFNRT' , RFNRT )

*-----Fraction carbon of total dry mass
         CALL RDSREA ('FCLV'  , FCLV  )
         CALL RDSREA ('FCST'  , FCST  )
         CALL RDSREA ('FCSO'  , FCSO  )
         CALL RDSREA ('FCRT'  , FCRT  )
         CALL RDSREA ('FCSTR' , FCSTR )

*-----Fraction of stem weight at flowering that is remobilizable
         CALL RDSREA ('FSTR'  , FSTR  )

         CLOSE (IUNITD)

*-----Initialization of states
         RCRT   = 0.
```

```
      ELSE IF (ITASK.EQ.2) THEN

*----------------------------------------------------------------------*
*                        Rate calculation section                      *
*----------------------------------------------------------------------*

*-----Fractions of Nitrogen in plant organs

      FNLV   = ANLV/(WLVG+TINY)
      FNST   = ANST/(WSTS+TINY)
      FNRT   = ANRT/(WRTL+TINY)

************************************************************************
*-----Temperature effect on maintenance respiration

      TEFF   = Q10**((TAV-TREF)/10.)

*-----Activity coefficients of plant organs based on N content

      ACTLV = (FNLV-RFNLV)/(NMAXLX-RFNLV)
      ACTST = (FNST-RFNST)/(NMAXSX-RFNST)
      ACTRT = (FNRT-RFNRT)/(NMAXRX-RFNRT)

*-----Maintenance respiration

      RMLV   = WLVG*MAINLV*(1.+ACTLV)/2.*TEFF
      RMST   = WSTS*MAINST*(1.+ACTST)/2.*TEFF
      RMRT   = WRTL*MAINRT*(1.+ACTRT)/2.*TEFF
      RMSO   = WSO *MAINSO*TEFF
      RMCR   = RMLV+RMST+RMSO+RMRT

      RMCCO2 = 44./30.*RMCR

************************************************************************
*-----Growth respiration

      CO2RT  = 44./12. * (CRGRT *12./30. - FCRT)
      CO2LV  = 44./12. * (CRGLV *12./30. - FCLV)
      CO2ST  = 44./12. * (CRGST *12./30. - FCST)
      CO2STR = 44./12. * (CRGSTR*12./30. - FCSTR)
      CO2SO  = 44./12. * (CRGSO *12./30. - FCSO)

      RGCR = GRT*CO2RT + GLV*CO2LV + GSTS*CO2ST + GSO*CO2SO +
     $       GSTR*CO2STR

************************************************************************
*-----Fraction carbon of total dry mass in the crop

      FCCR   = FSH* (FLV*FCLV + FST*(1.-FSTR)*FCST + FSO*FCSO +
     $         FCSTR*FST*FSTR) + FRT*FCRT

************************************************************************
*-----Output section

      IF (OUTPUT) THEN
         CALL OUTDAT (2, 0, 'ACTLV',     ACTLV)
         CALL OUTDAT (2, 0, 'ACTRT',     ACTRT)
         CALL OUTDAT (2, 0, 'ACTST',     ACTST)
         CALL OUTDAT (2, 0, 'CO2LV',     CO2LV)
         CALL OUTDAT (2, 0, 'CO2RT',     CO2RT)
         CALL OUTDAT (2, 0, 'CO2SO',     CO2SO)
         CALL OUTDAT (2, 0, 'CO2ST',     CO2ST)
         CALL OUTDAT (2, 0, 'CO2STR',   CO2STR)
         CALL OUTDAT (2, 0, 'FCCR',       FCCR)
         CALL OUTDAT (2, 0, 'RCRT',       RCRT)
         CALL OUTDAT (2, 0, 'RGCR',       RGCR)
         CALL OUTDAT (2, 0, 'RMCCO2',   RMCCO2)
         CALL OUTDAT (2, 0, 'RMCR',       RMCR)
         CALL OUTDAT (2, 0, 'RMLV',       RMLV)
         CALL OUTDAT (2, 0, 'RMRT',       RMRT)
         CALL OUTDAT (2, 0, 'RMSO',       RMSO)
         CALL OUTDAT (2, 0, 'RMST',       RMST)
         CALL OUTDAT (2, 0, 'TEFF',       TEFF)
      END IF
************************************************************************

      ELSE IF (ITASK.EQ.3) THEN

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

*-----Total respiration in crop

      RCRT = INTGR2 (RCRT , RMCCO2 + RGCR, DELT,FILEI1,'RCRT')

      ELSE IF (ITASK.EQ.4) THEN

*----------------------------------------------------------------------*
*                        Terminal section                              *
*----------------------------------------------------------------------*

         CONTINUE

      END IF

      RETURN
      END


*----------------------------------------------------------------------*
* SUBROUTINE GROWTH                                                    *
*                                                                      *
* Authors: SARP                                                        *
* Date   : December 1994                                               *
* Version: 2.0                                                         *
*                                                                      *
```

```
* Research Institute for Agrobiology and Soil Fertility (AB-DLO),      *
* P.O.Box 14, 6700 AA Wageningen, The Netherlands                      *
*                                                                      *
* International Rice Research Institute, P.O. Box 933,                 *
* 1099 Manila, The Philippines and                                     *
*                                                                      *
* Department of Theoretical Production Ecology, P.O. Box 430,          *
* 6700 AK Wageningen, The Netherlands.                                 *
*                                                                      *
*                                                                      *
* Purpose: This subroutines computes the growth of the crop            *
*                                                                      *
* FORMAL PARAMETERS:(I=input,O=output,C=control,IN=init,T=time)        *
* name   type meaning                                    units   class *
* ----   ---- -------                                    -----   ----- *
* 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 input file no. 1                     -       I   *
* OUTPUT  L4  Flag to indicate if output should be done    -       I   *
* DELT    R4  Time step of integration                     d       I   *
* DVS     R4  Phenological development stage crop          -       I   *
* LAI     R4  Leaf area index                              -       I   *
* DTGA    R4  Photosynthesis canopy, gross (in CO2)      kg/ha/d   I   *
* RMCR    R4  Maintenance respiration of whole crop      kg/ha/d   I   *
* FNLV    R4  Fraction of N in leaves                      -       I   *
* GSOM    R4  Maximum growth rate of storage organs      kg/ha/d   I   *
* FLV     R4  Fraction of daily dry matter increment                   *
*             allocated to leaves                          -       I   *
* FRT     R4  Fraction of daily dry matter increment                   *
*             allocated to roots                           -       I   *
* FSH     R4  Fraction of daily dry matter increment                   *
*             allocated to shoots                          -       I   *
* FSO     R4  Fraction of daily dry matter increment                   *
*             allocated to storage organs                  -       I   *
* FST     R4  Fraction of daily dry matter increment                   *
*             allocated to stems including leaf sheaths    -       I   *
* LLV     R4  Rate of loss of leaf weight                kg/ha/d   O   *
* LRT     R4  Rate of loss of root weight                kg/ha/d   O   *
* LSTR    R4  Loss rate of stem reserves                 kg/ha/d   O   *
* CRGCR   R4  Weight of carbohydrates required for                     *
*             dry matter growth of the crop              kg/kg     O   *
* GCR     R4  Growth rate of the whole crop              kg/ha/d   O   *
* GRT     R4  Growth rate of roots                       kg/ha/d   O   *
* GLV     R4  Growth rate of leaves                      kg/ha/d   O   *
* GSTS    R4  Growth rate of stems                       kg/ha/d   O   *
* GSTR    R4  Growth rate of shielded reserves           kg/ha/d   O   *
* GSO     R4  Growth rate of storage organs              kg/ha/d   O   *
* GSH     R4  Growth rate of shoots                      kg/ha/d   O   *
* WLVG    R4  Weight green leaves                        kg/ha     O   *
* WLVD    R4  Weight dead leaves                         kg/ha     O   *
* WSTS    R4  Weight stems minus WSTR                    kg/ha     O   *
* WSTR    R4  Weight of shielded reserves                kg/ha     O   *
* WSO     R4  Weight storage organs                      kg/ha     O   *
* WRTL    R4  Weight live roots                          kg/ha     O   *
* WRTD    R4  Weight dead roots                          kg/ha     O   *
* WCR     R4  Weight of the crop                         kg/ha     O   *
* WSHG    R4  Weight of the living shoot                 kg/ha     O   *
*                                                                      *
*                                                                      *
* Warnings          : none                                             *
* Subprograms called: SLLOSS                                           *
* File usage        : IUNITD, IUNITL, FILEI1                           *
* Libraries used    : TTUTIL, COME_ON                                  *
*                                                                      *
*----------------------------------------------------------------------*
      SUBROUTINE GROWTH (ITASK, IUNITD, IUNITL, FILEI1,
     &                   OUTPUT, DELT,
     &                   DVS, LAI, DTGA, RMCR, FNLV, GSOM,
     &                   FLV, FRT, FSH, FSO, FST,
     &                   LLV, LRT, LSTR, CRGCR,
     &                   GCR, GRT, GLV, GSTS, GSTR, GSO, GSH,
     &                   WLVG, WLVD, WSTS, WSTR, WSO, WRTL, WRTD,
     &                   WCR, WSHG)


      IMPLICIT REAL (A-Z)

*-----Formal parameters
      INTEGER   ITASK,  IUNITD, IUNITL
      LOGICAL   OUTPUT
      CHARACTER*(*) FILEI1

*-----Standard local declarations
      INTEGER IMNP
      PARAMETER (IMNP=40)

*-----Function declarations
      LOGICAL INQOBS

*-----Minimum N concentration in leaves
      INTEGER ILNMNL
      REAL NMINLT(IMNP)

*-----Parameters
      PARAMETER (GPR = 0.90)
      PARAMETER (GMC = 0.86)

      SAVE

      IF (ITASK.EQ.1) THEN

*======================================================================*
*                            Initialization                            *
*======================================================================*

*-----Message
      IF (DELT.LT.1.0) CALL ERROR
     &      ('GROWTH','DELT too small for GROWTH')
```

```
      CALL RDINIT (IUNITD, IUNITL, FILEI1)

*-----Initial weights of the plant organs
      CALL RDSREA ('WLVGI' , WLVGI )
      CALL RDSREA ('WSTSI' , WSTSI )
      CALL RDSREA ('WRTLI' , WRTLI )

*-----Minimum N concentration in leaves
      CALL RDAREA ('NMINLT', NMINLT, IMNP, ILNMNL)

*-----Weights of carbohydrates required for dry matter growth
      CALL RDSREA ('CRGLV' , CRGLV )
      CALL RDSREA ('CRGST' , CRGST )
      CALL RDSREA ('CRGRT' , CRGRT )
      CALL RDSREA ('CRGSO' , CRGSO )
      CALL RDSREA ('CRGSTR', CRGSTR)

*-----Relative death rate root and leaf
      CALL RDSREA ('RDR'   , RDR   )

*-----Time coefficient for loss of stem reserves
      CALL RDSREA ('TCLSTR', TCLSTR)

*-----Leaf area index reference
      CALL RDSREA ('LAIREF', LAIREF)

*-----Fraction carbon of total dry matter in shielded reserves
      CALL RDSREA ('FCSTR' , FCSTR )

*-----DVS when grain formation ends
      CALL RDSREA ('DVSG2' , DVSG2 )

*-----Fraction of stem weight that is remobilizable
      CALL RDSREA ('FSTR'  , FSTR  )

      CLOSE (IUNITD)

*-----Initialization of states/rates
      WLVG   = WLVGI
      WLVD   = 0.
      WRTD   = 0.
      WRTL   = WRTLI
      WSO    = 0.
      WSTR   = 0.
      WSTS   = WSTSI

      XXWCR  = 0.
*-----Init to -99 in case of missing observed values.
      XXWLVG = -99.
      XXWLVD = -99.
      XXWRTL = -99.
      XXWSO  = -99.
      XXWSTS = -99.

      WSTT   = WSTS + WSTR
      WSHG   = WLVG + WSTS  + WSO  + WSTR
      WSHT   = WLVG + WSTS  + WSO  + WSTR + WLVD
      WCR    = WSHG + WRTL
      WRR    = WSO * GPR / GMC
      HI     = WSO * GPR / WCR

      ELSE IF (ITASK.EQ.2) THEN

*======================================================================*
*                       Rate calculation section                       *
*======================================================================*

*-----Reading of Measured Data

      IF (INQOBS(FILEI1, 'WLVG')) XXWLVG = GETOBS(FILEI1, 'WLVG')
      IF (INQOBS(FILEI1, 'WSTS')) XXWSTS = GETOBS(FILEI1, 'WSTS')
      IF (INQOBS(FILEI1, 'WRTL')) XXWRTL = GETOBS(FILEI1, 'WRTL')
      IF (INQOBS(FILEI1,  'WSO')) XXWSO  = GETOBS(FILEI1, 'WSO')
      IF (INQOBS(FILEI1, 'WLVD')) XXWLVD = GETOBS(FILEI1, 'WLVD')

      XXWCR  = XXWLVG + XXWSTS + XXWRTL + XXWSO

************************************************************************
*-----Weight of carbohydrates required for dry matter growth of crop

      CRGCR = FSH*(CRGLV*FLV  + CRGST*FST*(1.-FSTR) +
     &        CRGSTR*FSTR*FST + CRGSO*FSO) + CRGRT*FRT

************************************************************************
*-----Minimum N concentration in leaves

      NMINL = LINT (NMINLT, ILNMNL, DVS)

************************************************************************
*-----Rate of loss of leaf weight, root weight, and stem reserves

      IF (FST.LT.0.01) THEN
         LSTR = WSTR/TCLSTR
      ELSE
         LSTR = 0.
      END IF

      CALL SLLOSS (DVSG2,DVS,FNLV,NMINL,RDR,LAI,LAIREF,
     &             WLVG,WRTL,LLV,LRT)

