A STRUCTURED APPROACH TO MODELLING THE ASSIMILATION OF A HETEROGENEOUS CANOPY, IMPLEMENTED AS A MODEL FOR THE GROWTH OF COMPETING SPRING WHEAT CULTIVARS

H.J. Rennau & C.J.T. Spitters
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CABO-TT
Bornsesteeg 65
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Centre for Agrobiological Research

VAKGROEP THEORETISCHE TEELTKUNDE (TT), Landbouwhogeschool
Department of Theoretical Production Ecology, Agricultural University.
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1. INTRODUCTION

The model presented in this paper was written for simulating the growth of several wheat cultivars in mixture. Notwithstanding this specific purpose, an effort has been made to develop a model structure which may be of use in simulating photosynthesis of heterogeneous canopies in general. A distinction between different types of light absorbing and photosynthesizing surfaces of heterogeneous canopies may be necessary because they belong to different, competing populations, or they differ in optical behaviour (extinction coefficient), or they differ in photosynthetic behaviour. Such a situation is for example given when growth of competing species is modelled or when assimilation not only of leaves but also of other organs (e.g. ears) has to be accounted for.

Modelling of the light distribution and photosynthesis is essentially based on the model of de Wit et al. (1978) for homogeneous monocultures and the extension of this model by Spitters & Aerts (1983) to mixed canopies. This latter model is improved here by introducing a rigorous modular structure and by incorporating the revised procedures to calculate and to handle the different components of incoming radiation (Spitters et al., 1986; Spitters, 1986) and to integrate photosynthesis over time intervals within the day (Goudriaan, 1986). Furthermore, different types of photosynthesizing organs (leaf blades, leaf sheaths + stems, ears) are distinguished in the presented model. The derivation of daily net assimilation from daily gross assimilation and the distribution of net assimilates over plant organs proceed according to Van Keulen et al. (1982).

2. SCOPE OF THE MODEL

The model simulates plant growth under potential conditions: gross production is only dependent on light absorption and temperature and unrestricted by the supplies of water and nutrients or the occurrence of pests, diseases and weeds.

As stated above, the model was written to simulate the growth of wheat. Features of wheat are largely restricted to the actual values of parameters. Still, there are two structural accommodations to the species wheat:
1) light absorption and photosynthesis of ears and stems is included;
2) the total yellow fraction of leaves is assumed to be positioned below the total green fraction.

If a potential user of our model decides that point (2) is inappropriate, he has to perform structural adjustments (replacement of the subroutine YELDII). Such adjustments are unnecessary for the omission of point (1), which can be achieved by assigning appropriate values to switch parameters.
3. DESCRIPTION OF THE MODEL

3.1 Concepts underlying the model

a) For each type of assimilating surface (e.g. the leaves of one competitor) a 2-parametric light response curve is assumed:

\[ A(I) = AMAX \cdot (1 - \exp(-I \cdot EFF/AMAX)) \]  

I : absorbed photosynthetically active radiation (J/m^2/s)  
A : assimilation rate (kg CO_2/ha/h)  
AMAX : assimilation rate at light saturation (kg CO_2/ha/h)  
EFF : initial light use efficiency (kg CO_2/ha/h)/(J/m^2/s), defined as

\[ \lim_{I \to 0} \frac{A(I)}{I} \]  

b) From the daily global irradiance, the diurnal courses of diffuse and direct photosynthetically active radiation are estimated.

c) On their vertical path through the canopy, the direct and diffuse flux attenuate exponentially:

\[ I(x_1) = I(x_2) \cdot \exp\left(- \sum_{s=1}^{NST} A_{is}(x_1, x_2) \cdot K(s) \right) \quad x_1 < x_2 \]  

x : height above ground (cm)  
I(x) : light intensity (J/m^2/s) at height x above the ground  
A_{is}(x_1, x_2): area index (ha surface/ha ground) of the fraction of surface type s that is positioned between the boundaries x1 and x2.  
NST : number of distinguished surface types  
K(s) : extinction coefficient of surface type s  
The extinction coefficients K(s) differ for diffuse and direct light.