************************************************************************
*-----Growth rate of the whole crop

      GCR    = ((DTGA*30./44.)-RMCR+(LSTR*FCSTR*30./12.))/CRGCR

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

```
*-----Growth rates of the plant organs

      GRT  = GCR * FRT
      GLV  = GCR * FSH * FLV
      GSTS = GCR * FSH * FST * (1.-FSTR)
      GSH  = GCR * FSH

      IF ((FSO*GSH).LT.GSOM) THEN
         GSTREX = 0.
      ELSE
         GSTREX = (FSO*GSH)-GSOM
      END IF

      GSTR = GCR * FSH * FST * FSTR + GSTREX
      GSO  = MIN ((GCR * FSH * FSO), GSOM)

***********************************************************************
*-----Output section

      IF (OUTPUT) THEN
         CALL OUTDAT (2, 0, 'GCR',         GCR)
         CALL OUTDAT (2, 0, 'GLV',         GLV)
         CALL OUTDAT (2, 0, 'GRT',         GRT)
         CALL OUTDAT (2, 0, 'GSH',         GSH)
         CALL OUTDAT (2, 0, 'GSO',         GSO)
         CALL OUTDAT (2, 0, 'GSTR',       GSTR)
         CALL OUTDAT (2, 0, 'GSTREX',   GSTREX)
         CALL OUTDAT (2, 0, 'GSTS',       GSTS)
         CALL OUTDAT (2, 0, 'HI',           HI)
         CALL OUTDAT (2, 0, 'LLV',         LLV)
         CALL OUTDAT (2, 0, 'LRT',         LRT)
         CALL OUTDAT (2, 0, 'LSTR',       LSTR)
         CALL OUTDAT (2, 0, 'RLRLV',     RLRLV)
         CALL OUTDAT (2, 0, 'RLRRT',     RLRRT)
         CALL OUTDAT (2, 0, 'WCR',         WCR)
         CALL OUTDAT (2, 0, 'WLVD',       WLVD)
         CALL OUTDAT (2, 0, 'WLVG',       WLVG)
         CALL OUTDAT (2, 0, 'WRR',         WRR)
         CALL OUTDAT (2, 0, 'WRTD',       WRTD)
         CALL OUTDAT (2, 0, 'WRTL',       WRTL)
         CALL OUTDAT (2, 0, 'WSHG',       WSHG)
         CALL OUTDAT (2, 0, 'WSHT',       WSHT)
         CALL OUTDAT (2, 0, 'WSO',         WSO)
         CALL OUTDAT (2, 0, 'WSTR',       WSTR)
         CALL OUTDAT (2, 0, 'WSTT',       WSTT)
         CALL OUTDAT (2, 0, 'XXWCR',     XXWCR)
         CALL OUTDAT (2, 0, 'XXWLVD',   XXWLVD)
         CALL OUTDAT (2, 0, 'XXWLVG',   XXWLVG)
         CALL OUTDAT (2, 0, 'XXWRTL',   XXWRTL)
         CALL OUTDAT (2, 0, 'XXWSO',     XXWSO)
         CALL OUTDAT (2, 0, 'XXWSTS',   XXWSTS)
      END IF

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

      ELSE IF (ITASK.EQ.3) THEN

*=====================================================================*
*                        Integration section                          *
*=====================================================================*
*-----Dry matter Production

      WLVG = INTGR2 (WLVG, GLV - LLV,   DELT, FILEI1, 'WLVG')
      WLVD = INTGR2 (WLVD, LLV  ,       DELT, FILEI1, 'WLVD')
      WSTS = INTGR2 (WSTS, GSTS,        DELT, FILEI1, 'WSTS')
      WSTR = INTGR2 (WSTR, GSTR - LSTR, DELT, FILEI1, 'WSTR')
      WSO  = INTGR2 (WSO,  GSO  ,       DELT, FILEI1, 'WSO ')
      WRTL = INTGR2 (WRTL, GRT-LRT  ,   DELT, FILEI1, 'WRTL')
      WRTD = INTGR2 (WRTD, LRT,         DELT, FILEI1, 'WRTD')

      WSTT = WSTS + WSTR
      WSHG = WLVG + WSTS  + WSO  + WSTR
      WSHT = WLVG + WSTS  + WSO  + WSTR + WLVD
      WCR  = WSHG + WRTL
      WRR  = WSO * GPR / GMC
      HI   = WSO * GPR / WCR

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

      ELSE IF (ITASK.EQ.4) THEN

*=====================================================================*
*                         Terminal section                            *
*=====================================================================*

         CONTINUE

      END IF

      RETURN
      END

*---------------------------------------------------------------------*
*  SUBROUTINE SINK                                                    *
*                                                                     *
* Authors: SARP                                                       *
* Date   : December 1994                                              *
* Version: 2.0                                                        *
*                                                                     *
* Research Institute for Agrobiology and Soil Fertility (AB-DLO),     *
* P.O.Box 14, 6700 AA Wageningen, The Netherlands                     *
*                                                                     *
* International Rice Research Institute, P.O. Box 933,                *
* 1099 Manila, The Philippines and                                    *
*                                                                     *
* Department of Theoretical Production Ecology, P.O. Box 430,         *
* 6700 AK Wageningen, The Netherlands.                                *
*                                                                     *
*                                                                     *
```

```
* History: This module contains components derived from the          *
*          TIL module described by                                    *
*          Penning de Vries F.W.T. et al., 1989. Simulation of        *
*          ecophysiological processes of growth in several            *
*          annual crops. Simulation Monographs 29, Pudoc,             *
*          Wageningen and IRRI, Los Banos, 271 pp.                    *
*                                                                     *
* Purpose: This subroutine computes the tiller and grain production  *
*                                                                     *
* FORMAL PARAMETERS:(I=input,O=output,C=control,IN=init,T=time)      *
* name   type meaning                                   units  class *
* ----   ---- -------                                   -----  ----- *
* 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 input file no. 1                    -      I   *
* OUTPUT  L4  Flag to indicate if output should be done   -      I   *
* DELT    R4  Time step of integration                    d      I   *
* SWISIN  I4  Switch for sink limitation                             *
*             (1 = no sink limitation, 2 = sink limitation) -    IC  *
* DVS     R4  Phenelogical development stage crop         -      I   *
* DRR     R4  Development rate crop in reproductive ph.  1/d     I   *
* TAV     R4  24h average air temperature               deg C    I   *
* WSO     R4  Weight of storage organs                  kg/ha    I   *
* FNLV    R4  fraction N in leaves                        -      I   *
* GCR     R4  growth rate of crop                      kg/ha/d   I   *
* CRGCR   R4  weight of carb.hydrates req. for dry                   *
*             matter growth of the crop                 kg/kg    I   *
* GSOM    R4  maximum growth rate storage organs       kg/ha/d   O   *
* NTI     R4  number of tillers, including main stems   1/ha     O   *
* NGR     R4  number of grains                          1/ha     O   *
*                                                                     *
* Fatal error checks: If one of the characters of WSTAT = '4'         *
*                     indicates missing weather                       *
* Warnings          : none                                            *
* Subprograms called: none                                            *
* File usage        : IUNITD, IUNITL, FILEI1                          *
* Libraries used    : TTUTIL, COME_ON                                 *
*                                                                     *
*---------------------------------------------------------------------*
      SUBROUTINE SINK (ITASK, IUNITD, IUNITL, FILEI1,
     &                 OUTPUT, DELT,
     &                 SWISIN,
     &                 DVS, DRR, TAV, WSO, FNLV, GCR, CRGCR,
     &                 GSOM, NTI, NGR)

      IMPLICIT REAL (A-Z)

*-----Formal parameters
      INTEGER   ITASK,  IUNITD, IUNITL
      LOGICAL   OUTPUT
      CHARACTER*(*) FILEI1
      INTEGER SWISIN

*-----Standard local declarations
      INTEGER IMNP
      PARAMETER (IMNP=40)

*-----Tiller and Grain Development
      INTEGER ILGRT, ILCNTI, ILRTIL
      REAL CNTIT(IMNP), GGRT(IMNP), RTILT(IMNP)

      SAVE

      IF (ITASK.EQ.1) THEN

*=====================================================================*
*                            Initialization                           *
*=====================================================================*

*-----Message
      IF (DELT.LT.1.0) CALL ERROR
     &      ('SINK','DELT too small for SINK')

*-----Message send to output file
      IF (SWISIN.EQ.1) THEN
         CALL OUTCOM ('SWISIN=1 ; no sink limitation, no GSOM')
      ELSE IF (SWISIN.EQ.2) THEN
         CALL OUTCOM ('SWISIN=2 ; sink limitation, use of GSOM')
      ELSE
         CALL ERROR ('SINK', 'illegal value used for switch SWISIN')
      END IF

      CALL RDINIT (IUNITD, IUNITL, FILEI1)

*-----Tiller and Grain Development
      CALL RDSREA ('TCFT'  , TCFT  )
      CALL RDSREA ('TCDT'  , TCDT  )
      CALL RDSREA ('TCFG'  , TCFG  )
      CALL RDSREA ('WGRMX' , WGRMX )
      CALL RDSREA ('DVST1' , DVST1 )
      CALL RDSREA ('DVSG1' , DVSG1 )
      CALL RDSREA ('DVST2' , DVST2 )
      CALL RDSREA ('DVSG2' , DVSG2 )
      CALL RDSREA ('PLNUM' , PLNUM )
      CALL RDSREA ('TILMX' , TILMX )
      CALL RDAREA ('CNTIT' , CNTIT , IMNP, ILCNTI)
      CALL RDAREA ('GGRT'  , GGRT  , IMNP, ILGRT)
      CALL RDAREA ('RTILT' , RTILT , IMNP, ILRTIL)

      CLOSE (IUNITD)

*-----Initialization of states
      NTI    = 0.
      NGR    = 0.

      ELSE IF (ITASK.EQ.2) THEN

*=====================================================================*
```

```
*                       Rate calculation section                        *
*=======================================================================*

*---- Tiller and Grain Development

      IF (SWISIN.EQ.1) THEN

         GSOM  = 1000.

      ELSE

         IF (DVS.GE.DVSG1.AND.DVS.LE.DVSG2) THEN
            DVSGR = 1.
         ELSE
            DVSGR = 0.
         END IF

         TEFG   = LINT (GGRT, ILGRT, TAV)
         GFP    = 1./(1.33*NOTNUL(DRR))
         GGRMN  = WGRMX/GFP
         GGRMX  = GGRMN*2.
         GSOM   = NGR * GGRMX * TEFG

         NGRP   = GCR * CRGCR/GGRMN
         NGRMX  = NTI * 100.
         GNGR   = DVSGR * MAX(0.,MIN(NGRP-NGR, NGRMX-NGR)/TCFG)
         WGR    = WSO/(MAX(NGR,1000.))


         IF (DVS.GE.DVST1.AND.DVS.LE.DVST2) THEN
            DVSTF = 1.
         ELSE
            DVSTF = 0.
         END IF

         CNTI   = LINT (CNTIT, ILCNTI, DVS)
         TIL    = TILMX *  LINT (RTILT, ILRTIL, FNLV)
         NTIP   = MIN (GCR*CRGCR/CNTI, PLNUM*TIL)
         GNTI   = DVSTF * MAX (0.,(NTIP-NTI)/TCFT)

         IF (DVS.GE.DVST1.AND.DVS.LE.(DVST2+0.15)) THEN
            DVSTD = 1.
         ELSE
            DVSTD = 0.
         END IF

         LNTI   = DVSTD * MAX (0.,(NTI-NTIP)/TCDT)


      END IF

*************************************************************************
*-----Output section

      IF (OUTPUT) THEN
         CALL OUTDAT (2, 0, 'CNTI',      CNTI)
         CALL OUTDAT (2, 0, 'DVSGR',    DVSGR)
         CALL OUTDAT (2, 0, 'DVSTD',    DVSTD)
         CALL OUTDAT (2, 0, 'DVSTF',    DVSTF)
         CALL OUTDAT (2, 0, 'GFP',        GFP)
         CALL OUTDAT (2, 0, 'GGRMN',    GGRMN)
         CALL OUTDAT (2, 0, 'GGRMX',    GGRMX)
         CALL OUTDAT (2, 0, 'GNGR',      GNGR)
         CALL OUTDAT (2, 0, 'GNTI',      GNTI)
         CALL OUTDAT (2, 0, 'GSOM',      GSOM)
         CALL OUTDAT (2, 0, 'LNTI',      LNTI)
         CALL OUTDAT (2, 0, 'NGR',        NGR)
         CALL OUTDAT (2, 0, 'NGRMX',    NGRMX)
         CALL OUTDAT (2, 0, 'NGRP',      NGRP)
         CALL OUTDAT (2, 0, 'NTI',        NTI)
         CALL OUTDAT (2, 0, 'NTIP',      NTIP)
         CALL OUTDAT (2, 0, 'TEFG',      TEFG)
         CALL OUTDAT (2, 0, 'TIL',        TIL)
         CALL OUTDAT (2, 0, 'WGR',        WGR)

      END IF
*************************************************************************

      ELSE IF (ITASK.EQ.3) THEN

*=======================================================================*
*                       Integration section                             *
*=======================================================================*

*-----Tiller and Grain Development

      NTI  = INTGR2 (PLNUM, GNTI-LNTI   , DELT,FILEI1,'NTI ')
      NGR  = INTGR2 (NGR  , GNGR        , DELT,FILEI1,'NGR ')

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

      ELSE IF (ITASK.EQ.4) THEN

*=======================================================================*
*                       Terminal section                                *
*=======================================================================*

         CONTINUE

      END IF

      RETURN
      END

*-----------------------------------------------------------------------*
*  SUBROUTINE NDEMND                                                    *
*                                                                       *
* Authors: SARP                                                         *
```

```
* Date    : December 1994                                                *
* Version: 2.0                                                          *
*                                                                       *
* Research Institute for Agrobiology and Soil Fertility (AB-DLO),       *
* P.O.Box 14, 6700 AA Wageningen, The Netherlands                       *
*                                                                       *
* International Rice Research Institute, P.O. Box 933,                  *
* 1099 Manila, The Philippines and                                      *
*                                                                       *
* Department of Theoretical Production Ecology, P.O. Box 430,           *
* 6700 AK Wageningen, The Netherlands.                                  *
*                                                                       *
*                                                                       *
*  Purpose: Compute the nitrogen demand of the plant.                   *
*                                                                       *
* FORMAL PARAMETERS:(I=input,O=output,C=control,IN=init,T=time)         *
* name   type meaning                                     units  class *
* ----   ---- -------                                     -----  ----- *
* 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 input file no. 1                      -      I   *
* OUTPUT  L4  Flag to indicate if output should be done     -      I   *
* DELT    R4  Time step of integration                      d      I   *
* DVS     R4  Phenelogical development stage crop           -      I   *
* GSO     R4  Growth rate of storage organs              kg/ha/d   I   *
* GLV     R4  Growth rate of leaves                      kg/ha/d   I   *
* GSTS    R4  Growth rate of stems                       kg/ha/d   I   *
* GRT     R4  Growth rate of roots                       kg/ha/d   I   *
* ANLV    R4  Amount of N (nitrogen) in the leaves       kg/ha     I   *
* ANST    R4  Amount of N (nitrogen) in the stems        kg/ha     I   *
* ANRT    R4  Amount of N (nitrogen) in the roots        kg/ha     I   *
* ANCR    R4  Amount of N (nitrogen) in the crop         kg/ha     I   *
* WLVG    R4  Weight of the leaves                       kg/ha     I   *
* WSTS    R4  Weight of the stems                        kg/ha     I   *
* WRTL    R4  Weight of the roots                        kg/ha     I   *
* WSO     R4  Weight of the storage organs               kg/ha     I   *
* NDEML   R4  N (nitrogen) demand of leaves              kg/ha/d   O   *
* NDEMS   R4  N (nitrogen) demand of stems               kg/ha/d   O   *
* NDEMR   R4  N (nitrogen) demand of roots               kg/ha/d   O   *
* NDEMG   R4  N (nitrogen) demand of grains              kg/ha/d   O   *
* NDEMV   R4  N (nitrogen) demandof leaves plus                        *
*               stems and roots                          kg/ha/d   O   *
* NDEMT   R4  Total N (nitrogen) demand of crop          kg/ha/d   O   *
* NDEMGX  R4  maximum N demand of the storage organs     kg/ha/d   O   *
*                                                                       *
* Warnings          : none                                              *
* Subprograms called: none                                              *
* File usage        : IUNITD, IUNITL, FILEI1                            *
* Libraries used    : TTUTIL                                            *
*                                                                       *
*-----------------------------------------------------------------------*
      SUBROUTINE NDEMND (ITASK, IUNITD, IUNITL, FILEI1,
     &                   OUTPUT, DELT,
     &                   DVS, GSO, GLV, GSTS, GRT,
     &                   ANLV, ANST, ANRT, ANCR,
     &                   WLVG, WSTS, WRTL, WSO,
     &                   NDEML, NDEMS, NDEMR, NDEMG, NDEMV, NDEMT,
     &                   NDEMGX)

      IMPLICIT REAL (A-Z)

*-----Formal parameters
      INTEGER   ITASK,  IUNITD, IUNITL
      INTEGER   SWIFLO
      LOGICAL   OUTPUT
      CHARACTER*(*) FILEI1

*-----Standard local declarations
      INTEGER IMNP
      PARAMETER (IMNP=100)

*-----Other local declarations:
      INTEGER ILNMXL, ILNNSO
      REAL NMAXLT(IMNP), NMNSOT(IMNP)

      SAVE

      IF (ITASK.EQ.1) THEN

*=======================================================================*
*                          Initialization                               *
*=======================================================================*

*-----Message
      IF (DELT.LT.1.0) CALL ERROR
     &      ('NDEMND','DELT too small for NDEMND')


      CALL RDINIT (IUNITD, IUNITL, FILEI1)

*-----Time coefficient for N acquisition
      CALL RDSREA ('TCNA'  , TCNA  )

*-----Maximum and minimum N fractions in storage organs and leaves
      CALL RDSREA ('NMAXSO', NMAXSO )
      CALL RDAREA ('NMAXLT', NMAXLT, IMNP, ILNMXL)
      CALL RDAREA ('NMNSOT', NMNSOT, IMNP, ILNNSO)

      CLOSE (IUNITD)

*-----Initialization of states/rates
      SWIFLO = 0
      ANCRF  = 0.
      NDEML  = 0.
      NDEMS  = 0.
      NDEMG  = 0.
      NDEMR  = 0.
```

```
      ELSE IF (ITASK.EQ.2) THEN

*----------------------------------------------------------------------*
*                     Rate calculation section                         *
*----------------------------------------------------------------------*

*-----Maximum N fractions in plant organs

      NMAXL = LINT(NMAXLT, ILNMXL, DVS)
      NMAXS = 0.50 * NMAXL
      NMAXR = 0.37 * NMAXL

*-----Determination of amount of N in the crop at flowering

      IF (SWIFLO.EQ.0.AND.DVS.GT.1.0) THEN
          SWIFLO = 1
          ANCRF  = ANCR
      END IF

*-----Minimum N fraction in the storage organs

      NMINSO = LINT (NMNSOT, ILNNSO, ANCRF)

*-----Nitrogen demand of the leaves, stems, roots and grains

      NDEML  = (NMAXL*(WLVG+GLV)  - ANLV)/TCNA
      NDEMS  = (NMAXS*(WSTS+GSTS) - ANST)/TCNA
      NDEMR  = (NMAXR*(WRTL+GRT)  - ANRT)/TCNA

      IF(WSO.LT.10.) THEN
         NDEMG=0.
         NDEMGX=0.
      ELSE
         NDEMG =NMINSO*GSO
         NDEMGX=NMAXSO*GSO
      ENDIF

      NDEMV  = NDEML + NDEMS + NDEMR
      NDEMT  = NDEMV + NDEMG

***********************************************************************
*-----Output section

      IF (OUTPUT) THEN

        CALL OUTDAT (2, 0, 'ANCRF',     ANCRF)
        CALL OUTDAT (2, 0, 'NDEMG',     NDEMG)
        CALL OUTDAT (2, 0, 'NDEMGX',   NDEMGX)
        CALL OUTDAT (2, 0, 'NDEML',     NDEML)
        CALL OUTDAT (2, 0, 'NDEMR',     NDEMR)
        CALL OUTDAT (2, 0, 'NDEMS',     NDEMS)
        CALL OUTDAT (2, 0, 'NDEMT',     NDEMT)
        CALL OUTDAT (2, 0, 'NDEMV',     NDEMV)
        CALL OUTDAT (2, 0, 'NMINSO',   NMINSO)

      END IF
***********************************************************************

      ELSE IF (ITASK.EQ.3) THEN

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

*     No integration here for NDEMND

         CONTINUE

      ELSE IF (ITASK.EQ.4) THEN

*----------------------------------------------------------------------*
*                     Terminal section                                 *
*----------------------------------------------------------------------*

         CONTINUE

      END IF

      RETURN
      END


*----------------------------------------------------------------------*
* SUBROUTINE NUPTK                                                     *
*                                                                      *
* Authors: SARP                                                        *
* Date   : December 1994                                               *
* Version: 2.0                                                         *
*                                                                      *
* Research Institute for Agrobiology and Soil Fertility (AB-DLO),      *
* P.O.Box 14, 6700 AA Wageningen, The Netherlands                      *
*                                                                      *
* International Rice Research Institute, P.O. Box 933,                 *
* 1099 Manila, The Philippines and                                     *
*                                                                      *
* Department of Theoretical Production Ecology, P.O. Box 430,          *
* 6700 AK Wageningen, The Netherlands.                                 *
*                                                                      *
*                                                                      *
* Purpose: This subroutine computes the N uptake                       *
*                                                                      *
* FORMAL PARAMETERS:(I=input,O=output,C=control,IN=init,T=time)        *
* name   type meaning                                   units  class   *
* ----   ---- -------                                   -----  -----   *
* 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 input file no. 1                    -      I     *
* OUTPUT  L4  Flag to indicate if output should be done   -      I     *
* TIME    R4  Time of simulation                          d      I     *
```

```
* STTIME  R4  Start time of simulation                      d       I  *
* DELT    R4  Time step of integration                      d       I  *
* SWINUP  I4  Switch for choosing nitrogen input option                *
*              (1 = N uptake as forcing function,                      *
*               2 = potential production)                   -       IC *
* ANLCR   R4  Amount of N in the crop (live material)       kg/ha   I  *
* NDEMV   R4  N demand of leaves plus stems and roots       kg/ha/d I  *
* DVS     R4  Phenological development stage                -       I  *
* GLV     R4  Growth rate of the leaves                     kg/ha/d I  *
* GSTS    R4  Growth rate of the stems                      kg/ha/d I  *
* GRT     R4  Growth rate of the roots                      kg/ha/d I  *
* NUPT    R4  N uptake rate by crop                         kg/ha/d O  *
* NUPTOT  R4  Total N uptake, cumulative since initial      kg/ha   O  *
* ANTOT   R4  Total amount of N in the crop                 kg/ha   O  *
* NUPNEG  R4  excess N available in organs                  kg/ha/d O  *
* NTOTM   R4  Total N in crop measured, (cumulative                    *
*             uptake), forcing function                     kg/ha   O  *
*                                                                      *
* Warnings           : none                                            *
* Subprograms called: SUNUPT                                           *
* File usage         : IUNITD, IUNITL, FILEI1                          *
* Libraries used     : TTUTIL, COME_ON                                 *
*                                                                      *
*----------------------------------------------------------------------*
      SUBROUTINE NUPTK (ITASK, IUNITD, IUNITL, FILEI1,
     &                  OUTPUT, TIME, STTIME, DELT,
     &                  SWINUP,
     &                  ANLCR, NDEMV, DVS, GLV, GSTS, GRT,
     &                  NUPT, NUPTOT, ANTOT, NUPNEG, NTOTM)


      IMPLICIT REAL (A-Z)

*-----Formal parameters
      INTEGER   ITASK,   IUNITD, IUNITL
      LOGICAL   OUTPUT
      CHARACTER*(*) FILEI1
      INTEGER SWINUP

*-----Standard local declarations
      INTEGER IMNP
      PARAMETER (IMNP=40)

*-----N application
      INTEGER NA
      INTEGER ILDNAP
      REAL DNAPT(IMNP)

*-----N sampling
      INTEGER NS
      INTEGER ILDNOS, ILNTOT
      REAL DNOST(IMNP) , NTOTMT(IMNP)

*-----Maximum N fraction in plant organs
      INTEGER ILNMXL
      REAL NMAXLT(IMNP)

      SAVE

      IF (ITASK.EQ.1) THEN

*======================================================================*
*                           Initialization                             *
*======================================================================*

*-----Message
      IF (DELT.LT.1.0) CALL ERROR
     &     ('NUPT','DELT too small for NUPT')

      CALL RDINIT (IUNITD, IUNITL, FILEI1)

*-----Message send to output file
      IF (SWINUP.EQ.1) THEN
         CALL OUTCOM ('SWINUP=1 ; N limited Production')
      ELSE IF (SWINUP.EQ.2) THEN
         CALL OUTCOM ('SWINUP=2 ; Potential Production')
      ELSE
         CALL ERROR ('NUPTK', 'illegal value used for switch SWINUP')
      END IF

*-----Number of days between sowing and transplanting
      CALL RDSREA ('DTRP ' , DTRP  )

*-----Initial weights of the plant organs
      CALL RDSREA ('WLVGI' , WLVGI )
      CALL RDSREA ('WSTSI' , WSTSI )
      CALL RDSREA ('WRTLI' , WRTLI )

*-----Initial fraction of N in plant organs
      CALL RDSREA ('FNLVI' , FNLVI )

*-----Maximum N fraction in plant organs
      CALL RDAREA ('NMAXLT', NMAXLT, IMNP, ILNMXL)

*-----N application
      CALL RDSINT ('NA'    , NA    )
      CALL RDSREA ('CRDN'  , CRDN  )
      CALL RDAREA ('DNAPT' , DNAPT , IMNP, ILDNAP)

*-----Leaf:stem N ratio and leaf:root N ratio
      CALL RDSREA ('LSNR'  , LSNR  )
      CALL RDSREA ('LRNR'  , LRNR  )

*-----N sampling
      CALL RDSINT ('NS'    , NS    )
      CALL RDAREA ('DNOST' , DNOST , IMNP, ILDNOS)
      CALL RDAREA ('NTOTMT', NTOTMT, IMNP, ILNTOT)

      CLOSE (IUNITD)
```

```
*-----Initialization of states/rates
      NUPTOT = 0.
      NUPNEG = 0.

      FNSTI = LSNR * FNLVI
      FNRTI = LRNR * FNLVI

      ANSTI  = FNSTI * WSTSI
      ANLVI  = FNLVI * WLVGI
      ANRTI  = FNRTI * WRTLI
      ANTOTI = ANLVI+ANSTI+ANRTI
      ANTOT  = ANTOTI

      ANSO   = 0.
      ANLV   = ANLVI
      ANLD   = 0.
      ANST   = ANSTI
      ANRT   = ANRTI
      ANRD   = 0.

      ANCR   = ANSO+ANLV+ANLD+ANST+ANRT+ANRD
      ANLCR  = ANCR-ANLD-ANRD

      DATEX  = 0.
      NUPT   = 0.

      DOYS  = STTIME-DTRP

      ELSE IF (ITASK.EQ.2) THEN

*======================================================================*
*                       Rate calculation section                       *
*======================================================================*

*-----Maximum N fraction in plant organs

      NMAXL = LINT(NMAXLT, ILNMXL, DVS)
      NMAXS = LSNR * NMAXL
      NMAXR = LRNR * NMAXL

************************************************************************
*-----Nitrogen uptake rate by crop

      IF (SWINUP.EQ.1) THEN

         CALL SUNUPT(TIME,DOYS,ANLCR,NS,NA,NTOTMT,DNOST,
     $               DNAPT,CRDN,F1,NUPT,DNAP,DNOS,NTOTM)

      ELSE IF (SWINUP.EQ.2) THEN

         NUPT = NDEMV + GLV*NMAXL + GSTS*NMAXS + GRT*NMAXR

         F1     = 0.
         DNAP   = 0.
         DNOS   = 0.
         NTOTM  = 0.

      ENDIF

************************************************************************
*-----Output section

      IF (OUTPUT) THEN

         CALL OUTDAT (2, 0, 'ANTOT',    ANTOT)
         CALL OUTDAT (2, 0, 'DNAP',      DNAP)
         CALL OUTDAT (2, 0, 'DNOS',      DNOS)
         CALL OUTDAT (2, 0, 'F1',          F1)
         CALL OUTDAT (2, 0, 'NTOTM',    NTOTM)
         CALL OUTDAT (2, 0, 'NUPNEG',  NUPNEG)
         CALL OUTDAT (2, 0, 'NUPT',      NUPT)
         CALL OUTDAT (2, 0, 'NUPTOT',  NUPTOT)
         CALL OUTDAT (2, 0, 'NUPTP',    NUPTP)

      END IF
************************************************************************

      ELSE IF (ITASK.EQ.3) THEN

*======================================================================*
*                        Integration section                           *
*======================================================================*

*-----Total nitrogen uptake

         NUPTOT = INTGR2 (NUPTOT,NUPT      ,   DELT,FILEI1,'NUPTOT')
         ANTOT  = INTGR2 (ANTOT ,NUPT      ,   DELT,FILEI1,'ANTOT')
         NUPNEG = INTGR2 (NUPNEG,MIN(0.,NUPT), DELT,FILEI1,'NUPNEG')

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

      ELSE IF (ITASK.EQ.4) THEN

*======================================================================*
*                          Terminal section                            *
*======================================================================*

         CONTINUE

      END IF

      RETURN
      END

*----------------------------------------------------------------------*
* SUBROUTINE NCROP                                                     *
*                                                                      *
* Authors: SARP                                                        *
```

```
* Date   : December1994                                                *
* Version: 2.0                                                         *
*                                                                      *
* Research Institute for Agrobiology and Soil Fertility (AB-DLO),      *
* P.O.Box 14, 6700 AA Wageningen, The Netherlands                      *
*                                                                      *
* International Rice Research Institute, P.O. Box 933,                 *
* 1099 Manila, The Philippines and                                     *
*                                                                      *
* Department of Theoretical Production Ecology, P.O. Box 430,          *
* 6700 AK Wageningen, The Netherlands.                                 *
*                                                                      *
*                                                                      *
* Purpose: Computes N fractions in the plant organs and                *
*          the amount of N in the plant organs.                        *
*                                                                      *
* FORMAL PARAMETERS:(I=input,O=output,C=control,IN=init,T=time)        *
* name   type meaning                                    units  class *
* ----   ---- -------                                    -----  ----- *
* 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 input file no. 1                     -      I   *
* OUTPUT  L4  Flag to indicate if output should be done    -      I   *
* DELT    R4  Time step of integration                     d      I   *
* SWINUP  I4  Switch for choosing nitrogen input option               *
*             (1 = N uptake as forcing function,                      *
*              2 = potential production)                   -      IC  *
* DVS     R4  Phenelogical development stage crop          -      I   *
* DAT     R4  Day after transplanting                      d      I   *
* WLVG    R4  Weight of the leaves                       kg/ha    I   *
* WSTS    R4  Weight of the stems                        kg/ha    I   *
* WRTL    R4  Weight of the roots                        kg/ha    I   *
* WSO     R4  Weight of the storage organs               kg/ha    I   *
* LLV     R4  Rate of loss of leaf weight                kg/ha/d  I   *
* LRT     R4  Rate of loss of root weight                kg/ha/d  I   *
* GLV     R4  Growth rate of leaves                      kg/ha/d  I   *
* GSTS    R4  Growth rate of stems                       kg/ha/d  I   *
* GRT     R4  Growth rate of roots                       kg/ha/d  I   *
* NDEMG   R4  N (nitrogen) demand of grains              kg/ha/d  I   *
* NDEMGX  R4  maximum N demand of the storage organs     kg/ha/d  I   *
* NDEML   R4  N (nitrogen) demand of leaves              kg/ha/d  I   *
* NDEMS   R4  N (nitrogen) demand of stems               kg/ha/d  I   *
* NDEMR   R4  N (nitrogen) demand of roots               kg/ha/d  I   *
* NUPT    R4  N (nitrogen) uptake rate by crop           kg/ha/d  I   *
* FNLV    R4  Fraction of N in leaves                      -      O   *
* FNRT    R4  Fraction of N in roots                       -      O   *
* FNST    R4  Fraction of N in stems                       -      O   *
* FNSO    R4  Fraction of N in storage organs              -      O   *
* ANLV    R4  Amount of N in leaves                      kg/ha    O   *
* ANST    R4  Amount of N in stems                       kg/ha    O   *
* ANRT    R4  Amount of N in roots                       kg/ha    O   *
* ANSO    R4  Amount of N in stairage organs             kg/ha    O   *
* ANLCR   R4  Amount of N in the crop (live material)    kg/ha    O   *
* ANCR    R4  Amount of N in the crop (live and dead)    kg/ha    O   *
*                                                                      *
* Fatal error checks: If one of the characters of WSTAT = '4'         *
*                     indicates missing weather                       *
* Warnings          : none                                            *
* Subprograms called: SNALLC, SNTRAN                                  *
* File usage        : IUNITD, IUNITL, FILEI1                          *
* Libraries used    : TTUTIL, COME_ON                                 *
*                                                                      *
*----------------------------------------------------------------------*
      SUBROUTINE NCROP (ITASK, IUNITD, IUNITL, FILEI1,
     &                  OUTPUT, DELT,
     &                  SWINUP,
     &                  DVS, DAT,
     &                  WLVG, WSTS, WRTL, WSO,
     &                  LLV, LRT, GLV, GSTS, GRT,
     &                  NDEMG, NDEMGX, NDEML, NDEMS, NDEMR, NUPT,
     &                  FNLV, FNRT, FNST, FNSO,
     &                  ANLV, ANST, ANRT, ANSO, ANLCR, ANCR)

      IMPLICIT REAL (A-Z)

*-----Formal parameters
      INTEGER   ITASK,  IUNITD, IUNITL
      LOGICAL   OUTPUT
      CHARACTER*(*) FILEI1
      INTEGER SWINUP

*-----Standard local declarations
      INTEGER IMNP
      PARAMETER (IMNP=100)

*-----Function declarations
      LOGICAL INQOBS

*-----Nitrogen in Biomass
      INTEGER ILNMXL, ILNMNL
      REAL NMAXLT(IMNP), NMINLT(IMNP)

      REAL TINY

      SAVE

      DATA TINY /1.E-4/

      IF (ITASK.EQ.1) THEN

*======================================================================*
*                              Initialization                          *
*======================================================================*

*-----Message
      IF (DELT.LT.1.0) CALL ERROR
     &      ('NITRO','DELT too small for NITRO')
```

```
      CALL RDINIT (IUNITD, IUNITL, FILEI1)

*-----Nitrogen in biomass
      CALL RDAREA ('NMAXLT', NMAXLT, IMNP, ILNMXL)
      CALL RDAREA ('NMINLT', NMINLT, IMNP, ILNMNL)
      CALL RDSREA ('TCNT'  , TCNT  )
      CALL RDSREA ('FNLVI' , FNLVI )

*-----Residual N fractions
      CALL RDSREA ('RFNLV' , RFNLV )
      CALL RDSREA ('RFNST' , RFNST )
      CALL RDSREA ('RFNRT' , RFNRT )

*-----Leaf:stem N ratio and leaf:root N ratio
      CALL RDSREA ('LSNR'  , LSNR  )
      CALL RDSREA ('LRNR'  , LRNR  )

*-----Initial weights of plant organs
      CALL RDSREA ('WLVGI',  WLVGI)
      CALL RDSREA ('WSTSI',  WSTSI)
      CALL RDSREA ('WRTLI',  WRTLI)

*-----First grain harvest day
      CALL RDSREA ('FGHDAY', FGHDAY)

      CLOSE (IUNITD)

*-----Initialization of states/rates
      XXNLV  = -99.
      XXNLD  = -99.
      XXNST  = -99.
      XXNRT  = -99.
      XXNSO  = -99.
*-----(JJ) Jet ik heb deze maar verwijderd.
*      XXNCR  = XXNLV + XXNLD + XXNST + XXNRT
*      XXNLCR = XXNLV + XXNST + XXNRT

      FNSTI  = LSNR * FNLVI
      FNRTI  = LRNR * FNLVI

      ANSTI  = FNSTI * WSTSI
      ANLVI  = FNLVI * WLVGI
      ANRTI  = FNRTI * WRTLI

      ANSO   = 0.
      ANLV   = ANLVI
      ANLD   = 0.
      ANST   = ANSTI
      ANRT   = ANRTI
      ANRD   = 0.

      NLDLV  = 0.
      NLDRT  = 0.
      FNLV   = 0.
      FNST   = 0.
      FNRT   = 0.
      FNSO   = 0.
      NALV   = 0.
      NAST   = 0.
      NART   = 0.
      NTLV   = 0.
      NTST   = 0.
      NTRT   = 0.
      NSUPG  = 0.

      ANCR   = ANSO+ANLV+ANLD+ANST+ANRT+ANRD
      ANLCR  = ANCR-ANLD-ANRD

      ELSE IF (ITASK.EQ.2) THEN

*=========================================================================*
*                        Rate calculation section                        *
*=========================================================================*

*-----Reading of measured data

      IF (INQOBS(FILEI1, 'ANLV')) XXNLV  = GETOBS(FILEI1, 'ANLV')
      IF (INQOBS(FILEI1, 'ANLD')) XXNLD  = GETOBS(FILEI1, 'ANLD')
      IF (INQOBS(FILEI1, 'ANST')) XXNST  = GETOBS(FILEI1, 'ANST')
      IF (INQOBS(FILEI1, 'ANRT')) XXNRT  = GETOBS(FILEI1, 'ANRT')
      IF (INQOBS(FILEI1, 'ANSO')) XXNSO  = GETOBS(FILEI1, 'ANSO')

      IF ((DAT-FGHDAY).LE.0) THEN
         XXNCR  = XXNLV + XXNLD + XXNST + XXNRT
         XXNLCR = XXNLV + XXNST + XXNRT
      ELSE
         XXNCR  = XXNLV + XXNLD + XXNST + XXNRT + XXNSO
         XXNLCR = XXNLV + XXNST + XXNRT + XXNSO
      END IF

*-----Nitrogen fractions in plant organs

      NMAXL = LINT(NMAXLT, ILNMXL, DVS)
      NMAXS = LSNR * NMAXL
      NMAXR = LRNR * NMAXL

      NMINL = LINT(NMINLT, ILNMNL, DVS)
      NMINS = LSNR * NMINL
      NMINR = LRNR * NMINL

      FNLV  = ANLV/(WLVG+TINY)
      FNST  = ANST/(WSTS+TINY)
      FNRT  = ANRT/(WRTL+TINY)
      FNSO  = ANSO/(WSO+TINY)

*-----Nitrogen loss rate by dying of leaves and roots

      NLDLV = LLV * MAX(RFNLV,0.5*FNLV)
      NLDRT = LRT * RFNRT
```

```
**********************************************************************
*-----Nitrogen allocation rates to different organs

      CALL SNALLC(SWINUP,ANLV,ANST,ANRT,GLV,GSTS,GRT,
     $            NDEML,NDEMS,NDEMR,NUPT,NMAXL,NMAXS,NMAXR,
     $            NALV,NAST,NART,EXCESS,ANRTRE,ANSTRE,ANLVRE,AVAIL)

**********************************************************************
*-----Nitrogen translocation rates from different organs
*     Nitrogen supply rate to grains

      CALL SNTRAN (SWINUP,ANLV,ANST,ANRT,WLVG,WSTS,WRTL,WSO,
     $            RFNLV,RFNST,RFNRT,TCNT,NDEMG,NDEMGX,
     $            NALV,NAST,NART,EXCESS,ANRTRE,ANSTRE,ANLVRE,
     $            NTLV,NTST,NTRT,NSUPG,EXCTOG,EXCPOL)

**********************************************************************
*-----Output section

      IF (OUTPUT) THEN
         CALL OUTDAT (2, 0, 'ANCR',      ANCR)
         CALL OUTDAT (2, 0, 'ANLCR',    ANLCR)
         CALL OUTDAT (2, 0, 'ANLD',      ANLD)
         CALL OUTDAT (2, 0, 'ANLV',      ANLV)
         CALL OUTDAT (2, 0, 'ANLVRE',  ANLVRE)
         CALL OUTDAT (2, 0, 'ANRD',      ANRD)
         CALL OUTDAT (2, 0, 'ANRT',      ANRT)
         CALL OUTDAT (2, 0, 'ANRTRE',  ANRTRE)
         CALL OUTDAT (2, 0, 'ANSO',      ANSO)
         CALL OUTDAT (2, 0, 'ANST',      ANST)
         CALL OUTDAT (2, 0, 'ANSTRE',  ANSTRE)
         CALL OUTDAT (2, 0, 'AVAIL',    AVAIL)
         CALL OUTDAT (2, 0, 'EXCESS',  EXCESS)
         CALL OUTDAT (2, 0, 'EXCPOL',  EXCPOL)
         CALL OUTDAT (2, 0, 'EXCTOG',  EXCTOG)
         CALL OUTDAT (2, 0, 'FNLV',      FNLV)
         CALL OUTDAT (2, 0, 'FNRT',      FNRT)
         CALL OUTDAT (2, 0, 'FNSO',      FNSO)
         CALL OUTDAT (2, 0, 'FNST',      FNST)
         CALL OUTDAT (2, 0, 'NALV',      NALV)
         CALL OUTDAT (2, 0, 'NART',      NART)
         CALL OUTDAT (2, 0, 'NAST',      NAST)
         CALL OUTDAT (2, 0, 'NLDLV',    NLDLV)
         CALL OUTDAT (2, 0, 'NLDRT',    NLDRT)
         CALL OUTDAT (2, 0, 'NMAXL',    NMAXL)
         CALL OUTDAT (2, 0, 'NMAXR',    NMAXR)
         CALL OUTDAT (2, 0, 'NMAXS',    NMAXS)
         CALL OUTDAT (2, 0, 'NMINL',    NMINL)
         CALL OUTDAT (2, 0, 'NMINR',    NMINR)
         CALL OUTDAT (2, 0, 'NMINS',    NMINS)
         CALL OUTDAT (2, 0, 'NSUPG',    NSUPG)
         CALL OUTDAT (2, 0, 'NTLV',      NTLV)
         CALL OUTDAT (2, 0, 'NTRT',      NTRT)
         CALL OUTDAT (2, 0, 'NTST',      NTST)
         CALL OUTDAT (2, 0, 'XXNLV' ,   XXNLV)
         CALL OUTDAT (2, 0, 'XXNLD' ,   XXNLD)
         CALL OUTDAT (2, 0, 'XXNRT' ,   XXNRT)
         CALL OUTDAT (2, 0, 'XXNSO' ,   XXNSO)
         CALL OUTDAT (2, 0, 'XXNST' ,   XXNST)
         CALL OUTDAT (2, 0, 'XXNCR' ,   XXNCR)
         CALL OUTDAT (2, 0, 'XXNLCR',  XXNLCR)

      END IF
**********************************************************************

      ELSE IF (ITASK.EQ.3) THEN

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

*-----Nitrogen in biomass

      ANSO  = INTGR2(ANSO, NSUPG          ,    DELT, FILEI1, 'ANSO')
      ANLV  = INTGR2(ANLV, NALV-ANLVRE-NTLV-NLDLV+EXCPOL, DELT,
     $                                             FILEI1, 'ANLV')
      ANLD  = INTGR2(ANLD, NLDLV          ,    DELT,FILEI1,'ANLD')
      ANST  = INTGR2(ANST, NAST-ANSTRE-NTST   ,    DELT,FILEI1,'ANST')
      ANRT  = INTGR2(ANRT, NART-ANRTRE-NTRT-NLDRT, DELT,FILEI1,'ANRT')
      ANRD  = INTGR2(ANRD, NLDRT          ,    DELT,FILEI1, 'ANRD')

      ANCR  = ANSO+ANLV+ANLD+ANST+ANRT+ANRD
      ANLCR = ANCR-ANLD-ANRD
**********************************************************************

      ELSE IF (ITASK.EQ.4) THEN

*====================================================================*
*                  Terminator section                                *
*====================================================================*

         CONTINUE

      END IF

      RETURN
      END

*--------------------------------------------------------------------*
*  SUBROUTINE ASTRO                                                  *
*  Purpose: This subroutine calculates astronomic daylength,         *
*           diurnal radiation characteristics such as the daily      *
*           integral of sine of solar elevation and solar constant.  *
*                                                                    *
*  FORMAL PARAMETERS:  (I=input,O=output,C=control,IN=init,T=time)   *
*  name   type meaning                                  units  class *
*  ----   ---- -------                                  -----  ----- *
```

```
*  DOY     R4  Daynumber (Jan 1st = 1)                       -       I  *
*  LAT     R4  Latitude of the site                      degrees     I  *
*  SC      R4  Solar constant                            J m-2 s-1 O  *
*  DSO     R4  Daily extraterrestrial radiation          J m-2 d-1 O  *
*  SINLD   R4  Seasonal offset of sine of solar height       -       O  *
*  COSLD   R4  Amplitude of sine of solar height             -       O  *
*  DAYL    R4  Astronomic daylength (base = 0 degrees)       h       O  *
*  DSINB   R4  Daily total of sine of solar height           s       O  *
*  DSINBE  R4  Daily total of effective solar height         s       O  *
*                                                                       *
*  FATAL ERROR CHECKS (execution terminated, message)                   *
*  condition: LAT > 67, LAT < -67                                       *
*                                                                       *
*  FILE usage : none                                                    *
*-----------------------------------------------------------------------*

      SUBROUTINE ASTRO (DOY, LAT,
     &                  SC , DSO, SINLD, COSLD, DAYL, DSINB, DSINBE)
      IMPLICIT REAL (A-Z)

      PARAMETER (PI  = 3.141592654)
      PARAMETER (RAD = PI/180.)

      SAVE

*-----check on input range of parameters
      IF (LAT.GT.67.)  STOP 'ERROR IN ASTRO: LAT> 67'
      IF (LAT.LT.-67.) STOP 'ERROR IN ASTRO: LAT>-67'

*-----declination of the sun as function of daynumber (DOY)
      DEC   = -ASIN (SIN (23.45*RAD)*COS (2.*PI*(DOY+10.)/365.))

*-----SINLD, COSLD and AOB are intermediate variables

      SINLD = SIN (RAD*LAT)*SIN (DEC)
      COSLD = COS (RAD*LAT)*COS (DEC)
      AOB   = SINLD/COSLD

*-----daylength (DAYL)
      DAYL   = 12.0*(1.+2.*ASIN (AOB)/PI)

      DSINB  = 3600.*(DAYL*SINLD+24.*COSLD*SQRT (1.-AOB*AOB)/PI)
      DSINBE = 3600.*(DAYL*(SINLD+0.4*(SINLD*SINLD+COSLD*COSLD*0.5))+
     &         12.0*COSLD*(2.0+3.0*0.4*SINLD)*SQRT (1.-AOB*AOB)/PI)

*-----solar constant (SC) and daily extraterrestrial radiation (DSO)
      SC  = 1370.*(1.+0.033*COS (2.*PI*DOY/365.))
      DSO = SC*DSINB

      RETURN
      END

*-----------------------------------------------------------------------*
*  SUBROUTINE TOTASN                                                    *
*                                                                       *
*  Author : SARP                                                        *
*  Date   : March 1994                                                  *
*  Version: 1.0                                                         *
*                                                                       *
*  History: This subroutine is an adapted version of the subroutine     *
*           TOTASS described by                                         *
*           Laar, H.H. van, J. Goudriaan & H. van Keulen, 1992.         *
*           Simulation of crop growth for potential and water-          *
*           limited production situations. Simulation Reports 27,       *
*           CABO-TPE, Wageningen, The Netherlands, 72 pp.               *
*                                                                       *
*  Purpose: This subroutine calculates daily total gross                *
*           assimilation (DTGA) by performing a Gaussian integration    *
*           over time. At three different times of the day,             *
*           radiation is computed and used to determine assimilation    *
*           whereafter integration takes place.                         *
*                                                                       *
*  FORMAL PARAMETERS:  (I=input,O=output,C=control,IN=init,T=time)      *
*  name   type meaning                                   units  class *
*  ----   ---- -------                                   -----  ----- *
*  DOY     R4  Daynumber (January 1 = 1)                   -       I  *
*  LAT     R4  Latitude of the site                      degrees   I  *
*  DTR     R4  Daily total of global radiation           J/m2/d    I  *
*  SCP     R4  Scattering coefficient of leaves for visible             *
*              radiation (PAR)                             -       I  *
*  EFF     R4  Initial light use efficiency             kg CO2/J/  I  *
*                                                       ha/h m2 s     *
*  KDF     R4  Extinction coefficient for diffuse light            I  *
*  LAI     R4  Leaf area index                            ha/ha    I  *
*  KDIFN   R4  Extinction coefficient for N in canopy       -      I  *
*  ANLV    R4  Amount of N in the leaves                  kg/ha    I  *
*  ALPHAN  R4  Slope of AMAX versus NPA                kg CO2/ha/h I  *
*  NB      R4  Min N concentration leaf at AMAX=0          g/m2    I  *
*  REDFT   R4  Temperature correction for AMAX              -      I  *
*  AMAXT   R4  Maximum rate of photosynthesis of single  kg/       I  *
*              leaves at top of canopy                  ha leaf/h     *
*  DTGA    R4  Daily total gross Assimilation          kg CO2/ha/d O  *
*                                                                       *
*                                                                       *
*  Fatal error checks: none                                             *
*  Warnings          : none                                             *
*  Subprograms called: ASTRO, ASSIMN                                    *
*  File usage        : none                                             *
*  Libraries used    : none                                             *
*                                                                       *
*-----------------------------------------------------------------------*
      SUBROUTINE TOTASN (DOY,  LAT , DTR, SCP, EFF, KDF, LAI,
     &                   KDIFN, ANLV, ALPHAN, NB, REDFT,
     &                   AMAXT, DTGA)
      IMPLICIT REAL(A-Z)
      REAL XGAUSS(3), WGAUSS(3)
      INTEGER I1, IGAUSS

      PARAMETER (PI  = 3.141592654)
```

```
      SAVE

      DATA IGAUSS /3/
      DATA XGAUSS /0.112702, 0.500000, 0.887298/
      DATA WGAUSS /0.277778, 0.444444, 0.277778/

      CALL ASTRO(DOY,LAT,SC,DSO,SINLD,COSLD,DAYL,DSINB,DSINBE)

*-----assimilation set to zero and three different times of the day (HOUR)
      DTGA = 0.

***---ORYZAN specific part

      NT=(ANLV)*1000./10000.
      IF (KDIFN.GT.0.) THEN
         AMAX01=ALPHAN*KDIFN*(NT-NB*LAI)/(1.-EXP(-KDIFN*LAI))
      ELSE
         AMAX01=ALPHAN*(NT/LAI-NB)
      ENDIF

*      AMAXT=MAX(MIN(70.,REDFT*AMAX01),1.)

      AMAXT = LIMIT(1., 70., REDFT*AMAX01)

      LAIL  =MIN(10.,LAI)

***---End of ORYZAN specific part

      DO 10 I1=1,IGAUSS

*--------at the specified HOUR, radiation is computed and used to compute
*        assimilation
         HOUR = 12.0+DAYL*0.5*XGAUSS(I1)

*--------sine of solar elevation
         SINB  = MAX (0., SINLD+COSLD*COS (2.*PI*(HOUR+12.)/24.))

*--------diffuse light fraction (FRDF) from atmospheric
*        transmission (ATMTR)
         PAR   = 0.5*DTR*SINB*(1.+0.4*SINB)/DSINBE

         ATMTR = PAR/(0.5*SC*SINB)

         IF (ATMTR.LE.0.22) THEN
            FRDF = 1.
         ELSE IF (ATMTR.GT.0.22 .AND. ATMTR.LE.0.35) THEN
            FRDF = 1.-6.4*(ATMTR-0.22)**2
         ELSE
            FRDF = 1.47-1.66*ATMTR
         END IF

         FRDF = MAX (FRDF, 0.15+0.85*(1.-EXP (-0.1/SINB)))

*--------diffuse PAR (PARDF) and direct PAR (PARDR)
         PARDF = PAR * FRDF
         PARDR = PAR - PARDF

         CALL ASSIMN (SCP, EFF, KDF, LAIL, SINB, PARDR, PARDF, KDIFN,
     &                AMAXT, FGROS)

*--------integration of assimilation rate to a daily total (DTGA)
         DTGA = DTGA+FGROS*WGAUSS(I1)

10    CONTINUE

      DTGA = DTGA * DAYL

      RETURN
      END

*----------------------------------------------------------------------*
*  SUBROUTINE ASSIMN                                                   *
*                                                                      *
*  Author : SARP                                                       *
*  Date   : March 1994                                                 *
*  Version: 1.0                                                        *
*                                                                      *
*  History: This subroutine is an adapted version of the subroutine    *
*           ASSIM described by                                         *
*           Laar, H.H. van, J. Goudriaan & H. van Keulen, 1992.        *
*           Simulation of crop growth for potential and water-         *
*           limited production situations. Simulation Reports 27,      *
*           CABO-TPE, Wageningen, The Netherlands, 72 pp.              *
*  Purpose: This subroutine performs a Gaussian integration over       *
*           depth of canopy by selecting three different LAI's and     *
*           computing assimilation at these LAI levels. The            *
*           integrated variable is FGROS.                              *
*                                                                      *
*  FORMAL PARAMETERS:  (I=input,O=output,C=control,IN=init,T=time)     *
*  name   type meaning                                    units  class *
*  ----   ---- -------                                    -----  ----- *
*  SCP     R4  Scattering coefficient of leaves for visible            *
*              radiation (PAR)                              -      I   *
*  EFF     R4  Initial light use efficiency              kg CO2/J/ I   *
*                                                        ha/h m2 s     *
*  KDF     R4  Extinction coefficient for diffuse light           I    *
*  LAI     R4  Leaf area index                             ha/ha   I   *
*  SINB    R4  Sine of solar height                          -     I   *
*  PARDR   R4  Instantaneous flux of direct radiation (PAR) W/m2   I   *
*  PARDF   R4  Instantaneous flux of diffuse radiation(PAR) W/m2   I   *
*  KDIFN   R4  Extinction coefficient for N in canopy        -     I   *
*  AMAXT   R4  Maximum rate of photosynthesis of single  kg/       I   *
*              leaves at top of canopy                   ha leaf/h     *
*  FGROS   R4  Instantaneous assimilation rate of         kg CO2/  O   *
*              whole canopy                              ha soil/h     *
*                                                                      *
*  Fatal error checks: none                                            *
*  Warnings          : none                                            *
```

```
*  Subprograms called: none                                          *
*  File usage        : none                                          *
*  Libraries used    : none                                          *
*                                                                    *
*--------------------------------------------------------------------*

      SUBROUTINE ASSIMN (SCP, EFF, KDF, LAI, SINB, PARDR, PARDF, KDIFN,
     &                   AMAXT, FGROS)
      IMPLICIT REAL(A-Z)
      REAL XGAUSS(3), WGAUSS(3)
      INTEGER I1, I2, IGAUSS

      SAVE

*-----Gauss weights for three point Gauss
      DATA IGAUSS /3/
      DATA XGAUSS /0.112702, 0.500000, 0.887298/
      DATA WGAUSS /0.277778, 0.444444, 0.277778/

*-----reflection of horizontal and spherical leaf angle distribution
      SQV  = SQRT(1.-SCP)
      REFH = (1.-SQV)/(1.+SQV)
      REFS = REFH*2./(1.+2.*SINB)

*-----extinction coefficient for direct radiation and total direct flux
      CLUSTF = KDF / (0.8*SQV)
      KBL    = (0.5/SINB) * CLUSTF
      KDRT   = KBL * SQV

*-----selection of depth of canopy, canopy assimilation is set to zero
      FGROS = 0.

      DO 10 I1=1,IGAUSS

        LAIC = LAI * XGAUSS(I1)

***---ORYZAN specific
        AMAX = AMAXT*EXP(-KDIFN*LAIC)

*--------absorbed fluxes per unit leaf area: diffuse flux, total direct
*        flux, direct component of direct flux.
         VISDF = (1.-REFH)*PARDF*KDF  *EXP (-KDF  *LAIC)
         VIST  = (1.-REFS)*PARDR*KDRT *EXP (-KDRT *LAIC)
         VISD  = (1.-SCP) *PARDR*KBL  *EXP (-KBL  *LAIC)

*--------absorbed flux (J/M2 leaf/s) for shaded leaves and assimilation of
*        shaded leaves
         VISSHD = VISDF + VIST - VISD
         IF (AMAX.GT.0.) THEN
            FGRSH  = AMAX * (1.-EXP(-VISSHD*EFF/AMAX))
         ELSE
            FGRSH = 0.
         END IF

*--------direct flux absorbed by leaves perpendicular on direct beam and
*        assimilation of sunlit leaf area

         VISPP  = (1.-SCP) * PARDR / SINB
         FGRSUN = 0.
         DO 20 I2=1,IGAUSS
            VISSUN = VISSHD + VISPP * XGAUSS(I2)
            IF (AMAX.GT.0.) THEN
               FGRS = AMAX * (1.-EXP(-VISSUN*EFF/AMAX))
            ELSE
               FGRS = 0.
            END IF
            FGRSUN = FGRSUN + FGRS * WGAUSS(I2)
20       CONTINUE

*--------fraction sunlit leaf area (FSLLA) and local assimilation
*        rate (FGL)
         FSLLA = CLUSTF * EXP(-KBL*LAIC)
         FGL   = FSLLA  * FGRSUN + (1.-FSLLA) * FGRSH

*--------integration of local assimilation rate to canopy
*        assimilation (FGROS)
         FGROS = FGROS + FGL * WGAUSS(I1)
10    CONTINUE

      FGROS = FGROS * LAI

      RETURN
      END


*--------------------------------------------------------------------*
*  SUBROUTINE SLLOSS                                                 *
*                                                                    *
*  Authors: SARP                                                     *
*  Date   : March 1994                                               *
*  Version: 1.1                                                      *
*                                                                    *
*  Research Institute for Agrobiology and Soil Fertility (AB-DLO),   *
*  P.O.Box 14, 6700 AA Wageningen, The Netherlands                   *
*                                                                    *
*  International Rice Research Institute, P.O. Box 933,              *
*  1099 Manila, The Philippines and                                  *
*                                                                    *
*  Department of Theoretical Production Ecology, P.O. Box 430,       *
*  6700 AK Wageningen, The Netherlands.                              *
*                                                                    *
*  Purpose: This subroutine computes the loss rates of leaves and    *
*           roots depending on N (nitrogen) concentration in the     *
*           leaves and leaf area.                                    *
*                                                                    *
*  FORMAL PARAMETERS:(I=input,O=output,C=control,IN=init,T=time)     *
*  name   type meaning                                  units  class *
*  ----   ---- -------                                  -----  ----- *
*  DVSG2   R4  DVS when grain formation ends              -      I   *
*  DVS     R4  Development stage                          -      I   *
```

```
*  FNLV     R4  Fraction of N (nitrogen) in leaves            -      I    *
*  NMINL    R4  Maximum N (nitrogen) in leaves              kg/kg    I    *
*  RDR      R4  Relative death rate root and leaf            1/d     I    *
*  LAI      R4  Leaf area index                               -      I    *
*  LAIREF   R4  Leaf area index reference                     -      I    *
*  WLVG     R4  Weight of the leaves                        kg/ha    I    *
*  WRTL     R4  Weight of the roots                         kg/ha    I    *
*  LLV      R4  Rate of loss of leaf weight                 kg/ha/d  O    *
*  LRT      R4  Rate of loss of root weight                 kg/ha/d  O    *
*                                                                         *
*  Fatal error checks: none                                               *
*  Warnings          : none                                               *
*  Subprograms called: none                                               *
*  File usage        : none                                               *
*  Libraries used    : none                                               *
*                                                                         *
*-------------------------------------------------------------------------*

      SUBROUTINE SLLOSS(DVSG2, DVS, FNLV, NMINL, RDR, LAI, LAIREF,
     &                  WLVG, WRTL, LLV, LRT)

      IMPLICIT REAL(A-Z)

      SAVE

      IF (FNLV.LT.1.1*NMINL) THEN
          RDRL = RDR * 5.
        ELSE IF (FNLV.GT.1.5*NMINL) THEN
          RDRL = RDR
        ELSE
          RDRL = RDR * (5.-(FNLV-1.1*NMINL)/(0.4*NMINL)*4.)
      END IF

      RLRLV    = (LAI/LAIREF)*RDRL
      RLRRT    = RLRLV

      IF (DVS.LT.DVSG2) THEN
         LLV   = 0.
         LRT   = 0.
      ELSE
         LLV   = WLVG*RLRLV
         LRT   = WRTL*RLRRT
      END IF


      RETURN
      END

*-------------------------------------------------------------------------*
*  SUBROUTINE SNALLC                                                      *
*                                                                         *
*  Authors: SARP                                                          *
*  Date   : March 1994                                                    *
*  Version: 1.0                                                           *
*                                                                         *
*  Research Institute for Agrobiology and Soil Fertility (AB-DLO),        *
*  P.O.Box 14, 6700 AA Wageningen, The Netherlands                        *
*                                                                         *
*  International Rice Research Institute, P.O. Box 933,                   *
*  1099 Manila, The Philippines and                                       *
*                                                                         *
*  Department of Theoretical Production Ecology, P.O. Box 430,            *
*  6700 AK Wageningen, The Netherlands.                                   *
*                                                                         *
*  Purpose: This subroutine calculates the nitrogen allocation            *
*           by and removal from plant organs                              *
*                                                                         *
*  FORMAL PARAMETERS:(I=input,O=output,C=control,IN=init,T=time)          *
*  name   type meaning                                  units  class      *
*  ----   ---- -------                                  -----  -----      *
*  SWINUP  I4  Switch for choosing nitrogen input option                  *
*              (1 = N uptake as forcing function,                         *
*               2 = potential production)                 -      IC       *
*  ANLV    R4  Amount of N (nitrogen) in the leaves     kg/ha    I        *
*  ANST    R4  Amount of N (nitrogen) in the stems      kg/ha    I        *
*  ANRT    R4  Amount of N (nitrogen) in the roots      kg/ha    I        *
*  GLV     R4  Growth rate (dry matter) of the leaves   kg/ha/d  I        *
*  GSTS    R4  Growth rate (dry matter) of the stems    kg/ha/d  I        *
*  GRT     R4  Growth rate (dry matter) of the roots    kg/ha/d  I        *
*  NDEML   R4  N (nitrogen) demand of leaves            kg/ha/d  I        *
*  NDEMS   R4  N (nitrogen) demand of stems             kg/ha/d  I        *
*  NDEMR   R4  N (nitrogen) demand of roots             kg/ha/d  I        *
*  NUPT    R4  N (nitrogen) uptake rate by crop         kg/ha/d  I        *
*  NMAXL   R4  Maximum N concentration in leaves        kg/kg    I        *
*  NMAXS   R4  Maximum N concentration in stems         kg/kg    I        *
*  NMAXR   R4  Maximum N concentration in roots         kg/kg    I        *
*  NALV    R4  N (nitrogen) acquisition by leaves       kg/ha/d  O        *
*  NAST    R4  N (nitrogen) acquisition by stems        kg/ha/d  O        *
*  NART    R4  N (nitrogen) acquisition by roots        kg/ha/d  O        *
*  EXCESS  R4  Excess of N in the crop                  kg/ha/d  O        *
*  ANRTRE  R4  Total amount of N removed from roots     kg/ha/d  O        *
*  ANSTRE  R4  Total amount of N removed from stems     kg/ha/d  O        *
*  ANLVRE  R4  Total amount of N removed from leaves    kg/ha/d  O        *
*  AVAIL   R4  Net pool of N available for allocation   kg/ha/d  O        *
*                                                                         *
*  Fatal error checks: none                                               *
*  Warnings          : none                                               *
*  Subprograms called: none                                               *
*  File usage        : none                                               *
*  Libraries used    : none                                               *
*                                                                         *
*-------------------------------------------------------------------------*

      SUBROUTINE SNALLC(SWINUP,ANLV,ANST,ANRT,GLV,GSTS,GRT,
     $                  NDEML,NDEMS,NDEMR,NUPT,NMAXL,NMAXS,NMAXR,
     $                  NALV,NAST,NART,EXCESS,ANRTRE,ANSTRE,ANLVRE,
     $                  AVAIL)

      IMPLICIT REAL(A-Z)
```

```
      INTEGER SWINUP
      DATA TINY/1.E-10/


      IF (SWINUP.EQ.1) THEN

*-----Nitrogen limited production

*-----Total positive and negative demand of N in plant
         POSDEM = (MAX(0.,NDEML)+MAX(0.,NDEMR)+MAX(0.,NDEMS))
         NEGDEM =-(MIN(0.,NDEML)+MIN(0.,NDEMR)+MIN(0.,NDEMS))

*-----Avail is the net pool of N available for allocation on each day
         AVAIL  = NEGDEM+NUPT

*-----Nitrogen allocation rates to the plant organs

         IF(AVAIL.GT.0.) THEN

            IF(NDEMR.GT.0.) NART=MIN(NDEMR,AVAIL*(NDEMR/(POSDEM+TINY)))
            IF(NDEMR.LE.0.) NART= 0.
            IF(NDEMS.GT.0.) NAST=MIN(NDEMS,AVAIL*(NDEMS/(POSDEM+TINY)))
            IF(NDEMS.LE.0.) NAST= 0.
            IF(NDEML.GT.0.) NALV=MIN(NDEML,AVAIL*(NDEML/(POSDEM+TINY)))
            IF(NDEML.LE.0.) NALV= 0.
            EXCESS = AVAIL - NART - NAST -NALV

*-----No extra removal by forcing, since NEGDEM is enough to
*     cover negative uptake (NUPT) if that would exist
            ANRTRX = 0.
            ANSTRX = 0.
            ANLVRX = 0.

         ELSE

            NART = 0.
            NAST = 0.
            NALV = 0.
            EXCESS = 0.

*-----Extra removal by force. NEGDEM (if exists) does not cover
*     negative uptake.
            ANRTRX = (ANRT/(ANLV+ANST+ANRT)) * AVAIL
            ANSTRX = (ANST/(ANLV+ANST+ANRT)) * AVAIL
            ANLVRX = (ANLV/(ANLV+ANST+ANRT)) * AVAIL

         ENDIF

*-----Total removed: due to negative demands plus removal by force
         ANRTRE = -(MIN(0.,NDEMR) + ANRTRX)
         ANSTRE = -(MIN(0.,NDEMS) + ANSTRX)
         ANLVRE = -(MIN(0.,NDEML) + ANLVRX)


      ELSEIF(SWINUP.EQ.2) THEN

*-----Potential production

         NALV   = NDEML+ GLV  * NMAXL
         NART   = NDEMR+ GRT  * NMAXR
         NAST   = NDEMS+ GSTS * NMAXS
         EXCESS = 0.
         ANRTRE = 0.
         ANSTRE = 0.
         ANLVRE = 0.

      ENDIF

      RETURN
      END

*----------------------------------------------------------------------*
*  SUBROUTINE SNTRAN                                                   *
*                                                                      *
*  Authors: SARP                                                       *
*  Date   : March 1994                                                 *
*  Version: 1.1                                                        *
*                                                                      *
*  Research Institute for Agrobiology and Soil Fertility (AB-DLO),     *
*  P.O.Box 14, 6700 AA Wageningen, The Netherlands                     *
*                                                                      *
*  International Rice Research Institute, P.O. Box 933,                *
*  1099 Manila, The Philippines and                                    *
*                                                                      *
*  Department of Theoretical Production Ecology, P.O. Box 430,         *
*  6700 AK Wageningen, The Netherlands.                                *
*                                                                      *
*  Purpose: This subroutine calculates N (nitrogen) supply to the      *
*           grains based upon the amount of translocatable N(nitrogen)*
*           from the leaves, stems and roots.                          *
*                                                                      *
*  FORMAL PARAMETERS:(I=input,O=output,C=control,IN=init,T=time)       *
*  name   type meaning                                   units  class *
*  ----   ---- -------                                   -----  ----- *
*  SWINUP  I4  Switch for choosing nitrogen input option               *
*              (1 = N uptake as forcing function,                      *
*               2 = potential production)                  -       IC *
*  ANLV    R4  Amount of N (nitrogen) in the leaves        kg/ha    I  *
*  ANST    R4  Amount of N (nitrogen) in the stems         kg/ha    I  *
*  ANRT    R4  Amount of N (nitrogen) in the roots         kg/ha    I  *
*  WLVG    R4  Weight of the leaves                        kg/ha    I  *
*  WSTS    R4  Weight of the stems                         kg/ha    I  *
*  WRTL    R4  Weight of the roots                         kg/ha    I  *
*  WSO     R4  Weight of the storage organs                kg/ha    I  *
*  RFNLV   R4  Residual N (nitrogen) fraction of leaves    kg/kg    I  *
*  RFNST   R4  Residual N (nitrogen) fraction of stems     kg/kg    I  *
*  RFNRT   R4  Residual N (nitrogen) fraction of roots     kg/kg    I  *
*  TCNT    R4  Time coefficient for N (nitrogen)                       *
*              translocation                                 d      I  *
```

```
*  NDEMG    R4  N (nitrogen) demand of grains             kg/ha/d  I   *
*  NDEMGX   R4  Maximum N demand of the storage organ     kg/ha/d  I   *
*  NALV     R4  N (nitrogen) acquisition by leaves        kg/ha/d  O   *
*  NAST     R4  N (nitrogen) acquisition by stems         kg/ha/d  O   *
*  NART     R4  N (nitrogen) acquisition by roots         kg/ha/d  O   *
*  EXCESS   R4  Excess of N in the crop                   kg/ha/d  O   *
*  ANRTRE   R4  Total amount of N removed from roots      kg/ha/d  O   *
*  ANSTRE   R4  Total amount of N removed from stems      kg/ha/d  O   *
*  ANLVRE   R4  Total amount of N removed from leaves     kg/ha/d  O   *
*  NTLV     R4  N (nitrogen) translocated from leaves     kg/ha/d  O   *
*  NTST     R4  N (nitrogen) translocated from stems      kg/ha/d  O   *
*  NTRT     R4  N (nitrogen) translocated from roots      kg/ha/d  O   *
*  NSUPG    R4  Rate of N (nitrogen) supply to grains     kg/ha/d  O   *
*  EXCTOG   R4  Amount of N from EXCESS translocated                   *
*               to the grains                             kg/ha/d  O   *
*  EXCPOL   R4  Pool of excess N                          kg/ha/d  O   *
*                                                                      *
*  Fatal error checks: none                                            *
*  Warnings          : none                                            *
*  Subprograms called: none                                            *
*  File usage        : none                                            *
*  Libraries used    : none                                            *
*                                                                      *
*----------------------------------------------------------------------*
      SUBROUTINE SNTRAN (SWINUP,ANLV,ANST,ANRT,WLVG,WSTS,WRTL,WSO,
     $                  RFNLV,RFNST,RFNRT,TCNT,NDEMG,NDEMGX,
     $                  NALV,NAST,NART,EXCESS,ANRTRE,ANSTRE,ANLVRE,
     $                  NTLV,NTST,NTRT,NSUPG,EXCTOG,EXCPOL)

      IMPLICIT REAL(A-Z)
      INTEGER SWINUP
      SAVE

*-----Potential rate (temperature-corrected) of N translocation
*     from organs, in kg/ha/d

      ATNLV  = MAX(0.,(ANLV - ANLVRE + NALV - WLVG*RFNLV)/TCNT)
      ATNST  = MAX(0.,(ANST - ANSTRE + NAST - WSTS*RFNST)/TCNT)
      ATNRT  = MAX(0.,(ANRT - ANRTRE + NART - WRTL*RFNRT)/TCNT)
      ATN    = ATNLV+ATNST+ATNRT


*-----Actual N supply rates by plant organs, in kg/ha/d

      IF (WSO.LT.10.) THEN
         NTLV=0.
         NTST=0.
         NTRT=0.

*-----Excess nitrogen in plant in nitrogen pool
         EXCPOL = EXCESS
         EXCTOG = 0.

      ELSE IF (NDEMG-EXCESS.GE.0.) THEN
         IF(ATN.GE.(NDEMG-EXCESS)) THEN
*-----Conversion potential to actual translocation
            NTLV  = MAX(0.,(NDEMG-EXCESS))*ATNLV/ATN
            NTST  = MAX(0.,(NDEMG-EXCESS))*ATNST/ATN
            NTRT  = MAX(0.,(NDEMG-EXCESS))*ATNRT/ATN
         ELSE
            NTLV  = ATNLV
            NTST  = ATNST
            NTRT  = ATNRT
         ENDIF

*-----All excess nitrogen in plant translocated to grains
         EXCTOG = EXCESS
         EXCPOL = 0.

      ELSE

         NTLV = 0.
         NTST = 0.
         NTRT = 0.

*-----Excess nitrogen in plant translocated to grains up to maximum
*     demand of the grains
         EXCTOG = MIN(NDEMGX, EXCESS)
         EXCPOL = EXCESS - EXCTOG

      ENDIF


*-----Actual N supply to grains by translocation

      IF (SWINUP.EQ.1) THEN
         NSUPG = NTLV+NTST+NTRT+EXCTOG

      ELSEIF (SWINUP.EQ.2) THEN
         NSUPG = NDEMG

      ENDIF

      RETURN
      END


*----------------------------------------------------------------------*
*  SUBROUTINE SUNUPT                                                   *
*                                                                      *
*  Authors: SARP                                                       *
*  Date   : March 1994                                                 *
*  Version: 1.1                                                        *
*                                                                      *
*  Research Institute for Agrobiology and Soil Fertility (AB-DLO),     *
*  P.O.Box 14, 6700 AA Wageningen, The Netherlands                     *
*                                                                      *
*  International Rice Research Institute, P.O. Box 933,                *
*  1099 Manila, The Philippines and                                    *
```

```
*                                                                       *
*  Department of Theoretical Production Ecology, P.O. Box 430,          *
*  6700 AK Wageningen, The Netherlands.                                 *
*                                                                       *
*  Purpose: This subroutine calculates the daily N (nitrogen) uptake    *
*           from an observation set given in kg N/ha in live biomass    *
*           at sampling dates.                                          *
*                                                                       *
*  FORMAL PARAMETERS:(I=input,O=output,C=control,IN=init,T=time)        *
*  name   type meaning                                   units  class   *
*  ----   ---- -------                                   -----  -----   *
*  TIME    R4  Time of simulation                          d      I     *
*  DOYS    R4  Starting time of simulation                 d      I     *
*  ANLCR   R4  Amount of N (nitrogen) in the crop (live) kg/ha    I     *
*  NS      I4  number of sampling dates for total                       *
*              N (nitrogen) in the crop                    -      I     *
*  NA      I4  Number of N (nitrogen) applications dates   -      I     *
*  NTOTMT  R4  Tabulated total N (nitrogen) measured     kg/ha    I     *
*  DNOST   R4  Table of julian dates at which NTOTMT                    *
*              was measured                                -      I     *
*  DNAPT   R4  Daynumberof N (nitrogen) applications       d      I     *
*  CRDN    R4  Critical daynumber which affects the rate                *
*              at which uptake declines after                           *
*              N (nitrogen) application                    -      O     *
*  F1      R4  Leaf area fraction in 0-30 and 30-60                     *
*              degree leaf angle classes for layes 1 to 5  -      O     *
*  NUPT    R4  N (nitrogen) uptake rate by crop          kg/ha/d  O     *
*  DNAP    R4  Daynumber of nitrogen applications          -      O     *
*  DNOS    R4  Daynumber of crop sampling for N(nitrogen)  -      O     *
*  NTOTM   R4  Total N (nitrogen) in crop measured       kg/ha    O     *
*                                                                       *
*  Fatal error checks: none                                             *
*  Warnings          : none                                             *
*  Subprograms called: none                                             *
*  File usage        : none                                             *
*  Libraries used    : none                                             *
*                                                                       *
*-----------------------------------------------------------------------*
      SUBROUTINE SUNUPT(TIME, DOYS, ANLCR, NS, NA,
     $                  NTOTMT, DNOST, DNAPT, CRDN,
     $                  F1, NUPT, DNAP, DNOS, NTOTM)


      IMPLICIT REAL (A-Z)
      INTEGER NA,NS,I
      REAL NTOTMT(20),DNOST(20),DNAPT(20),CRDN,F1,NUPT
      REAL DSLA,NTOTM,ANLCR,DNOS,DNAP,DATEX

      SAVE

*-----Identification of next target sampling date to match
*     'simulated' with measured uptake

      DATEX=TIME

      DO 10 I=1,NS
         IF(DATEX.GT.DNOST(I)) THEN
            CONTINUE
         ELSE
            NTOTM  = NTOTMT(I)
            NTOTMN = NTOTMT(I+1)
            DNOS   = DNOST(I)
            DNOSN  = DNOST(I+1)
            GOTO 20
         ENDIF
10    CONTINUE
20    CONTINUE

*-----Identification of next nitrogen application date
      DO 30 I=1,NA
         IF(ABS(DATEX-DOYS).LT.0.1) THEN
            DNAP=DOYS
            DSLA=1.
            GOTO 40
         ELSEIF(DATEX.GT.DNAPT(I)) THEN
            CONTINUE
         ELSE
            DNAP=DNAPT(I-1)
            DSLA=DATEX-DNAP
            GOTO 40
         ENDIF
30    CONTINUE
40    CONTINUE

*-----Coefficient determining the N uptake rate after N application
      IF (DSLA.LE.CRDN) THEN
         F1 = 1.* SQRT(CRDN/MAX(1.,DSLA))
      ELSE
         F1 = 1.
      ENDIF


*-----Nitrogen uptake rate

      IF (DATEX.GE.DNOST(NS)) THEN

        NUPT=0.

      ELSE

         IF (NINT(DATEX).EQ.NINT(DNOS)) THEN

            IF (NTOTMN.GT.ANLCR)  THEN
               NUPT=MIN(NTOTMN-ANLCR,
     $         F1*(NTOTMN-ANLCR)/NOTNUL(DNOSN-DATEX))
            ELSE
               NUPT=MAX(NTOTMN-ANLCR,
     $         (NTOTMN-ANLCR)/NOTNUL(DNOSN-DATEX))
```

```
            ENDIF

         ELSE

            IF (NTOTM.GT.ANLCR) THEN
               NUPT=MIN(NTOTM-ANLCR,
     $         F1*(NTOTM-ANLCR)/NOTNUL(DNOS-DATEX))
            ELSE
               NUPT=MAX(NTOTM-ANLCR,
     $         (NTOTM-ANLCR)/NOTNUL(DNOS-DATEX))
            ENDIF

         ENDIF

      ENDIF

      RETURN
      END



      REAL FUNCTION FUNCHK(CKNIN,CKNFL,TIME)
      IMPLICIT REAL (A-Z)

      SAVE

* check on crop nitrogen balance.
* ten Berge, August 1992
      FUNCHK=2.0*(CKNIN-CKNFL)/(CKNIN+CKNFL+1.E-10)
      IF(ABS(FUNCHK).GT.0.01) THEN
       WRITE(40,10) FUNCHK, CKNIN,CKNFL,TIME
10     FORMAT(/'*** ERROR IN NITROGEN BALANCE, PLS CHECK***',/,
     $ ' CKNRD=',F6.3,' CKNIN=',F8.2,' CKNFL=',F8.2,' AT TIME=',
     $ F6.1)
      ENDIF
      RETURN
      END


      REAL FUNCTION CBCHK(CKCIN,CKCFL,TIME)
      IMPLICIT REAL (A-Z)

      SAVE

C check on crop carbon balance. used in L1D, L1Q. 03/87
      CBCHK=2.0*(CKCIN-CKCFL)/(CKCIN+CKCFL+1.E-10)
      IF (ABS(CBCHK).GT.0.01.AND.ABS(CKCIN-CKCFL).GT.1.) THEN
         WRITE (40,10) CBCHK, CKCIN, CKCFL, TIME
      END IF
 10   FORMAT(/'* * *error in carbon balance, please check* * *',/,'CKCRD
     $=',F6.3,' CKCIN=',F8.2,' CKCFL=',F8.2,' AT  TIME=',F6.1)

      RETURN
      END
```

Appendix 9 Listing of the ORYZA_0 modules

```
*----------------------------------------------------------------------*
*                                                                      *
*                                                                      *
*              FORTRAN Simulation Environment (FSE 2.0b)               *
*                          September, 1994                             *
*                                                                      *
*     FSE 2.0 is a simulation environment suited for simulation of     *
*     biological processes in time, such as crop and vegetation growth,*
*     insect population development etc.                              *
*                                                                      *
*     The MAIN program, subroutine FSE and subroutine MODELS are       *
*     programmed by D.W.G. van Kraalingen, DLO Centre for              *
*     Agrobiological Research, PO Box 14, 6700 AA, Wageningen, The     *
*     Netherlands (e-mail: d.w.g.van.kraalingen@cabo.agro.nl).         *
*                                                                      *
*     A manual of FSE 2.0 is in preparation.                           *
*                                                                      *
*     Version 1.0 of FSE is described in:                              *
*     Kraalingen, D.W.G. van 1991. The FSE system for crop simulation, *
*     Simulation Report CABO-TT No.23, Centre for Agrobiological       *
*     Research, Dept. of Theoretical Production Ecology, 77 pp.        *
*                                                                      *
*     Data files needed for FSE 2.0:                                   *
*          (excluding data files used by models called from MODELS):   *
*        - CONTROL.DAT (contains file names to be used),               *
*        - timer file whose name is specified in CONTROL.DAT,          *
*        - optionally, a rerun file whose name is specified in         *
*          CONTROL.DAT,                                                *
*        - weather data files as specified in timer file               *
*     Object libraries needed for FSE 2.0:                             *
*        - TTUTIL (at least version 3.2)                               *
*        - WEATHER (at least version from 17-Jan-1990)                 *
*----------------------------------------------------------------------*
      PROGRAM MAIN
      CALL FSE
      END


      SUBROUTINE FSE

      IMPLICIT REAL (A-Z)

*-----Standard declarations for simulation and output control

      INTEGER   ITASK   , INSETS, ISET  , IPFORM, IL, ILEN
      LOGICAL   OUTPUT  , TERMNL, RDINQR, STRUNF, ENDRNF
      CHARACTER COPINF*1, DELTMP*1
      INTEGER   INPRS   , STRUN , ENDRUN

      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 weather system
      INTEGER   IFLAG    , ISTAT1, ISTAT2 , ISTN
      REAL      ANGA     , ANGB  , ELEV   , LAT , LONG, RDD
      REAL      TMMN     , TMMX  , VP     , WN  , RAIN
      LOGICAL   WTRMES   , WTRTER
      CHARACTER WTRDIR*80, CNTR*7, WSTAT*6, DUMMY*1

*-----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

*-----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

*-----Unit numbers for control file (C), data files (D),
*     output file (O), log file (L) and rerun file (R). File name for
*     control file and empty strings for input files 1-5.
*     WTRMES flags any messages from the weather system

      DATA IUNITC /10/, IUNITD /20/, IUNITO /30/
      DATA IUNITL /40/, IUNITR /50/
      DATA FILEIC /'CONTROL.DAT'/
      DATA FILEI1 /' '/, FILEI2 /' '/, FILEI3 /' '/
      DATA FILEI4 /' '/, FILEI5 /' '/
      DATA WTRMES /.FALSE./

      DATA STRUNF /.FALSE./, ENDRNF /.FALSE./

*-----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)
      IF (RDINQR('STRUN'))  THEN
         CALL RDSINT ('STRUN',STRUN)
         STRUNF = .TRUE.
      END IF
      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

*-----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
         ENDRUN = INSETS
      ELSE
         ENDRUN = MAX (ENDRUN, 0)
         ENDRUN = MIN (ENDRUN, INSETS)
      END IF

      IF (.NOT.STRUNF) THEN
         STRUN = 0
      ELSE
         STRUN = MAX (STRUN, 0)
         STRUN = MIN (STRUN, ENDRUN)
      END IF

      DO 10 ISET=STRUN,ENDRUN

      WRITE (*,'(A)') '   FSE 2.0b: Initialize model'

*-----Select data set
      CALL RDFROM (ISET, .FALSE.)


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

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

*-----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)

*-----Read time, control and weather variables from timer file
      CALL RDINIT (IUNITD  , IUNITL, FILEIT)
      CALL RDSREA ('STTIME', STTIME)
      CALL RDSREA ('FINTIM', FINTIM)
      CALL RDSREA ('PRDEL' , PRDEL )
      CALL RDSREA ('DELT'  , DELT  )
      CALL RDSINT ('IYEAR' , IYEAR )
      CALL RDSINT ('ISTN'  , ISTN  )
      CALL RDSINT ('IPFORM', IPFORM)
      CALL RDSCHA ('COPINF', COPINF)
      CALL RDSCHA ('DELTMP', DELTMP )
      CALL RDSCHA ('WTRDIR', WTRDIR)
      CALL RDSCHA ('CNTR'  , CNTR)
      CALL RDSINT ('IFLAG' , IFLAG)

*-----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)

      CLOSE (IUNITD)

*-----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)

*-----Open weather file and read station information and return
*     weather data for start day of simulation.
*     Check status of weather system, WTRMES flags if warnings or errors
*     have occurred during the whole simulation. WTRTER flags if the run
*     should be terminated because of missing weather

      CALL STINFO (IFLAG , WTRDIR, ' ', CNTR, ISTN, IYEAR,
     &             ISTAT1, LONG  , LAT, ELEV, ANGA, ANGB)
      CALL WEATHR (IDOY  , ISTAT2, RDD, TMMN, TMMX, VP, WN, RAIN)
      IF (ISTAT1.NE.0.OR.ISTAT2.NE.0) WTRMES = .TRUE.
      WSTAT  = '444444'
```

```
      IF (ABS (ISTAT2).GE.111111) THEN
         WRITE (WSTAT,'(I6)') ABS (ISTAT2)
      ELSE IF (ISTAT2.EQ.0) THEN
         WSTAT = '111111'
      END IF

*-----initialize OBSSYS routine
      IF (ITASK.EQ.1) CALL OBSINI

*-----Conversion of total daily radiation from kJ/m2/d to J/m2/d
      RDD = RDD*1000.

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


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

      WRITE (*,'(A)') '   FSE 2.0b: 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,
     &                DOY   , IDOY  , YEAR  , IYEAR ,
     &                TIME  , STTIME, FINTIM, DELT  ,
     &                LAT   , 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)
      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 STINFO (IFLAG , WTRDIR, ' ', CNTR, ISTN, IYEAR,
     &             ISTAT1, LONG  , LAT, ELEV, ANGA, ANGB)
      CALL WEATHR (IDOY, ISTAT2, RDD, TMMN, TMMX, VP, WN, RAIN)
      IF (ISTAT1.NE.0.OR.ISTAT2.NE.0) WTRMES = .TRUE.
      WSTAT  = '444444'
      IF (ABS (ISTAT2).GE.111111) THEN
         WRITE (WSTAT,'(I6)') ABS (ISTAT2)
      ELSE IF (ISTAT2.EQ.0) THEN
         WSTAT = '111111'
      END IF

*-----Conversion of total daily radiation from kJ/m2/d to J/m2/d
      RDD = RDD*1000.

*----------------------------------------------------------------------*
*              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,
     &             DOY   , IDOY  , YEAR  , IYEAR ,
     &             TIME  , STTIME, FINTIM, DELT  ,
     &             LAT   , 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 MODELS (ITASK , IUNITD, IUNITO, IUNITL,
     &                FILEIT, FILEI1, FILEI2, FILEI3, FILEI4, FILEI5,
     &                OUTPUT, TERMNL,
     &                DOY   , IDOY  , YEAR  , IYEAR ,
     &                TIME  , STTIME, FINTIM, DELT  ,
     &                LAT   , 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

*======================================================================*
*                                                                      *
*                         Terminal section                             *
*                                                                      *
*======================================================================*

      ITASK = 4

      WRITE (*,'(A)') '   FSE 2.0b: Terminate model'

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

*-----Generate output file dependent on option from timer file
      IF (IPFORM.GE.4) THEN
         IF (INPRS.EQ.0) THEN
            CALL OUTDAT (IPFORM, 0, 'Simulation results',0.)
         ELSE
*           Selection of output variables was in timer file
*           write tables according to output selection array PRSEL
            CALL OUTSEL (PRSEL,IMNPRS,INPRS,IPFORM,'Simulation results')
         END IF
      END IF

      IF (WTRTER) THEN
         WRITE (*,'(/,A,/,/,/)')
     &     ' The run was terminated due to missing weather'
         WRITE (IUNITO,'(/,A,/,/,/)')
     &     ' The run was terminated due to missing weather'
         IF (IUNITO.NE.IUNITL) WRITE (IUNITL,'(/,A,/,/,/)')
     &     ' The run was terminated due to missing weather'
      END IF

*-----Delete temporary output file dependent on switch from timer file
      IF (DELTMP.EQ.'Y'.OR.DELTMP.EQ.'y') CALL OUTDAT (99, 0, ' ', 0.)

10    CONTINUE

      IF (INSETS.GT.0) CLOSE (IUNITR)

*-----If input files should be copied to the output file,
*     copy rerun file (if present) and timer file and if there, input
*     files 1-5

      IF (COPINF.EQ.'Y'.OR.COPINF.EQ.'y') THEN
         IF (INSETS.GT.0) CALL COPFL2 (IUNITR, FILEIR, IUNITO, .TRUE.)
         CALL COPFL2 (IUNITD, FILEIT, IUNITO, .TRUE.)
         IF (FILEI1.NE.' ') CALL COPFL2 (IUNITD, FILEI1, IUNITO, .TRUE.)
         IF (FILEI2.NE.' ') CALL COPFL2 (IUNITD, FILEI2, IUNITO, .TRUE.)
         IF (FILEI3.NE.' ') CALL COPFL2 (IUNITD, FILEI3, IUNITO, .TRUE.)
         IF (FILEI4.NE.' ') CALL COPFL2 (IUNITD, FILEI4, IUNITO, .TRUE.)
         IF (FILEI5.NE.' ') CALL COPFL2 (IUNITD, FILEI5, IUNITO, .TRUE.)
      END IF

*-----Delete all .TMP files that were created by the RD* routines
*     during simulation
      CALL RDDTMP (IUNITD)

*-----Write to screen which files contain what
      IL = ILEN (FILEON)
      WRITE (*,'(/,3A)') ' File: ',FILEON(1:IL),
     & ' contains simulation results'
      WRITE (*,'(2A)') ' File: WEATHER.LOG',
     & ' contains messages from the weather system'
      IL = ILEN (FILEOL)
      WRITE (*,'(3A,/)') ' File: ',FILEOL(1:IL),
     & ' contains messages from the rest of the model'

*-----Write message to screen and output file if warnings and/or errors
*     have occurred from the weather system, pause and wait for return
*     from user to make sure he has seen this message
```

```
      IF (WTRMES) THEN

         WRITE (*,'(/,A,/,A,/,A)') ' WARNING from FSE:',
     &      ' There have been errors and/or warnings from',
     &      ' the weather system, check file WEATHER.LOG'
         WRITE (IUNITO,'(A,/,A,/,A)') ' WARNING from FSE:',
     &      ' There have been errors and/or warnings from',
     &      ' the weather system, check file WEATHER.LOG'

         WRITE (*,'(A)') ' Press <Enter>'
         READ  (*,'(A)') DUMMY

      END IF

*-----Close output file and temporary file of OUTDAT
      CLOSE (IUNITO)
      CLOSE (IUNITO+1)

*-----Close log file (if used)
      IF (FILEOL.NE.FILEON) CLOSE (IUNITL)

*-----Close log file of weather system
      CLOSE (91)

      RETURN
      END
*----------------------------------------------------------------------*
* SUBROUTINE MODELS                                                    *
* Authors: Daniel van Kraalingen                                       *
* Date   : 5-Jul-1993                                                  *
* Purpose: This subroutine is the interface routine between the FSE-   *
*          driver and the simulation models. This routine is called    *
*          by the FSE-driver at each new task at each time step. It    *
*          can be used by the user to specify calls to the different   *
*          models that have to be simulated                            *
*                                                                      *
* FORMAL PARAMETERS:  (I=input,O=output,C=control,IN=init,T=time)      *
* name   type meaning                                    units  class *
* ----   ---- -------                                    -----  ----- *
* 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  *
* 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  *
* LAT     R4  Latitude of site                        dec.degr.    I  *
* WSTAT   C7  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               degrees C    I  *
* TMMX    R4  Daily maximum temperature               degrees 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  *
*                                                                      *
* Fatal error checks: none                                             *
* Warnings          : none                                             *
* Subprograms called: models as specified by the user                  *
* File usage        : none                                             *
*----------------------------------------------------------------------*

      SUBROUTINE MODELS (ITASK , IUNITD, IUNITO, IUNITL, FILEIT,
     &                   FILEI1, FILEI2, FILEI3, FILEI4, FILEI5,
     &                   OUTPUT, TERMNL,
     &                   DOY   , IDOY  , YEAR  , IYEAR,
     &                   TIME  , STTIME, FINTIM, DELT ,
     &                   LAT   , WSTAT , WTRTER,
     &                   RDD   , TMMN  , TMMX  , VP   , WN, RAIN)
      IMPLICIT REAL (A-Z)

*     Formal parameters
      INTEGER   ITASK, IUNITD, IUNITO, IUNITL, IDOY, IYEAR
      CHARACTER FILEIT*(*), FILEI1*(*), FILEI2*(*), FILEI3*(*)
      CHARACTER FILEI4*(*), FILEI5*(*)
      LOGICAL   OUTPUT, TERMNL, WTRTER
      CHARACTER WSTAT*7

      SAVE

      CALL ORYZA0      (ITASK , IUNITD, IUNITO, IUNITL,
     &                  FILEI1, FILEI2, FILEI3, FILEI4, FILEI5,
     &                  FILEIT, OUTPUT, TERMNL,
     &                  DOY   , IDOY  , YEAR  , IYEAR,
     &                  TIME  , STTIME, FINTIM, DELT ,
     &                  LAT   , WSTAT , WTRTER,
     &                  RDD   , TMMN  , TMMX  , VP   , WN, RAIN)

      RETURN
      END
```

```
*----------------------------------------------------------------------*
*                                                                      *
*                               ORYZA0                                 *
*                                                                      *
*                                SARP                                  *
*                           December  1994                             *
*                            Version: 2.0                              *
*                                                                      *
*                                                                      *
*    Research Institute for Agrobiology and Soil Fertility (AB-DLO),   *
*    P.O.Box 14, 6700 AA Wageningen, The Netherlands                   *
*                                                                      *
*    International Rice Research Institute, P.O. Box 933,              *
*    1099 Manila, The Philippines and                                  *
*                                                                      *
*    Department of Theoretical Production Ecology, P.O. Box 430,       *
*    6700 AK Wageningen, The Netherlands.                              *
*                                                                      *
*                                                                      *
* Purpose: Module for simulation of rice production under different    *
*          N application levels and patterns                           *
*                                                                      *
*                                                                      *
* FORMAL PARAMETERS:  (I=input,O=output,C=control,IN=init,T=time)      *
* name   type meaning                                    units  class *
* ----   ---- -------                                    -----  ----- *
* ITASK   I4  Task that subroutine should perform           -      I   *
* IUNITD  I4  Unit of input file with model data            -      I   *
* IUNITO  I4  Unit of output file                           -      I   *
* IUNITL  I4  Unit number for log file messages             -      I   *
* FILEIN  C*  Name of file with input model 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  *
* 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   *
* STTIME  R4  Start time of simulation (=day number)        d      I   *
* FINTIM  R4  Finish time of simulation (=day number)       d      I   *
* DELT    R4  Time step of integration                      d      I   *
* LAT     R4  Latitude of site                          dec.degr.  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   *
* TMN     R4  Daily minimum temperature                degrees C   I   *
* TMX     R4  Daily maximum temperature                degrees C   I   *
* VP      R4  Early morning vapour pressure               kPa      I   *
* WN      R4  Daily average windspeed                     m/s      I   *
* RAIN    R4  Daily amount of rainfall                    mm/d     I   *
*                                                                      *
* Fatal error checks: if one of the characters of WSTAT = '4',         *
*                     indicates missing weather                        *
* Warnings          : none                                             *
* Subprograms called: TIMENV, BIOMS2                                   *
* File usage        : IUNITD,IUNITD+1,IUNITO,IUNITO+1,IUNITL           *
* Libraries used    : TTUTIL, COME_ON                                  *
*                                                                      *
*----------------------------------------------------------------------*
      SUBROUTINE ORYZA0 (ITASK , IUNITD, IUNITO, IUNITL,
     &                   FILEI1, FILEI2, FILEI3, FILEI4, FILEI5,
     &                   FILEIT, OUTPUT, TERMNL,
     &                   DOY   , IDOY  , YEAR  , IYEAR,
     &                   TIME  , STTIME, FINTIM, DELT ,
     &                   LAT   , WSTAT , WTRTER,
     &                   RDD   , TMN   , TMX   , VP   , WN, RAIN)

      IMPLICIT REAL (A-Z)

*     Formal parameters
      INTEGER  ITASK , IUNITD, IUNITO, IUNITL, IDOY, IYEAR
      LOGICAL  OUTPUT, TERMNL, WTRTER
      CHARACTER*(*) FILEI1, FILEI2, FILEI3, FILEI4, FILEI5
      CHARACTER*(*) FILEIT, WSTAT
      REAL DOY, YEAR, TIME, STTIME, FINTIM, DELT
      REAL LAT, RDD, TMN, TMX, VP, WN, RAIN

*     Standard local declarations
      INTEGER IWVAR,ITOLD
      CHARACTER WUSED*6

*     Used functions
      REAL LINT  , INSW  , REAAND

      SAVE

*     code for the use of RDD, TMMN, TMMX, VP, WN, RAIN  (in that order)
*     a letter 'U' indicates that the variable is Used in calculations
      DATA WUSED/'UUU---'/

*     Check weather data availability
      IF (ITASK.EQ.1.OR.ITASK.EQ.2.OR.ITASK.EQ.4) THEN
         DO 10 IWVAR=1,6
*           is there an error in the IWVAR-th weather variable ?
            IF (WUSED(IWVAR:IWVAR).EQ.'U' .AND.
     &           WSTAT(IWVAR:IWVAR).EQ.'4') THEN
               WTRTER = .TRUE.
               TERMNL = .TRUE.
               ITOLD  = ITASK
               RETURN
            END IF
10       CONTINUE
      END IF

      IF (ITASK.EQ.1) THEN

*----------------------------------------------------------------------*
*                     Initialization section                           *
*----------------------------------------------------------------------*
*        send title(s) to OUTCOM
```

```
      CALL OUTCOM ('ORYZA_O FOR N LIMITED PRODUCTION')

      CONTINUE

   ELSE IF (ITASK.EQ.2) THEN

*=====================================================================*
*                    Rate calculation section                         *
*=====================================================================*

      CONTINUE

   ELSE IF (ITASK.EQ.3) THEN

*=====================================================================*
*                     Integration section                             *
*=====================================================================*

      CONTINUE

   ELSE IF (ITASK.EQ.4) THEN

*=====================================================================*
*                      Terminal section                               *
*=====================================================================*

      CONTINUE

   END IF

      CALL TIMENV   (ITASK , IUNITD, IUNITL, FILEI1,
  &                  OUTPUT, TERMNL, WSTAT , WTRTER,
  &                  TIME  , STTIME, DOY   , YEAR  , DELT  ,
  &                  RDD   , TMN   , TMX   ,
  &                  DAT   , DATEH , HU    , HULV  , TAV   ,
  &                  TAVD  , TS    , TSLV)

      CALL BIOMS2   (ITASK , IUNITD, IUNITL, FILEI1, FILEIT,
  &                  OUTPUT, TERMNL,
  &                  TIME  , DELT  , DOY, STTIME,
  &                  WSTAT , WTRTER,
  &                  RDD   , DATEH , DAT,
  &                  NL    , WCR)

   RETURN
   END

*--------------------------------------------------------------------*
*  SUBROUTINE BIOMS2                                                 *
*                                                                    *
*  Author : SARP                                                     *
*  Date   : December 1994                                            *
*  Version: 2.0                                                      *
*                                                                    *
*  Research Institute for Agrobiology and Soil Fertility (AB-DLO),   *
*  P.O.Box 14, 6700 AA Wageningen, The Netherlands                   *
*                                                                    *
*  International Rice Research Institute, P.O. Box 933,              *
*  1099 Manila, The Philippines and                                  *
*                                                                    *
*  Department of Theoretical Production Ecology, P.O. Box 430,       *
*  6700 AK Wageningen, The Netherlands.                              *
*                                                                    *
*                                                                    *
*  Purpose: Computes the biomass of the crop                         *
*                                                                    *
*  FORMAL PARAMETERS:(I=input,O=output,C=control,IN=init,T=time)     *
*  name   type meaning                                 units  class  *
*  ----   ---- -------                                 -----  -----  *
* 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 input file no. 1                  -      I    *
* FILEIT  C*   Name of the timerfile                     -      IC   *
* OUTPUT  L4   Flag to indicate if output should be done -      I    *
* TERMNL  L4   Flag to indicate if simulation is to stop -     I/O   *
* TIME    R4   Time of simulation                        d      I    *
* DELT    R4   Time step of integration                  d      I    *
* DOY     R4   Day of year                               d      I    *
* STTIME  R4   Starting time                             d      I    *
* WSTAT   C7   Status code from weather system           -      I    *
* WTRTER  L4   Flag whether weather can be used by model -      I    *
* RDD     R4   Radiation, daily total global, measured  J/m2/d  I    *
* DATEH   R4   harvest date in DAT                       -      I    *
* DAT     R4   Day after transplanting                   d      I    *
* NL      R4   leaf N, as ANLV, but expressed in ------> g/m2   O    *
* WCR     R4   Weight of the crop                      kg/ha    O    *
*                                                                    *
* Warnings          : none                                           *
* Subprograms called: GROWO, NAPO, DEMO, NUPO, NALO                  *
* File usage        : IUNITD, IUNITL                                 *
* Libraries used    : TTUTIL, COME_ON                                *
*                                                                    *
*--------------------------------------------------------------------*
      SUBROUTINE BIOMS2(ITASK , IUNITD, IUNITL, FILEI1, FILEIT,
     &                  OUTPUT, TERMNL,
     &                  TIME  , DELT  , DOY, STTIME,
     &                  WSTAT , WTRTER,
     &                  RDD   , DATEH , DAT   ,
     &                  NL    , WCR)

      IMPLICIT REAL (A-Z)

*     Formal parameters
      INTEGER   ITASK , IUNITD, IUNITL
      LOGICAL   OUTPUT, TERMNL, WTRTER
      CHARACTER*(*) FILEI1 , FILEIT
      CHARACTER*(*) WSTAT
```

```
      REAL TIME, DELT
      REAL RDD , DAT, DATEH

*     Model parameter
      INTEGER SWINLV

*     Auxiliary variables
      REAL NL1, FNLV, WLV , NL2, NL

*     Used functions
      REAL INSW, GETOBS
      LOGICAL INQOBS

*     Other local declaration
      CHARACTER*80  TREATM

      SAVE

      IF (ITASK.EQ.1) THEN

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

*        Open input file
         CALL RDINIT (IUNITD, IUNITL, FILEIT)

         CALL RDSINT ('SWINLV', SWINLV)

         CLOSE (IUNITD)

*        send title(s) to OUTCOM
         CALL OUTCOM ('ORYZA_0 FOR N LIMITED PRODUCTION')

         CALL RDINIT (IUNITD, IUNITL, FILEI1)

*--------Dataset used printed in output file
         CALL RDSCHA ('TREATM',TREATM)
         CALL OUTCOM (TREATM)

         CLOSE (IUNITD)

*--------Initialise missing (observed) values
         FNLV = -99.
         WLV  = -99.


      ELSE IF (ITASK.EQ.2) THEN

*=====================================================================*
*                       Rate calculation section                      *
*=====================================================================*

      NL1  = MAX(0., ANLV/10.)
      IF (INQOBS(FILEI1, 'FNLV')) FNLV = GETOBS(FILEI1, 'FNLV')/100.
      IF (INQOBS(FILEI1, 'WLV' )) WLV  = GETOBS(FILEI1, 'WLV ')
      NL2  = MAX(0., FNLV*WLV /10.)

      NL   = INSW (0.5-SWINLV, NL2, NL1)

***********************************************************************
*-----Output section

         IF (OUTPUT) THEN

            CALL OUTDAT (2,0,'NL     ',NL     )
            CALL OUTDAT (2,0,'NL1    ',NL1    )
            CALL OUTDAT (2,0,'NL2    ',NL2    )
            CALL OUTDAT (2,0,'WLV    ',WLV    )
            CALL OUTDAT (2,0,'FNLV   ',FNLV   )

         END IF


      ELSE IF (ITASK.EQ.3) THEN

*=====================================================================*
*                       Integration section                           *
*=====================================================================*

*-----Finish conditions

      IF (TIME.GE.DATEH)    TERMNL = .TRUE.


      ELSE IF (ITASK.EQ.4) THEN
*=====================================================================*
*                       Terminal section                              *
*=====================================================================*

         CONTINUE

      END IF


         CALL GROWO    (ITASK , IUNITD, IUNITL, FILEI1,
     &                  OUTPUT, TERMNL,
     &                  DELT  , DOY, STTIME,
     &                  WSTAT , WTRTER,
     &                  RDD   , DAT   , NL,
     &                  RNEFF , LNUC  , GRUC  ,
     &                  GCR   , XXWCR , WCR   , WRR)

         CALL NAPO     (ITASK , IUNITD, IUNITL, FILEI1,
     &                  OUTPUT, DELT  , DAT   ,
     &                  X     , APSLOP, RECOV , NAVAIL, APCUM, NAPPLD)

         CALL DEMO     (ITASK , IUNITD, IUNITL, FILEI1,
     &                  OUTPUT, DELT  , DAT   ,
```

```
     &                  ANCR  , GCR   , WCR   , ANLV  ,
     &                  SWIEXP, MAXUP0, MAXUP2, MAXUP3, MAXUP4,
     &                  MAXUP5, DEMAND )

      CALL NUPO        (ITASK , IUNITD, IUNITL, FILEI1,
     &                  OUTPUT, DELT  ,
     &                  DEMAND, NAVAIL,
     &                  NUPT  , ANCR  , NHRVST)

      CALL NALO        (ITASK , IUNITD, IUNITL, FILEI1,
     &                  OUTPUT, DELT  ,
     &                  DAT   , GCR   , NUPT  ,
     &                  ANSOCH, ANLVCH, ANLV)

      RETURN

      END

*----------------------------------------------------------------------*
*  SUBROUTINE GROWO                                                    *
*                                                                      *
*  Author : SARP                                                       *
*  Date   : December 1994                                              *
*  Version: 2.0                                                        *
*                                                                      *
*  Research Institute for Agrobiology and Soil Fertility (AB-DLO),    *
*  P.O.Box 14, 6700 AA Wageningen, The Netherlands                    *
*                                                                      *
*  International Rice Research Institute, P.O. Box 933,               *
*  1099 Manila, The Philippines and                                   *
*                                                                      *
*  Department of Theoretical Production Ecology, P.O. Box 430,        *
*  6700 AK Wageningen, The Netherlands.                               *
*                                                                      *
*                                                                      *
*  Purpose: Computes the growth of the crop                           *
*                                                                      *
*  FORMAL PARAMETERS:(I=input,O=output,C=control,IN=init,T=time)      *
*  name   type meaning                                   units  class *
*  ----   ---- -------                                   -----  ----- *
* 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 input file no. 1                     -      I   *
* OUTPUT  L4  Flag to indicate if output should be done    -      I   *
* TERMNL  L4  Flag to indicate if simulation is to stop    -     I/O  *
* DELT    R4  Time step of integration                     d      I   *
* DOY     R4  Day of year                                  -      I   *
* STTIME  R4  Starting time of simulation                  -      I   *
* WSTAT   C7  Status code from weather system              -      I   *
* WTRTER  L4  Flag whether weather can be used by model    -      I   *
* RDD     R4  Radiation, daily total global, measured    J/m2/d   I   *
* DAT     R4  Day after transplanting                      d      I   *
* NL      R4  Leaf N, as ANLV, but expressed in ----->    g/m2    I   *
* RNEFF   R4  Growth per unit radiation & unit leaf N  g/g/(MJ/m2) O  *
* LNUC    R4  Growth per day per unit leaf N               g/g/d  O   *
* GRUC    R4  Growth per unit incident radiation           g/MJ   O   *
* GCR     R4  Growth rate of the whole crop             kg/ha/d   O   *
* XXWCR   R4  Measured weight of the crop               kg/ha     O   *
* WCR     R4  Weight of the crop                        kg/ha     O   *
* WRR     R4  Weight of the rough rice                  kg/ha     O   *
*                                                                      *
*                                                                      *
* Fatal error checks: If one of the characters of WSTAT = '4'          *
*                     indicates missing weather                        *
* Warnings          : none                                             *
* Subprograms called: none                                             *
* File usage        : IUNITD, IUNITL                                   *
* Libraries used    : TTUTIL, COME_ON                                  *
*                                                                      *
*----------------------------------------------------------------------*
      SUBROUTINE GROWO  (ITASK , IUNITD, IUNITL, FILEI1,
     &                   OUTPUT, TERMNL,
     &                   DELT  , DOY, STTIME,
     &                   WSTAT , WTRTER,
     &                   RDD   , DAT   , NL    ,
     &                   RNEFF , LNUC  , GRUC  ,
     &                   GCR   , XXWCR , WCR   , WRR)

      IMPLICIT REAL (A-Z)

*     Formal parameters
      INTEGER  ITASK , IUNITD, IUNITL
      LOGICAL  OUTPUT, TERMNL, WTRTER
      CHARACTER*(*) FILEI1, WSTAT
      REAL DELT, DOY, STTIME
      REAL RDD

*     Standard local declarations
      INTEGER IWVAR,ITOLD
      REAL TINY
      CHARACTER WUSED*6

*     State variables, initial values and rates
      REAL WCR, WCRI, GCR

*     Model parameter
      REAL DATFSV, FSV1, FSV2, EPSIL, HI
      INTEGER RTINCL
      REAL    DATEF

*     Auxiliary variables
      REAL XXWCR, WRR, P, RNEFF, LNUC, GRUC

*     AFGEN functions
      REAL RSRT
      INTEGER IMRSRT, ILRSRT
      PARAMETER (IMRSRT =  40)
```

```
      DIMENSION RSRT  (IMRSRT)

*     Parameters
      PARAMETER (P     = 10.)
      PARAMETER (EPSIL = 2.5)

*     Used functions
      REAL INSW, LINT, GETOBS, INTGR2
      LOGICAL INQOBS

      SAVE

      DATA TINY /1.E-3/


*     code for the use of RDD, TMMN, TMMX, VP, WN, RAIN  (in that order)
*     a letter 'U' indicates that the variable is Used in calculations
      DATA WUSED/'UUU---'/

*     Check weather data availability
      IF (ITASK.EQ.1.OR.ITASK.EQ.2.OR.ITASK.EQ.4) THEN
         DO 10 IWVAR=1,6
*           is there an error in the IWVAR-th weather variable ?
            IF (WUSED(IWVAR:IWVAR).EQ.'U' .AND.
     &          WSTAT(IWVAR:IWVAR).EQ.'4') THEN
               WTRTER = .TRUE.
               TERMNL = .TRUE.
               ITOLD  = ITASK
               RETURN
            END IF
10       CONTINUE
      END IF


      IF (ITASK.EQ.1) THEN

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

*        Open input file
         CALL RDINIT (IUNITD, IUNITL, FILEI1)

*        Read initial states
         CALL RDSREA ('WCRI  ',WCRI  )
*        Read switch that defines method of weighing WCR
         CALL RDSINT ('RTINCL', RTINCL)

*        Message to file
         IF (RTINCL.EQ.1) THEN
            CALL OUTCOM ('RTINCL = 1; root biomass was measured')
         ELSE
            CALL OUTCOM ('RTINCL = 0; root biomass was not measured')
         END IF

*        Read model parameters
         CALL RDSREA ('DATFSV ',DATFSV )
         CALL RDSREA ('DATEF ',DATEF )
         CALL RDSREA ('FSV1   ',FSV1   )
         CALL RDSREA ('FSV2   ',FSV2   )
         CALL RDSREA ('HI     ',HI     )

*        Read AFGEN functions
         CALL RDAREA ('RSRT   ',RSRT   ,IMRSRT,ILRSRT)

         CLOSE (IUNITD)

*        Initialize state variables

         IF (RTINCL.EQ.1) THEN
            WCR    = WCRI
            WSHT   = -99.0
         ELSE
            WSHT   = WCRI
            RELTME = (DOY-STTIME)/DATEF
            RSR    = LINT(RSRT, ILRSRT, RELTME)
            WRT    = RSR * WSHT
            WCR    = WSHT + WRT
         ENDIF

*        Initialise missing (observed) values
         XXWCR = -99.


      ELSE IF (ITASK.EQ.2) THEN

*----------------------------------------------------------------------*
*                      Rate calculation section                        *
*----------------------------------------------------------------------*
*-----FSV value may change at flowering: FSV1 for pre-,
*     FSV2 for post-flowering

         FSV     = INSW(DAT-DATFSV, FSV1, FSV2)


*-----Growth per unit rad and unit leaf N (g g-1/(MJ m-2))

         RNEFF = FSV*((P/(RDD*1.E-06))*(1.-EXP(-EPSIL*(RDD*1.E-06)/
     &               (P*NL+TINY))))

*-----Output only:overall leaf N use efficiency (g g-1 d-1)

         LNUC   = RNEFF*(RDD*1.E-06)


*-----Output only: overall radiation use efficiency (g MJ-1)

         GRUC   = RNEFF*NL
```

```
*-----Crop growth rate (with conversion to kg ha-1 d-1)

         GCR    = 10.* RNEFF * (RDD*1.E-06) * NL

*-----Measured weight of the crop

         IF (INQOBS(FILEI1, 'WCR')) XXWCR  = GETOBS(FILEI1, 'WCR')

***********************************************************************
*-----Output section

         IF (OUTPUT) THEN

            CALL OUTDAT (2,0,'WCR     ',WCR     )
            CALL OUTDAT (2,0,'P       ',P       )
            CALL OUTDAT (2,0,'EPSIL   ',EPSIL   )
            CALL OUTDAT (2,0,'FSV1    ',FSV1    )
            CALL OUTDAT (2,0,'FSV2    ',FSV2    )
            CALL OUTDAT (2,0,'FSV     ',FSV     )
            CALL OUTDAT (2,0,'RNEFF   ',RNEFF   )
            CALL OUTDAT (2,0,'LNUC    ',LNUC    )
            CALL OUTDAT (2,0,'GRUC    ',GRUC    )
            CALL OUTDAT (2,0,'GCR     ',GCR     )
            CALL OUTDAT (2,0,'WSHT '  ,WSHT     )
            CALL OUTDAT (2,0,'XXWCR ' ,XXWCR    )
            CALL OUTDAT (2,0,'RSR'    ,RSR      )
            CALL OUTDAT (2,0,'RELTME' ,RELTME   )

         END IF
***********************************************************************

      ELSE IF (ITASK.EQ.3) THEN

*=====================================================================*
*                         Integration section                         *
*=====================================================================*
*-----Weight of the crop

         WCR     = INTGR2 (WCR    ,GCR   ,DELT, FILEI1, 'WCR')

         IF (RTINCL.EQ.1) THEN
            WSHT = -99.0
         ELSE
            IF (DOY.LT.(DATEF+STTIME)) THEN
                RELTME = (DOY-STTIME)/DATEF
                RSR    = LINT(RSRT, ILRSRT, RELTME)
                WSHT   = WCR/(1.+RSR)
            ELSE
                WSHT = WCR/(1.+0.15)
            END IF
         END IF


      ELSE IF (ITASK.EQ.4) THEN

*=====================================================================*
*                          Terminal section                           *
*=====================================================================*
*-----Rough rice yield (kg ha-1)

         WRR    = HI*WCR

*-----Terminal output

         CALL OUTDAT (2,0,'WRR    ',WRR    )

         IF (RTINCL.EQ.0) THEN
            WRITE(*,*) 'NO ROOT BIOMASS WAS MEASURED!'
            WRITE(*,*) 'SO MEASURED XXWCR SHOULD BE COMPARED WITH '
            WRITE(*,*) 'SIMULATED WSHT!'
         ENDIF
***********************************************************************

      END IF

      RETURN
      END


*---------------------------------------------------------------------*
*  SUBROUTINE NAPO                                                    *
*                                                                     *
*  Author : SARP                                                      *
*  Date   : December 1994                                             *
*  Version: 2.0                                                       *
*                                                                     *
*  Research Institute for Agrobiology and Soil Fertility (AB-DLO),    *
*  P.O.Box 14, 6700 AA Wageningen, The Netherlands                    *
*                                                                     *
*  International Rice Research Institute, P.O. Box 933,               *
*  1099 Manila, The Philippines and                                   *
*                                                                     *
*  Department of Theoretical Production Ecology, P.O. Box 430,        *
*  6700 AK Wageningen, The Netherlands.                               *
*                                                                     *
*                                                                     *
*  Purpose: Computes nitrogen application                             *
*                                                                     *
*  FORMAL PARAMETERS:(I=input,O=output,C=control,IN=init,T=time)      *
*  name   type meaning                                  units  class  *
*  ----   ---- -------                                  -----  -----  *
* 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 input file no. 1                   -      I    *
* OUTPUT  L4   Flag to indicate if output should be done  -      I    *
* DELT    R4   Time step of integration                   d      I    *
* DAT     R4   Day after transplanting                    d      I    *
* X       R4   Derivative of logistic application                     *
```

```
*             curve plus soil N                                   kg/ha/d  O  *
* APSLOP  R4  Daily fertilizer N application                     kg/ha/d  O  *
* RECOV   R4  Best attainable recovery                           kg/kg    O  *
* NAVAIL  R4  Total N availibility (soil and fertilizer)         kg/ha/d  O  *
* APCUM   R4  Cumulative N application curve                     kg/ha    O  *
* NAPPLD  R4  Total amount of N applied                          kg/ha    O  *
*                                                                            *
*                                                                            *
* Warnings          : none                                                   *
* Subprograms called: none                                                   *
* File usage        : IUNITD, IUNITL                                         *
* Libraries used    : TTUTIL                                                 *
*                                                                            *
*----------------------------------------------------------------------------*
      SUBROUTINE NAPO  (ITASK , IUNITD, IUNITL, FILEI1,
     &                  OUTPUT, DELT  , DAT   ,
     &                  X     , APSLOP, RECOV , NAVAIL , APCUM, NAPPLD)


      IMPLICIT REAL (A-Z)

*     Formal parameters
      INTEGER  ITASK , IUNITD, IUNITL
      LOGICAL  OUTPUT
      CHARACTER*(*) FILEI1
      REAL DELT
      REAL DAT

*     State variables, initial values and rates
      REAL APCUM , APCUMI, APSLOP

*     Model parameter
      REAL A      , B      , C
      REAL M      , FERTMX, SOLSUP

*     Auxiliary variables
      REAL NAVAIL, RECOV , X, NAPPLD

*     AFGEN functions
      REAL RECT
      INTEGER IMRECT, ILRECT
      PARAMETER (IMRECT =  40)
      DIMENSION RECT   (IMRECT)

*     Used functions
      REAL LINT, INTGR2

      SAVE

      IF (ITASK.EQ.1) THEN

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

*        Open input file
         CALL RDINIT (IUNITD, IUNITL, FILEI1)

*        Read initial states
         CALL RDSREA ('APCUMI',APCUMI)

*        Read model parameters
         CALL RDSREA ('A     ',A     )
         CALL RDSREA ('B     ',B     )
         CALL RDSREA ('C     ',C     )
         CALL RDSREA ('M     ',M     )
         CALL RDSREA ('FERTMX',FERTMX)
         CALL RDSREA ('SOLSUP',SOLSUP)

*        Read AFGEN functions
         CALL RDAREA ('RECT  ',RECT  ,IMRECT,ILRECT)

         CLOSE (IUNITD)

*        initially known variables to output
         CALL OUTDAT (2,0,'FERTMX',FERTMX)

*        Initialize state variables
         APCUM  = APCUMI

      ELSE IF (ITASK.EQ.2) THEN

*----------------------------------------------------------------------------*
*                        Rate calculation section                            *
*----------------------------------------------------------------------------*
*-----N supply per day (kg N/ha.d),
*     derivative of logistic application curve plus soil N

         X      = EXP(-B*(DAT-M))

*-----Daily fertilizer N application (kg N ha-1 d-1)

         APSLOP = MIN(FERTMX-APCUM, B*C*X*(1.+ A*X)**(-1.-1./A))

*-----Best attainable recovery (kg uptake/kg applied)

         RECOV  = LINT(RECT,ILRECT,DAT)

*-----Total N availibility (kg N ha-1 d-1)

         NAVAIL = RECOV*APSLOP + SOLSUP

******************************************************************************
*-----Output section

         IF (OUTPUT) THEN

            CALL OUTDAT (2,0,'X     ',X     )
            CALL OUTDAT (2,0,'APSLOP ',APSLOP )
            CALL OUTDAT (2,0,'RECOV  ',RECOV  )
```

```
         CALL OUTDAT (2,0,'NAVAIL ',NAVAIL )
         CALL OUTDAT (2,0,'APCUM  ',APCUM  )

      END IF
***********************************************************************

    ELSE IF (ITASK.EQ.3) THEN

*=====================================================================*
*                      Integration section                            *
*=====================================================================*
*-----Cumulative N application

      APCUM  = INTGR2 (APCUM ,APSLOP,DELT, FILEI1, 'APCUM')

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

    ELSE IF (ITASK.EQ.4) THEN

*=====================================================================*
*                       Terminal section                              *
*=====================================================================*
*-----Total amount N applied (kg N ha-1)
      NAPPLD = APCUM

*-----Terminal output
      CALL OUTDAT (2,0,'NAPPLD',NAPPLD)

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

    END IF

    RETURN
    END

*--------------------------------------------------------------------*
*  SUBROUTINE DEMO                                                   *
*                                                                    *
*  Author : SARP                                                     *
*  Date   : December 1994                                            *
*  Version: 2.0                                                      *
*                                                                    *
*  Research Institute for Agrobiology and Soil Fertility (AB-DLO),   *
*  P.O.Box 14, 6700 AA Wageningen, The Netherlands                   *
*                                                                    *
*  International Rice Research Institute, P.O. Box 933,              *
*  1099 Manila, The Philippines and                                  *
*                                                                    *
*  Department of Theoretical Production Ecology, P.O. Box 430,       *
*  6700 AK Wageningen, The Netherlands.                              *
*                                                                    *
*                                                                    *
*  Purpose: Computes the nitrogen demand of the crop                 *
*                                                                    *
*  FORMAL PARAMETERS:(I=input,O=output,C=control,IN=init,T=time)     *
*  name   type meaning                                  units  class *
*  ----   ---- -------                                  -----  ----- *
* 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 input file no. 1                    -      I   *
* OUTPUT  L4  Flag to indicate if output should be done   -      I   *
* DELT    R4  Time step of integration                    d      I   *
* DAT     R4  Day after transplanting                     d      I   *
* ANCR    R4  Amount of N in the crop                   kg/ha    I   *
* GCR     R4  Growth rate of the whole crop            kg/ha/d   I   *
* WCR     R4  Weight of the crop                        kg/ha    I   *
* ANLV    R4  Amount of N in the leaves                 kg/ha    I   *
* SWIEXP  R4  Switch to define the end of exponential phase -    I   *
* MAXUP0  R4  Maximum N uptake rate during exponential               *
*             growth phase                             kg/ha/d   O   *
* MAXUP2  R4  N uptake rate as limited by the maximum                *
*             N fraction per unit new dry matter       kg/ha/d   O   *
* MAXUP3  R4  N uptake rate as limited by maximum                    *
*             overall fraction of N in total                         *
*             existing biomass                         kg/ha/d   O   *
* MAXUP4  R4  N uptake rate as limited by the maximum                *
*             bulk amount leaf N reached               kg/ha/d   O   *
* MAXUP5  R4  N uptake rate as limited by nearing                    *
*             maturity stage                           kg/ha/d   O   *
* DEMAND  R4  Demand of N                              kg/ha/d   O   *
*                                                                    *
*                                                                    *
* Warnings          : none                                           *
* Subprograms called: none                                           *
* File usage        : IUNITD, IUNITL                                 *
* Libraries used    : TTUTIL                                         *
*                                                                    *
*--------------------------------------------------------------------*
      SUBROUTINE DEMO  (ITASK , IUNITD, IUNITL, FILEI1,
     &                  OUTPUT, DELT  , DAT   ,
     &                  ANCR  , GCR   , WCR   , ANLV  ,
     &                  SWIEXP, MAXUP0, MAXUP2, MAXUP3, MAXUP4,
     &                  MAXUP5, DEMAND )


      IMPLICIT REAL (A-Z)

*     Formal parameters
      INTEGER  ITASK , IUNITD, IUNITL
      LOGICAL  OUTPUT
      CHARACTER*(*) FILEI1
      REAL DELT
      REAL DAT, ANCR, GCR, WCR, ANLV

*     Model parameter
      REAL RUR, NUPCO, ANLVMX, LARGE, DATH, MAXUP1
```

```
*     Auxiliary variables
      REAL SWIEXP, MAXUP0, MAXUP2, MAXUP3, FNMAX
      REAL MAXUP4, MAXUP5, M12345, DEMAND

*     AFGEN functions
      REAL FNMAXT
      INTEGER IMFNMA, ILFNMA
      PARAMETER (IMFNMA =  40)
      DIMENSION FNMAXT(IMFNMA)

*     Parameters
      PARAMETER (MAXNCR = 35.)
      PARAMETER (MAXDAT = 20.)

*     Used functions
      REAL LINT

      SAVE

      IF (ITASK.EQ.1) THEN

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

*        Open input file
         CALL RDINIT (IUNITD, IUNITL, FILEI1)

*        Read model parameters
         CALL RDSREA ('RUR   ',RUR   )
         CALL RDSREA ('NUPCO ',NUPCO )
         CALL RDSREA ('ANLVMX',ANLVMX)
         CALL RDSREA ('LARGE ',LARGE )
         CALL RDSREA ('DATH  ',DATH  )
         CALL RDSREA ('MAXUP1',MAXUP1)

*        Read AFGEN functions
         CALL RDAREA ('FNMAXT',FNMAXT,IMFNMA,ILFNMA)

         CLOSE (IUNITD)

      ELSE IF (ITASK.EQ.2) THEN

*=====================================================================*
*                       Rate calculation section                      *
*=====================================================================*

*-----Uptake limitations MAXUP due to limited demand,all in kg N/(ha.d)

*-----Max uptake during exponential phase

         SWIEXP = 0.

         IF(MAXNCR-ANCR.GT.0.0.AND.MAXDAT-DAT.GT.0.0) SWIEXP = 1.

         MAXUP0 = RUR*ANCR

*-----MAXUP1 was defined as a parameter: max absolute uptake rate

*-----Uptake as limited by max fraction N per unit new dry

         MAXUP2 = NUPCO * GCR

*-----Uptake as limited by max overall fraction of N in total
*     existing biomass

         FNMAX  = LINT(FNMAXT,ILFNMA,DAT)
         MAXUP3 = ((WCR+GCR*DELT)*FNMAX - ANCR)/DELT

*-----Limitation due to max leaf N amount reached

         IF (ANLVMX-ANLV.LT.0.0) THEN
            MAXUP4 = 0.
         ELSE
            MAXUP4 = LARGE
         ENDIF

*-----Limitation due to nearing maturity stage

         IF (DATH-DAT-7.0.LT.0.) THEN
           MAXUP5 = 0.
         ELSE
           MAXUP5 = LARGE
         END IF

*-----Actual demand is minimum value of all limitations

         M12345 = MIN(MAXUP1,MAXUP2,MAXUP3,MAXUP4,MAXUP5)

         IF((0.5-SWIEXP).LT.0.) THEN
           DEMAND = MAXUP0
         ELSE
           DEMAND = M12345
         END IF

***********************************************************************
*-----Output section

         IF (OUTPUT) THEN

           CALL OUTDAT (2,0,'SWIEXP ',SWIEXP )
           CALL OUTDAT (2,0,'MAXUP0 ',MAXUP0 )
           CALL OUTDAT (2,0,'MAXUP2 ',MAXUP2 )
           CALL OUTDAT (2,0,'FNMAX  ',FNMAX  )
           CALL OUTDAT (2,0,'MAXUP3 ',MAXUP3 )
           CALL OUTDAT (2,0,'MAXUP4 ',MAXUP4 )
           CALL OUTDAT (2,0,'MAXUP5 ',MAXUP5 )
           CALL OUTDAT (2,0,'M12345 ',M12345 )
           CALL OUTDAT (2,0,'DEMAND ',DEMAND )
```

```
      END IF
***********************************************************************

      ELSE IF (ITASK.EQ.3) THEN

*=====================================================================*
*                       Integration section                           *
*=====================================================================*

***********************************************************************
*-----No integration in DEMO
      CONTINUE
***********************************************************************

      ELSE IF (ITASK.EQ.4) THEN

*=====================================================================*
*                        Terminal section                             *
*=====================================================================*

         CONTINUE

      END IF

      RETURN
      END

*--------------------------------------------------------------------*
*  SUBROUTINE NUPO                                                    *
*                                                                     *
*  Author : SARP                                                      *
*  Date   : December 1994                                             *
*  Version: 2.0                                                       *
*                                                                     *
*  Research Institute for Agrobiology and Soil Fertility (AB-DLO),   *
*  P.O.Box 14, 6700 AA Wageningen, The Netherlands                    *
*                                                                     *
*  International Rice Research Institute, P.O. Box 933,              *
*  1099 Manila, The Philippines and                                   *
*                                                                     *
*  Department of Theoretical Production Ecology, P.O. Box 430,       *
*  6700 AK Wageningen, The Netherlands.                               *
*                                                                     *
*                                                                     *
*  Purpose: Computes nitrogen uptake                                  *
*                                                                     *
*  FORMAL PARAMETERS:(I=input,O=output,C=control,IN=init,T=time)     *
*  name   type meaning                                  units  class *
*  ----   ---- -------                                  -----  ----- *
* 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 input file no. 1                    -       I  *
* OUTPUT  L4  Flag to indicate if output should be done   -       I  *
* DELT    R4  Time step of integration                          d       I  *
* DEMAND  R4  Total crop demand of N                          kg/ha/d I  *
* NAVAIL  R4  Total N availibility (soil and fertilizer)      kg/ha/d I  *
* NUPT    R4  N uptake rate                                   kg/ha/d O  *
* ANCR    R4  Amount of N in the crop                         kg/ha   O  *
* NHRVST  R4  Total N uptake at harvest                       kg/ha   O  *
*                                                                     *
*                                                                     *
* Warnings          : none                                            *
* Subprograms called: none                                            *
* File usage        : IUNITD, IUNITL                                  *
* Libraries used    : TTUTIL                                          *
*                                                                     *
*---------------------------------------------------------------------*
      SUBROUTINE NUPO  (ITASK , IUNITD, IUNITL, FILEI1,
     &                  OUTPUT, DELT  ,
     &                  DEMAND, NAVAIL,
     &                  NUPT  , ANCR  , NHRVST)


      IMPLICIT REAL (A-Z)

*     Formal parameters
      INTEGER  ITASK , IUNITD, IUNITL
      LOGICAL  OUTPUT
      CHARACTER*(*) FILEI1
      REAL DELT
      REAL DEMAND, NAVAIL

*     State variables, initial values and rates
      REAL ANCR  , ANCRI , NUPT

*     Auxiliary variables
      REAL NHRVST

*     Function declarations
      REAL INTGR2

      SAVE

      IF (ITASK.EQ.1) THEN

*=====================================================================*
*                       Initialization section                        *
*=====================================================================*
*        Open input file
         CALL RDINIT (IUNITD, IUNITL, FILEI1)

*        Read initial states
         CALL RDSREA ('ANCRI  ',ANCRI  )

         CLOSE (IUNITD)

*        Initialize state variables
```

```
      ANCR   = ANCRI

     ELSE IF (ITASK.EQ.2) THEN

*=======================================================================*
*                        Rate calculation section                       *
*=======================================================================*

*-----Actual N uptake, demand vs supply

*-----N uptake rate (kg N ha-1 d-1)
      NUPT   = MAX(0., MIN(DEMAND , NAVAIL))

*************************************************************************
*-----Output section

      IF (OUTPUT) THEN

         CALL OUTDAT (2,0,'NUPT   ',NUPT   )
         CALL OUTDAT (2,0,'ANCR   ',ANCR   )

      END IF

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

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

*-----Total amount of N in crop (kg/ha)

      ANCR   = INTGR2 (ANCR  ,NUPT  ,DELT, FILEI1, 'ANCR')

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

     ELSE IF (ITASK.EQ.4) THEN

*=======================================================================*
*                          Terminal section                             *
*=======================================================================*

*-----Total N uptake at harvest (kg N ha-1)
      NHRVST  = ANCR

*-----Terminal output
      CALL OUTDAT (2,0,'NHRVST',NHRVST)

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

     END IF

     RETURN
     END
```

```
*----------------------------------------------------------------------*
*  SUBROUTINE NALO                                                     *
*                                                                      *
*  Author : SARP                                                       *
*  Date   : December 1994                                              *
*  Version: 2.0                                                        *
*                                                                      *
*  Research Institute for Agrobiology and Soil Fertility (AB-DLO),     *
*  P.O.Box 14, 6700 AA Wageningen, The Netherlands                     *
*                                                                      *
*  International Rice Research Institute, P.O. Box 933,                *
*  1099 Manila, The Philippines and                                    *
*                                                                      *
*  Department of Theoretical Production Ecology, P.O. Box 430,         *
*  6700 AK Wageningen, The Netherlands.                                *
*                                                                      *
*                                                                      *
*  Purpose: Computes nitrogen allocation to the grains and the leaves *
*                                                                      *
*  FORMAL PARAMETERS:(I=input,O=output,C=control,IN=init,T=time)       *
*  name   type meaning                                    units  class *
*  ----   ---- -------                                    -----  ----- *
* 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 input file no. 1                      -      I   *
* OUTPUT  L4  Flag to indicate if output should be done     -      I   *
* DELT    R4  Time step of integration                      d      I   *
* DAT     R4  Day after transplanting                       d      I   *
* GCR     R4  Growth rate of the whole crop               kg/ha/d  I   *
* NUPT    R4  N uptake rate                               kg/ha/d  I   *
* ANSOCH  R4  rate of N allocation to grains              kg/ha    O   *
* ANLVCH  R4  rate of N allocation to leaves              kg/ha    O   *
* ANLV    R4  Amount of nitrogen in the leaves            kg/ha    O   *
*                                                                      *
*                                                                      *
* Warnings           : none                                            *
* Subprograms called: none                                             *
* File usage         : IUNITD, IUNITL                                  *
* Libraries used     : TTUTIL                                          *
*                                                                      *
*----------------------------------------------------------------------*
      SUBROUTINE NALO  (ITASK , IUNITD, IUNITL, FILEI1,
     &                  OUTPUT, DELT  ,
     &                  DAT   , GCR   , NUPT,
     &                  ANSOCH, ANLVCH, ANLV)


      IMPLICIT REAL (A-Z)

*     Formal parameters
      INTEGER  ITASK , IUNITD, IUNITL
```

```
      LOGICAL  OUTPUT
      CHARACTER*(*) FILEI1
      REAL DELT
      REAL DAT, GCR, NUPT

*     State variables, initial values and rates
      REAL ANLV  , ANLVI , ANLVCH

*     Model parameter
      REAL DATFF, FNSO, FNCLV

*     Auxiliary variables
      REAL ANSOCH

*     Used functions
      REAL INSW, INTGR2

      SAVE

      IF (ITASK.EQ.1) THEN

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

*        Open input file
         CALL RDINIT (IUNITD, IUNITL, FILEI1)

*        Read initial states
         CALL RDSREA ('ANCRI ',ANCRI )

*        Read model parameters
         CALL RDSREA ('FNCLV ',FNCLV )
         CALL RDSREA ('FNSO  ',FNSO  )
         CALL RDSREA ('DATFF ',DATFF )

         CLOSE (IUNITD)

*        Initial calculations
         ANLVI  = FNCLV*ANCRI

*        Initialize state variables
         ANLV   = ANLVI

      ELSE IF (ITASK.EQ.2) THEN

*----------------------------------------------------------------------*
*                        Rate calculation section                      *
*----------------------------------------------------------------------*

*-----N allocation to leaves and grains

*-----N allocation to grains (kg N ha-1 d-1)

         ANSOCH = INSW(DAT-DATFF,0.,GCR*FNSO)

*-----N allocation to leaves (kg N ha-1 d-1)

         ANLVCH = INSW(DAT-DATFF,NUPT*FNCLV,(NUPT-ANSOCH)*FNCLV)

************************************************************************
*-----Output section

         IF (OUTPUT) THEN

            CALL OUTDAT (2,0,'ANSOCH ',ANSOCH )
            CALL OUTDAT (2,0,'ANLVCH ',ANLVCH )
            CALL OUTDAT (2,0,'ANLV   ',ANLV   )

         END IF
************************************************************************

      ELSE IF (ITASK.EQ.3) THEN

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

*-----Total amount of N in the leaves (kg/ha)

         ANLV   = INTGR2 (ANLV  ,ANLVCH  ,DELT, FILEI1, 'ANLV')

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

      ELSE IF (ITASK.EQ.4) THEN

*----------------------------------------------------------------------*
*                        Terminal section                              *
*----------------------------------------------------------------------*

         CONTINUE

      END IF

      RETURN
      END
```

□

Appendix 10 Data sets used for validation of ORYZA_N and ORYZA_0

TNAU-TNRRI, Aduthurai, India, 1988-1989
Experimental data from: T.M. Thiyagarajan & S.N. Mohandass

General information:

variety: ADT 39
year: 1988-1989
seeding: 1 nov (306)
planting: 10 dec (345)

N treatment	50% Flowering		Harvest	
kg N	DAT	DOY	DAT	DOY
0	53	32	89	68
100	53	32	89	68
200	58	37	94	73
300	58	37	94	73
400	61	40	97	76

DAT= days after transplanting

Nitrogen application scheme:

Calendar date	DOY	DAT	Quantity applied
10 Dec	345	0	50% of the treatment level
05 Jan	5	26	16.66% of the treatment level
27 Jan	27	48	16.66% of the treatment level
04 Feb	62	62	16.66% of the treatment level

DAT= days after transplanting, DOY= day of the year

```
***************************************
* Thiyagarajan, Tamil Nadu, India
* 1988-1989
* variety:   ADT 39
* treatment: 0 KG/HA
***************************************
TREATM='THIYAGARAJAN,1989, ADT39, 0 kg/ha N'

* dummy initialisation
RADTOI = 0.

DATH   = 89.
DTRP   = 38.
FGHDAY = 63.0
WLVGI = 47.0
WSTSI = 38.0
WRTLI = 19.0
*FNSTI = 0.0168
FNLVI = 0.0315
*FNRTI = 0.0034
DVSI  = 0.531
TSI   = 676.9
FSTR  = 0.39
*RGRL  =
DVRV  = 0.000784
DVRR  = 0.001674
NS    = 11
DNOST = 344.,362.,369.,376.,383.,390.,397.,
       407.,425.,433.,441.
NTOTMT= 2.18,13.90,16.98,28.14,37.87,41.69,
       43.51,41.78,52.48,54.87,54.87
NA    = 6
DNAPT = 306.,344.,370.,392.,406.,600.

* NOTE first value of NSO is dummy
*      first two values of WSO are dummy's
*      last value of W/NLV, W/NST, W/NRT,
W/NSO are dummy's
WSTS_OBS   =
1988., 344.,38.0,
1988., 362., 420.0,
1989.,   3., 715.,
1989.,  10.,1165.,
1989.,  17.,1673.,
1989.,  24.,2115.,
1989.,  31.,2630.,
1989.,  41.,2146.,
1989.,  59.,1883.,
1989.,  67.,1615.

WSTS_TRG = 1900.,1.,0.,
          2000.,1.,0.

WSTS_FRC = 0

WLVG_OBS   =
1988., 344.,  47.0,
1988., 362., 286.0,
1989.,   3., 469.,
1989.,  10., 715.,
1989.,  17., 828.,
1989.,  24., 943.,
1989.,  31., 936.,
1989.,  41., 840.,
1989.,  59., 792.,
1989.,  67., 767.

WLVG_TRG = 1900.,1.,0.,
          2000.,1.,0.

WLVG_FRC = 0

* Dummy values or ANLD
WLVD_OBS = 1900.,1.,0.,
          2000.,1.,0.
WLVD_TRG = 1900.,1.,0.,
          2000.,1.,0.
WLVD_FRC = 0

WRTL_OBS   =
1988., 344., 19.,
1988., 362., 260.,
1989.,   3., 326.,
1989.,  10., 370.,
1989.,  17., 421.,
1989.,  24., 463.,
1989.,  31., 482.,
1989.,  41., 537.,
1989.,  59., 530.,
1989.,  67., 530.

WRTL_TRG = 1900.,1.,0.,
          2000.,1.,0.

WRTL_FRC = 0

WSO_OBS    =
1988., 344.,    0.,
1989.,  21.,    0.,
1989.,  41., 1317.,
1989.,  59., 2803.,
1989.,  67., 3456.

WSO_TRG = 1900.,1.,0.,
         1989.,30.,2.,
         1989.,50.,2.,
         2000.,1.,0.

WSO_FRC = 0

ANST_OBS    =
1988., 344.,0.64,
1988., 362.,5.80,
1989.,   3.,5.93,
1989.,  10.,11.30,
1989.,  17.,17.23,
1989.,  24.,19.88,
1989.,  31.,26.04,
1989.,  41.,13.73,
1989.,  59.,9.98,
1989.,  67.,7.75

ANST_TRG = 1900.,1.,0.,
          2000.,1.,0.

ANST_FRC = 0

ANLV_OBS    =
1988., 344.,1.48,
1988., 362.,6.72,
1989.,   3.,9.38,
1989.,  10.,14.8,
1989.,  17.,17.14,
1989.,  24.,18.2,
1989.,  31.,13.57,
1989.,  41.,9.24,
1989.,  59.,7.68,
1989.,  67.,5.37

ANLV_TRG = 1900.,1.,0.,
          2000.,1.,0.
ANLV_FRC = 0

ANRT_OBS    =
1988., 344.,0.06,
1988., 362.,1.38,
1989.,   3.,1.66,
1989.,  10.,2.04,
1989.,  17.,3.49,
1989.,  24.,3.61,
1989.,  31.,3.90,
1989.,  41.,4.19,
1989.,  59.,3.71,
1989.,  67.,3.39

ANRT_TRG = 1900.,1.,0.,
          2000.,1.,0.

ANRT_FRC = 0

ANSO_OBS    =
1988., 344.,0.,
1989.,  21.,0.,
1989.,  41.,14.62,
1989.,  59.,31.11,
1989.,  67., 38.36
```

```
ANSO_TRG = 1900.,1.,0.,
          2000.,1.,0.

ANSO_FRC = 0

* Dummy values or ANLD
ANLD_OBS = 1900.,1.,0.,
          2000.,1.,0.
ANLD_TRG = 1900.,1.,0.,
          2000.,1.,0.
ANLD_FRC = 0

* Dummy values or LAI
LAI_OBS = 1900.,1.,0.,
          2000.,1.,0.
LAI_TRG = 1900.,1.,0.,
          2000.,1.,0.
LAI_FRC = 0

* value at 2.1 is dummy
FSTTB  = 0.,0.62,
         0.50,0.62,0.65,0.62,0.73,0.65,
         0.81,0.82,0.89,0.79,1.00,0.00,
         1.14,0.00,1.52,0.00,1.90,0.00,
         2.1,0.
FLVTB  = 0.,0.38,
         0.50,0.38,0.65,0.38,0.73,0.35,
         0.81,0.18,0.89,0.21,1.00,0.00,
         1.14,0.00,1.52,0.00,1.90,0.00,
         2.1,0.
FSHTB  = 0.,0.72,
         0.50,0.72,0.65,0.88,0.73,0.94,
         0.81,0.92,0.89,0.93,0.97,0.96,
         1.14,0.93,1.52,1.00,1.90,1.00,
         2.1,0.
FSOTB  = 0.,0.00,
         0.50,0.00,0.65,0.00,0.73,0.00,
         0.81,0.00,0.89,0.00,1.00,1.00,
         1.14,1.00,1.52,1.00,1.90,1.00,
         2.1,1.


***************************************
* Thiyagarajan, Tamil
* 1988-1989
* variety:   ADT 39
* treatment: 100 kg N/ha
***************************************
TREATM='THIYAGARAJAN, 1989, ADT39, 100 kg/ha
N'

* dummy initialisation
RADTOI = 0.

DATH   = 89.
DTRP   = 38.
FGHDAY = 63.0
WLVGI  = 47.0
WSTSI  = 38.0
WRTLI  = 19.0
FNSTI  = 0.0168
FNLVI  = 0.0315
FNRTI  = 0.0034
DVSI   = 0.531
TSI    = 676.9
FSTR   = 0.29
*RGRL  =
DVRV   = 0.000784
DVRR   = 0.001674
NS     = 11
DNOST = 344.,362.,369.,376.,383.,390.,397.,
        407.,425.,433.,441.
NTOTMT= 2.18,22.9,38.46,53.71,60.67,71.05,
       88.00,96.03,108.03,104.48,104.48
NA     = 6
DNAPT = 306.,344.,370.,392.,406.,600.

WSTS_OBS =
1988., 344.,  38.,
1988., 362., 522.,
1989.,   3.,1028.,
1989.,  10.,1710.,
1989.,  17.,2312.,
1989.,  24.,2974.,
1989.,  31.,3904.,
1989.,  41.,4505.,
1989.,  59.,3691.,
1989.,  67.,3216.

WSTS_TRG = 1900.,1.,0.,
           2000.,1.,0.

WSTS_FRC = 0

WLVG_OBS =
1988., 344.,  47.,
1988., 362., 394.,
1989.,   3., 717.,
1989.,  10.,1047.,
1989.,  17.,1281.,
1989.,  24.,1448.,
1989.,  31.,1628.,
1989.,  41.,1765.,
1989.,  59.,1680.,
1989.,  67.,1616.

WLVG_TRG = 1900.,1.,0.,
           2000.,1.,0.

WLVG_FRC = 0

* Dummy values or WLVD
WLVD_OBS = 1900.,1.,0.,
           2000.,1.,0.
WLVD_TRG = 1900.,1.,0.,
           2000.,1.,0.
WLVD_FRC = 0

WRTL_OBS =
1988., 344., 19.,
1988., 362.,377.,
1989.,   3.,494.,
1989.,  10.,590.,
1989.,  17.,672.,
1989.,  24.,734.,
1989.,  31.,848.,
1989.,  41.,836.,
1989.,  59.,836.,
1989.,  67.,836.

WRTL_TRG = 1900.,1.,0.,
           2000.,1.,0.

WRTL_FRC = 0

WSO_OBS =
1988., 344.,    0.,
1989.,  35.,    0.,
1989.,  41.,1536.,
1989.,  59.,4520.,
1989.,  67.,5525.

WSO_TRG = 1900.,1.,0.,
          1989.,30.,2.,
          1989.,50.,2.,
          2000.,1.,0.

WSO_FRC = 0

ANST_OBS   =
1988., 344., 0.64,
1988., 362., 9.19,
1989.,   3.,15.63,
1989.,  10.,21.20,
1989.,  17.,23.81,
1989.,  24.,33.61,
1989.,  31.,44.90,
1989.,  41.,37.84,
1989.,  59.,25.47,
1989.,  67.,17.04

ANST_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANST_FRC = 0

ANLV_OBS   =
1988., 344., 1.48,
1988., 362.,10.32,
1989.,   3.,18.79,
```

```
1989.,  10.,27.43,
1989.,  17.,30.74,
1989.,  24.,31.28,
1989.,  31.,35.98,
1989.,  41.,32.12,
1989.,  59.,20.16,
1989.,  67.,13.57

ANLV_TRG = 1900.,1.,0.,
           2000.,1.,0.
ANLV_FRC = 0

ANRT_OBS   =
1988., 344.,0.06,
1988., 362.,3.39,
1989.,   3.,4.05,
1989.,  10.,5.07,
1989.,  17.,6.12,
1989.,  24.,6.17,
1989.,  31.,7.12,
1989.,  41.,7.02,
1989.,  59.,6.35,
1989.,  67.,5.35

ANRT_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANRT_FRC = 0

ANSO_OBS   =
1988., 344., 0.00,
1989.,  35., 0.00,
1989.,  41.,19.05,
1989.,  59.,56.05,
1989.,  67.,68.51

ANSO_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANSO_FRC = 0

* Dummy values or ANLD
ANLD_OBS = 1900.,1.,0.,
          2000.,1.,0.
ANLD_TRG = 1900.,1.,0.,
          2000.,1.,0.
ANLD_FRC = 0

* Dummy values or LAI
LAI_OBS = 1900.,1.,0.,
          2000.,1.,0.
LAI_TRG = 1900.,1.,0.,
          2000.,1.,0.
LAI_FRC = 0

* NOTE the first values are dummy's
FSTTB  = 0.00,0.58,
         0.50,0.58,0.65,0.61,0.73,0.67,
         0.81,0.72,0.89,0.80,1.14,0.26,
         1.52,0.00,1.90,0.00,2.10,0.00
FLVTB  = 0.00,0.42,
         0.50,0.42,0.65,0.39,0.73,0.33,
         0.81,0.28, 0.89,0.20,1.14,0.06,
         1.52,0.00,1.90,0.00,2.10,0.00
FSHTB  = 0.00,0.70,
         0.50,0.70,0.65,0.88,0.73,0.91,
         0.81,0.91,0.89,0.93,0.97,0.91,
         1.14,1.00,1.52,1.00,1.90,1.00,
         2.10,0.00
FSOTB  = 0.00,0.00,
         0.50,0.00,0.65,0.00,0.73,0.00,
         0.81,0.00,0.89,0.00,1.14,0.00,
         1.52,1.00,1.90,1.00,2.10,1.00


****************************************
* Thiyagarajan, Tamil Nadu, India
* 1988-1989
* variety:   ADT 39
* treatment: 200 kg N/ha
****************************************
TREATM='THIYAGARAJAN, 1989, ADT39, 200 kg/ha
N'

* dummy initialisation
RADTOI = 0.

DATH   = 94.
DTRP   = 38.
FGHDAY = 63.0
WLVGI = 47.0
WSTSI = 38.0
WRTLI = 19.0
FNSTI = 0.0168
FNLVI = 0.0315
FNRTI = 0.0034
DVSI = 0.501
TSI  = 676.9
FSTR = 0.43
*RGRL =
DVRV = 0.000740
DVRR = 0.001606
NS = 11
DNOST  = 344.,362.,369.,376.,383.,390.,
         397.,407.,425.,438.,441.
NTOTMT = 2.18,27.80,64.75,81.85,96.98,
         108.91,130.08,165.60,166.76,
         144.08,144.08
NA    = 6
DNAPT = 306.,344.,370.,392.,406.,600.

WSTS_OBS =
1988., 344.,  38.,
1988., 362., 555.,
1989.,   3.,1238.,
1989.,  10.,2253.,
1989.,  17.,3143.,
1989.,  24.,3992.,
1989.,  31.,5029.,
1989.,  41.,5338.,
1989.,  59.,4139.,
1989.,  72.,3067.

WSTS_TRG = 1900.,1.,0.,
           2000.,1.,0.

WSTS_FRC = 0

WLVG_OBS =
1988., 344.,  47.,
1988., 362., 429.,
1989.,   3.,1103.,
1989.,  10.,1590.,
1989.,  17.,1868.,
1989.,  24.,2140.,
1989.,  31.,2361.,
1989.,  41.,2759.,
1989.,  59.,2304.,
1989.,  72.,1530.

WLVG_TRG = 1900.,1.,0.,
           2000.,1.,0.

WLVG_FRC = 0

* Dummy values or WLVD
WLVD_OBS = 1900.,1.,0.,
           2000.,1.,0.
WLVD_TRG = 1900.,1.,0.,
           2000.,1.,0.
WLVD_FRC = 0

WRTL_OBS =
1988., 344.,  19.,
1988., 362., 491.,
1989.,   3., 620.,
1989.,  10., 764.,
1989.,  17., 880.,
1989.,  24., 930.,
1989.,  31.,1120.,
1989.,  41.,1183.,
1989.,  59., 997.,
1989.,  72., 950.

WRTL_TRG = 1900.,1.,0.,
           2000.,1.,0.

WRTL_FRC = 0

WSO_OBS  =
```

```
1988., 344.,   0.,
1989.,  28.,   0.,
1989.,  41.,1712.,
1989.,  59.,5413.,
1989.,  72.,6706.

WSO_TRG = 1900.,1.,0.,
          1989.,30.,2.,
          1989.,50.,2.,
          2000.,1.,0.

WSO_FRC = 0

ANST_OBS   =
1988., 344., 0.64,
1988., 362.,10.55,
1989.,   3.,24.39,
1989.,  10.,31.09,
1989.,  17.,38.97,
1989.,  24.,49.90,
1989.,  31.,62.36,
1989.,  41.,66.19,
1989.,  59.,42.63,
1989.,  72.,19.02

ANST_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANST_FRC = 0

ANLV_OBS   =
1988., 344.,1.48,
1988., 362.,12.44,
1989.,   3.,34.97,
1989.,  10.,43.88,
1989.,  17.,48.94,
1989.,  24.,49.43,
1989.,  31.,56.90,
1989.,  41.,60.97,
1989.,  59.,31.80,
1989.,  72.,14.38

ANLV_TRG = 1900.,1.,0.,
           2000.,1.,0.
ANLV_FRC = 0

ANRT_OBS   =
1988., 344., 0.06,
1988., 362., 4.81,
1989.,   3., 5.39,
1989.,  10., 6.88,
1989.,  17., 9.06,
1989.,  24., 9.58,
1989.,  31.,11.54,
1989.,  41.,12.07,
1989.,  59., 8.97,
1989.,  72., 7.41

ANRT_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANRT_FRC = 0

ANSO_OBS   =
1988., 344.,  0.00,
1989.,  28.,  0.00,
1989.,  41., 26.36,
1989.,  59., 83.36,
1989.,  72.,103.27

ANSO_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANSO_FRC = 0

* Dummy values or ANLD
ANLD_OBS = 1900.,1.,0.,
          2000.,1.,0.
ANLD_TRG = 1900.,1.,0.,
          2000.,1.,0.
ANLD_FRC = 0

* Dummy values or LAI
LAI_OBS = 1900.,1.,0.,
          2000.,1.,0.

LAI_TRG = 1900.,1.,0.,
          2000.,1.,0.
LAI_FRC = 0

* NOTE the first values of the functions are
dummy's
*       the values at 2.1 are dummy's
FSTTB   = 0.00,0.58,
          0.48,0.58,0.62,0.50,0.69,0.68,
          0.77,0.76,0.84,0.76,0.92,0.82,
          1.00,0.13,1.38,0.00,1.74,0.00,
          2.10,0.00
FLVTB   = 0.00,0.42,
          0.48,0.42,0.62,0.50,0.69,0.32,
          0.77,0.24,0.84,0.24,0.92,0.18,
          1.00,0.16,1.38,0.00,1.74,0.00,
          2.10,0.00
FSHTB   = 0.00,0.66,
          0.48,0.66,0.62,0.91,0.69,0.91,
          0.77,0.91,0.84,0.96,0.92,0.87,
          1.00,0.97,1.38,1.00,1.74,1.00,
          2.10,0.00
FSOTB   = 0.00,0.00,
          0.48,0.00,0.62,0.00,0.69,0.00,
          0.77,0.00,0.84,0.00,0.92,0.00,
          1.00,0.71,1.38,1.00,1.74,1.00,
          2.10,1.00


****************************************
* Thiyagarajan, Tamil Nadu, India
* 1988-1989
* variety:   ADT 39
* treatment: 300 kg N/ha
****************************************
TREATM='THIYAGARAJAN,1989,ADT39,300 kg/ha N'

* dummy initialisation
RADTOI = 0.

DATH   = 94.
DTRP   = 38.
FGHDAY = 63.0
WLVGI  = 47.0
WSTSI  = 38.0
WRTLI  = 19.0
FNSTI  = 0.0168
FNLVI  = 0.0315
FNRTI  = 0.0034
DVSI   = 0.501
TSI    = 676.9
FSTR   = 0.37
*RGRL  =
DVRV   = 0.000740
DVRR   = 0.001606
NS     = 11
DNOST  = 344.,362.,369.,376.,383.,390.,
         397.,407.,425.,438.,441.
NTOTMT= 2.18,38.24,91.48,128.14,155.89,
         171.09,182.60,240.41,217.71,
         181.80,181.80
NA     = 6
DNAPT  = 306.,344.,370.,392.,406.,600.

WSTS_OBS =
1988., 344.,  38.,
1988., 362., 640.,
1989.,   3.,1438.,
1989.,  10.,2385.,
1989.,  17.,3257.,
1989.,  24.,4221.,
1989.,  31.,5500.,
1989.,  41.,6073.,
1989.,  59.,5136.,
1989.,  72.,3828.

WSTS_TRG = 1900.,1.,0.,
           2000.,1.,0.

WSTS_FRC = 0

WLVG_OBS =
1988., 344.,  47.,
1988., 362., 571.,
1989.,   3.,1300.,
```

```
1989.,  10.,2080.,
1989.,  17.,2695.,
1989.,  24.,3150.,
1989.,  31.,3486.,
1989.,  41.,3899.,
1989.,  59.,3761.,
1989.,  72.,2808.

WLVG_TRG = 1900.,1.,0.,
           2000.,1.,0.

WLVG_FRC = 0

* Dummy values or WLVD
WLVD_OBS = 1900.,1.,0.,
           2000.,1.,0.
WLVD_TRG = 1900.,1.,0.,
           2000.,1.,0.
WLVD_FRC = 0

WRTL_OBS =
1988., 344.,  19.,
1988., 362., 500.,
1989.,   3., 710.,
1989.,  10., 925.,
1989.,  17.,1150.,
1989.,  24.,1324.,
1989.,  31.,1502.,
1989.,  41.,1790.,
1989.,  59.,1507.,
1989.,  72.,1507.

WRTL_TRG = 1900.,1.,0.,
           2000.,1.,0.

WRTL_FRC = 0

WSO_OBS  =
1988., 344.,   0.,
1989.,  28.,   0.,
1989.,  41.,2542.,
1989.,  60.,4763.,
1989.,  72.,6450.

WSO_TRG = 1900.,1.,0.,
          1989.,30.,2.,
          1989.,50.,2.,
          2000.,1.,0.

WSO_FRC = 0

ANST_OBS   =
1988., 344.,0.64,
1988., 362.,14.14,
1989.,   3.,33.65,
1989.,  10.,42.69,
1989.,  17.,53.74,
1989.,  24.,66.27,
1989.,  31.,72.05,
1989.,  41.,79.56,
1989.,  59.,57.01,
1989.,  72.,30.62

ANST_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANST_FRC = 0

ANLV_OBS   =
1988., 344., 1.48,
1988., 362.,18.50,
1989.,   3.,51.09,
1989.,  10.,75.92,
1989.,  17.,87.32,
1989.,  24.,89.46,
1989.,  31.,93.42,
1989.,  41.,97.09,
1989.,  59.,63.56,
1989.,  72.,26.68

ANLV_TRG = 1900.,1.,0.,
           2000.,1.,0.
ANLV_FRC = 0

ANRT_OBS   =
1988., 344., 0.06,
1988., 362., 5.60,
1989.,   3., 6.75,
1989.,  10., 9.53,
1989.,  17.,14.84,
1989.,  24.,15.36,
1989.,  31.,17.12,
1989.,  41.,20.05,
1989.,  59.,15.22,
1989.,  72.,13.56

ANRT_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANRT_FRC = 0

ANSO_OBS   =
1988., 344.,  0.00,
1989.,  28.,  0.00,
1989.,  41., 43.72,
1989.,  59., 81.92,
1989.,  72.,110.94

ANSO_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANSO_FRC = 0

* Dummy values or ANLD
ANLD_OBS = 1900.,1.,0.,
          2000.,1.,0.
ANLD_TRG = 1900.,1.,0.,
          2000.,1.,0.
ANLD_FRC = 0

* Dummy values or LAI
LAI_OBS = 1900.,1.,0.,
          2000.,1.,0.
LAI_TRG = 1900.,1.,0.,
          2000.,1.,0.
LAI_FRC = 0

* NOTE the first values of the functions are
dummy's
*      the values at 2.1 are dummy's
FSTTB   = 0.00,0.53,
          0.48,0.53,0.62,0.52,0.69,0.55,
          0.77,0.59,0.84,0.68,0.92,0.79,
          1.00,0.16,1.38,0.00,1.82,0.00,
          2.10,0.00
FLVTB   = 0.00,0.47,
          0.48,0.47,0.62,0.48,0.69,0.45,
          0.77,0.41,0.84,0.32,0.92,0.21,
          1.00,0.12,1.38,0.00,1.82,0.00,
          2.10,0.00
FSHTB   = 0.00,0.70,
          0.48,0.70,0.62,0.88,0.69,0.89,
          0.77,0.87,0.84,0.89,0.92,0.90,
          1.00,0.92,1.38,1.00,1.82,1.00,
          2.10,0.00
FSOTB   = 0.00,0.00,
          0.48,0.00,0.62,0.00,0.69,0.00,
          0.77,0.00,0.84,0.00,0.92,0.00,
          1.00,0.72,1.38,1.00,1.82,1.00,
          2.10,1.00


****************************************
* Thiyagarajan, Tamil Nadu, India
* 1988-1989
* variety:   ADT 39
* treatment: 400 KG/HA
****************************************
TREATM='THIYAGARAJAN,1989,ADT39,400 kg/ha N'

* dummy initialisation
RADTOI = 0.

DATH   = 97.
DTRP   = 38.
FGHDAY = 63.0
WLVGI  = 47.0
WSTSI  = 38.0
WRTLI  = 19.0
FNSTI  = 0.0168
```

```
FNLVI = 0.0315
FNRTI = 0.0034
DVSI   = 0.485
TSI    = 676.9
FSTR  = 0.30
*RGRL  =
DVRV  = 0.000716
DVRR  = 0.001582
NS    = 10
DNOST = 344.,362.,369.,376.,383.,390.,
        397.,407.,425.,441.
NTOTMT= 2.18,49.64,110.56,159.91,201.37,
        212.66,246.23,303.82,
        277.76,212.78
NA    = 6
DNAPT = 306.,344.,370.,392.,406.,600.

WSTS_OBS =
1988., 344.,  38.,
1988., 362., 718.,
1989.,   3.,1612.,
1989.,  10.,2650.,
1989.,  17.,3855.,
1989.,  24.,4627.,
1989.,  31.,5736.,
1989.,  41.,6619.,
1989.,  59.,5021.,
1989.,  75.,4558.

WSTS_TRG = 1900.,1.,0.,
           2000.,1.,0.

WSTS_FRC = 0

WLVG_OBS =
1988., 344.,  47.,
1988., 362., 652.,
1989.,   3.,1438.,
1989.,  10.,2500.,
1989.,  17.,3329.,
1989.,  24.,4009.,
1989.,  31.,4707.,
1989.,  41.,5624.,
1989.,  59.,4285.,
1989.,  75.,3208.

WLVG_TRG = 1900.,1.,0.,
           2000.,1.,0.

WLVG_FRC = 0

* Dummy values or WLVD
WLVD_OBS = 1900.,1.,0.,
           2000.,1.,0.
WLVD_TRG = 1900.,1.,0.,
           2000.,1.,0.
WLVD_FRC = 0

WRTL_OBS =
1988., 344.,  19.,
1988., 362., 521.,
1989.,   3., 775.,
1989.,  10.,1030.,
1989.,  17.,1250.,
1989.,  24.,1525.,
1989.,  31.,1750.,
1989.,  41.,2003.,
1989.,  59.,1968.,
1989.,  75.,1968.

WRTL_TRG = 1900.,1.,0.,
           2000.,1.,0.

WRTL_FRC = 0

WSO_OBS  =
1988., 344.,    0.,
1989.,  29.,    0.,
1989.,  41.,1426.,
1989.,  59.,5365.,
1989.,  75.,6337.

WSO_TRG = 1900.,1.,0.,
          1989.,30.,2.,
          1989.,50.,2.,
          2000.,1.,0.

WSO_FRC = 0

ANST_OBS    =
1988., 344., 0.64,
1988., 362.,17.30,
1989.,   3.,43.04,
1989.,  10.,54.86,
1989.,  17.,67.85,
1989.,  24.,74.96,
1989.,  31.,91.78,
1989.,  41.,97.96,
1989.,  59.,64.77,
1989.,  75.,48.31

ANST_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANST_FRC = 0

ANLV_OBS    =
1988., 344.,  1.48,
1988., 362., 26.08,
1989.,   3., 59.53,
1989.,  10., 91.25,
1989.,  17.,112.52,
1989.,  24.,113.45,
1989.,  31.,128.03,
1989.,  41.,152.97,
1989.,  59., 95.98,
1989.,  75., 31.44

ANLV_TRG = 1900.,1.,0.,
           2000.,1.,0.
ANLV_FRC = 0

ANRT_OBS    =
1988., 344., 0.06,
1988., 362., 6.25,
1989.,   3., 7.98,
1989.,  10.,13.80,
1989.,  17.,21.00,
1989.,  24.,24.25,
1989.,  31.,26.43,
1989.,  41.,27.64,
1989.,  59.,22.04,
1989.,  75.,20.86

ANRT_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANRT_FRC = 0

ANSO_OBS    =
1988., 344.,  0.00,
1989.,  29.,  0.00,
1989.,  41., 25.24,
1989.,  59., 94.96,
1989.,  75.,112.16

ANSO_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANSO_FRC = 0

* Dummy values or ANLD
ANLD_OBS = 1900.,1.,0.,
          2000.,1.,0.
ANLD_TRG = 1900.,1.,0.,
          2000.,1.,0.
ANLD_FRC = 0

* Dummy values or LAI
LAI_OBS = 1900.,1.,0.,
          2000.,1.,0.
LAI_TRG = 1900.,1.,0.,
          2000.,1.,0.
LAI_FRC = 0

* NOTE the first values of the functions are
dummy's
*       the values at 2.1 are dummy's
FSTTB  = 0.,0.53,
         0.46,0.53,0.60,0.53,0.68,0.49,
```

```
         0.75,0.59,0.82,0.53,0.89,0.61,
         1.00,0.00,1.30,0.00,1.77,0.00,
         2.10,0.00
FLVTB  = 0.,0.47,
         0.46,0.47,0.60,0.47,0.68,0.51,
         0.75,0.41,0.82,0.47,0.89,0.39,
         1.00,0.00,1.30,0.00,1.77,0.00,
         2.10,0.00
FSHTB  = 0.,0.72,
         0.46,0.72,0.60,0.87,0.68,0.89,
         0.75,0.90,0.82,0.84,0.89,0.89,
         0.98,0.93,1.30,1.00,1.77,1.00,
         2.10,0.00
FSOTB  = 0.,0.00,
         0.46,0.00,0.60,0.00,0.68,0.00,
         0.75,0.00,0.82,0.00,0.89,0.00,
         1.00,1.00,1.30,1.00,1.77,1.00,
         2.10,1.00
```

Data sets for validation of ORYZA_0

```
***************************************
* Thiyagarajan, Tamil Nadu, India
* 1988-1989
* variety:   ADT 39
* treatment: 0 KG/HA
***************************************
TREATM='THIYAGARAJAN, 1989, ADT39,0 kg/ha N'

* dummy variables
DVSI = 0.
TBD  = 0.
TBLV = 0.

* Initial constants
* -----------------
WCRI   = 104.0
ANCRI  = 2.18
RADTOI = 0.
APCUMI = 0.
DVSI   = 0.

* Model parameters
* ----------------
RTINCL = 1
DATFSV = 53.
DATEF  = 53.
*Flowering is at 53 DAT, DATFF is 53-7
DATFF  = 46.
DATH   = 89.
FSV1   = 0.87
FSV2   = 0.87
FNSO   = 0.01
FNCLV  = 0.50
ANLVMX = 100.
MAXUP1 = 5.
RUR    = 0.2
NUPCO  = 0.03
HI     = 0.5
SOLSUP = 0.6
FERTMX = 200.
A      = 1.
B      = 0.1
C      = 300.
M      = 30.
LARGE  = 100.
TINY   = 0.001

* AFGEN functions
* ---------------
FNMAXT =
   0., 0.03,
   40., 0.017,
   60., 0.015,
   80., 0.01,
   130., 0.07

RECT   =
   0., 0.0,
   60., 0.8,
   65., 0.4,
   70., 0.0,
   150., 0.

RSRT =
   0., 0.4,
   1.1, 0.15

* Observed values
* ---------------

WLV_OBS   =
1988., 344.,  47.0,
1988., 362., 286.0,
1989.,   3., 469.0,
1989.,  10., 715.0,
1989.,  17., 828.0,
1989.,  24., 943.0,
1989.,  31., 936.0,
1989.,  41., 840.0,
1989.,  59., 792.0,
1989.,  67., 767.0

WCR_OBS =
1988., 344.0,   104.0,
1988., 362.0,   966.0,
1989.,   3.0,  1510.0,
1989.,  10.0,  2250.0,
1989.,  17.0,  2922.0,
1989.,  24.0,  3718.6,
1989.,  31.0,  4706.5,
1989.,  41.0,  4840.0,
1989.,  59.0,  6008.0,
1989.,  67.0,  6368.0

FNLV_OBS =
1988., 344.0, 3.15,
1988., 362.0, 2.35,
1989.,   3.0, 2.00,
1989.,  10.0, 2.07,
1989.,  17.0, 2.07,
1989.,  24.0, 1.93,
1989.,  31.0, 1.45,
1989.,  41.0, 1.10,
1989.,  59.0, 0.97,
1989.,  67.0, 0.70


***************************************
* Thiyagarajan, Tamil Nadu, India
* 1988-1989
* variety:   ADT 39
* treatment: 0 KG/HA
***************************************
TREATM='THIYAGARAJAN,1989,ADT39,100 kg/ha N'

* dummy variables
DVSI = 0.
TBD  = 0.
TBLV = 0.

* Initial constants
* -----------------
WCRI   = 104.0
ANCRI  = 2.18
RADTOI = 0.
APCUMI = 0.
DVSI   = 0.

* Model parameters
* ----------------
RTINCL = 1
DATFSV = 53.
DATEF  = 53.
*Flowering is at 53 DAT, DATFF is 53-7
DATFF  = 46.
DATH   = 89.
FSV1   = 0.87
FSV2   = 0.87
FNSO   = 0.01
FNCLV  = 0.50
ANLVMX = 100.
MAXUP1 = 5.
RUR    = 0.2
NUPCO  = 0.03
HI     = 0.5
SOLSUP = 0.6
FERTMX = 200.
A      = 1.
```

```
B      = 0.1
C      = 300.
M      = 30.
LARGE  = 100.
TINY   = 0.001

* AFGEN functions
* ---------------
FNMAXT =
   0., 0.03,
   40., 0.017,
   60., 0.015,
   80., 0.01,
   130., 0.07

RECT   =
   0., 0.0,
   60., 0.8,
   65., 0.4,
   70., 0.0,
   150., 0.

RSRT   =
    0., 0.4,
   1.1, 0.15

* Observed values
* ---------------

WLV_OBS =
1988., 344.,  47.,
1988., 362., 394.,
1989.,   3., 717.,
1989.,  10.,1047.,
1989.,  17.,1281.,
1989.,  24.,1448.,
1989.,  31.,1628.,
1989.,  41.,1765.,
1989.,  59.,1680.,
1989.,  67.,1616.

WCR_OBS =
1988., 344.0,    104.0,
1988., 362.0,   1293.0,
1989.,   3.0,   2239.0,
1989.,  10.0,   3347.0,
1989.,  17.0,   4265.0,
1989.,  24.0,   5156.0,
1989.,  31.0,   6380.0,
1989.,  41.0,   8642.0,
1989.,  59.0,  10727.0,
1989.,  67.0,  11193.0

FNLV_OBS =
1988., 344.0, 3.15,
1988., 362.0, 2.62,
1989.,   3.0, 2.62,
1989.,  10.0, 2.62,
1989.,  17.0, 2.40,
1989.,  24.0, 2.16,
1989.,  31.0, 2.21,
1989.,  41.0, 1.82,
1989.,  59.0, 1.20,
1989.,  67.0, 0.84


***************************************
* Thiyagarajan, Tamil Nadu, India
* 1988-1989
* variety:   ADT 39
* treatment: 0 KG/HA
***************************************
TREATM='THIYAGARAJAN,1989,ADT39,200 kg/ha N'

* dummy variables
DVSI = 0.
TBD  = 0.
TBLV = 0.

* Initial constants
* -----------------
WCRI   = 104.0
ANCRI  = 2.18
RADTOI = 0.
APCUMI = 0.
DVSI   = 0.

* Model parameters
* ----------------
RTINCL = 1
DATFSV = 58.
DATEF  = 58.
*Flowering is at 58 DAT, DATFF is 58-7
DATFF  = 51.
DATH   = 94.
FSV1   = 0.87
FSV2   = 0.87
FNSO   = 0.01
FNCLV  = 0.50
ANLVMX = 100.
MAXUP1 = 5.
RUR    = 0.2
NUPCO  = 0.03
HI     = 0.5
SOLSUP = 0.6
FERTMX = 200.
A      = 1.
B      = 0.1
C      = 300.
M      = 30.
LARGE  = 100.
TINY   = 0.001

* AFGEN functions
* ---------------
FNMAXT =
   0., 0.03,
   40., 0.017,
   60., 0.015,
   80., 0.01,
   130., 0.07

RECT   =
   0., 0.0,
   60., 0.8,
   65., 0.4,
   70., 0.0,
   150., 0.

RSRT   =
    0., 0.4,
   1.1, 0.15

* Observed values
* ---------------

WLV_OBS =
1988., 344.,  47.,
1988., 362., 429.,
1989.,   3.,1103.,
1989.,  10.,1590.,
1989.,  17.,1868.,
1989.,  24.,2140.,
1989.,  31.,2361.,
1989.,  41.,2759.,
1989.,  59.,2304.,
1989.,  72.,1530.

WCR_OBS =
1988., 344.,  104.0,
1988., 362., 1475.0,
1989.,   3., 2961.0,
1989.,  10., 4607.0,
1989.,  17., 5891.0,
1989.,  24., 7062.0,
1989.,  31., 8905.1,
1989.,  41.,10992.0,
1989.,  59.,12853.0,
1989.,  72.,12253.0

FNLV_OBS =
1988., 344.,3.15,
1988., 362.,2.90,
1989.,   3.,3.17,
1989.,  10.,2.76,
1989.,  17.,2.62,
1989.,  24.,2.31,
1989.,  31.,2.41,
1989.,  41.,2.21,
1989.,  59.,1.38,
```

```
1989.,  72.,0.94


***************************************
* Thiyagarajan, Tamil Nadu, India
* 1988-1989
* variety:   ADT 39
* treatment: 300 KG/HA
***************************************
TREATM='THIYAGARAJAN,1989,ADT39,300 kg/ha N'

* dummy variables
DVSI = 0.
TBD  = 0.
TBLV = 0.

* Initial constants
* ----------------
WCRI   = 104.0
ANCRI  = 2.18
RADTOI = 0.
APCUMI = 0.
DVSI   = 0.

* Model parameters
* ----------------
RTINCL = 1
DATFSV = 58.
DATEF  = 58.
*Flowering is at 58 DAT, DATFF is 58-7
DATFF  = 51.
DATH   = 94.
FSV1   = 0.87
FSV2   = 0.87
FNSO   = 0.01
FNCLV  = 0.50
ANLVMX = 100.
MAXUP1 = 5.
RUR    = 0.2
NUPCO  = 0.03
HI     = 0.5
SOLSUP = 0.6
FERTMX = 200.
A      = 1.
B      = 0.1
C      = 300.
M      = 30.
LARGE  = 100.
TINY   = 0.001

* AFGEN functions
* ---------------
FNMAXT =
   0., 0.03,
   40., 0.017,
   60., 0.015,
   80., 0.01,
   130., 0.07

RECT   =
   0., 0.0,
   60., 0.8,
   65., 0.4,
   70., 0.0,
   150., 0.

RSRT =
   0., 0.4,
  1.1, 0.15

* Observed values
* ---------------

WLV_OBS =
1988., 344.,  47.,
1988., 362., 571.,
1989.,   3.,1300.,
1989.,  10.,2080.,
1989.,  17.,2695.,
1989.,  24.,3150.,
1989.,  31.,3486.,
1989.,  41.,3899.,
1989.,  59.,3761.,
1989.,  72.,2808.

WCR_OBS =
1988., 344.,  104.0,
1988., 362., 1711.0,
1989.,   3., 3448.0,
1989.,  10., 5390.0,
1989.,  17., 7102.0,
1989.,  24., 8695.0,
1989.,  31.,11075.0,
1989.,  41.,14304.0,
1989.,  59.,15050.0,
1989.,  72.,14593.0

FNLV_OBS =
1988., 344.,3.15,
1988., 362.,3.24,
1989.,   3.,3.93,
1989.,  10.,3.65,
1989.,  17.,3.24,
1989.,  24.,2.84,
1989.,  31.,2.68,
1989.,  41.,2.49,
1989.,  59.,1.69,
1989.,  72.,0.95


***************************************
* Thiyagarajan, Tamil Nadu, India
* 1988-1989
* variety:   ADT 39
* treatment: 400 KG/HA
***************************************
TREATM='THIYAGARAJAN,1989,ADT39,400 kg/ha N'

* dummy variables
DVSI = 0.
TBD  = 0.
TBLV = 0.

* Initial constants
* ----------------
WCRI   = 104.0
ANCRI  = 2.18
RADTOI = 0.
APCUMI = 0.
DVSI   = 0.

* Model parameters
* ----------------
RTINCL = 1
DATFSV = 61.
DATEF  = 61.
*Flowering is at 58 DAT, DATFF is 61-7
DATFF  = 54.
DATH   = 97.
FSV1   = 0.87
FSV2   = 0.87
FNSO   = 0.01
FNCLV  = 0.50
ANLVMX = 100.
MAXUP1 = 5.
RUR    = 0.2
NUPCO  = 0.03
HI     = 0.5
SOLSUP = 0.6
FERTMX = 200.
A      = 1.
B      = 0.1
C      = 300.
M      = 30.
LARGE  = 100.
TINY   = 0.001

* AFGEN functions
* ---------------
FNMAXT =
   0., 0.03,
   40., 0.017,
   60., 0.015,
   80., 0.01,
   130., 0.07

RECT   =
   0., 0.0,
   60., 0.8,
   65., 0.4,
```

```
   70., 0.0,
   150., 0.

RSRT    =
      0., 0.4,
     1.1, 0.15

* Observed values
* ---------------

WLV_OBS =
1988., 344.,  47.,
1988., 362., 652.,
1989.,   3.,1438.,
1989.,  10.,2500.,
1989.,  17.,3329.,
1989.,  24.,4009.,
1989.,  31.,4707.,
1989.,  41.,5624.,
1989.,  59.,4285.,
1989.,  75.,3208.

WCR_OBS =
1988., 344.,    104.0,
1988., 362.,   1891.0,
1989.,   3.,   3825.0,
1989.,  10.,   6180.0,
1989.,  17.,   8434.0,
1989.,  24.,  10161.0,
1989.,  31.,  12431.0,
1989.,  41.,  15672.0,
1989.,  59.,  16639.0,
1989.,  75.,  16071.0

FNLV_OBS =
1988., 344.,3.15,
1988., 362.,4.00,
1989.,   3.,4.14,
1989.,  10.,3.65,
1989.,  17.,3.38,
1989.,  24.,2.83,
1989.,  31.,2.72,
1989.,  41.,2.72,
1989.,  59.,2.24,
1989.,  75.,0.98
```

CRRI, Cuttack, India, 1990
Experimental data from: R.N. Dash & K.S. Rao

General information:

variety: IR 36
year: 1990

	Calendar date	DOY	DAT
seeding	18 Dec,89	352	
transplanting	25 Jan	25	0
flowering	9 Apr	99	74
harvest	28 Apr	118	93

DAT= days after transplanting, DOY= day of the year

Nitrogen application scheme:

Calendar date	DOY	DAT	Quantity applied
25 Jan	25	0	50% of the treatment level
14 Feb	45	20	25% of the treatment level
19 Mar	78	53	25% of the treatment level

DAT= days after transplanting, DOY= day of the year

Data sets for validation of ORYZA_N

```
***************************************
* R.N. Dash & K.S. Rao, Cuttack, India
* dry season, 1990
* variety:   IR 36
* treatment: 0 KG N/HA
***************************************
TREATM='RAO, 1990, IR36, 0 kg N/ha'
* in DAT
* dummy initialisation
RADTOI = 0.

DATH   = 93.
DTRP   = 38.
FGHDAY = 70.0
WLVGI  = 32.0
WSTSI  = 48.0
WRTLI  = 44.0
*FNSTI = 0.02
FNLVI  = 0.025
*FNRTI = 0.01
DVSI   = 0.32
TSI    = 497.50
FSTR   = 0.411
*RGRL  =
DVRV   = 6.2E-04
DVRR   = 2.4E-03
*NS    = 6
*DNOST = 45.,75.,95.,105.,117.,125.
*NTOTMT= 21.98,57.88,60.46,60.74,73.38,
         73.38
NS     = 5
DNOST = 45.,75.,95.,105.,117.
NTOTMT= 21.98,57.88,60.46,60.74,73.38
NA     = 5
DNAPT =  1.,25.,45.,78.,365.
*DNAPT = 352.,391.,411.,444.,600.

* NOTE first value of NSO is dummy
*      first two values of WSO are dummy's
*      last value of W/NLV, W/NST, W/NRT,
W/NSO are dummy's
WLVG_OBS =
1989.,352., 32.,
1990.,25.,  32.,
1990.,45., 272.,
1990.,55., 440.,
1990.,65., 679.,
1990.,75., 872.,
1990.,95., 754.,
1990.,105., 761.,
1990.,117., 776.,
1990.,120.,776.

WLVG_TRG = 1900.,1.,0.,
           2000.,1.,0.

WLVG_FRC = 0

WSTS_OBS =
1989.,352., 48.,
1990.,25.,  48.,
1990.,45.,  267.,
1990.,55.,  745.,
1990.,65., 1441.,
1990.,75., 2420.,
1990.,95., 3779.,
1990.,105.,2101.,
1990.,117.,2225.,
1990.,120.,2225.

WSTS_TRG = 1900.,1.,0.,
           2000.,1.,0.

WSTS_FRC = 0

WRTL_OBS =
1989., 352., 44.,
1990., 25.,  44.,
1990., 45.,  223.,
1990., 55.,  323.,
1990., 65.,  605.,
1990., 75.,  602.,
1990., 95.,  535.,
1990., 105., 500.,
1990., 117., 500.,
1990., 120.,500.

WRTL_TRG = 1900.,1.,0.,
           2000.,1.,0.

WRTL_FRC = 0

WSO_OBS  =
1989., 352.,     0.,
1990., 25.,      0.,
1990., 89.,      0.,
1990., 95.,    443.,
1990., 105., 2783.,
1990., 117., 4246.,
1990., 120., 4246.

WSO_TRG = 1900.,1.,0.,
          1989.,30.,2.,
          1989.,50.,2.,
          2000.,1.,0.

WSO_FRC = 0

WLVD_OBS = 1900.,1.,0.,
           2000.,1.,0.
WLVD_TRG = 1900.,1.,0.,
           2000.,1.,0.
WLVD_FRC = 0

ANST_OBS   =
1989., 352.,1.05,
1990., 25., 1.05,
1990., 45., 5.05,
1990., 75., 31.70,
1990., 95., 34.39,
1990., 105.,14.50,
1990., 117.,15.35,
1990., 120.,15.35

ANST_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANST_FRC = 0

ANLV_OBS   =
1989., 352.,0.80,
1990., 25., 0.80,
1990., 45., 13.27,
1990., 75., 19.62,
1990., 95., 13.50,
1990., 105.,10.81,
1990., 117.,11.02,
1990., 120.,11.02

ANLV_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANLV_FRC = 0

ANRT_OBS   =
1989., 352.,0.70,
1990., 25., 0.70,
1990., 45., 3.66,
1990., 75., 6.56,
1990., 95., 4.87,
1990., 105.,4.55,
1990., 117.,4.55,
1990., 120.,4.55

ANRT_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANRT_FRC = 0

ANSO_OBS   =
1989.,352.,  0.00,
1990., 25.,  0.00,
1990., 89.,  0.00,
1990., 95.,  7.71,
1990., 105.,30.89,
1990., 117.,42.46,
1990., 120.,42.46
```

```
ANSO_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANSO_FRC = 0

ANLD_OBS = 1900.,1.,0.,
           2000.,1.,0.
ANLD_TRG = 1900.,1.,0.,
           2000.,1.,0.
ANLD_FRC = 0

* Dummy values or LAI
LAI_OBS = 1900.,1.,0.,
          2000.,1.,0.
LAI_TRG = 1900.,1.,0.,
          2000.,1.,0.
LAI_FRC = 0

* NOTE first and last values are dummy's
FSHTB  = 0.00,0.70,
         0.36,0.72,0.51,0.87,0.61,0.77,
         0.71,1.00,0.86,1.00,1.06,1.00,
         1.64,1.00,2.10,1.00
FLVTB  = 0.00,0.52,
         0.36,0.52,0.51,0.26,0.61,0.26,
         0.71,0.16,0.81,0.16,0.86,0.00,
         1.0,0.0,1.06,0.00,1.64,0.01,
         2.10,0.01
FSTTB  = 0.00,0.48,
         0.36,0.48,0.51,0.74,0.61,0.74,
         0.71,0.84,0.81,0.84,0.86,0.68,
         1.0,0.0,1.06,0.00,1.64,0.08,
         2.10,0.08
FSOTB  = 0.00,0.00,
         0.36,0.00,0.51,0.00,0.61,0.00,
         0.71,0.00,0.81,0.00,0.86,0.32,
         1.0,1.0,1.06,1.00,1.64,0.91,
         2.10,0.91


***************************************
* R.N. Dash & K.S. Rao, Cuttack, India
* dry season, 1990
* variety:   IR 36
* treatment: 50 KG N/HA
***************************************
TREATM='RAO, 1990, IR36, 50 kg N/ha'
* in DAT
FGHDAY = 70.0

WLVGI = 32.0
WSTSI = 48.0
WRTLI = 44.0
*FNSTI = 0.02
FNLVI = 0.025
*FNRTI = 0.01
DVSI  = 0.32
TSI   = 497.50
FSTR  = 0.34
*RGRL  =
DVRV  = 6.2E-04
DVRR  = 2.4E-03
*NS    = 6
*DNOST = 45.,75.,95.,105.,117.,125.
*NTOTMT= 20.33,83.97,90.12,91.06,112.06,
        112.06
NS    = 5
DNOST = 45.,75.,95.,105.,117.
NTOTMT= 20.33,83.97,90.12,91.06,112.06,
        112.06
NA    = 5
DNAPT = 1.,25.,45.,78.,365.
*DNAPT = 352.,391.,411.,444.,600.

* NOTE first value of NSO is dummy
*      first two values of WSO are dummy's
*      last value of W/NLV, W/NST, W/NRT,
W/NSO are dummy's
WLVG_OBS =
1989.,352.,  32.,
1990.,25.,   32.,
1990.,45.,  270.,
1990.,55.,  528.,
1990.,65.,  888.,
1990.,75., 1202.,
1990.,95.,  998.,
1990.,105.,1058.,
1990.,117.,1064.,
1990.,120.,1064.

WLVG_TRG = 1900.,1.,0.,
           2000.,1.,0.

WLVG_FRC = 0

WSTS_OBS =
1989.,352.,  48.,
1990.,25.,   48.,
1990.,45.,  289.,
1990.,55.,  809.,
1990.,65., 1766.,
1990.,75., 3088.,
1990.,95., 4682.,
1990.,105.,2708.,
1990.,117.,3075.,
1990.,120.,3075.

WSTS_TRG = 1900.,1.,0.,
          2000.,1.,0.

WSTS_FRC = 0

WRTL_OBS =
1989.,352., 44.,
1990.,25.,  44.,
1990.,45.,  237.,
1990.,55.,  523.,
1990.,65.,  743.,
1990.,75.,  905.,
1990.,95.,  704.,
1990.,105., 861.,
1990.,117., 820.,
1990.,120., 820.

WRTL_TRG = 1900.,1.,0.,
           2000.,1.,0.

WRTL_FRC = 0

WSO_OBS  =
1989., 352.,     0.,
1990., 25.,      0.,
1990., 89.,      0.,
1990., 95.,    741.,
1990., 105., 4194.,
1990., 117., 6095.,
1990., 120., 6095.

WSO_TRG = 1900.,1.,0.,
          1990.,30.,2.,
          1990.,50.,2.,
          2000.,1.,0.

WSO_FRC = 0

WLVD_OBS = 1900.,1.,0.,
          2000.,1.,0.
WLVD_TRG = 1900.,1.,0.,
          2000.,1.,0.
WLVD_FRC = 0

ANST_OBS =
1989., 352., 1.05,
1990., 25.,  1.05,
1990., 45.,  4.62,
1990., 75., 40.45,
1990., 95., 47.76,
1990., 105.,16.79,
1990., 117.,19.07,
1990., 120.,19.07

ANST_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANST_FRC = 0

ANLV_OBS =
1989., 352.,  0.8,
1990., 25.,  0.8,
```

```
1990., 45., 11.39,
1990., 75., 33.66,
1990., 95., 21.46,
1990., 105.,18.09,
1990., 117.,18.19,
1990., 120.,18.19

ANLV_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANLV_FRC = 0

ANRT_OBS =
1989., 352.,0.70,
1990., 25., 0.70,
1990., 45., 4.31,
1990., 75., 9.86,
1990., 95., 6.90,
1990., 105.,8.78,
1990., 117.,8.36,
1990., 120.,8.36

ANRT_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANRT_FRC = 0

ANSO_OBS =
1989.,352.,  0.00,
1990., 25.,  0.00,
1990., 89.,     0.,
1990., 95., 14.00,
1990., 105.,47.39,
1990., 117.,66.44,
1990., 120.,66.44

ANSO_TRG = 1900.,1.,0.,
          2000.,1.,0.

ANSO_FRC = 0

ANLD_OBS = 1900.,1.,0.,
           2000.,1.,0.
ANLD_TRG = 1900.,1.,0.,
           2000.,1.,0.
ANLD_FRC = 0

* Dummy values or LAI
LAI_OBS = 1900.,1.,0.,
          2000.,1.,0.
LAI_TRG = 1900.,1.,0.,
          2000.,1.,0.
LAI_FRC = 0

* NOTE first and last values are dummy's
FSHTB = 0.00,0.71,
        0.36,0.71,0.51,0.73,0.61,0.86,
        0.71,0.91,0.86,1.00,1.06,0.96,
        1.64,1.00,2.10,1.00
FLVTB = 0.00,0.50,
        0.36,0.50,0.51,0.33,0.61,0.27,
        0.71,0.19,0.81,0.19,0.86,0.00,
        1.0,0.0,1.06,0.02,1.64,0.00,
        2.10,0.00
FSTTB = 0.00,0.50,
        0.36,0.50,0.51,0.67,0.61,0.73,
        0.71,0.81,0.81,0.81,0.86,0.68,
        1.0,0.0,1.06,0.00,1.64,0.16,
        2.10,0.16
FSOTB = 0.00,0.00,
        0.36,0.00,0.51,0.00,0.61,0.00,
        0.71,0.00,0.81,0.00,0.86,0.32,
        1.0,1.0,1.06,0.98,1.64,0.84,
        2.10,0.84


****************************************
* R.N. Dash & K.S. Rao, Cuttack, India
* dry season, 1990
* variety:   IR 36
* treatment: 100 KG N/HA
****************************************
TREATM='RAO, 1990, IR36, 100 kg N/ha'
* in DAT
* dummy initialisation
RADTOI = 0.

DATH   = 93.
DTRP   = 38.
FGHDAY = 70.0
WLVGI = 32.0
WSTSI = 48.0
WRTLI = 44.0
*FNSTI = 0.02
FNLVI = 0.025
*FNRTI = 0.01
DVSI  = 0.32
TSI   = 497.50
FSTR  = 0.41
*RGRL  =
DVRV  = 6.2E-04
DVRR  = 2.4E-03
*NS   = 6
*DNOST = 45.,75.,95.,105.,117.,125.
*NTOTMT= 25.95,119.92,120.10,121.67,140.0,
         140.0
NS    = 5
DNOST = 45.,75.,95.,105.,117.
NTOTMT= 25.95,119.92,120.10,121.67,140.0,
        140.0
NA    = 5
DNAPT = 1., 25.,45.,78.,365.
*DNAPT = 352.,391.,411.,444.,600.

* NOTE first value of NSO is dummy
*      first two values of WSO are dummy's
*      last value of W/NLV, W/NST, W/NRT,
W/NSO are dummy's
WLVG_OBS =
1989.,352., 32.,
1990.,25.,  32.,
1990.,45.,  333.,
1990.,55.,  726.,
1990.,65., 1292.,
1990.,75., 1537.,
1990.,95., 1340.,
1990.,105.,1555.,
1990.,117.,1191.,
1990.,120.,1191.

WLVG_TRG = 1900.,1.,0.,
          2000.,1.,0.

WLVG_FRC = 0

WSTS_OBS =
1989., 352.,48.,
1990.,25.,   48.,
1990.,45.,  338.,
1990.,55., 1042.,
1990.,65., 2431.,
1990.,75., 3985.,
1990.,95., 5590.,
1990.,105.,3320.,
1990.,117.,3314.,
1990.,120.,3314.

WSTS_TRG = 1900.,1.,0.,
           2000.,1.,0.

WSTS_FRC = 0

WRTL_OBS =
1989.,352.,44.,
1990.,25.,   44.,
1990.,45.,  286.,
1990.,55.,  539.,
1990.,65.,  979.,
1990.,75., 1116.,
1990.,95.,  803.,
1990.,105., 952.,
1990.,117., 858.,
1990.,120., 858.

WRTL_TRG = 1900.,1.,0.,
          2000.,1.,0.

WRTL_FRC = 0

WSO_OBS  =
```

```
1989.,352.,0.,
1990., 25.,   0.,
1990., 89.,   0.,
1990.,95., 1187.,
1990.,105.,5145.,
1990.,117.,6915.,
1990.,120.,6915.

WSO_TRG = 1900.,1.,0.,
          1990.,30.,2.,
          1990.,50.,2.,
          2000.,1.,0.

WSO_FRC = 0

WLVD_OBS = 1900.,1.,0.,
           2000.,1.,0.
WLVD_TRG = 1900.,1.,0.,
           2000.,1.,0.
WLVD_FRC = 0

ANST_OBS   =
1989.,352., 1.05,
1990.,25.,  1.05,
1990.,45.,  6.15,
1990.,75., 65.35,
1990.,95., 61.49,
1990.,105.,22.91,
1990.,117.,22.87,
1990.,120.,22.87

ANST_TRG = 1900.,1.,0.,
          2000.,1.,0.

ANST_FRC = 0

ANLV_OBS   =
1989.,352., 0.80,
1990.,25.,  0.80,
1990.,45., 15.02,
1990.,75., 41.96,
1990.,95., 28.27,
1990.,105.,26.59,
1990.,117.,20.37,
1990.,120.,20.37

ANLV_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANLV_FRC = 0

ANRT_OBS   =
1989.,352., 0.70,
1990.,25.,  0.70,
1990.,45.,  4.78,
1990.,75., 12.61,
1990.,95.,  7.55,
1990.,105., 8.38,
1990.,117., 6.86,
1990.,120., 6.86

ANRT_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANRT_FRC = 0

ANSO_OBS   =
1989.,352.,  0.00,
1990.,25.,   0.00,
1990., 89.,   0.,
1990.,95.,   22.79,
1990.,105.,  63.80,
1990.,117.,  89.90,
1990.,120.,  89.90

ANSO_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANSO_FRC = 0

ANLD_OBS = 1900.,1.,0.,
           2000.,1.,0.
ANLD_TRG = 1900.,1.,0.,
           2000.,1.,0.
ANLD_FRC = 0

* Dummy values or LAI
LAI_OBS = 1900.,1.,0.,
          2000.,1.,0.
LAI_TRG = 1900.,1.,0.,
          2000.,1.,0.
LAI_FRC = 0

* NOTE first and last values are dummy's
FSHTB = 0.00,0.71,
        0.36,0.71,0.51,0.81,0.61,0.82,
        0.71,0.93,0.86,1.00,1.06,0.97,
        1.64,1.00,2.10,1.00
FLVTB = 0.00,0.51,
        0.36,0.51,0.51,0.36,0.61,0.29,
        0.71,0.14,0.81,0.14,0.86,0.00,
        1.0,0.0,1.06,0.05,1.64,0.00,
        2.10,0.00
FSTTB = 0.00,0.49,
        0.36,0.49,0.51,0.64,0.61,0.71,
        0.71,0.86,0.81,0.86,0.86,0.57,
        1.0,0.0,1.06,0.00,1.64,0.00,
        2.10,0.00
FSOTB = 0.00,0.00,
        0.36,0.00,0.51,0.00,0.61,0.00,
        0.71,0.00,0.81,0.00,0.86,0.43,
        1.0,1.0,1.06,0.95,1.64,1.00,
        2.10,1.00


****************************************
* R.N. Dash & K.S. Rao, Cuttack, India
* dry season, 1990
* variety:   IR 36
* treatment: 150 KG N/HA
****************************************
TREATM='RAO, 1990, IR36, 150 kg N/ha'

* dummy initialisation
RADTOI = 0.

DATH   = 93.
DTRP   = 38.
FGHDAY = 70.0
WLVGI = 32.0
WSTSI = 48.0
WRTLI = 44.0
*FNSTI = 0.02
FNLVI = 0.025
*FNRTI = 0.01
DVSI  = 0.32
TSI   = 497.50
FSTR  = 0.42
*RGRL  =
DVRV  = 6.2E-04
DVRR  = 2.4E-03
*NS   = 6
*DNOST = 45.,75.,95.,105.,117.,125.
*NTOTMT= 30.10,157.54,160.79,160.81,
        181.41,181.41
NS    = 5
DNOST = 45.,75.,95.,105.,117.
NTOTMT= 30.10,157.54,160.79,160.81,
       181.41,181.41
NA    = 5
DNAPT = 1.,25.,45.,78.,365.
*DNAPT = 352.,391.,411.,444.,600.

* NOTE first value of NSO is dummy
*      first two values of WSO are dummy's
*      last value of W/NLV, W/NST, W/NRT,
W/NSO are dummy's
WLVG_OBS =
1989.,352., 32.,
1990.,25.,  32.,
1990.,45.,  366.,
1990.,55.,  872.,
1990.,65., 1576.,
1990.,75., 1898.,
1990.,95., 1789.,
1990.,105.,1589.,
1990.,117.,1485.,
1990.,120.,1485.

WLVG_TRG = 1900.,1.,0.,
```

```
         2000.,1.,0.

WLVG_FRC = 0

WSTS_OBS =
1989.,352., 48.,
1990.,25.,  48.,
1990.,45.,  341.,
1990.,55., 1023.,
1990.,65., 2585.,
1990.,75., 4202.,
1990.,95., 5702.,
1990.,105.,3340.,
1990.,117.,3303.,
1990.,120.,3303.

WSTS_TRG = 1900.,1.,0.,
         2000.,1.,0.

WSTS_FRC = 0

WRTL_OBS =
1989.,352., 44.,
1990.,25.,  44.,
1990.,45.,  333.,
1990.,55.,  561.,
1990.,65., 1078.,
1990.,75., 1317.,
1990.,95.,  825.,
1990.,105., 932.,
1990.,117., 899.,
1990.,120., 899.

WRTL_TRG = 1900.,1.,0.,
         2000.,1.,0.

WRTL_FRC = 0

WSO_OBS  =
1989.,352.,    0.,
1990., 25.,    0.,
1990., 89.,    0.,
1990., 95.,2467.,
1990.,105.,5156.,
1990.,117.,7326.,
1990.,120.,7326.

WSO_TRG = 1900.,1.,0.,
         1990.,30.,2.,
         1990.,50.,2.,
         2000.,1.,0.

WSO_FRC = 0

WLVD_OBS = 1900.,1.,0.,
         2000.,1.,0.
WLVD_TRG = 1900.,1.,0.,
         2000.,1.,0.
WLVD_FRC = 0

ANST_OBS =
1989.,352., 1.05,
1990.,25.,  1.05,
1990.,45.,  6.21,
1990.,75., 75.22,
1990.,95., 64.43,
1990.,105.,30.39,
1990.,117.,30.10,
1990.,120.,30.10

ANST_TRG = 1900.,1.,0.,
         2000.,1.,0.

ANST_FRC = 0

ANLV_OBS =
1989.,352., 0.80,
1990.,25.,  0.80,
1990.,45., 18.67,
1990.,75., 64.15,
1990.,95., 39.18,
1990.,105.,38.14,
1990.,117.,35.64,
1990.,120.,35.64

ANLV_TRG = 1900.,1.,0.,
         2000.,1.,0.

ANLV_FRC = 0

ANRT_OBS =
1989.,352., 0.70,
1990.,25.,  0.70,
1990.,45.,  5.23,
1990.,75., 18.17,
1990.,95.,  8.09,
1990.,105., 9.79,
1990.,117., 9.44,
1990.,120., 9.44

ANRT_TRG = 1900.,1.,0.,
         2000.,1.,0.

ANRT_FRC = 0

ANSO_OBS =
1989., 352.,  0.00,
1990.,  25.,  0.00,
1990., 89.,   0.,
1990.,  95., 49.09,
1990., 105., 82.50,
1990., 117.,106.23,
1990., 120.,106.23

ANSO_TRG = 1900.,1.,0.,
         2000.,1.,0.

ANSO_FRC = 0

ANLD_OBS = 1900.,1.,0.,
          2000.,1.,0.
ANLD_TRG = 1900.,1.,0.,
          2000.,1.,0.
ANLD_FRC = 0

* Dummy values or LAI
LAI_OBS = 1900.,1.,0.,
        2000.,1.,0.
LAI_TRG = 1900.,1.,0.,
        2000.,1.,0.
LAI_FRC = 0

* NOTE first and last values are dummy's
FSHTB = 0.00,0.68,
        0.36,0.68,0.51,0.84,0.61,0.81,
        0.71,0.89,0.86,1.00,1.06,0.96,
        1.64,1.00,2.10,1.00
FLVTB = 0.00,0.53,
        0.36,0.53,0.51,0.43,0.61,0.31,
        0.71,0.17,0.81,0.17,0.86,0.00,
        1.0,0.0,1.06,0.00,1.64,0.00,
        2.10,0.00
FSTTB = 0.00,0.47,
        0.36,0.47,0.51,0.57,0.61,0.69,
        0.71,0.83,0.81,0.83,0.86,0.38,
        1.0,0.0,1.06,0.00,1.64,0.00,
        2.10,0.00
FSOTB = 0.00,0.00,
        0.36,0.00,0.51,0.00,0.61,0.00,
        0.71,0.00,0.81,0.00,0.86,0.62,
        1.0,1.0,1.06,1.00,1.64,1.00,
        2.10,1.00
```

Data sets for validation of ORYZA_0

```
**************************************
* R.N. Dash & K.S. Rao, Cuttack, India
* dry season, 1990
* variety:  IR 36
* treatment: 0 KG N/HA
**************************************
TREATM='RAO, 1990, IR36, 0 kg N/ha'

* dummy variables
DVSI = 0.
TBD  = 0.
TBLV = 0.

* Initial constants
```

```
* -----------------
WCRI   = 124.0
ANCRI  = 2.55
RADTOI = 0.
APCUMI = 0.
DVSI   = 0.

* Model parameters
* ----------------
RTINCL = 1
DATFSV = 74.
DATEF  = 74.
*Flowering is at 74 DAT, DATFF is 74-7
DATFF  = 67.
DATH   = 93.
FSV1   = 0.87
FSV2   = 0.87
FNSO   = 0.01
FNCLV  = 0.50
ANLVMX = 100.
MAXUP1 = 5.
RUR    = 0.2
NUPCO  = 0.03
HI     = 0.5
SOLSUP = 0.6
FERTMX = 200.
A      = 1.
B      = 0.1
C      = 300.
M      = 30.
LARGE  = 100.
TINY   = 0.001

* AFGEN functions
* ---------------
FNMAXT =
   0., 0.03,
   40., 0.017,
   60., 0.015,
   80., 0.01,
   130., 0.07

RECT   =
   0., 0.0,
   60., 0.8,
   65., 0.4,
   70., 0.0,
   150., 0.

RSRT   =
    0., 0.4,
   1.1, 0.15

* Observed values
* ---------------

WLV_OBS =
1989.,352.,  32.,
1990., 25.,  32.,
1990., 45., 272.,
1990., 55., 440.,
1990., 65., 679.,
1990., 75., 872.,
1990., 95., 754.,
1990.,105., 761.,
1990.,117., 776.,
1990.,120., 776.

WCR_OBS =
1989.,352.,  124.0,
1990., 25.,  124.0,
1990., 45.,  762.0,
1990., 55., 1508.0,
1990., 65., 2725.0,
1990., 75., 3894.0,
1990., 95., 5511.0,
1990.,105., 6145.0,
1990.,117., 7747.0,
1990.,120., 7747.0

FNLV_OBS =
1989.,352., 2.50,
1990., 25., 2.50,
1990., 45., 4.88,
1990., 75., 2.25,
1990., 95., 1.79,
1990.,105., 1.42,
1990.,117., 1.42,
1990.,120., 1.42

***************************************
* R.N. Dash & K.S. Rao, Cuttack, India
* dry season, 1990
* variety:   IR 36
* treatment: 50 KG N/HA
***************************************
TREATM='RAO, 1990, IR36, 50 kg N/ha'

* dummy variables
DVSI = 0.
TBD  = 0.
TBLV = 0.

* Initial constants
* -----------------
WCRI   = 124.0
ANCRI  = 2.55
RADTOI = 0.
APCUMI = 0.
DVSI   = 0.

* Model parameters
* ----------------
RTINCL = 1
DATFSV = 74.
DATEF  = 74.
*Flowering is at 74 DAT, DATFF is 74-7
DATFF  = 67.
DATH   = 93.
FSV1   = 0.87
FSV2   = 0.87
FNSO   = 0.01
FNCLV  = 0.50
ANLVMX = 100.
MAXUP1 = 5.
RUR    = 0.2
NUPCO  = 0.03
HI     = 0.5
SOLSUP = 0.6
FERTMX = 200.
A      = 1.
B      = 0.1
C      = 300.
M      = 30.
LARGE  = 100.
TINY   = 0.001

* AFGEN functions
* ---------------
FNMAXT =
   0., 0.03,
   40., 0.017,
   60., 0.015,
   80., 0.01,
   130., 0.07

RECT   =
   0., 0.0,
   60., 0.8,
   65., 0.4,
   70., 0.0,
   150., 0.

RSRT   =
    0., 0.4,
   1.1, 0.15

* Observed values
* ---------------

WLV_OBS =
1989.,352.,  32.,
1990.,25.,   32.,
1990.,45.,  270.,
1990.,55.,  528.,
1990.,65.,  888.,
1990.,75., 1202.,
1990.,95.,  998.,
1990.,105.,1058.,
```

```
1990.,117.,1064.,
1990.,120.,1064.

WCR_OBS =
1989.,352.,   124.0,
1990., 25.,   124.0,
1990., 45.,   796.0,
1990., 55.,  1860.0,
1990., 65.,  3397.0,
1990., 75.,  5195.0,
1990., 95.,  7125.0,
1990.,105.,  8821.0,
1990.,117., 11054.0,
1990.,120., 11054.0

FNLV_OBS =
1989.,352., 2.50,
1990., 25., 2.50,
1990., 45., 4.22,
1990., 75., 2.80,
1990., 95., 2.15,
1990.,105., 1.71,
1990.,117., 1.71,
1990.,120., 1.71


***************************************
* R.N. Dash & K.S. Rao, Cuttack, India
* dry season, 1990
* variety:   IR 36
* treatment: 100 KG N/HA
***************************************
TREATM='RAO, 1990, IR36, 100 kg N/ha'

* dummy variables
DVSI = 0.
TBD  = 0.
TBLV = 0.

* Initial constants
* -----------------
WCRI   = 124.0
ANCRI  = 2.55
RADTOI = 0.
APCUMI = 0.
DVSI   = 0.

* Model parameters
* ----------------
RTINCL = 1
DATFSV = 74.
DATEF  = 74.
*Flowering is at 74 DAT, DATFF is 74-7
DATFF  = 67.
DATH   = 93.
FSV1   = 0.87
FSV2   = 0.87
FNSO   = 0.01
FNCLV  = 0.50
ANLVMX = 100.
MAXUP1 = 5.
RUR    = 0.2
NUPCO  = 0.03
HI     = 0.5
SOLSUP = 0.6
FERTMX = 200.
A      = 1.
B      = 0.1
C      = 300.
M      = 30.
LARGE  = 100.
TINY   = 0.001

* AFGEN functions
* ---------------
FNMAXT =
   0., 0.03,
   40., 0.017,
   60., 0.015,
   80., 0.01,
   130., 0.07

RECT   =
   0., 0.0,
   60., 0.8,
   65., 0.4,
   70., 0.0,
   150., 0.

RSRT   =
    0., 0.4,
   1.1, 0.15

* Observed values
* ---------------

WLV_OBS =
1989.,352., 32.,
1990.,25.,  32.,
1990.,45.,  333.,
1990.,55.,  726.,
1990.,65., 1292.,
1990.,75., 1537.,
1990.,95., 1340.,
1990.,105.,1555.,
1990.,117.,1191.,
1990.,120.,1191.

WCR_OBS =
1989.,352.,  124.0,
1990.,25.,   124.0,
1990.,45.,   957.0,
1990.,55.,  2307.0,
1990.,65.,  4702.0,
1990.,75.,  6638.0,
1990.,95.,  8920.0,
1990.,105.,10972.0,
1990.,117.,12278.0,
1990.,120.,12278.0

FNLV_OBS =
1989.,352., 2.50,
1990., 25., 2.50,
1990., 45., 4.51,
1990., 75., 2.73,
1990., 95., 2.11,
1990.,105., 1.71,
1990.,117., 1.71,
1990.,120., 1.71


***************************************
* R.N. Dash & K.S. Rao, Cuttack, India
* dry season, 1990
* variety:   IR 36
* treatment: 150 KG N/HA
***************************************
TREATM='RAO, 1990, IR36, 150 kg N/ha'

* dummy variables
DVSI = 0.
TBD  = 0.
TBLV = 0.

* Initial constants
* -----------------
WCRI   = 124.0
ANCRI  = 2.55
RADTOI = 0.
APCUMI = 0.
DVSI   = 0.

* Model parameters
* ----------------
RTINCL = 1
DATFSV = 74.
DATEF  = 74.
*Flowering is at 74 DAT, DATFF is 74-7
DATFF  = 67.
DATH   = 93.
FSV1   = 0.87
FSV2   = 0.87
FNSO   = 0.01
FNCLV  = 0.50
ANLVMX = 100.
MAXUP1 = 5.
RUR    = 0.2
NUPCO  = 0.03
HI     = 0.5
SOLSUP = 0.6
```

```
FERTMX = 200.
A      = 1.
B      = 0.1
C      = 300.
M      = 30.
LARGE  = 100.
TINY   = 0.001

* AFGEN functions
* ---------------
FNMAXT =
   0., 0.03,
   40., 0.017,
   60., 0.015,
   80., 0.01,
   130., 0.07

RECT   =
   0., 0.0,
   60., 0.8,
   65., 0.4,
   70., 0.0,
   150., 0.

RSRT   =
    0., 0.4,
   1.1, 0.15

* Observed values
* ---------------

WLV_OBS =
1989.,352., 32.,
1990.,25.,  32.,
1990.,45.,  366.,
1990.,55.,  872.,
1990.,65., 1576.,
1990.,75., 1898.,
1990.,95., 1789.,
1990.,105.,1589.,
1990.,117.,1485.,
1990.,120.,1485.

WCR_OBS =
1989.,352.,    124.0,
1990., 25.,    124.0,
1990., 45.,   1040.0,
1990., 55.,   2456.0,
1990., 65.,   5239.0,
1990., 75.,   7417.0,
1990., 95.,  10783.0,
1990.,105.,  11017.0,
1990.,117.,  13013.0,
1990.,120.,  13013.0

FNLV_OBS =
1989.,352., 2.50,
1990., 25., 2.50,
1990., 45., 5.10,
1990., 75., 3.38,
1990., 95., 2.19,
1990.,105., 2.40,
1990.,117., 2.40,
1990.,120., 2.40
```

IRRI, Los Baños, Philippines, 1990-1991
Experimental data from: L. Bastiaans

General information:

variety: IR 50
year: 1990-1991

	Calendar date	DOY	DAT
seeding	23 Nov,90	327	
transplanting	5 Dec,90	339	0
flowering	6 Feb,91	402	63
harvest	9 Mar,91	433	93

DAT= days after transplanting, DOY= day of the year

Nitrogen application scheme:

Calendar date	DOY	DAT	Quantity applied (kg N /ha)
5 Dec	339	0	60
27 Dec	361	22	30
23 Jan	388	49	20
31 Jan	396	57	20

DAT= days after transplanting, DOY= day of the year

Data sets for validation of ORYZA_N

```
*****************************************
* L. Bastiaans, IRRI, Los Banos, Philippines
* 1990/1991, wetland site
* variety:   IR 50
* treatment: PLOT 1
*****************************************
TREATM = 'BASTIAANS, IRRI, IR50, PLOT 1,
1990/1991'
* in DAT
* dummy initialisation
RADTOI = 0.

DATH   = 93.
DTRP   = 12.
FGHDAY = 63.0
WLVGI  = 47.5
WSTSI  = 30.8
WRTLI  = 12.75
* based on the maximum values at DVS=0.4
*FNSTI = 0.03
FNLVI = 0.05
*FNRTI = 0.013
DVSI   = 0.173
TSI    = 213.9
FSTR   = 0.25
* RGRL  = 0.152
DVRV   = 0.000807
DVRR   = 0.001901
SLAC   = 0.0027
SLAFAC = 0.0,1.63,
         0.303,1.63,0.390,1.44,0.488,
         1.09,0.533,0.95,0.589,1.29,
         0.646,1.26,0.716,1.17,0.800,
         1.14,0.896,1.09,1.011,1.00,
         1.330,0.82,1.562,0.69,1.783,
         0.62,2.011,0.54
* based on green leaf
*LAILNT = 229.95,-1.82,336.45,-1.06,457.05,
*          0.15,511.05,0.64,580.1 , 1.30,
*          650.75, 1.49,737.00,1.67,841.40,
*          1.90,960.75, 2.04,1101.6, 2.01,
*          1263.6,1.75,1383.1,1.49,1499.3,
*          1.27,1619.3, 1.03,1739.4,1.03

* based on green leaf
WLVG_OBS =
1990., 327.,   47.5,
1990., 339.,   47.5,
1990., 352.,  36.54,
1990., 358.,  88.00,
1990., 365., 391.05,
1991.,   3., 733.80,
1991.,   7.,1042.84,
1991.,  11.,1284.64,
1991.,  16.,1681.50,
1991.,  22.,2170.50,
1991.,  29.,2581.48,
1991.,  37.,2734.56,
1991.,  46.,2582.72,
1991.,  53.,2387.44,
1991.,  60.,2119.68,
1991.,  67.,1904.25,
1991.,  74.,1904.25

WLVG_TRG = 1900.,1.,0.,
           2000.,1.,0.

WLVG_FRC = 0

WSTS_OBS =
1990., 327.,  30.8,
1990., 339.,  30.8,
1990., 352.,  26.46,
1990., 358.,  72.00,
1990., 365., 319.95,
1991.,   3., 489.20,
1991.,   7., 755.16,
1991.,  11.,1009.36,
1991.,  16.,1681.50,
1991.,  22.,2170.50,
1991.,  29.,3285.52,
1991.,  37.,4481.64,
1991.,  46.,4058.56,
1991.,  53.,3472.64,
1991.,  60.,3415.04,
1991.,  67.,3427.65,
1991.,  74.,3427.65

WSTS_TRG = 1900.,1.,0.,
           2000.,1.,0.

WSTS_FRC = 0

WRTL_OBS = 1900.,1.,0.,
           2000.,1.,0.
WRTL_TRG = 1900.,1.,0.,
           2000.,1.,0.
WRTL_FRC = 0

WSO_OBS  =
1990., 327.,   0.00,
1990., 339.,   0.00,
1990., 352.,   0.00,
1990., 358.,   0.00,
1990., 365.,   0.00,
1991.,   3.,   0.00,
1991.,   7.,   0.00,
1991.,  11.,   0.00,
1991.,  16.,   0.00,
1991.,  22.,   0.00,
1991.,  29.,   0.00,
1991.,  37., 379.80,
1991.,  46.,2582.72,
1991.,  53.,4991.92,
1991.,  60.,6241.28,
1991.,  67.,7363.10,
1991.,  74.,7363.10

WSO_TRG = 1900.,1.,0.,
          1989.,30.,2.,
          1989.,50.,2.,
          2000.,1.,0.

WSO_FRC = 0

* Dummy values or ANLD
WLVD_OBS = 1900.,1.,0.,
          2000.,1.,0.
WLVD_TRG = 1900.,1.,0.,
          2000.,1.,0.
WLVD_FRC = 0


ANLV_OBS =
1990.,327.,  2.38,
1990.,339.,  2.38,
1990.,352.,  1.94,
1990.,358.,  4.93,
1990.,365., 20.53,
1991.,  3., 37.86,
1991.,  7., 49.33,
1991., 11., 58.07,
1991., 16., 78.19,
1991., 22., 85.52,
1991., 29.,111.26,
1991., 37.,108.29,
1991., 46., 92.98,
1991., 53., 79.02,
1991., 60., 62.95,
1991., 67., 48.37,
1991., 74., 48.37

ANLV_TRG = 1900.,1.,0.,
           2000.,1.,0.
ANLV_FRC = 0

* N amount in stems in kg/ha versus DAT
ANST_OBS =
1990., 327., 33.0,
1990., 339., 33.0,
1991.,  22., 33.0,
1991.,  29., 56.7,
1991.,  37., 65.9,
1991.,  46., 58.1,
1991.,  53., 39.7,
1991.,  60., 33.8,
1991.,  67., 26.8,
```

```
1991.,  74., 26.8

ANST_TRG = 1900.,1.,0.,
         2000.,1.,0.

ANST_FRC = 0

* N amount in storage organs in kg/ha versus
DAT
ANSO_OBS =
1990., 327.,  0.0,
1990., 339.,  0.0,
1991.,  22.,  0.0,
1991.,  29.,  0.0,
1991.,  37.,  5.8,
1991.,  46., 39.2,
1991.,  53., 73.6,
1991.,  60., 95.1,
1991.,  67.,111.6,
1991.,  74.,111.6

ANSO_TRG = 1900.,1.,0.,
         2000.,1.,0.

ANSO_FRC = 0


ANRT_OBS = 1900.,1.,0.,
           2000.,1.,0.
ANRT_TRG = 1900.,1.,0.,
           2000.,1.,0.
ANRT_FRC = 0


ANLD_OBS = 1900.,1.,0.,
           2000.,1.,0.
ANLD_TRG = 1900.,1.,0.,
           2000.,1.,0.
ANLD_FRC = 0


* Dummy values or LAI
LAI_OBS = 1900.,1.,0.,
         2000.,1.,0.
LAI_TRG = 1900.,1.,0.,
         2000.,1.,0.
LAI_FRC = 0


* first and last values are dummy's
FLVTB  =  0.,0.53,0.303,0.53,
         0.347,0.53,0.439,0.55,0.511,0.67,
         0.561,0.54,0.618,0.49,0.681,0.37,
         0.758,0.50,0.848,0.27,0.954,0.09,
         1.171,0.00,1.446,0.00,1.673,0.00,
         1.897,0.00,2.10,0.00
FSTTB  =  0.,0.47,0.303,0.47,
         0.347,0.47,0.439,0.45,0.511,0.33,
         0.561,0.46,0.618,0.51,0.681,0.63,
         0.758,0.50,0.848,0.73,0.954,0.69,
         1.171,0.00,1.446,0.00,1.673,0.00,
         1.897,0.01,2.10,0.00
FSOTB  =  0.,0.00,0.303,0.00,
         0.347,0.00,0.439,0.00,0.511,0.00,
         0.561,0.00,0.618,0.00,0.681,0.00,
         0.758,0.00,0.848,0.00,0.954,0.22,
         1.171,1.00,1.446,1.00,1.673,1.00,
         1.897,0.99,2.10,1.00

* Penning de Vries et al, 1989
FSHTB  = 0.0,0.86,0.5,0.86,0.6,0.86,0.7,
         0.95,0.8,0.94,1.0,0.89,1.1,1.00,
         2.10,1.00


NA = 5
DNAPT  = 327.,339.,361.,388.,396.,
         432.
NS = 7
DNOST  = 387.,394.,402.,411.,418.,425.,
         432.
NTOTMT = 115.7,164.7,179.3,184.3,180.9,
         178.1,174.9
```

```
****************************************
* L. Bastiaans, IRRI, Los Banos, Philippines
* 1990/1991, wetland site
* variety:   IR 50
* treatment: PLOT 5
****************************************
TREATM = 'BASTIAANS, IRRI, IR50, PLOT 5,
1990/1991'

* dummy initialisation
RADTOI = 0.

DATH   = 93.
DTRP   = 12.
FGHDAY = 63.0
WLVGI  = 47.5
WSTSI  = 30.8
WRTLI  = 12.75
* based on the maximum values at DVS=0.4
*FNSTI = 0.03
FNLVI = 0.05
*FNRTI = 0.013
DVSI   = 0.173
TSI    = 213.9
FSTR   = 0.25
* RGRL  = 0.127
DVRV   = 0.000807
DVRR   = 0.001901
SLAC   = 0.0027
SLAFAC = 0.000,1.80,
         0.303,1.80,0.390,1.30,0.488,
         1.24,0.533,0.93,0.589,1.29,
         0.646,1.24,0.716,1.15,0.800,
         1.06,0.896,1.18,1.011,1.00,
         1.330,0.80,1.562,0.65,1.783,
         0.60,2.011,0.44

* based on green leaf
*LAILNT = 229.95,-1.15,336.45,-0.64,
*          457.05,0.48,511.05,0.68,
*          580.10, 1.21,650.75, 1.37,
*          737.00,1.54,841.40,1.72,
*          960.75, 2.08,1101.6, 1.90,
*          1263.6,1.63,1383.1,1.39,
*          1499.3, 1.19,1619.3, 0.82,
*          1739.4,0.82

* based on green leaf
WLVG_OBS =
1990., 327.,  47.50,
1990., 339.,  47.50,
1990., 352.,  66.00,
1990., 358., 153.12,
1990., 365., 492.00,
1991.,   3., 798.56,
1991.,   7., 976.64,
1991.,  11.,1189.62,
1991.,  16.,1531.02,
1991.,  22.,1986.22,
1991.,  29.,2556.84,
1991.,  37.,2501.38,
1991.,  46.,2389.14,
1991.,  53.,2324.52,
1991.,  60.,2073.60,
1991.,  67.,1946.72,
1991.,  74.,1946.72

WLVG_TRG = 1900.,1.,0.,
          2000.,1.,0.

WLVG_FRC = 0


WSTS_OBS =
1990., 327.,  30.80,
1990., 339.,  30.80,
1990., 352.,  44.00,
1990., 358., 110.88,
1990., 365., 328.00,
1991.,   3., 489.44,
1991.,   7., 767.36,
1991.,  11.,1013.38,
1991.,  16.,1470.98,
1991.,  22.,2239.78,
1991.,  29.,3254.16,
```

```
1991.,  37.,4267.06,
1991.,  46.,4043.16,
1991.,  53.,3803.76,
1991.,  60.,3456.00,
1991.,  67.,3285.09,
1991.,  74.,3285.09

WSTS_TRG = 1900.,1.,0.,
          2000.,1.,0.

WSTS_FRC = 0

WRTL_OBS = 1900.,1.,0.,
           2000.,1.,0.
WRTL_TRG = 1900.,1.,0.,
           2000.,1.,0.
WRTL_FRC = 0


WSO_OBS  =
1990., 327.,   0.00,
1990., 339.,   0.00,
1990., 352.,   0.00,
1990., 358.,   0.00,
1990., 365.,   0.00,
1991.,   3.,   0.00,
1991.,   7.,   0.00,
1991.,  11.,   0.00,
1991.,  16.,   0.00,
1991.,  22.,   0.00,
1991.,  29.,   0.00,
1991.,  37., 514.99,
1991.,  46.,2848.59,
1991.,  53.,4543.38,
1991.,  60.,5990.40,
1991.,  67.,6935.19,
1991.,  74.,6935.19

WSO_TRG = 1900.,1.,0.,
          1989.,30.,2.,
          1989.,50.,2.,
          2000.,1.,0.

WSO_FRC = 0

* Dummy values or ANLD
WLVD_OBS = 1900.,1.,0.,
          2000.,1.,0.
WLVD_TRG = 1900.,1.,0.,
          2000.,1.,0.
WLVD_FRC = 0


ANLV_OBS   =
1990.,327.,  2.38,
1990.,339.,  2.38,
1990.,352.,  3.43,
1990.,358.,  8.36,
1990.,365., 25.63,
1991.,  3., 39.85,
1991.,  7., 43.56,
1991., 11., 51.39,
1991., 16., 67.06,
1991., 22., 73.89,
1991., 29.,106.36,
1991., 37., 87.05,
1991., 46., 82.43,
1991., 53., 76.01,
1991., 60., 60.13,
1991., 67., 47.69,
1991., 74., 47.69

ANLV_TRG = 1900.,1.,0.,
          2000.,1.,0.

ANLV_FRC = 0


* N amount in stems in kg/ha versus DAT
ANST_OBS   =
1990., 327.,31.0,
1990., 339.,31.0,
1991.,  22.,31.0,
1991.,  29.,54.3,
1991.,  37.,57.4,
1991.,  46.,51.1,
1991.,  53.,42.0,
1991.,  60.,28.3,
1991.,  67.,23.6,
1991.,  74.,23.6

ANST_TRG = 1900.,1.,0.,
          2000.,1.,0.

ANST_FRC = 0


* N amount in storage organs in kg/ha versus
DAT
ANSO_OBS   =
1990., 327.,  0.0,
1990., 339.,  0.0,
1991.,  22.,  0.0,
1991.,  29.,  0.0,
1991.,  37.,  7.4,
1991.,  46., 42.3,
1991.,  53., 69.6,
1991.,  60., 88.6,
1991.,  67.,100.7,
1991.,  74.,100.7

ANSO_TRG = 1900.,1.,0.,
          2000.,1.,0.

ANSO_FRC = 0


ANRT_OBS = 1900.,1.,0.,
           2000.,1.,0.
ANRT_TRG = 1900.,1.,0.,
           2000.,1.,0.
ANRT_FRC = 0


ANLD_OBS = 1900.,1.,0.,
           2000.,1.,0.
ANLD_TRG = 1900.,1.,0.,
           2000.,1.,0.
ANLD_FRC = 0


* Dummy values or LAI
LAI_OBS = 1900.,1.,0.,
          2000.,1.,0.
LAI_TRG = 1900.,1.,0.,
          2000.,1.,0.
LAI_FRC = 0


* first and last values are dummy's
FLVTB  =  0.,0.57,0.303,0.57,
         0.347,0.57,0.439,0.61,0.511,0.66,
         0.561,0.39,0.618,0.46,0.681,0.43,
         0.758,0.37,0.848,0.36,0.954,0.00,
         1.171,0.00,1.446,0.00,1.673,0.00,
         1.897,0.00,2.10,0.00
FSTTB  =  0.,0.43,0.303,0.43,
         0.347,0.43,0.439,0.39,0.511,0.34,
         0.561,0.61,0.618,0.54,0.681,0.57,
         0.758,0.63,0.848,0.64,0.954,0.66,
         1.171,0.00,1.446,0.00,1.673,0.00,
         1.897,0.00,2.10,0.00
FSOTB  =  0.,0.00,0.303,0.00,
         0.347,0.00,0.439,0.00,0.511,0.00,
         0.561,0.00,0.618,0.00,0.681,0.00,
         0.758,0.00,0.848,0.00,0.954,0.34,
         1.171,1.00,1.446,1.00,1.673,1.00,
         1.897,1.00,2.10,1.00

* Penning de Vries et al, 1989
FSHTB  = 0.0,0.86,0.5,0.86,0.6,0.86,0.7,
         0.95,0.8,0.94,1.0,0.89,1.1,1.00,
         2.10,1.00

NA = 5
DNAPT  = 327.,339.,361.,388.,396.,432.
NS = 7
DNOST  = 387.,394.,402.,411.,418.,425.,432.
NTOTMT = 100.8,154.5,148.6,165.0,171.2,159.
         8,156.7
```

IRRI, Los Baños, Philippines, 1991

Experimental data from: M.J. Kropff, K.G. Cassman, S. Liboon, R. Torres

General information:

year: 1991

variety: LINE

	Calendar date	DOY	DAT
seeding	1 Jul	182	
transplanting	13 Jul	194	0
panicle initiation	6 Sep	249	55
flowering	6 Oct	279	85
harvest	20 Oct	302	108

DAT= days after transplanting, DOY= day of the year

variety: IR72

	Calendar date	DOY	DAT
seeding	1 Jul	182	
transplanting	13 Jul	194	0
panicle initiation	28 Aug	241	46
flowering	18 Sep	261	67
harvest	15 Oct	288	94

DAT= days after transplanting, DOY= day of the year

Nitrogen application scheme:

Calendar date	DOY	N Treatment (kg N/ha)		
		0	80	110
12 Jul	193	-	50	30
12 Aug	224	-	30	-
06 Aug	218	-	-	30
10 Sept	253	-	-	20
03 Oct	276	-	-	30

DAT= days after transplanting, DOY= day of the year

Data sets for validation of ORYZA_N

```
****************************************
* R. Torres, IRRI, The Philippines
* 1991
* variety:   IR72
* treatment: 0 KG/HA
****************************************
TREATM = 'IRRI, 1991, IR72, 0 kg/ha N'

* dummy initialisation
RADTOI = 0.

DATH   = 94.
DTRP   = 12.
FGHDAY = 67.
WLVGI =  8.5
WSTSI =  7.5
WRTLI = 16.0
*FNSTI = 0.01890
FNLVI = 0.03020
*FNRTI = 0.01890
DVSI  = 0.167
TSI   = 242.1
FSTR  = 0.20
* RGRL  = 0.0060
DVRV  = 0.000689
DVRR  = 0.001895
NS    = 9
DNOST  = 194.,202.,211.,219.,241.,254.,
         261.,273.,288.
NTOTMT = 0.40,1.74,4.21,11.73,31.08,34.03,
         35.67,37.72,45.66
NA    = 3
DNAPT  = 180.,193.,296.
* first and last values are dummy's
SLAC   = 0.0019
SLAFAC = 0.0,1.85,0.167,1.85,0.222,1.43,
         0.34,1.24,0.446,1.45,
         0.735,1.06,0.913,0.97,1.011,1.00,
         1.457,1.02,2.011,0.90,2.1,0.90

** OBSERVED VALUES
WSTS_OBS =
1991., 180.,    7.5,
1991., 194.,    7.5,
1991., 202.,   20.0,
1991., 211.,   52.0,
1991., 219.,  173.3,
1991., 240.,1056.5,
1991., 254.,2469.8,
1991., 261.,2937.8,
1991., 273.,2273.5,
1991., 288.,1851.0

WSTS_TRG = 1900.,1.,0.,
           2000.,1.,0.

WSTS_FRC = 0

WLVG_OBS =
1991., 180., 8.5,
1991., 194., 8.5,
1991., 202.,   29.3,
1991., 211.,   76.0,
1991., 219.,  220.8,
1991., 240.,  944.8,
1991., 254.,1175.8,
1991., 261.,1099.0,
1991., 273.,  761.8,
1991., 288.,  390.5

WLVG_TRG = 1900.,1.,0.,
           2000.,1.,0.

WLVG_FRC = 0

WLVD_OBS =
1991., 180.,    0.0,
1991., 240.,    0.0,
1991., 254.,  287.0,
1991., 261.,  498.0,
1991., 273.,  659.0,
1991., 288.,1510.0

WLVD_TRG = 1900.,1.,0.,
           2000.,1.,0.
WLVD_FRC = 0

WRTL_OBS =
1991., 180.,0.,
1991., 288.,0.

WRTL_TRG = 1900.,1.,0.,
           2000.,1.,0.

WRTL_FRC = 0

WSO_OBS =
1991., 180.,    0.0,
1991., 194.,    0.0,
1991., 254.,    0.0,
1991., 261.,  635.8,
1991., 273.,2481.8,
1991., 288.,3857.5

WSO_TRG = 1900.,1.,0.,
          1989.,30.,2.,
          1989.,50.,2.,
          2000.,1.,0.

WSO_FRC = 0

WTDM_OBS =
1991., 180.,   16.0,
1991., 194.,   16.0,
1991., 202.,   49.3,
1991., 211.,  128.0,
1991., 219.,  394.0,
1991., 240.,2001.3,
1991., 254.,3932.5,
1991., 261.,5170.5,
1991., 273.,6176.0,
1991., 288.,7609.0

WTDM_TRG = 1900.,1.,0.,
           1989.,30.,2.,
           1989.,50.,2.,
           2000.,1.,0.

WTDM_FRC = 0

*XNLV = 180.0,3.02,
*       194.0,3.02,202.0,4.14,211.0,3.88,
*       219.0,3.73,241.0,2.32,
*       254.0,1.70,261.0,1.65,
*       273.0,1.40,288.0,1.04

ANST_OBS =
1991., 180.0, 0.14,
1991., 194.0, 0.14,
1991., 202.0, 0.52,
1991., 211.0, 1.26,
1991., 219.0, 3.50,
1991., 241.0, 9.13,
1991., 254.0,14.00,
1991., 261.0,13.51,
1991., 273.0, 9.03,
1991., 288.0, 7.59

ANST_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANST_FRC = 0

ANLV_OBS =
1991., 180.0, 0.26,
1991., 194.0, 0.26,
1991., 202.0, 1.21,
1991., 211.0, 2.95,
1991., 219.0, 8.23,
1991., 241.0,21.95,
1991., 254.0,20.02,
1991., 261.0,18.17,
1991., 273.0,10.63,
1991., 288.0, 4.05

ANLV_TRG = 1900.,1.,0.,
           2000.,1.,0.
```

```
ANLV_FRC = 0

ANRT_OBS =
1991., 180.,0.00,
1991., 194.,0.00,
1991., 288.,0.00

ANRT_TRG = 1900.,1.,0.,
           2000.,1.,0.


ANLD_OBS =
1991., 180.,0.00,
1991., 194.,0.00,
1991., 288.,0.00

ANLD_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANLD_FRC = 0

ANSO_OBS =
1991., 180.0, 0.00,
1991., 194.0, 0.00,
1991., 202.0, 0.00,
1991., 211.0, 0.00,
1991., 219.0, 0.00,
1991., 241.0, 0.00,
1991., 254.0, 0.00,
1991., 261.0, 3.99,
1991., 273.0,18.07,
1991., 288.0,34.02

ANSO_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANSO_FRC = 0

LAI_OBS =
1991., 180.,0.03,
1991., 194.,0.03,
1991., 202.,0.08,
1991., 211.,0.18,
1991., 219.,0.61,
1991., 240.,1.92,
1991., 254.,2.18,
1991., 261.,2.10,
1991., 273.,1.49,
1991., 288.,0.67

LAI_TRG = 1900.,1.,0.,
          2000.,1.,0.
LAI_FRC = 0

FSHTB  = 0.0,0.5,0.43,0.75,1.0,1.0,2.1,1.0

FLVTB = 0.000,0.560,0.193,0.624,0.281,0.594,
        0.393,0.544,0.584,0.450,0.817,0.140,
        0.962,0.000,1.000,0.000,1.234,0.000,
        1.730,0.000,2.1,0.0
FSTTB = 0.000,0.440,0.193,0.376,0.281,0.406,
        0.393,0.456,0.584,0.550,0.817,0.860,
        0.962,0.424,1.000,0.000,1.234,0.000,
        1.730,0.000,2.1,0.0
FSOTB = 0.000,0.000,0.180,0.000,0.817,0.000,
        0.962,0.576,1.000,1.000,1.234,1.000,
        1.730,1.000,2.1,1.0

*XNFLVT = 180.,0.917,
*          194.,0.917,202.,1.442,211.,1.639,
*          219.,1.360,
*          240.,1.144,254.,0.917,261.,0.864,
*          273.,0.659,288.,0.604
SLATB  = 180.,.0033,
         194.,.0033,202.,.0029,211.,.0024,
         219.,.0027,240.,.0020,254.,.0019,
         261.,.0019,273.,.0020,288.,.0017

***************************************
* R. Torres, IRRI, The Philippines
* 1991
* variety:   IR72
* treatment: 110 KG/HA
***************************************
TREATM = 'IRRI, 1991, IR72, 110 kg/ha N'

* dummy initialisation
RADTOI = 0.

DATH   =  94.
DTRP   =  12.
FGHDAY =  67.0
WLVGI =  8.5
WSTSI =  7.5
WRTLI = 16.0
*FNSTI = 0.01890
FNLVI = 0.03020
*FNRTI = 0.01890
DVSI  = 0.167
TSI   = 242.1
FSTR  = 0.20
* RGRL  = 0.0090
DVRV  = 0.000689
DVRR  = 0.001895
NS    = 9
DNOST  = 194.,202.,211.,219.,241.,254.,
         261.,273.,288.
NTOTMT = 0.40,1.02,7.51,19.16,55.46,65.09,
         78.95,86.11,99.67
NA     = 6
DNAPT  = 180.,193.,218.,244.,262.,296.
* first and last values are dummy's
SLAC   = 0.0021
SLAFAC = 0.0,1.67,0.167,1.67,0.34,1.02,
         0.446,1.30,0.735,0.94,0.913,1.04,
         1.011,1.00,1.457,1.03,2.011,0.96,
         2.1,0.96

** OBSERVED VALUES FOR
WSTS_OBS =
1991., 180.,7.5,
1991., 194.,7.5,
1991., 202.,10.0,
1991., 211.,88.5,
1991., 219.,275.8,
1991., 240.,1458.3,
1991., 254.,3208.5,
1991., 261.,3856.3,
1991., 273.,2965.0,
1991., 288.,3119.8

WSTS_TRG = 1900.,1.,0.,
           2000.,1.,0.

WSTS_FRC = 0

WLVG_OBS =
1991., 180.,8.5,
1991., 194.,8.5,
1991., 202.,16.8,
1991., 211.,133.8,
1991., 219.,342.5,
1991., 240.,1503.3,
1991., 254.,1935.3,
1991., 261.,2028.5,
1991., 273.,1564.8,
1991., 288., 892.8

WLVG_TRG = 1900.,1.,0.,
           2000.,1.,0.

WLVG_FRC = 0

WLVD_OBS =
1991., 180.,0.,
1991., 240.,0.,
1991., 254.,296.,
1991., 261.,616.,
1991., 273.,796.,
1991., 288.,1848.

WLVD_TRG = 1900.,1.,0.,
           2000.,1.,0.

WLVD_FRC = 0

WRTL_OBS =
1991., 180.,0.,
1991., 288.,0.
```

```
WRTL_TRG = 1900.,1.,0.,
           2000.,1.,0.

WRTL_FRC = 0

WSO_OBS =
1991., 180.,0.0,
1991., 194.,0.0,
1991., 254.,0.0,
1991., 261.,1002.5,
1991., 273.,3997.0,
1991., 288.,5674.0

WSO_TRG = 1900.,1.,0.,
          1989.,30.,2.,
          1989.,50.,2.,
          2000.,1.,0.

WSO_FRC = 0

WTDM_OBS =
1991., 180.,16.0,
1991., 194.,16.0,
1991., 202.,26.8,
1991., 211.,222.3,
1991., 219.,618.3,
1991., 240.,2961.5,
1991., 254.,5439.,
1991., 261.,7503.,
1991., 273.,9322.5,
1991., 288.,11534.5

WTDM_TRG = 1900.,1.,0.,
           1989.,30.,2.,
           1989.,50.,2.,
           2000.,1.,0.

WTDM_FRC = 0

ANST_OBS =
1991., 180.0, 0.14,
1991., 194.0, 0.14,
1991., 202.0, 0.29,
1991., 211.0, 2.12,
1991., 219.0, 5.76,
1991., 241.0,15.09,
1991., 254.0,24.64,
1991., 261.0,26.34,
1991., 273.0,16.99,
1991., 288.0,18.19

ANST_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANST_FRC = 0

ANLV_OBS =
1991., 180.0, 0.26,
1991., 194.0, 0.26,
1991., 202.0, 0.73,
1991., 211.0, 5.38,
1991., 219.0,13.40,
1991., 241.0,40.36,
1991., 254.0,40.45,
1991., 261.0,42.29,
1991., 273.0,27.99,
1991., 288.0,11.24

ANLV_TRG = 1900.,1.,0.,
           2000.,1.,0.
ANLV_FRC = 0

ANRT_OBS =
1991., 180.,0.00,
1991., 194.,0.00,
1991., 288.,0.00

ANRT_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANRT_FRC = 0

ANSO_OBS =
1991., 180.0, 0.00,
1991., 194.0, 0.00,
1991., 202.0, 0.00,
1991., 211.0, 0.00,
1991., 219.0, 0.00,
1991., 241.0, 0.00,
1991., 254.0, 0.00,
1991., 261.0,10.32,
1991., 273.0,41.13,
1991., 288.0,70.24

ANSO_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANSO_FRC = 0

ANLD_OBS =
1991., 180.,0.00,
1991., 194.,0.00,
1991., 288.,0.00

ANLD_TRG = 1900.,1.,0.,
           2000.,1.,0.
ANLD_FRC = 0

LAI_OBS =
1991., 180.,0.03,
1991., 194.,0.03,
1991., 202.,0.15,
1991., 211.,0.29,
1991., 219.,0.94,
1991., 240.,3.00,
1991., 254.,4.27,
1991., 261.,4.29,
1991., 273.,3.42,
1991., 288.,1.81

LAI_TRG = 1900.,1.,0.,
          2000.,1.,0.
LAI_FRC = 0

FSHTB  = 0.0,0.5,0.43,0.75,1.0,1.0,2.1,1.0

FLVTB = 0.0,0.56, 0.193,0.767, 0.281,0.598,
       0.393,0.527,0.584,0.495, 0.817,0.198,
        0.962,0.053,1.000,0.000,1.234,0.0,
        1.73,0.0, 2.1,0.0
FSTTB = 0.0,0.44, 0.193,0.233, 0.281,0.402,
        0.393,0.473, 0.584,0.505,
        0.817,0.802,0.962,0.372,1.000,0.000,
        1.234,0.0,1.73,0.0,2.1,0.0
FSOTB = 0.0,0.0, 0.173,0.0, 0.817,0.0,
        0.962,0.575, 1.000,1.000,1.234,1.0,
        1.73,1.0, 2.1,1.0

*XNFLVT = 180.,0.917,
*          194.,0.917, 211.,1.830,
*          219.,1.421,240.,1.344, 254.,0.947,
*          261.,0.986, 273.,0.792,288.,0.621
SLATB  = 180.,0.0033,
         194.,0.0033,211.,.0022, 219.,.0028,
         254.,.0022, 261.,.0021, 273.,.0022,
         288.,.0020

****************************************
* R. Torres, IRRI, The Philippines
* 1991
* variety:   IR72
* treatment: 80 KG/HA
****************************************
TREATM = 'IRRI, 1991, IR72, 80 kg/ha N'

* dummy initialisation
RADTOI = 0.

DATH   = 94.
DTRP   = 12.
FGHDAY = 67.0
WLVGI =  8.5
WSTSI =  7.5
WRTLI = 16.0
*FNSTI = 0.01890
FNLVI = 0.03020
*FNRTI = 0.01890
DVSI  = 0.167
TSI   = 242.1
FSTR  = 0.20
```

```
* RGRL   = 0.0090
DVRV   = 0.000689
DVRR   = 0.001895
NS     = 9
DNOST  = 194.,202.,211.,219.,241.,254.,
         261.,273.,288.
NTOTMT = 0.40,3.35,7.78,22.38,66.53,69.73,
         70.95,71.00,75.66
NA     = 4
DNAPT  = 180.,193.,224.,296.

* first and last values are dummy's
SLAC   = 0.0023
SLAFAC = 0.0,1.54,0.167,1.54,0.222,1.82,
         0.34,1.04,0.446,1.26,
         0.735,0.95,0.913,0.97,1.011,
         1.00,1.457,1.00,2.011,0.81,
2.1,0.81

** OBSERVED VALUES
WSTS_OBS =
1991., 180.,7.5,
1991., 194.,7.5,
1991., 202.,40.0,
1991., 211.,88.5,
1991., 219.,289.5,
1991., 240.,1530.8,
1991., 254.,3696.8,
1991., 261.,3805.3,
1991., 273.,3168.8,
1991., 288.,2910.5

WSTS_TRG = 1900.,1.,0.,
           2000.,1.,0.

WSTS_FRC = 0

WLVG_OBS =
1991., 180.,8.5,
1991., 194.,8.5,
1991., 202.,45.5,
1991., 211.,139.0,
1991., 219.,364.8,
1991., 240.,1685.8,
1991., 254.,2260.8,
1991., 261.,2021.3,
1991., 273.,1530.3,
1991., 288.,1042.5

WLVG_TRG = 1900.,1.,0.,
           2000.,1.,0.

WLVG_FRC = 0

WLVD_OBS =
1991., 180.,0.,
1991., 240.,0.,
1991., 254.,384.,
1991., 261.,645.,
1991., 273.,1026.,
1991., 288.,2141.

WLVD_TRG = 1900.,1.,0.,
           2000.,1.,0.

WLVD_FRC = 0

WRTL_OBS =
1991., 180.,0.,
1991., 288.,0.

WRTL_TRG = 1900.,1.,0.,
           2000.,1.,0.

WRTL_FRC = 0

WSO_OBS =
1991., 180.,0.0,
1991., 194.,0.0,
1991., 254.,0.0,
1991., 261.,871.5,
1991., 273.,3614.0,
1991., 288.,5197.0

WSO_TRG = 1900.,1.,0.,
          1989.,30.,2.,
          1989.,50.,2.,
          2000.,1.,0.

WSO_FRC = 0

WTDM_OBS =
1991., 180.,16.,
1991., 194.,16.0,
1991., 202.,85.5,
1991., 211.,227.5,
1991., 219.,654.3,
1991., 240.,3216.5,
1991., 254.,6342.,
1991., 261.,7343.0,
1991., 273.,9339.5,
1991., 288.,11291.

WTDM_TRG = 1900.,1.,0.,
           1989.,30.,2.,
           1989.,50.,2.,
           2000.,1.,0.

WTDM_FRC = 0

ANST_OBS =
1991., 180.0, 0.14,
1991., 194.0, 0.14,
1991., 202.0, 1.23,
1991., 211.0, 2.22,
1991., 219.0, 6.87,
1991., 241.0,17.22,
1991., 254.0,23.77,
1991., 261.0,22.41,
1991., 273.0,14.73,
1991., 288.0,12.95

ANST_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANST_FRC = 0

ANLV_OBS =
1991., 180.0, 0.26,
1991., 194.0, 0.26,
1991., 202.0, 2.12,
1991., 211.0, 5.57,
1991., 219.0,15.51,
1991., 241.0,49.31,
1991., 254.0,45.96,
1991., 261.0,40.63,
1991., 273.0,24.82,
1991., 288.0,11.31

ANLV_TRG = 1900.,1.,0.,
           2000.,1.,0.
ANLV_FRC = 0

ANRT_OBS =
1991., 180.,0.00,
1991., 194.,0.00,
1991., 302.,0.00

ANRT_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANRT_FRC = 0

ANSO_OBS =
1991., 180.0, 0.00,
1991., 194.0, 0.00,
1991., 202.0, 0.00,
1991., 211.0, 0.00,
1991., 219.0, 0.00,
1991., 241.0, 0.00,
1991., 254.0, 0.00,
1991., 261.0, 7.91,
1991., 273.0,31.44,
1991., 288.0,51.40

ANSO_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANSO_FRC = 0
```

```
ANLD_OBS =
1991., 180.,0.00,
1991., 194.,0.00,
1991., 288.,0.00

ANLD_TRG = 1900.,1.,0.,
           2000.,1.,0.
ANLD_FRC = 0

LAI_OBS =
1991., 180.,0.03,
1991., 194.,0.03,
1991., 202.,0.19,
1991., 211.,0.33,
1991., 219.,1.05,
1991., 240.,3.68,
1991., 254.,5.01,
1991., 261.,4.63,
1991., 273.,3.52,
1991., 288.,1.94

LAI_TRG = 1900.,1.,0.,
          2000.,1.,0.
LAI_FRC = 0

FSHTB  = 0.0,0.5,0.43,0.75,1.0,1.0,2.1,1.0

FLVTB = 0.000,0.560,0.193,0.532,0.281,0.658,
        0.393,0.529,0.584,0.516,0.817,0.210,
        0.962,0.000,1.000,0.000,1.234,0.000,
        1.730,0.000,2.1,0.0
FSTTB = 0.000,0.440,0.193,0.468,0.281,0.342,
        0.393,0.471,0.584,0.484,0.817,0.790,
        0.962,0.111,1.000,0.000,1.234,0.000,
        1.730,0.000,2.1,0.0
FSOTB = 0.000,0.000,0.173,0.000,0.817,0.000,
        0.962,0.889,1.000,1.000,1.234,1.000,
        1.730,1.000,2.1,1.0
*XNFLVT = 180.,0.917,
*          194.,0.917,202.,1.140,211.,1.708,
*          219.,1.480,240.,1.341,254.,0.918,
*          261.,0.878,273.,0.681, 288.,0.584
SLATB =  180.,.0033,
         194.,.0033,202.,.0041,211.,.0023,
         219.,.0029,240.,.0022,254.,.0022,
         261.,.0023,273.,.0023,288.,.0019


***************************************
* R. Torres, IRRI, The Philippines
* 1991
* variety:   LINE
* treatment: 0 KG/HA
***************************************
TREATM = 'IRRI, 1991, LINE, 0 kg/ha N'

* dummy initialisation
RADTOI = 0.

DATH    = 108.
DTRP    =  12.
FGHDAY = 279.0
WLVGI   =  6.5
WSTSI   =  7.5
WRTLI   = 14.0
*FNSTI   = 0.0176
FNLVI   = 0.0272
*FNRTI   = 0.0176
DVSI    = 0.13410
TSI     = 242.1
FSTR    = 0.40
* RGRL    = 0.0060
DVRV    = 0.000554
DVRR    = 0.002278
NS      = 9
DNOST   = 194.,202.,211.,219.,249.,263.,
          279.,288.,302.
NTOTMT = 0.31,1.96,4.34,14.16,30.89,40.35,
          46.84,47.04,52.71
NA      = 3
DNAPT   = 180.,193.,310.
* first and last values are dummy's
SLAC    = 0.0016
SLAFAC = 0.0,1.87,0.134,1.87,0.178,1.87,
          0.273,1.45,0.359,1.84,
          0.678,1.37,0.835,1.40,1.008,
          1.00,1.406,1.18,2.008,0.78,
          2.10,0.78

WSTS_OBS =
1991., 180.,   7.5,
1991., 194.,   7.5,
1991., 202.,  20.0,
1991., 211.,  52.8,
1991., 219., 211.5,
1991., 249.,1210.8,
1991., 263.,2608.3,
1991., 279.,4236.0,
1991., 288.,3475.0,
1991., 302.,2188.5

WSTS_TRG = 1900.,1.,0.,
           2000.,1.,0.

WSTS_FRC = 0

WLVG_OBS =
1991., 180.,   6.5,
1991., 194.,   6.5,
1991., 202.,  29.3,
1991., 211.,  71.3,
1991., 219., 230.8,
1991., 249.,1099.8,
1991., 263.,1481.8,
1991., 279.,1471.5,
1991., 288.,1237.5,
1991., 302., 564.5

WLVG_TRG = 1900.,1.,0.,
           2000.,1.,0.

WLVG_FRC = 0

WLVD_OBS =
1991.,180.,   0.0,
1991.,249.,   0.0,
1991.,263., 369.0,
1991.,279., 2962.,
1991.,288.,1452.0,
1991.,302.,2657.0

WLVD_TRG = 1900.,1.,0.,
           2000.,1.,0.
WLVD_FRC = 0

WRTL_OBS =
1991.,180.,0.,
1991.,302.,0.

WRTL_TRG = 1900.,1.,0.,
           2000.,1.,0.

WRTL_FRC = 0

WSO_OBS  =
1991.,180.,   0.0,
1991.,194.,   0.0,
1991.,263.,   0.0,
1991.,279., 915.8,
1991.,288.,2553.3,
1991.,302.,4608.3

WSO_TRG = 1900.,1.,0.,
          1989.,30.,2.,
          1989.,50.,2.,
          2000.,1.,0.

WSO_FRC = 0

WTDM_OBS =
1991., 180.,  14.0,
1991., 194.,  14.0,
1991., 202.,  49.3,
1991., 211., 124.0,
1991., 219., 442.3,
1991., 249.,2610.5,
1991., 263.,4459.0,
1991., 279.,7585.3,
1991., 288.,8717.8,
1991., 302.,10018.3
```

```
WTDM_TRG = 1900.,1.,0.,
          1989.,30.,2.,
          1989.,50.,2.,
          2000.,1.,0.

WTDM_FRC = 0

ANST_OBS =
1991., 180., 0.13,
1991., 194., 0.13,
1991., 202., 0.61,
1991., 211., 1.45,
1991., 219., 4.67,
1991., 249., 8.58,
1991., 263.,16.22,
1991., 279.,17.37,
1991., 288.,11.99,
1991., 302., 7.35

ANST_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANST_FRC = 0

ANLV_OBS =
1991., 180., 0.18,
1991., 194., 0.18,
1991., 202., 1.35,
1991., 211., 2.89,
1991., 219., 9.49,
1991., 249.,22.30,
1991., 263.,24.12,
1991., 279.,20.79,
1991., 288.,15.59,
1991., 302., 4.76

ANLV_TRG = 1900.,1.,0.,
           2000.,1.,0.
ANLV_FRC = 0

ANRT_OBS =
1991., 180.,0.00,
1991., 194.,0.00,
1991., 302.,0.00

ANRT_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANRT_FRC = 0

ANSO_OBS =
1991., 180., 0.00,
1991., 194., 0.00,
1991., 202., 0.00,
1991., 211., 0.00,
1991., 219., 0.00,
1991., 249., 0.00,
1991., 263., 0.00,
1991., 279., 8.68,
1991., 288.,19.46,
1991., 302.,40.60

ANSO_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANSO_FRC = 0

ANLD_OBS = 1900.,1.,0.,
           2000.,1.,0.
ANLD_TRG = 1900.,1.,0.,
           2000.,1.,0.
ANLD_FRC = 0

LAI_OBS =
1991., 180.,0.02,
1991., 194.,0.02,
1991., 202.,0.09,
1991., 211.,0.17,
1991., 219.,0.70,
1991., 249.,2.47,
1991., 263.,3.41,
1991., 279.,2.42,
1991., 288.,2.40,
1991., 302.,0.72
```

```
LAI_TRG = 1900.,1.,0.,
          2000.,1.,0.
LAI_FRC = 0

FSHTB  = 0.0,0.5,0.43,0.75,1.0,1.0,2.1,1.0

FLVTB  = 0.000,0.560, 0.156,0.645,
         0.226,0.562,
         0.316,0.501, 0.518,0.401,
         0.756,0.258,
         0.922,0.000, 1.000,0.000,
         1.207,0.000,
         1.707,0.000, 2.1,0.0
FSTTB  = 0.000,0.440, 0.156,0.355,
         0.226,0.438,
         0.316,0.499, 0.518,0.599,
         0.756,0.742,
         0.922,0.640, 1.000,0.000,
         1.207,0.000,
         1.707,0.000, 2.1,0.0
FSOTB  = 0.000,0.000, 0.145,0.000,
         0.756,0.000,
         0.922,0.360, 1.000,1.000,
         1.207,1.000,
         1.707,1.000, 2.1,1.0

*XNFLVT = 180.,0.804,
*         194.,0.804,202.,1.545,211.,1.680,
*         219.,1.348,249.,0.903,263.,0.708,
*         279.,0.858,288.,0.572,302.,0.66

SLATB  = 180.,.0034,
         194.,.0034,202.,.0030,211.,.0024,
         219.,.0031,249.,.0022,263.,.0023,
         279.,.0016,288.,.0019,302.,.0013

***************************************
* R. Torres, IRRI, The Philippines
* 1991
* variety:   LINE
* treatment: 110 KG/HA
***************************************
TREATM = 'IRRI, 1991, LINE, 110 kg/ha N'

* dummy initialisation
RADTOI = 0.

DATH   = 108.
DTRP   = 12.
FGHDAY = 85.0
WLVGI  =  6.5
WSTSI  =  7.5
WRTLI  = 14.0
*FNSTI  = 0.0176
FNLVI  = 0.0272
*FNRTI  = 0.0176
DVSI   = 0.13410
TSI    = 242.1
FSTR   = 0.40
* RGRL   = 0.0090
DVRV   = 0.000554
DVRR   = 0.002278
NS     = 9
DNOST  = 194.,202.,211.,219.,249.,263.,
         279.,288.,302.
NTOTMT = 0.31,2.92,7.98,21.20,57.10,66.80,
         75.96,76.59,76.59
NA     = 6
DNAPT  = 180.,193.,218.,253.,276.,310.
* first and last values are dummy's
SLAC   = 0.0020
SLAFAC = 0.0,1.58,0.134,1.58,0.178,1.93,
         0.273,1.30,0.359,1.57,
         0.678,1.21,0.835,1.35,1.008,
         1.00,1.406,1.04,2.008,0.75,2.1,0.75

** OBSERVED VALUES FOR LINE-110N
WSTS_OBS =
1991., 180.,   7.5,
1991., 194.,   7.5,
1991., 202.,  30.0,
1991., 211.,  99.5,
1991., 219., 272.8,
1991., 249.,2062.3,
```

```
1991., 263.,3734.8,
1991., 279.,4828.8,
1991., 288.,3558.3,
1991., 302.,3008.3

WSTS_TRG = 1900.,1.,0.,
           2000.,1.,0.

WSTS_FRC = 0

WLVG_OBS =
1991., 180.,   6.5,
1991., 194.,   6.5,
1991., 202.,  42.5,
1991., 211., 126.5,
1991., 219., 337.3,
1991., 249.,1825.8,
1991., 263.,2048.5,
1991., 279.,2153.0,
1991., 288.,1992.8,
1991., 302.,1130.3

WLVG_TRG = 1900.,1.,0.,
           2000.,1.,0.

WLVG_FRC = 0

WLVD_OBS =
1991., 180.,   0.0,
1991., 249.,   0.0,
1991., 263., 552.0,
1991., 279.,1021.0,
1991., 288.,1709.0,
1991., 302.,2539.0

WLVD_TRG = 1900.,1.,0.,
           2000.,1.,0.
WLVD_FRC = 0

WRTL_OBS =
1991., 180.,0.,
1991., 302.,0.

WRTL_TRG = 1900.,1.,0.,
           2000.,1.,0.

WRTL_FRC = 0

WSO_OBS =
1991., 180.,   0.0,
1991., 194.,   0.0,
1991., 263.,   0.0,
1991., 279., 700.0,
1991., 288.,3787.5,
1991., 302.,6111.5

WSO_TRG = 1900.,1.,0.,
          1989.,30.,2.,
          1989.,50.,2.,
          2000.,1.,0.

WSO_FRC = 0

WTDM_OBS =
1991., 180.,  14.0,
1991., 194.,  14.0,
1991., 202.,  72.5,
1991., 211., 226.0,
1991., 219., 610.0,
1991., 249.,3888.0,
1991., 263.,6335.0,
1991., 279.,8702.8,
1991., 288.,11048.,
1991., 302.,12789.

WTDM_TRG = 1900.,1.,0.,
          1989.,30.,2.,
          1989.,50.,2.,
          2000.,1.,0.

WTDM_FRC = 0

ANST_OBS =
1991., 180.0, 0.13,
1991., 194.0, 0.13,
1991., 202.0, 0.96,
1991., 211.0, 2.69,
1991., 219.0, 6.50,
1991., 249.0,16.93,
1991., 263.0,25.32,
1991., 279.0,26.85,
1991., 288.0,19.78,
1991., 302.0,11.73

ANST_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANST_FRC = 0

ANLV_OBS =
1991., 180.0, 0.18,
1991., 194.0, 0.18,
1991., 202.0, 1.96,
1991., 211.0, 5.29,
1991., 219.0,14.70,
1991., 249.0,40.17,
1991., 263.0,41.48,
1991., 279.0,38.75,
1991., 288.0,38.52,
1991., 302.0,10.41

ANLV_TRG = 1900.,1.,0.,
           2000.,1.,0.
ANLV_FRC = 0

ANRT_OBS =
1991., 180.,0.00,
1991., 194.,0.00,
1991., 302.,0.00

ANRT_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANRT_FRC = 0

ANSO_OBS =
1991., 180.0,0.00,
1991., 194.0,0.00,
1991., 202.0,0.00,
1991., 211.0,0.00,
1991., 219.0,0.00,
1991., 249.0,0.00,
1991., 263.0,0.00,
1991., 279.0,10.35,
1991., 288.0,18.29,
1991., 302.0,31.69

ANSO_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANSO_FRC = 0

ANLD_OBS = 1900.,1.,0.,
           2000.,1.,0.
ANLD_TRG = 1900.,1.,0.,
           2000.,1.,0.
ANLD_FRC = 0

LAI_OBS =
1991., 180.,0.02,
1991., 194.,0.02,
1991., 202.,0.16,
1991., 211.,0.32,
1991., 219.,1.03,
1991., 249.,4.30,
1991., 263.,5.38,
1991., 279.,4.20,
1991., 288.,4.03,
1991., 302.,1.65

LAI_TRG = 1900.,1.,0.,
          2000.,1.,0.
LAI_FRC = 0

FSHTB  = 0.0,0.5,0.43,0.75,1.0,1.0,2.1,1.0

FLVTB = 0.000,0.560,0.226,0.547,0.316,0.549,
        0.518,0.454,0.600,0.350,0.756,0.118,
        0.922,0.055,1.000,0.000,1.707,0.000,
        2.1,0.0
```

```
FSTTB = 0.000,0.440,0.226,0.453,0.316,0.451,
        0.518,0.546,0.600,0.650,0.756,0.882,
        0.922,0.576,1.000,0.000,1.707,0.000,
        2.1,0.0
FSOTB = 0.000,0.000,0.135,0.000,0.756,0.000,
        0.922,0.369,1.000,1.000,1.707,1.000,
        2.1,1.0

*XNFLVT = 180.,0.804,
*         194.,0.804,202.,1.220,211.,1.647,
*         219.,1.428,249.,0.934,263.,0.771,
*         279.,0.923,288.,0.903,302.,0.629

SLATB  = 180.,0.0034,
         194.,.0034,211.,.0025,219.,.0031,
         249.,.0024,263.,.0026,279.,.0020,
         288.,.0020,302.,.0015

***************************************
* R. Torres, IRRI, The Philippines
* 1991
* variety:   LINE
* treatment: 80 KG/HA
***************************************
TREATM = 'IRRI, 1991, LINE, 80 kg/ha N'

* dummy initialisation
RADTOI = 0.

DATH   = 108.
DTRP   = 12.
FGHDAY = 85.
WLVGI  =  6.5
WSTSI  =  7.5
WRTLI  = 14.0
*FNSTI  = 0.0176
FNLVI  = 0.0272
*FNRTI  = 0.0176
DVSI   = 0.13410
TSI    = 242.1
FSTR   = 0.40
* RGRL   = 0.0090
DVRV   = 0.000554
DVRR   = 0.002278
NS     = 9
DNOST  = 194.,202.,211.,219.,249.,263.,
         279.,288.,302.
NTOTMT = 0.31,3.36,9.31,25.90,64.15,69.76,
         71.83,66.23,68.47
NA     = 4
DNAPT  = 180.,193.,224.,310.

* first and last values are dummy's
SLAC   = 0.0019
SLAFAC = 0.0,1.61,0.134,1.61,0.178,1.88,
         0.273,1.38,0.359,1.57,
         0.678,1.22,0.835,0.98,1.008,
         1.00,1.406,1.15,2.008,0.83,2.1,0.83

** OBSERVED VALUES FOR LINE-80N
WSTS_OBS =
1991., 180.,    7.5,
1991., 194.,    7.5,
1991., 202.,   30.0,
1991., 211.,  111.8,
1991., 219.,  338.5,
1991., 249.,2274.8,
1991., 263.,3986.8,
1991., 279.,5219.0,
1991., 288.,3333.3,
1991., 302.,2645.8

WSTS_TRG = 1900.,1.,0.,
           2000.,1.,0.
WSTS_FRC = 0

WLVG_OBS =
1991., 180.,    6.5,
1991., 194.,    6.5,
1991., 202.,   47.3,
1991., 211.,  147.5,
1991., 219.,  399.5,
1991., 249.,1927.3,
1991., 263.,2489.8,
1991., 279.,2380.8,
1991., 288.,1573.0,
1991., 302., 807.3

WLVG_TRG = 1900.,1.,0.,
           2000.,1.,0.
WLVG_FRC = 0

WLVD_OBS =
1991., 180.,    0.0,
1991., 249.,    0.0,
1991., 263.,  679.0,
1991., 279.,1230.0,
1991., 288.,2182.0,
1991., 302.,3000.0

WLVD_TRG = 1900.,1.,0.,
           2000.,1.,0.
WLVD_FRC = 0

WRTL_OBS =
1991., 180., 0.,
1991., 302., 0.

WRTL_TRG = 1900.,1.,0.,
           2000.,1.,0.
WRTL_FRC = 0

WSO_OBS =
1991., 180.,    0.0,
1991., 194.,    0.0,
1991., 263.,    0.0,
1991., 279.,  938.3,
1991., 288.,3984.5,
1991., 302.,5338.5

WSO_TRG = 1900.,1.,0.,
          1989.,30.,2.,
          1989.,50.,2.,
          2000.,1.,0.
 WSO_FRC = 0

WTDM_OBS =
1991., 180.,   17.0,
1991., 194.,   17.0,
1991., 202.,   77.3,
1991., 211.,  259.3,
1991., 219.,  738.0,
1991., 249.,4202.0,
1991., 263.,7155.5,
1991., 279.,9768.0,
1991., 288.,11073.,
1991., 302.,11791.5

WTDM_TRG = 1900.,1.,0.,
           1989.,30.,2.,
           1989.,50.,2.,
           2000.,1.,0.
WTDM_FRC = 0

ANST_OBS =
1991., 180.0, 0.13,
1991., 194.0, 0.13,
1991., 202.0, 0.97,
1991., 211.0, 3.03,
1991., 219.0, 8.34,
1991., 249.0,20.15,
1991., 263.0,26.31,
1991., 279.0,25.52,
1991., 288.0,12.07,
1991., 302.0, 8.84

ANST_TRG = 1900.,1.,0.,
           2000.,1.,0.
ANST_FRC = 0

ANLV_OBS =
1991., 180.0, 0.18,
1991., 194.0, 0.18,
1991., 202.0, 2.39,
1991., 211.0, 6.28,
1991., 219.0,17.56,
1991., 249.0,44.00,
1991., 263.0,43.45,
1991., 279.0,37.20,
1991., 288.0,20.34,
```

```
1991., 302.0, 7.48

ANLV_TRG = 1900.,1.,0.,
           2000.,1.,0.
ANLV_FRC = 0

ANRT_OBS =
1991., 180.,0.00,
1991., 194.,0.00,
1991., 302.,0.00

ANRT_TRG = 1900.,1.,0.,
           2000.,1.,0.
ANRT_FRC = 0

ANSO_OBS =
1991., 180.0, 0.00,
1991., 194.0, 0.00,
1991., 202.0, 0.00,
1991., 211.0, 0.00,
1991., 219.0, 0.00,
1991., 249.0, 0.00,
1991., 263.0, 0.00,
1991., 279.0, 9.10,
1991., 288.0,33.83,
1991., 302.0,52.16

ANSO_TRG = 1900.,1.,0.,
           2000.,1.,0.
ANSO_FRC = 0


ANLD_OBS = 1900.,1.,0.,
           2000.,1.,0.
ANLD_TRG = 1900.,1.,0.,
           2000.,1.,0.
ANLD_FRC = 0

LAI_OBS =
1991., 180.,0.02,
1991., 194.,0.02,
1991., 202.,0.17,
1991., 211.,0.39,
1991., 219.,1.20,
1991., 249.,4.49,
1991., 263.,4.68,
1991., 279.,4.55,
1991., 288.,3.47,
1991., 302.,1.28

LAI_TRG = 1900.,1.,0.,
          2000.,1.,0.
LAI_FRC = 0

FSHTB  = 0.0,0.5,0.43,0.75,1.0,1.0,2.1,1.0

FLVTB = 0.000,0.560,0.156,0.644,0.226,0.551,
        0.316,0.526,0.518,0.441,0.756,0.247,
        0.922,0.000,1.000,0.000,1.207,0.000,
        1.707,0.000,2.1,0.0
FSTTB = 0.000,0.440,0.156,0.356,0.226,0.449,
        0.316,0.474,0.518,0.559,0.756,0.753,
        0.922,0.568,1.000,0.000,1.207,0.000,
        1.707,0.000,2.1,0.0
FSOTB = 0.000,0.000,0.135,0.000,0.202,0.000,
        0.299,0.000,0.516,0.000,0.756,0.000,
        0.922,0.432,1.000,1.000,1.207,1.000,
        1.707,1.000,2.1,1.0

*XNFLVT = 180.,0.804,
*         194.,0.804,202.,1.430,211.,1.613,
*         219.,1.463,249.,0.979,263.,0.928,
*         279.,0.819,288.,0.532,302.,0.582

SLATB  = 180.,.0034,
         194.,.0034,211.,.0026,219.,.0030,
         249.,.0023,263.,.0019,279.,.0019,
         288.,.0022,302.,.0016
```

Data sets for validation of ORYZA_0

```
***************************************
* R. Torres, IRRI, The Philippines
* 1991
* variety:   IR72
* treatment: 0 KG/HA
***************************************
TREATM = 'IRRI, 1991, IR72, 0 kg/ha N'

* dummy variables
DVSI = 0.
TBD  = 0.
RBLV = 0.

* Initial constants
* -----------------
***NOTE !!! EXCLUDING ROOTS
*WCRI   = 32.0
WCRI   = 16.0
ANCRI  = 0.4
RADTOI = 0.
APCUMI = 0.
*DVSI   = 0.

* Model parameters
* ----------------
RTINCL = 0
DATFSV = 67.
DATEF  = 67.
*Flowering is at 67 DAT, DATFF is 67-7
DATFF  = 60.
DATH   = 94.
FSV1   = 0.87
FSV2   = 0.87
FNSO   = 0.01
FNCLV  = 0.50
ANLVMX = 100.
MAXUP1 = 5.
RUR    = 0.2
NUPCO  = 0.03
HI     = 0.5
SOLSUP = 0.6
FERTMX = 200.
A      = 1.
B      = 0.1
C      = 300.
M      = 30.
LARGE  = 100.
TINY   = 0.001

* AFGEN functions
* ---------------
FNMAXT =
   0., 0.03,
   40., 0.017,
   60., 0.015,
   80., 0.01,
   130., 0.07

RECT    =
   0., 0.0,
   60., 0.8,
   65., 0.4,
   70., 0.0,
   150., 0.

RSRT    =
     0., 0.4,
    1.1, 0.15

* Observed values
* ---------------

WLV_OBS =
1991., 180.,    8.5,
1991., 194.,    8.5,
1991., 202.,   29.3,
1991., 211.,   76.0,
1991., 219.,  220.8,
1991., 240.,  944.8,
1991., 254.,1175.8,
1991., 261.,1099.0,
1991., 273.,  761.8,
1991., 288.,  390.5

***NOTE !!! EXCLUDING ROOTS
WCR_OBS =
1991., 180.,   16.0,
```

```
1991., 194.,  16.0,
1991., 202.,  49.3,
1991., 211., 128.0,
1991., 219., 394.0,
1991., 240.,2001.3,
1991., 254.,3932.5,
1991., 261.,5170.5,
1991., 273.,6176.0,
1991., 288.,7609.0

FNLV_OBS  =
1991., 180., 3.02,
1991., 194., 3.02,
1991., 202., 4.14,
1991., 211., 3.88,
1991., 219., 3.73,
1991., 240., 2.32,
1991., 254., 1.70,
1991., 261., 1.65,
1991., 273., 1.40,
1991., 288., 1.04

****************************************
* R. Torres, IRRI, The Philippines
* 1991
* variety:   IR72
* treatment: 110 KG/HA
****************************************
TREATM = 'IRRI, 1991, IR72, 110 kg/ha N'

* dummy variables
DVSI = 0.
TBD  = 0.
TBLV = 0.

* Initial constants
* -----------------
** NOTE !!EXCLUDING ROOTS
WCRI   = 16.0
ANCRI  = 0.4
RADTOI = 0.
APCUMI = 0.
DVSI   = 0.

* Model parameters
* ----------------
RTINCL = 0
DATFSV = 67.
DATEF  = 67.
*Flowering is at 67 DAT, DATFF is 67-7
DATFF  = 60.
DATH   = 94.
FSV1   = 0.87
FSV2   = 0.87
FNSO   = 0.01
FNCLV  = 0.50
ANLVMX = 100.
MAXUP1 = 5.
RUR    = 0.2
NUPCO  = 0.03
HI     = 0.5
SOLSUP = 0.6
FERTMX = 200.
A      = 1.
B      = 0.1
C      = 300.
M      = 30.
LARGE  = 100.
TINY   = 0.001

* AFGEN functions
* ---------------
FNMAXT =
   0., 0.03,
   40., 0.017,
   60., 0.015,
   80., 0.01,
   130., 0.07

RECT   =
   0., 0.0,
   60., 0.8,
   65., 0.4,
   70., 0.0,
   150., 0.

RSRT   =
     0., 0.4,
    1.1, 0.15

* Observed values
* ---------------

WLV_OBS =
1991., 180.,8.5,
1991., 194.,8.5,
1991., 202.,16.8,
1991., 211.,133.8,
1991., 219.,342.5,
1991., 240.,1503.3,
1991., 254.,1935.3,
1991., 261.,2028.5,
1991., 273.,1564.8,
1991., 288., 892.8

***NOTE !!! EXCLUDING ROOTS

WCR_OBS =
1991., 180.,  16.0,
1991., 194.,  16.0,
1991., 202.,  26.8,
1991., 211., 222.3,
1991., 219., 618.3,
1991., 240.,2961.5,
1991., 254.,5439.0,
1991., 261.,7503.0,
1991., 273.,9322.5,
1991., 288.,11534.5

FNLV_OBS  =
1991., 180., 3.02,
1991., 194., 3.02,
1991., 202., 4.35,
1991., 211., 4.02,
1991., 219., 3.91,
1991., 240., 2.69,
1991., 254., 2.09,
1991., 261., 2.09,
1991., 273., 1.79,
1991., 288., 1.26

****************************************
* R. Torres, IRRI, The Philippines
* 1991
* variety:   IR72
* treatment: 80 KG/HA
****************************************
TREATM = 'IRRI, 1991, IR72, 80 kg/ha N'

* dummy variables
DVSI = 0.
TBD  = 0.
TBLV = 0.

* Initial constants
* -----------------
***NOTE !!! EXCLUDING ROOTS
WCRI   = 16.0
ANCRI  = 0.4
RADTOI = 0.
APCUMI = 0.
DVSI   = 0.

* Model parameters
* ----------------
RTINCL = 0
DATFSV = 67.
DATEF  = 67.
*Flowering is at 67 DAT, DATFF is 67-7
DATFF  = 60.
DATH   = 94.
FSV1   = 0.87
FSV2   = 0.87
FNSO   = 0.01
FNCLV  = 0.50
ANLVMX = 100.
MAXUP1 = 5.
RUR    = 0.2
NUPCO  = 0.03
HI     = 0.5
```

```
SOLSUP = 0.6
FERTMX = 200.
A      = 1.
B      = 0.1
C      = 300.
M      = 30.
LARGE  = 100.
TINY   = 0.001

* AFGEN functions
* ---------------
FNMAXT =
   0., 0.03,
   40., 0.017,
   60., 0.015,
   80., 0.01,
   130., 0.07

RECT   =
   0., 0.0,
   60., 0.8,
   65., 0.4,
   70., 0.0,
   150., 0.

RSRT     =
     0., 0.4,
    1.1, 0.15

* Observed values
* ---------------

WLV_OBS =
1991., 180.,8.5,
1991., 194.,8.5,
1991., 202.,45.5,
1991., 211.,139.0,
1991., 219.,364.8,
1991., 240.,1685.8,
1991., 254.,2260.8,
1991., 261.,2021.3,
1991., 273.,1530.3,
1991., 288.,1042.5

***NOTE !!! EXCLUDING ROOTS
WCR_OBS =
1991., 180.,  16.,
1991., 194.,  16.0,
1991., 202.,  85.5,
1991., 211., 227.5,
1991., 219., 654.3,
1991., 240.,3216.5,
1991., 254.,6342.0,
1991., 261.,7343.0,
1991., 273.,9339.5,
1991., 288.,11291.

FNLV_OBS  =
1991., 180., 3.02,
1991., 194., 3.02,
1991., 202., 4.66,
1991., 211., 4.01,
1991., 219., 4.25,
1991., 240., 2.93,
1991., 254., 2.03,
1991., 261., 2.01,
1991., 273., 1.62,
1991., 288., 1.09

*****************************************
* R. Torres, IRRI, The Philippines
* 1991
* variety:   LINE
* treatment: 0 KG/HA
*****************************************
TREATM = 'IRRI, 1991, LINE, 0 kg/ha N'

* dummy variables
DVSI = 0.
TBD  = 0.
TBLV = 0.

* Initial constants
* -----------------
***NOTE !!! EXCLUDING ROOTS
*WCRI   = 32.0
WCRI   = 14.0
ANCRI  = 0.31
RADTOI = 0.
APCUMI = 0.
DVSI   = 0.

* Model parameters
* ----------------
RTINCL = 0
DATFSV = 85.
DATEF  = 85.
*Flowering is at 85 DAT, DATFF is 85-7
DATFF  = 78.
DATH   = 108.
FSV1   = 0.87
FSV2   = 0.87
FNSO   = 0.01
FNCLV  = 0.50
ANLVMX = 100.
MAXUP1 = 5.
RUR    = 0.2
NUPCO  = 0.03
HI     = 0.5
SOLSUP = 0.6
FERTMX = 200.
A      = 1.
B      = 0.1
C      = 300.
M      = 30.
LARGE  = 100.
TINY   = 0.001

* AFGEN functions
* ---------------
FNMAXT =
   0., 0.03,
   40., 0.017,
   60., 0.015,
   80., 0.01,
   130., 0.07

RECT   =
   0., 0.0,
   60., 0.8,
   65., 0.4,
   70., 0.0,
   150., 0.

RSRT     =
     0., 0.4,
    1.1, 0.15

* Observed values
* ---------------

WLV_OBS =
1991., 180.,    6.5,
1991., 194.,    6.5,
1991., 202.,   29.3,
1991., 211.,   71.3,
1991., 219., 230.8,
1991., 249.,1099.8,
1991., 263.,1481.8,
1991., 279.,1471.5,
1991., 288.,1237.5,
1991., 302., 564.5

***NOTE !!! EXCLUDING ROOTS
WCR_OBS =
1991., 180.,   14.0,
1991., 194.,   14.0,
1991., 202.,   49.3,
1991., 211., 124.0,
1991., 219., 442.3,
1991., 249.,2610.5,
1991., 263.,4459.0,
1991., 279.,7585.3,
1991., 288.,8717.8,
1991., 302.,10018.3

FNLV_OBS  =
1991., 180.,2.72,
1991., 194.,2.72,
1991., 202.,4.60,
```

```
1991., 211.,4.06,
1991., 219.,4.11,
1991., 249.,2.03,
1991., 263.,1.63,
1991., 279.,1.41,
1991., 288.,1.26,
1991., 302.,0.84

****************************************
* R. Torres, IRRI, The Philippines
* 1991
* variety:   LINE
* treatment: 110 KG/HA
****************************************
TREATM = 'IRRI, 1991, LINE, 110 kg/ha N'

* dummy variables
DVSI = 0.
TBD  = 0.
TBLV = 0.

* Initial constants
* -----------------
***NOTE !!! EXCLUDING ROOTS
*WCRI   = 32.0
WCRI    = 14.0
ANCRI   = 0.31
RADTOI  = 0.
APCUMI  = 0.
DVSI    = 0.

* Model parameters
* ----------------
RTINCL = 0
DATFSV = 85.
DATEF  = 85.
*Flowering is at 85 DAT, DATFF is 85-7
DATFF  = 78.
DATH   = 108.
FSV1   = 0.87
FSV2   = 0.87
FNSO   = 0.01
FNCLV  = 0.50
ANLVMX = 100.
MAXUP1 = 5.
RUR    = 0.2
NUPCO  = 0.03
HI     = 0.5
SOLSUP = 0.6
FERTMX = 200.
A      = 1.
B      = 0.1
C      = 300.
M      = 30.
LARGE  = 100.
TINY   = 0.001

* AFGEN functions
* ---------------
FNMAXT =
   0., 0.03,
   40., 0.017,
   60., 0.015,
   80., 0.01,
   130., 0.07

RECT   =
   0., 0.0,
   60., 0.8,
   65., 0.4,
   70., 0.0,
   150., 0.

RSRT    =
     0., 0.4,
    1.1, 0.15

* Observed values
* ---------------

WLV_OBS =
1991., 180.,   6.5,
1991., 194.,   6.5,
1991., 202.,  42.5,
1991., 211., 126.5,
1991., 219., 337.3,
1991., 249.,1825.8,
1991., 263.,2048.5,
1991., 279.,2153.0,
1991., 288.,1992.8,
1991., 302.,1130.3

***NOTE !!! EXCLUDING ROOTS
WCR_OBS =
1991., 180.,  14.0,
1991., 194.,  14.0,
1991., 202.,  72.5,
1991., 211., 226.0,
1991., 219., 610.0,
1991., 249.,3888.0,
1991., 263.,6335.0,
1991., 279.,8702.8,
1991., 288.,11048.,
1991., 302.,12789.

FNLV_OBS  =
1991., 180.,2.72,
1991., 194.,2.72,
1991., 202.,4.62,
1991., 211.,4.18,
1991., 219.,4.36,
1991., 249.,2.20,
1991., 263.,2.03,
1991., 279.,1.80,
1991., 288.,1.93,
1991., 302.,0.92

****************************************
* R. Torres, IRRI, The Philippines
* 1991
* variety:   LINE
* treatment: 80 KG/HA
****************************************
TREATM = 'IRRI, 1991, LINE, 80 kg/ha N'

* dummy variables
DVSI = 0.
TBD  = 0.
TBLV = 0.

* Initial constants
* -----------------
***NOTE !!! EXCLUDING ROOTS
*WCRI   = 32.0
WCRI    = 14.0
ANCRI   = 0.31
RADTOI  = 0.
APCUMI  = 0.
DVSI    = 0.

* Model parameters
* ----------------
RTINCL = 0
DATFSV = 85.
DATEF  = 85.
*Flowering is at 85 DAT, DATFF is 85-7
DATFF  = 78.
DATH   = 108.
FSV1   = 0.87
FSV2   = 0.87
P      = 10.
EPSIL  = 2.5
FNSO   = 0.01
FNCLV  = 0.50
ANLVMX = 100.
MAXUP1 = 5.
RUR    = 0.2
NUPCO  = 0.03
HI     = 0.5
SOLSUP = 0.6
FERTMX = 200.
A      = 1.
B      = 0.1
C      = 300.
M      = 30.
LARGE  = 100.
TINY   = 0.001

* AFGEN functions
* ---------------
```

```
FNMAXT =
   0., 0.03,
   40., 0.017,
   60., 0.015,
   80., 0.01,
   130., 0.07

RECT   =
   0., 0.0,
   60., 0.8,
   65., 0.4,
   70., 0.0,
   150., 0.

RSRT    =
     0., 0.4,
    1.1, 0.15

* Observed values
* ---------------

WLV_OBS =
1991., 180.,    6.5,
1991., 194.,    6.5,
1991., 202.,   47.3,
1991., 211.,  147.5,
1991., 219.,  399.5,
1991., 249.,1927.3,
1991., 263.,2489.8,
1991., 279.,2380.8,
1991., 288.,1573.0,
1991., 302., 807.3

***NOTE !!! EXCLUDING ROOTS
WCR_OBS =
1991., 180.,   17.0,
1991., 194.,   17.0,
1991., 202.,   77.3,
1991., 211.,  259.3,
1991., 219.,  738.0,
1991., 249.,4202.0,
1991., 263.,7155.5,
1991., 279.,9768.0,
1991., 288.,11073.,
1991., 302.,11791.5

FNLV_OBS   =
1991., 180.,2.72,
1991., 194.,2.72,
1991., 202.,5.06,
1991., 211.,4.26,
1991., 219.,4.40,
1991., 249.,2.28,
1991., 263.,1.75,
1991., 279.,1.56,
1991., 288.,1.29,
1991., 302.,0.93
```

IRRI, Los Baños, Philippines, 1992

Experimental data from: M.J. Kropff, K.G. Cassman, S. Liboon, R. Torres

General information:

year: 1992

variety: LINE

	Calendar date	DOY	DAT
seeding	4 Jan	4	
transplanting	16 Jan	16	0
panicle initiation	11 Mar	70	54
flowering	8 Apr	98	82
harvest	8 May	128	112

DAT= days after transplanting, DOY= day of the year

variety: IR72

	Calendar date	DOY	DAT
seeding	4 Jan	4	
transplanting	16 Jan	16	0
panicle initiation	11 Mar	58	42
flowering	25 Mar	84	68
harvest	24 Apr	114	98

DAT= days after transplanting, DOY= day of the year

Nitrogen application scheme:

Calendar date	DOY	N Treatment (kg N ha^{-1})			
		0	180	225	
				LINE	IR72
16 Jan	16	-	120	60	60
3 Feb	34	-	60	60	60
27 Feb	58	-	-	-	60
11 Mar	70	-	-	60	-
25 Mar	84	-	-	-	45
8 Apr	98	-	-	45	-

DAT= days after transplanting, DOY= day of the year

```
****************************************
* R. Torres, IRRI, The Philippines
* 1992
* variety:   IR72
* treatment: 0 KG/HA
****************************************
TREATM = 'IRRI, 1992, IR72, 0 kg/ha N'

* dummy initialisation
RADTOI = 0.

DATH   = 98.
DTRP   = 12.
FGHDAY = 68.0
WLVGI = 6.4
WSTSI = 5.1
WRTLI = 11.5
*FNSTI = 0.0126
FNLVI = 0.0271
*FNRTI = 0.0126
DVSI  = 0.152
TSI   = 202.6
FSTR  = 0.20
* RGRL  = 0.0060
DVRV  = 0.000751
DVRR  = 0.00168
* first and last values are dummy's
SLAC   = 0.0013
SLAFAC = 0.0,3.62,0.152,3.62,0.323,2.26,
         0.653,1.72,0.787,1.01,1.011,
         1.00,1.464,1.26,2.011,1.03,
         2.1,1.03
NS     = 6
DNOST  = 16.,33.,58.,68.,84.,114.
NTOTMT = 0.24,8.30,22.33,37.41,51.03,58.84
NA     = 3
DNAPT  = 4.,16.,120.

** OBSERVED VALUES: M10. IR72-0N
WSTS_OBS =
1992.,  4.,5.1,
1992., 16.,5.1,
1992., 34.,90.2,
1992., 58.,844.0,
1992., 68.,2133.1,
1992., 84.,3632.2,
1992., 97.,2619.3,
1992.,114.,2202.7

WSTS_TRG = 1900.,1.,0.,
           2000.,1.,0.

WSTS_FRC = 0


WLVG_OBS =
1992.,4.,6.4,
1992.,16.,6.4,
1992.,34.,116.3,
1992.,58.,693.2,
1992.,68.,1203.5,
1992.,84.,1513.5,
1992.,97., 926.7,
1992.,114., 545.2

WLVG_TRG = 1900.,1.,0.,
           2000.,1.,0.

WLVG_FRC = 0


WSO_OBS =
1992.,4.,0.0,
1992.,16.,0.0,
1992.,34.,0.0,
1992.,58.,0.0,
1992.,68.,0.0,
1992.,84.,646.7,
1992.,97.,4003.5,
1992.,114.,5608.3

WSO_TRG = 1900.,1.,0.,
          1989.,30.,2.,
          1989.,50.,2.,
          2000.,1.,0.

WSO_FRC = 0


WLVD_OBS =
1992.,4.,0.0,
1992.,16.,0.0,
1992.,34.,0.0,
1992.,58.,59.6,
1992.,68.,277.6,
1992.,84.,663.9,
1992.,97.,1094.4,
1992.,114.,1608.2

WLVD_TRG = 1900.,1.,0.,
           2000.,1.,0.

WLVD_FRC = 0

WTDM_OBS =
1992.,4.,11.5,
1992.,16.,11.5,
1992.,34.,206.5,
1992.,58.,1596.8,
1992.,68.,3614.2,
1992.,84.,6456.3,
1992.,97.,8640.9,
1992.,114.,9964.4

WTDM_TRG = 1900.,1.,0.,
           2000.,1.,0.

WTDM_FRC = 0

WRTL_OBS =
1992., 4.,0.,
1992., 114.,0.

WRTL_TRG = 1900.,1.,0.,
           2000.,1.,0.

WRTL_FRC = 0


ANLV_OBS=
1992.,  4.0 , 0.17,
1992., 16.0,  0.17,
1992., 33.0,  5.80,
1992., 58.0, 16.26,
1992., 68.0, 23.81,
1992., 84.0, 24.97,
1992., 98.0, 12.12,
1992.,114.0,  5.21

ANLV_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANLV_FRC = 0


ANST_OBS=
1992.,  4.0, 0.06,
1992., 16.0, 0.06,
1992., 33.0, 2.49,
1992., 58.0, 6.08,
1992., 68.0,13.61,
1992., 84.0,19.32,
1992., 98.0, 9.09,
1992.,114.0, 7.64

ANST_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANST_FRC = 0


ANSO_OBS=
1992.,  4.0, 0.00,
1992., 16.0, 0.00,
1992., 33.0, 0.00,
1992., 58.0, 0.00,
1992., 68.0, 0.00,
```

```
1992., 84.0, 6.74,
1992.,114.0,45.99

ANSO_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANSO_FRC = 0


ANRT_OBS   =
1992., 4.0,0.00,
1992., 114.0,0.00

ANRT_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANRT_FRC = 0


LAI_OBS =
1992., 4.,0.03,
1992., 16.,0.03,
1992., 34.,0.34,
1992., 58.,1.54,
1992., 68.,1.57,
1992., 84.,1.96,
1992., 97.,1.51,
1992., 114.,0.73

LAI_TRG = 1900.,1.,0.,
           2000.,1.,0.

LAI_FRC = 0


FSHTB  = 0.0,0.5,0.43,0.75,1.0,1.0,2.1,1.0

FLVTB =0.000,0.55,0.244,0.563,0.495,0.434,
       0.720,0.284, 0.899,0.126, 1.0,0.0,
       1.221,0.0,1.72 ,0.0,   2.1  ,0.0
FSTTB = 0.0,0.45,0.244,0.437, 0.495,0.566,
        0.720,0.716, 0.899,0.610, 1.0,0.0,
        1.221,0.0,   1.72 ,0.0,   2.1,0.0
FSOTB = 0.0,0.0,   0.244,0.0, 0.495,0.0,
        0.720,0.0, 0.899,0.264, 1.0,1.0,
        1.221,1.0, 1.72 ,1.0,      2.1,1.0
*XNFLVT =  0.,0.578,
*          16.,0.578, 34.,1.707, 58.,1.056,
*          84.,1.274, 97.,0.806, 114.,0.713

SLATB =  0.,0.0047,
        16.,0.0047,34.,0.0029,58.,0.0022,
        68.,0.0013, 84.,0.0013,
        97.,0.0016, 114.,0.0013


**************************************
* R. Torres, IRRI, The Philippines
* 1992
* variety:   IR72
* treatment: 180 KG/HA
**************************************
TREATM = 'IRRI, 1992, IR72, 180 kg/ha N'

* dummy initialisation
RADTOI = 0.

DATH   = 98.
DTRP   = 12.
FGHDAY = 68.0     !
WLVGI = 6.4
WSTSI = 5.1
WRTLI = 11.5
*NSTI = 0.0126
FNLVI = 0.0271
*NRTI = 0.0126
DVSI  = 0.152
TSI   = 202.6
FSTR  = 0.20
* RGRL  = 0.0090
DVRV  = 0.000751
DVRR  = 0.00168
* first and last values are dummy's
SLAC  = 0.0019
SLAFAC= 0.0,2.56,0.152,2.46,0.323,
        1.63,0.653,1.15,0.787,1.11,
        1.011,1.00,1.464,0.92,
        2.011,0.83,2.1,0.83
NA    = 4
DNAPT = 4.,16.,34.,120.
NS    = 6
DNOST = 16.,33.,58.,68.,84.,114.
NTOTMT= 0.24,11.20,93.73,135.45,
        135.10,137.00

** OBSERVED VALUES FOR M10 IR72-180N
WLVG_OBS =
1992., 4.,6.4,
1992., 16.,6.4,
1992., 34.,148.1,
1992., 58.,2011.7,
1992., 68.,3024.3,
1992., 84.,3118.4,
1992., 97.,2430.7,
1992., 114.,1325.7

WLVG_TRG = 1900.,1.,0.,
           2000.,1.,0.

WLVG_FRC = 0

WSTS_OBS =
1992., 4.,5.1,
1992., 16.,5.1,
1992., 34.,112.1,
1992., 58.,1720.1,
1992., 68.,3317.4,
1992., 84.,4813.5,
1992., 97.,4307.5,
1992., 114.,3918.4

WSTS_TRG = 1900.,1.,0.,
           2000.,1.,0.

WSTS_FRC = 0

WSO_OBS =
1992., 4.,0.0,
1992., 16.,0.0,
1992., 34.,0.0,
1992., 58.,0.0,
1992., 68.,0.0,
1992., 84.,1195.7,
1992., 97.,6212.3,
1992., 114.,9944.8

WSO_TRG = 1900.,1.,0.,
          1989.,30.,2.,
          1989.,50.,2.,
          2000.,1.,0.

WSO_FRC = 0

WLVD_OBS =
1992., 4.,0.0,
1992., 16.,0.0,
1992., 34.,0.0,
1992., 58.,43.2,
1992., 68.,247.3,
1992., 84.,717.3,
1992., 97.,1889.4,
1992., 114.,3004.0

WLVD_TRG = 1900.,1.,0.,
           2000.,1.,0.

WLVD_FRC = 0

WTDM_OBS =
1992., 4.,11.5,
1992., 16.,11.5,
1992., 34.,260.2,
1992., 58.,3775.0,
1992., 68.,6589.0,
1992., 84.,9844.9,
1992., 97.,14839.9,
1992., 114.,18192.9

WTDM_TRG = 1900.,1.,0.,
           2000.,1.,0.
```

```
WTDM_FRC = 0

WRTL_OBS =
1992., 4.,0.,
1992., 114.,0.

WRTL_TRG = 1900.,1.,0.,
           2000.,1.,0.

WRTL_FRC = 0

ANLV_OBS =
1992.,  4.0, 0.17,
1992., 16.0, 0.17,
1992., 33.0, 7.75,
1992., 58.0,70.51,
1992., 68.0,96.48,
1992., 84.0,81.55,
1992., 98.0,48.25,
1992.,114.0,16.07

ANLV_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANLV_FRC = 0

ANST_OBS =
1992.,  4.0, 0.06,
1992., 16.0, 0.06,
1992., 33.0, 3.45,
1992., 58.0,23.22,
1992., 68.0,38.98,
1992., 84.0,41.16,
1992., 98.0,23.78,
1992.,114.0,19.40

ANST_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANST_FRC = 0

ANSO_OBS =
1992.,   4.0,  0.00,
1992.,  16.0,  0.00,
1992.,  33.0,  0.00,
1992.,  58.0,  0.00,
1992.,  68.0,  0.00,
1992.,  84.0, 12.40,
1992., 114.0,101.54

ANSO_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANSO_FRC = 0

ANRT_OBS=
1992., 4.0,0.00,
1992., 114.0,0.00

ANRT_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANRT_FRC = 0

LAI_OBS =
1992., 4.,0.03,
1992., 16.,0.03,
1992., 34.,0.46,

1992., 58.,4.43,
1992., 68.,6.40,
1992., 84.,5.95,
1992., 97.,4.28,
1992., 114.,2.11

LAI_TRG = 1900.,1.,0.,
           2000.,1.,0.

LAI_FRC = 0

FSHTB  = 0.0,0.5,0.43,0.75,1.0,1.0,2.1,1.0

FLVTB = 0.0,0.55,0.244,0.570, 0.495,0.537,
        0.720,0.388,0.899,0.034, 1.0,0.0,
        1.221,0.0, 1.72,0.0,2.1,0.0
FSTTB = 0.0,0.45,0.244,0.430, 0.495,0.463,
        0.720,0.612,0.899,0.537,1.0,0.0,
        1.221,0.0, 1.72,0.0, 2.1,0.0
FSOTB = 0.0,0.0, 0.183,0.0, 0.495,0.0,
        0.720,0.0,0.899,0.429,1.0,1.0,
        1.221,1.0, 1.72,1.0, 2.1,1.0
*XNFLVT =  0.,0.578,
*          16.,0.578, 34.,1.685, 58.,1.592,
*          68.,1.507, 84.,1.371, 97.,1.127,
*          114.,0.761
SLATB =  0.,0.0047,
        16.,0.0047, 34.,0.0031,58.,0.0022,
        68.,0.0021, 84.,0.0019,97.,0.0018,
       114.,0.0016

****************************************
* R. Torres, IRRI, The Philippines
* 1992
* variety:   IR72
* treatment: 225 KG/HA
****************************************
TREATM = 'IRRI, 1992, IR72, 225 kg/ha N'

* dummy initialisation
RADTOI = 0.

DATH   = 98.
DTRP   = 12.
FGHDAY = 68.0    !
WLVGI = 6.4
WSTSI = 5.1
WRTLI = 11.5
*FNSTI = 0.0126
FNLVI = 0.0271
*FNRTI = 0.0126
DVSI  = 0.152
TSI   = 202.6
FSTR  = 0.20
* RGRL  = 0.0090
DVRV  = 0.000751
DVRR  = 0.00168
NS    = 6
DNOST = 16.,33.,58.,68.,84.,114.
NTOTMT= 0.24,10.28,82.35,129.21,
        123.17,158.50
NA    = 6
DNAPT = 4.,16.,34.,58.,84.,120.
* first and last values are dummy's
SLAC  =0.0019
SLAFAC=0.0,2.42,0.152,2.42,0.323,1.72,
       0.653,1.44,0.787,1.08, 1.011,1.00,
       1.464,0.88,2.011,0.88, 2.1,0.88

WLVG_OBS  =
1992., 4.,0.0,
1992., 16.,6.4,
1992., 34.,138.1,
1992., 58.,1873.8,
1992., 68.,2840.1,
1992., 84.,3030.2,
1992., 97.,2828.6,
1992., 114.,1431.8

WLVG_TRG = 1900.,1.,0.,
           2000.,1.,0.

WLVG_FRC = 0

WSTS_OBS    =
1992., 4.,0.0,
1992., 16.,5.1,
1992., 34.,109.0,
1992., 58.,1577.2,
1992., 68.,2902.4,
1992., 84.,4771.4,
1992., 97.,4372.2,
1992., 114.,4243.4

WSTS_TRG = 1900.,1.,0.,
           2000.,1.,0.

WSTS_FRC = 0

WSO_OBS    =
```

```
1992., 4.,0.0,
1992., 16.,0.0,
1992., 34.,0.0,
1992., 58.,0.0,
1992., 68.,0.0,
1992., 84.,816.4,
1992., 97.,5714.9,
1992., 114.,9558.3

WSO_TRG = 1900.,1.,0.,
          2000.,1.,0.

WSO_FRC = 0

WLVD_OBS     =
1992., 4.,0.0,
1992., 16.,0.0,
1992., 34.,0.0,
1992., 58.,47.4,
1992., 68.,233.6,
1992., 84.,658.8,
1992., 97.,1448.1,
1992., 114.,2269.4

WLVD_TRG = 1900.,1.,0.,
           2000.,1.,0.

WLVD_FRC = 0

WTDM_OBS     =
1992., 4.,0.0,
1992., 16.,11.5,
1992., 34.,247.1,
1992., 58.,3498.4,
1992., 68.,5976.1,
1992., 84.,9276.8,
1992., 97.,14363.8,
1992., 114.,17503.

WTDM_TRG = 1900.,1.,0.,
           2000.,1.,0.

WTDM_FRC = 0

WRTL_OBS     =
1992., 4.,0.,
1992., 114.,0.

WRTL_TRG = 1900.,1.,0.,
           2000.,1.,0.

WRTL_FRC = 0

ANLV_OBS     =
1992.,  4.00, 0.17,
1992., 16.00, 0.17,
1992., 33.00, 7.04,
1992., 58.00,53.65,
1992., 68.00,92.93,
1992., 84.00,75.60,
1992., 98.00,66.19,
1992.,114.00,20.43

ANLV_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANLV_FRC = 0

ANST_OBS     =
1992.,  4.00, 0.06,
1992., 16.00, 0.06,
1992., 33.00, 3.24,
1992., 58.00,28.71,
1992., 68.00,36.28,
1992., 84.00,38.51,
1992., 98.00,31.26,
1992.,114.00,24.61

ANST_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANST_FRC = 0

ANSO_OBS     =
1992.,  4.00,  0.00,
1992., 16.00,  0.00,
1992., 33.00,  0.00,
1992., 58.00,  0.00,
1992., 68.00,  0.00,
1992., 84.00,  9.06,
1992.,114.00,113.46

ANSO_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANSO_FRC = 0

ANRT_OBS     =
1992., 4.0,0.00,
1992., 114.0,0.00

ANRT_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANRT_FRC = 0

LAI_OBS  =
1992., 4.,0.03,
1992., 16.,0.03,
1992., 34.,0.46,
1992., 58.,5.22,
1992., 68.,5.97,
1992., 84.,5.88,
1992., 97.,4.82,
1992., 114.,2.45

LAI_TRG = 1900.,1.,0.,
          2000.,1.,0.

LAI_FRC = 0

FSHTB  = 0.0,0.5,0.43,0.75,1.0,1.0,2.1,1.0

FLVTB = 0.000,0.600,0.244,0.559,
        0.495,0.542,0.720,0.388,
        0.899,0.034,1.0,0.0,1.221,
        0.0,1.720,0.000,2.1,0.0
FSTTB = 0.0,0.40,0.244,0.441,
        0.495,0.458,0.720,0.612,
        0.899,0.537, 1.0,0.0,1.221,0.0,
        1.720,0.0,2.1,0.0
FSOTB  =  0.0,0.0,0.217,0.0, 0.496,0.0,
          0.720,0.0,0.899,0.429, 1.0,1.0,
          1.221,1.0,1.720,1.0,2.1,1.0
*XNFLVT  = 0.,0.578, 16.,0.578, 34.,1.531,
*          58.,1.028, 68.,1.557, 84.,1.286,
*          97.,1.373, 114.,0.834

SLATB  = 0.,0.0047,16.,0.0047, 34.,0.0033,
        58.,0.0028,68.,0.0021, 84.,0.0019,
        97.,0.0017, 114.,0.0017


***************************************
* R. Torres, IRRI, The Philippines
* 1992
* variety:   LINE
* treatment: 0 KG/HA
***************************************
TREATM = 'IRRI, 1992, LINE, 0 kg/ha N'

* dummy initialisation
RADTOI = 0.

DATH   = 112.
DTRP   = 12.
FGHDAY = 128.0    !
WLVGI = 5.6
WSTSI = 5.1
WRTLI = 10.7
*FNSTI = 0.0134
FNLVI = 0.0261
*FNRTI = 0.0134
DVSI  = 0.127
TSI   = 202.6
FSTR  = 0.40
* RGRL  = 0.0060
DVRV  = 0.000625
DVRR  = 0.001629
NA    = 3
```

```
DNAPT  = 4.,16.,135.
NS     = 6
DNOST  = 16.,34.,70.,79.,98.,128.
NTOTMT = 0.21,17.22,32.11,40.13,43.64,56.38
* first and last values are dummy's
SLAC  = 0.0016
SLAFAC= 0.0,3.35,0.127,3.35,0.279,1.94,
        0.678,1.05,0.781,1.08,1.009,1.00,
        1.539,0.90,2.009,0.77,2.1,0.77

** OBSERVED VALUES FOR M10 LINE ON
WLVG_OBS =
1992., 4.,5.6,
1992., 16.,5.6,
1992., 34.,103.3,
1992., 70.,1055.3,
1992., 79.,1322.5,
1992., 98.,1531.5,
1992., 114.,1124.2,
1992., 128., 614.6

WLVG_TRG = 1900.,1.,0.,
           2000.,1.,0.

WLVG_FRC = 0

WSTS_OBS=
1992., 4.,5.1,
1992., 16.,5.1,
1992., 34.,74.1,
1992., 70.,1817.8,
1992., 79.,2492.7,
1992., 98.,4099.0,
1992., 114.,3659.7,
1992., 128.,2725.0

WSTS_TRG = 1900.,1.,0.,
           2000.,1.,0.

WSTS_FRC = 0

WSO_OBS =
1992., 4.,0.0,
1992., 16.,0.0,
1992., 79.,0.0,
1992., 98.,458.9,
1992., 114.,3597.2,
1992., 128.,5781.3

WSO_TRG = 1900.,1.,0.,
          1989.,30.,2.,
          1989.,50.,2.,
          2000.,1.,0.

WSO_FRC = 0

WLVD_OBS =
1992., 4.,0.0,
1992., 16.,0.0,
1992., 34.,0.0,
1992., 70.,252.4,
1992., 79.,349.3,
1992., 98.,1107.3,
1992., 114.,1682.7,
1992., 128.,2452.1

WLVD_TRG = 1900.,1.,0.,
           2000.,1.,0.

WLVD_FRC = 0

WTDM_OBS =
1992., 4.,10.7,
1992., 16.,10.7,
1992., 34.,177.4,
1992., 70.,3125.5,
1992., 79.,4164.5,
1992., 98.,7196.7,
1992., 114.,10063.8,
1992., 128.,11573.0

WTDM_TRG = 1900.,1.,0.,
           2000.,1.,0.

WTDM_FRC = 0

WRTL_OBS =
1992., 4.,0.,
1992., 128.,0.

WRTL_TRG = 1900.,1.,0.,
           2000.,1.,0.

WRTL_FRC = 0

ANLV_OBS=
1992.,  4.0, 0.15,
1992., 16.0, 0.15,
1992., 34.0, 5.21,
1992., 70.0,20.42,
1992., 79.0,24.80,
1992., 98.0,22.48,
1992.,114.0,11.95,
1992.,128.0, 4.90

ANLV_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANLV_FRC = 0

ANST_OBS=
1992.,  4.0, 0.07,
1992., 16.0, 0.07,
1992., 34.0, 2.01,
1992., 70.0,11.69,
1992., 79.0,15.33,
1992., 98.0,17.30,
1992.,114.0,13.25,
1992.,128.0, 8.99

ANST_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANST_FRC = 0

ANSO_OBS=
1992.,  4.0, 0.00,
1992., 16.0, 0.00,
1992., 34.0, 0.00,
1992., 70.0, 0.00,
1992., 79.0, 0.00,
1992., 98.0, 3.86,
1992.,128.0,42.49

ANSO_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANSO_FRC = 0

ANRT_OBS   =
1992., 4.0,0.00,
1992., 128.0,0.00

ANRT_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANRT_FRC = 0

LAI_OBS =
1992., 4.,0.03,
1992., 16.,0.03,
1992., 34.,0.32,
1992., 70.,1.78,
1992., 79.,2.28,
1992., 98.,2.45,
1992., 114.,1.61,
1992., 128.,0.76

LAI_TRG = 1900.,1.,0.,
          2000.,1.,0.

LAI_FRC = 0

FSHTB  = 0.0,0.5,0.43,0.75,1.0,1.0,2.1,1.0

FLVTB = 0.0,0.55,0.203,0.586, 0.478,0.353,
        0.730,0.388, 0.895,0.034, 1.0,0.0,
        1.274,0.0, 1.774,0.0, 2.1,0.0
FSTTB = 0.0,0.45,0.203,0.414, 0.478,0.647,
        0.730,0.612,0.895,0.537,  1.0,0.0,
```

```
        1.274,0.0,1.774,0.0, 2.1,0.0
FSOTB = 0.0,0.0, 0.152,0.0, 0.478,0.0,
        0.723,0.0, 0.895,0.429, 1.0,1.0,
        1.274,1.0, 1.774,1.0, 2.1,1.0
*XNFLVT =  0.,0.487,
*          16.,0.487, 34.,1.627, 70.,1.147,
*          79.,1.088,98.,0.918, 114.,0.742, *
128.,0.645

SLATB = 0.,0.0054,
       16.,0.0054,34.,0.0031, 70.,0.0017,
       79.,0.0017,98.,0.0016, 114.,0.0014,
      128.,0.0012


****************************************
* R. Torres, IRRI, The Philippines
* 1992
* variety:   LINE
* treatment: 180 KG/HA
****************************************
TREATM = 'IRRI, 1992, LINE, 180 kg/ha N'

* dummy initialisation
RADTOI = 0.

DATH   = 112.
DTRP   = 12.
FGHDAY = 128.0
WLVGI  = 5.6
WSTSI  = 5.1
WRTLI  = 10.7
*FNSTI = 0.0134
FNLVI  = 0.0261
*FNRTI = 0.0134
DVSI   = 0.127
TSI    = 202.6
FSTR   = 0.40
* RGRL  = 0.0090
DVRV   = 0.000625
DVRR   = 0.001629
NS     = 6
DNOST  = 16.,34.,70.,79.,98.,128.
NTOTMT =
0.21,9.74,90.55,120.95,151.72,151.72
NA     = 4
DNAPT  = 4.,16.,34.,135.
* first and last values are dummy's
SLAC   = 0.0018
SLAFAC= 0.0,2.94,0.127,2.94,0.279,
        1.60,0.678,1.04,0.781,1.05,
        1.009,1.00,1.539,0.85,2.009,
        0.93,2.1,0.93

** OBSERVED VALUES FOR M10 LINE 180N
WLVG_OBS =
1992., 4.,5.6,
1992., 16.,5.6,
1992., 34.,133.8,
1992., 70.,2189.2,
1992., 79.,3122.7,
1992., 98.,4400.2,
1992., 114.,2765.9,
1992., 128.,1488.5

WLVG_TRG = 1900.,1.,0.,
           2000.,1.,0.

WLVG_FRC = 0

WSTS_OBS=
1992., 4.,5.1,
1992., 16.,5.1,
1992., 34.,98.8,
1992., 70.,3107.5,
1992., 79.,4268.2,
1992., 98.,7824.8,
1992., 114.,5906.4,
1992., 128.,4443.8

WSTS_TRG = 1900.,1.,0.,
           2000.,1.,0.

WSTS_FRC = 0

WSO_OBS =
1992., 4.,0.0,
1992., 16.,0.0,
1992., 79.,0.0,
1992., 98.,748.6,
1992., 114.,6498.0,
1992., 128.,9304.2

WSO_TRG = 1900.,1.,0.,
          2000.,1.,0.

WSO_FRC = 0

WLVD_OBS =
1992.,4.,0.0,
1992.,16.,0.0,
1992.,34.,0.0,
1992.,70.,384.4,
1992.,79.,426.9,
1992.,98.,1809.1,
1992.,114.,2725.3,
1992.,128.,4508.3

WLVD_TRG = 1900.,1.,0.,
           2000.,1.,0.

WLVD_FRC = 0

WTDM_OBS =
1992.,4.0,10.7,
1992.,16.,10.7,
1992.,34.,232.6,
1992.,70.,5684.4,
1992.,79.,7817.8,
1992.,98.,14782.7,
1992.,114.,17895.6,
1992.,128.,19744.8

WTDM_TRG = 1900.,1.,0.,
           2000.,1.,0.

WTDM_FRC = 0

WRTL_OBS =
1992.,4.,0.,
1992.,128.,0.

WRTL_TRG = 1900.,1.,0.,
           2000.,1.,0.

WRTL_FRC = 0

ANLV_OBS=
1992.,  4.0, 0.15,
1992., 16.0, 0.15,
1992., 34.0, 6.86,
1992., 70.0,59.94,
1992., 79.0,80.19,
1992., 98.0,88.22,
1992.,114.0,44.06,
1992.,128.0,15.11

ANLV_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANLV_FRC = 0

ANST_OBS=
1992.,  4.0, 0.07,
1992., 16.0, 0.07,
1992., 34.0, 2.88,
1992., 70.0,30.61,
1992., 79.0,40.76,
1992., 98.0,55.95,
1992.,114.0,29.53,
1992.,128.0,18.89

ANST_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANST_FRC = 0

ANSO_OBS=
1992.,  4.0, 0.00,
1992., 16.0, 0.00,
```

```
1992., 34.0, 0.00,
1992., 70.0, 0.00,
1992., 79.0, 0.00,
1992., 98.0, 7.55,
1992.,128.0,87.55

ANSO_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANSO_FRC = 0

ANRT_OBS   =
1992.,4.0,0.00,
1992.,128.0,0.00

ANRT_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANRT_FRC = 0

LAI_OBS =
1992.,4.,0.03,
1992.,16.,0.03,
1992.,34.,0.39,
1992.,70.,4.13,
1992.,79.,5.99,
1992.,98.,8.02,
1992.,114.,4.31,
1992.,128.,2.52

LAI_TRG = 1900.,1.,0.,
          2000.,1.,0.

LAI_FRC = 0

FSHTB  = 0.0,0.5,0.43,0.75,1.0,1.0,2.1,1.0

FLVTB = 0.0,0.55,0.203,0.578, 0.478,0.406,
       0.730,0.388, 0.895,0.034, 1.0,0.0,
       1.274,0.0, 1.774,0.0, 2.1,0.0
FSTTB = 0.0,0.45,0.203,0.422, 0.478,0.594,
       0.730,0.612, 0.895,0.537,  1.0,0.0,
       1.274,0.0, 1.774,0.0, 2.1,0.0
FSOTB = 0.0,0.0, 0.180,0.0, 0.478,0.0,
       0.730,0.0, 0.895,0.429, 1.0,1.0,
       1.274,1.0, 1.774,1.0, 2.1,1.0
*XNFLVT =  0.,0.487,
*          16.,0.487,34.,1.760, 70.,1.451,
*          79.,1.339,98.,1.100, 114.,1.022,
*          128.,0.6

SLATB =  0.,0.0054,
         16.,0.0054,34.,0.0029, 70.,0.0019,
         79.,0.0019,98.,0.0018,114.,0.0016,
        128.,0.0017


***************************************
* R. Torres, IRRI, The Philippines
* 1992
* variety:   LINE
* treatment: 225 KG/HA
***************************************
TREATM = 'IRRI, 1992, LINE, 225 kg/ha N'

* dummy initialisation
RADTOI = 0.

DATH   = 112.
DTRP   = 12.
FGHDAY = 128.0    !
WLVGI = 5.6
WSTSI = 5.1
WRTLI = 10.7
*FNSTI = 0.0134
FNLVI = 0.0261
*FNRTI = 0.0134
DVSI  = 0.127
TSI   = 202.6
FSTR  = 0.40
* RGRL  = 0.0090
DVRV  = 0.000625
DVRR  = 0.001629
NS    = 6
DNOST  = 16.,34.,70.,79.,98.,128.

NTOTMT = 0.21,10.36,102.53,116.52,
         142.48,155.13
NA     = 6
DNAPT  = 4.,16.,34.,70.,98.,135.
* first and last values are dummy's
SLAC  = 0.0020
SLAFAC= 0.0,2.64,0.127,2.64,0.279,1.47,
        0.678,0.93,0.781,0.92,
        1.009,1.00,1.539,0.80,2.009,0.69,
        2.1,0.69

** OBSERVED VALUES FOR M10 LINE 225N
WLVG_OBS =
1992., 4. ,5.6,
1992., 16.,5.6,
1992., 34.,141.0,
1992., 70.,2469.1,
1992., 79.,3180.0,
1992., 98.,3755.6,
1992., 114.,3348.5,
1992., 128.,1507.3

WLVG_TRG = 1900.,1.,0.,
           2000.,1.,0.

WLVG_FRC = 0

WSTS_OBS =
1992., 4.,5.1,
1992., 16.,5.1,
1992., 34.,99.5,
1992., 70.,3487.7,
1992., 79.,4082.4,
1992., 98.,6846.6,
1992., 114.,5859.4,
1992., 128.,4297.9

WSTS_TRG = 1900.,1.,0.,
           2000.,1.,0.

WSTS_FRC = 0

WSO_OBS =
1992., 4.,0.0,
1992., 16.,0.0,
1992., 79.,0.0,
1992., 98.,991.6,
1992., 114.,7258.7,
1992., 128.,9709.4

WSO_TRG = 1900.,1.,0.,
          1989.,30.,2.,
          1989.,50.,2.,
          2000.,1.,0.

WSO_FRC = 0

WLVD_OBS =
1992., 4.,0.0,
1992., 16.,0.0,
1992., 34.,0.0,
1992., 70.,362.8,
1992., 79.,404.0,
1992., 98.,1665.8,
1992., 114.,2311.4,
1992., 128.,3995.8

WLVD_TRG = 1900.,1.,0.,
           2000.,1.,0.

WLVD_FRC = 0

WTDM_OBS =
1992., 4.,10.7,
1992., 16.,10.7,
1992., 34.,240.5,
1992., 70.,6319.6,
1992., 79.,7666.4,
1992., 98.,13259.6,
1992., 114.,18778.0,
1992., 128.,19510.4

WTDM_TRG = 1900.,1.,0.,
           2000.,1.,0.
```

```
WTDM_FRC = 0

WRTL_OBS =
1992., 4.,0.,
1992., 128.,0.

WRTL_TRG = 1900.,1.,0.,
           2000.,1.,0.

WRTL_FRC = 0

ANLV_OBS =
1992.,  4.0, 0.15,
1992., 16.0, 0.15,
1992., 34.0, 7.31,
1992., 70.0,67.90,
1992., 79.0,78.96,
1992., 98.0,81.87,
1992.,114.0,64.63,
1992.,128.0,16.31

ANLV_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANLV_FRC = 0

ANST_OBS =
1992.,  4.0, 0.07,
1992., 16.0, 0.07,
1992., 34.0, 3.05,
1992., 70.0,34.63,
1992., 79.0,37.56,
1992., 98.0,48.95,
1992.,114.0,33.98,
1992.,128.0,18.91

ANST_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANST_FRC = 0

ANSO_OBS =
1992.,  4.0,  0.00,
1992., 16.0,  0.00,
1992., 34.0,  0.00,
1992., 70.0,  0.00,
1992., 79.0,  0.00,
1992., 98.0, 11.65,
1992.,128.0,119.91

ANSO_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANSO_FRC = 0

ANRT_OBS    =
1992., 4.0,0.00,
1992., 128.0,0.00

ANRT_TRG = 1900.,1.,0.,
           2000.,1.,0.

ANRT_FRC = 0

LAI_OBS =
1992., 4.,0.03,
1992., 16.,0.03,
1992., 34.,0.42,
1992., 70.,4.65,
1992., 79.,5.91,
1992., 98.,7.608,
1992., 114.,5.42,
1992., 128.,2.11

LAI_TRG = 1900.,1.,0.,
          2000.,1.,0.

LAI_FRC = 0

FSHTB  = 0.0,0.5,0.43,0.75,1.0,1.0,2.1,1.0

FLVTB = 0.0,0.55,0.203,0.589, 0.478,0.407,
        0.730,0.388, 0.895,0.034, 1.0,0.0,
        1.274,0.0, 1.774,0.0, 2.1,0.0
FSTTB = 0.0,0.45,0.203,0.411, 0.478,0.593,
        0.730,0.612, 0.895,0.537, 1.0,0.0,
        1.274,0.0, 1.774,0.0, 2.1,0.0
FSOTB = 0.0,0.0, 0.203,0.0, 0.478,0.0,
        0.730,0.0, 0.895,0.429, 1.0,1.0,
        1.274,1.0, 1.774,1.0, 2.1,1.0
*XNFLVT =  0.,0.487,
*          16.,0.487,34.,1.740,70.,1.460,
*          79.,1.336, 98.,1.076, 114.,1.192,
*          128.,0.773
SLATB =  0.,0.0054,
        16.,0.0054,34.,0.0030, 70.,0.0019,
        79.,0.0019,98.,0.0020,114.,0.0016,
       128.,0.0014
```

Data sets for validation of ORYZA_0

```
***************************************
* R. Torres, IRRI, The Philippines
* 1992
* variety:   IR72
* treatment: 0 KG/HA
***************************************
TREATM = 'IRRI, 1992, IR72, 0 kg/ha N'

* dummy variables
DVSI = 0.
TBD  = 0.
TBLV = 0.

* Initial constants
* ----------------
***NOTE !!! EXCLUDING ROOTS
*WCRI   = 32.0
WCRI    = 11.5
ANCRI   = 0.23
RADTOI  = 0.
APCUMI  = 0.
DVSI    = 0.

* Model parameters
* ----------------
RTINCL = 0
DATFSV = 68.
DATEF  = 68.
*Flowering is at 68 DAT, DATFF is 68-7
DATFF  = 61.
DATH   = 98.
FSV1   = 0.87
FSV2   = 0.87
FNSO   = 0.01
FNCLV  = 0.50
ANLVMX = 100.
MAXUP1 = 5.
RUR    = 0.2
NUPCO  = 0.03
HI     = 0.5
SOLSUP = 0.6
FERTMX = 200.
A      = 1.
B      = 0.1
C      = 300.
M      = 30.
LARGE  = 100.
TINY   = 0.001

* AFGEN functions
* ---------------
FNMAXT =
   0., 0.03,
   40., 0.017,
   60., 0.015,
   80., 0.01,
   130., 0.07

RECT   =
   0., 0.0,
   60., 0.8,
   65., 0.4,
   70., 0.0,
   150., 0.

RSRT    =
     0., 0.4,
```

```
    1.1, 0.15

* Observed values
* ---------------

WLV_OBS =
1992.,4.,6.4,
1992.,16.,6.4,
1992.,34.,116.3,
1992.,58.,693.2,
1992.,68.,1203.5,
1992.,84.,1513.5,
1992.,97., 926.7,
1992.,114., 545.2

***NOTE !!! EXCLUDING ROOTS
WCR_OBS =
1992.,4.,11.5,
1992.,16.,11.5,
1992.,34.,206.5,
1992.,58.,1596.8,
1992.,68.,3614.2,
1992.,84.,6456.3,
1992.,97.,8640.9,
1992.,114.,9964.4

FNLV_OBS  =
1992.,  4.,2.71,
1992., 16.,2.71,
1992., 34.,4.99,
1992., 58.,2.35,
1992., 68.,1.98,
1992., 84.,1.65,
1992., 97.,1.31,
1992.,114.,0.96

***************************************
* R. Torres, IRRI, The Philippines
* 1992
* variety:   IR72
* treatment: 180 KG/HA
***************************************
TREATM = 'IRRI, 1992, IR72, 180 kg/ha N'

* dummy variables
DVSI = 0.
TBD  = 0.
TBLV = 0.

* Initial constants
* -----------------
***NOTE !!! EXCLUDING ROOTS
*WCRI   = 32.0
WCRI   = 11.5
ANCRI  = 0.23
RADTOI = 0.
APCUMI = 0.
DVSI   = 0.

* Model parameters
* ----------------
RTINCL = 0
DATFSV = 68.
DATEF  = 68.
*Flowering is at 68 DAT, DATFF is 68-7
DATFF  = 61.
DATH   = 98.
FSV1   = 0.87
FSV2   = 0.87
FNSO   = 0.01
FNCLV  = 0.50
ANLVMX = 100.
MAXUP1 = 5.
RUR    = 0.2
NUPCO  = 0.03
HI     = 0.5
SOLSUP = 0.6
FERTMX = 200.
A      = 1.
B      = 0.1
C      = 300.
M      = 30.
LARGE  = 100.
TINY   = 0.001
```

```
* AFGEN functions
* ---------------
FNMAXT =
   0., 0.03,
   40., 0.017,
   60., 0.015,
   80., 0.01,
   130., 0.07

RECT   =
   0., 0.0,
   60., 0.8,
   65., 0.4,
   70., 0.0,
   150., 0.

RSRT    =
     0., 0.4,
    1.1, 0.15

* Observed values
* ---------------

WLV_OBS =
1992., 4.,6.4,
1992., 16.,6.4,
1992., 34.,148.1,
1992., 58.,2011.7,
1992., 68.,3024.3,
1992., 84.,3118.4,
1992., 97.,2430.7,
1992., 114.,1325.7

***NOTE !!! EXCLUDING ROOTS
WCR_OBS =
1992., 4.,11.5,
1992., 16.,11.5,
1992., 34.,260.2,
1992., 58.,3775.0,
1992., 68.,6589.0,
1992., 84.,9844.9,
1992., 97.,14839.9,
1992., 114.,18192.9

FNLV_OBS  =
1992.,   4.,2.71,
1992.,  16.,2.71,
1992.,  34.,5.23,
1992.,  58.,3.51,
1992.,  68.,3.19,
1992.,  84.,2.62,
1992.,  97.,1.99,
1992., 114.,1.21

***************************************
* R. Torres, IRRI, The Philippines
* 1992
* variety:   IR72
* treatment: 225 KG/HA
***************************************
TREATM = 'IRRI, 1992, IR72, 225 kg/ha N'

* dummy variables
DVSI = 0.
TBD  = 0.
TBLV = 0.

* Initial constants
* -----------------
***NOTE !!! EXCLUDING ROOTS
*WCRI   = 32.0
WCRI   = 11.5
ANCRI  = 0.23
RADTOI = 0.
APCUMI = 0.
DVSI   = 0.

* Model parameters
* ----------------
RTINCL = 0
DATFSV = 68.
DATEF  = 68.
*Flowering is at 68 DAT, DATFF is 68-7
DATFF  = 61.
DATH   = 98.
```

```
FSV1   = 0.87
FSV2   = 0.87
FNSO   = 0.01
FNCLV  = 0.50
ANLVMX = 100.
MAXUP1 = 5.
RUR    = 0.2
NUPCO  = 0.03
HI     = 0.5
SOLSUP = 0.6
FERTMX = 200.
A      = 1.
B      = 0.1
C      = 300.
M      = 30.
LARGE  = 100.
TINY   = 0.001

* AFGEN functions
* ---------------
FNMAXT =
   0., 0.03,
   40., 0.017,
   60., 0.015,
   80., 0.01,
   130., 0.07

RECT   =
   0., 0.0,
   60., 0.8,
   65., 0.4,
   70., 0.0,
   150., 0.

RSRT   =
     0., 0.4,
    1.1, 0.15

* Observed values
* ---------------

WLV_OBS  =
1992., 4.,0.0,
1992., 16.,6.4,
1992., 34.,138.1,
1992., 58.,1873.8,
1992., 68.,2840.1,
1992., 84.,3030.2,
1992., 97.,2828.6,
1992., 114.,1431.8

***NOTE !!! EXCLUDING ROOTS
WCR_OBS =
1992., 4.,0.0,
1992., 16.,11.5,
1992., 34.,247.1,
1992., 58.,3498.4,
1992., 68.,5976.1,
1992., 84.,9276.8,
1992., 97.,14363.8,
1992., 114.,17503.

FNLV_OBS  =
1992.,   4.,2.71,
1992.,  16.,2.71,
1992.,  34.,5.10,
1992.,  58.,2.86,
1992.,  68.,3.27,
1992.,  84.,2.50,
1992.,  97.,2.34,
1992., 114.,1.43

***************************************
* R. Torres, IRRI, The Philippines
* 1992
* variety:   LINE
* treatment: 0 KG/HA
***************************************
TREATM = 'IRRI, 1992, LINE, 0 kg/ha N'

* dummy variables
DVSI = 0.
TBD  = 0.
TBLV = 0.
```

```
* Initial constants
* -----------------
***NOTE !!! EXCLUDING ROOTS
*WCRI   = 32.0
WCRI   = 10.7
ANCRI  = 0.22
RADTOI = 0.
APCUMI = 0.
DVSI   = 0.

* Model parameters
* ----------------
RTINCL = 0
DATFSV = 82.
DATEF  = 82.
*Flowering is at 82 DAT, DATFF is 82-7
DATFF  = 75.
DATH   = 112.
FSV1   = 0.87
FSV2   = 0.87
FNSO   = 0.01
FNCLV  = 0.50
ANLVMX = 100.
MAXUP1 = 5.
RUR    = 0.2
NUPCO  = 0.03
HI     = 0.5
SOLSUP = 0.6
FERTMX = 200.
A      = 1.
B      = 0.1
C      = 300.
M      = 30.
LARGE  = 100.
TINY   = 0.001

* AFGEN functions
* ---------------
FNMAXT =
   0., 0.03,
   40., 0.017,
   60., 0.015,
   80., 0.01,
   130., 0.07

RECT   =
   0., 0.0,
   60., 0.8,
   65., 0.4,
   70., 0.0,
   150., 0.

RSRT   =
     0., 0.4,
    1.1, 0.15

* Observed values
* ---------------

WLV_OBS =
1992., 4.,5.6,
1992., 16.,5.6,
1992., 34.,103.3,
1992., 70.,1055.3,
1992., 79.,1322.5,
1992., 98.,1531.5,
1992., 114.,1124.2,
1992., 128., 614.6

***NOTE !!! EXCLUDING ROOTS
WCR_OBS =
1992.,   4.,10.7,
1992.,  16.,10.7,
1992.,  34.,177.4,
1992.,  70.,3125.5,
1992.,  79.,4164.5,
1992.,  98.,7196.7,
1992., 114.,10063.8,
1992., 128.,11573.0

FNLV_OBS  =
1992.,   4.,2.61,
1992.,  16.,2.61,
1992.,  34.,5.04,
1992.,  70.,1.94,
```

```
1992.,  79.,1.88,
1992.,  98.,1.47,
1992., 114.,1.06,
1992., 128.,0.80

****************************************
* R. Torres, IRRI, The Philippines
* 1992
* variety:   LINE
* treatment: 180 KG/HA
****************************************
TREATM = 'IRRI, 1992, LINE, 180 kg/ha N'

* dummy variables
DVSI = 0.
TBD  = 0.
TBLV = 0.

* Initial constants
* -----------------
***NOTE !!! EXCLUDING ROOTS
*WCRI   = 32.0
WCRI   = 10.7
ANCRI  = 0.22
RADTOI = 0.
APCUMI = 0.
DVSI   = 0.

* Model parameters
* ----------------
RTINCL = 0
DATFSV = 82.
DATEF  = 82.
*Flowering is at 82 DAT, DATFF is 82-7
DATFF  = 75.
DATH   = 112.
FSV1   = 0.87
FSV2   = 0.87
P      = 10.
EPSIL  = 2.5
FNSO   = 0.01
FNCLV  = 0.50
ANLVMX = 100.
MAXUP1 = 5.
RUR    = 0.2
NUPCO  = 0.03
HI     = 0.5
SOLSUP = 0.6
FERTMX = 200.
A      = 1.
B      = 0.1
C      = 300.
M      = 30.
LARGE  = 100.
TINY   = 0.001

* AFGEN functions
* ---------------
FNMAXT =
   0., 0.03,
   40., 0.017,
   60., 0.015,
   80., 0.01,
   130., 0.07

RECT   =
   0., 0.0,
   60., 0.8,
   65., 0.4,
   70., 0.0,
   150., 0.

RSRT    =
     0., 0.4,
    1.1, 0.15

* Observed values
* ---------------

WLV_OBS =
1992., 4.,5.6,
1992., 16.,5.6,
1992., 34.,133.8,
1992., 70.,2189.2,
1992., 79.,3122.7,
1992., 98.,4400.2,
1992., 114.,2765.9,
1992., 128.,1488.5

***NOTE !!! EXCLUDING ROOTS
WCR_OBS =
1992.,4.0,10.7,
1992.,16.,10.7,
1992.,34.,232.6,
1992.,70.,5684.4,
1992.,79.,7817.8,
1992.,98.,14782.7,
1992.,114.,17895.6,
1992.,128.,19744.8

FNLV_OBS  =
1992.,  4.,2.61,
1992., 16.,2.61,
1992., 34.,5.13,
1992., 70.,2.74,
1992., 79.,2.57,
1992., 98.,2.01,
1992.,114.,1.59,
1992.,128.,1.02

****************************************
* R. Torres, IRRI, The Philippines
* 1992
* variety:   LINE
* treatment: 225 KG/HA        .
****************************************
TREATM = 'IRRI, 1992, LINE, 225 kg/ha N'

* dummy variables
DVSI = 0.
TBD  = 0.
TBLV = 0.

* Initial constants
* -----------------
***NOTE !!! EXCLUDING ROOTS
*WCRI   = 32.0
WCRI   = 10.7
ANCRI  = 0.22
RADTOI = 0.
APCUMI = 0.
DVSI   = 0.

* Model parameters
* ----------------
RTINCL = 0
DATFSV = 82.
DATEF  = 82.
*Flowering is at 82 DAT, DATFF is 82-7
DATFF  = 75.
DATH   = 112.
FSV1   = 0.87
FSV2   = 0.87
FNSO   = 0.01
FNCLV  = 0.50
ANLVMX = 100.
MAXUP1 = 5.
RUR    = 0.2
NUPCO  = 0.03
HI     = 0.5
SOLSUP = 0.6
FERTMX = 200.
A      = 1.
B      = 0.1
C      = 300.
M      = 30.
LARGE  = 100.
TINY   = 0.001

* AFGEN functions
* ---------------
FNMAXT =
   0., 0.03,
   40., 0.017,
   60., 0.015,
   80., 0.01,
   130., 0.07

RECT   =
   0., 0.0,
```

```
   60., 0.8,
   65., 0.4,
   70., 0.0,
   150., 0.

RSRT     =
     0., 0.4,
    1.1, 0.15

* Observed values
* ---------------

WLV_OBS =
1992., 4. ,5.6,
1992., 16.,5.6,
1992., 34.,141.0,
1992., 70.,2469.1,
1992., 79.,3180.0,
1992., 98.,3755.6,
1992., 114.,3348.5,
1992., 128.,1507.3

***NOTE !!! EXCLUDING ROOTS
WCR_OBS =
1992., 4.,10.7,
1992., 16.,10.7,
1992., 34.,240.5,
1992., 70.,6319.6,
1992., 79.,7666.4,
1992., 98.,13259.6,
1992., 114.,18778.0,
1992., 128.,19510.4

FNLV_OBS  =
1992.,   4.,2.61,
1992.,  16.,2.61,
1992.,  34.,5.18,
1992.,  70.,2.75,
1992.,  79.,2.48,
1992.,  98.,2.18,
1992., 114.,1.93,
1992., 128.,1.08
```