d) The light absorbed by a vertically homogeneous mixture of surface types is distributed over the constituent surface types according to their areas, weighted by their extinction coefficients.
e) Maintenance respiration of each plant organ is obtained by multiplying its weight by an organ specific relative rate of respiration and a factor accounting for the influence of temperature.

f) The allocation of dry matter over the various organs (leaves, stems, roots, ears) is a function of the developmental state. This developmental state is defined as a linear function of the temperature sum.

g) The efficiency of transforming net assimilates into dry matter is an organ specific constant.

3.2 Model structure

The model is written in CSMP. It can be viewed as being composed of 3 main modules which encompass submodules. This structure is outlined in Table 1, the program flow in Table 2.

3.3 Description of the modules

3.3.1 Vertical distribution of light absorbing surfaces

Principle

The basic principle is characterized as follows. The vertical distribution of a surface type is described by a density function \( AID \) of the argument \( h' \) (height above ground/height of the plant top). \( AID \) may be an arbitrary function fulfilling the constraints

\[
AID(h') \geq 0 \quad \text{for} \quad 0 \leq h' \leq 1 \quad (4i)
\]

\[
\int_{0}^{1} AID(h') \, dh' = 1 \quad (4ii)
\]

Let the total area index of surface type \( s \) be \( TAI_s \) and \( x1(l) \), \( x2(l) \) (cm above ground) the boundaries of canopy layer 1. Then \( AI_{s,1} \), the area index of surface type \( s \) positioned in canopy layer 1, is calculated as
Table 1:
Module structure of the model. (MP) denotes that the respective calculations are performed by the main program.

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<th>Module function</th>
<th>Subroutines</th>
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<td>III.1</td>
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<td>allocation of net production and resulting rates of biosynthesis; dying process of organ tissues</td>
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Table 2:
Program flow of the model. MP denotes the main program. Module numbers explained in Table 1.

<table>
<thead>
<tr>
<th>MODULE</th>
<th>SUBROUTINES</th>
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<td></td>
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<td></td>
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<td>II.4</td>
<td>MP → DAYASS → ASTRO</td>
<td></td>
</tr>
<tr>
<td>II.1</td>
<td>MP</td>
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<tr>
<td>II.2</td>
<td>MP</td>
<td></td>
</tr>
<tr>
<td>II.3</td>
<td>MP</td>
<td></td>
</tr>
<tr>
<td>III.1</td>
<td>MP</td>
<td></td>
</tr>
<tr>
<td>III.2</td>
<td>MP</td>
<td></td>
</tr>
</tbody>
</table>
\[ A_{s,1} = A_{s} (x_1(1),x_2(1)) = TAI_s \cdot \int_{h'(x_1)}^{h'(x_2)} AID_s(h') \, dh' \quad (5) \]

where \( h'(x) = \begin{cases} x/H(s) & 0 \leq x \leq H(s) \\ 1 & x > H(s) \end{cases} \)

with \( H(s) \) denoting the height (cm) of the genotype to which surface type \( s \) belongs.

**Module I.1: Area indices**

For leaves and stems (including leaf sheaths) the area indices are obtained by multiplying the respective dry matter weights by their surface area ratios. The area index of ears is assumed to be zero until anthesis. Then its value is determined by multiplying the aboveground biomass with a conversion factor. During post anthesis growth the ear area is assumed to be constant. The yellow fraction of the ear area is introduced as a forcing function of days after emergence.

**Module I.2: Definition of canopy layers**

The canopy is stratified into layers of equal thickness. The number of layers is chosen dependent on the summed leaf area indices of all competitors.

**Module I.3: Distribution of surface area over the layers**

Stems and leaves are each distributed vertically according to the three parametric density function.

\[ AID(h') = (-a h' z + a + c) \times \text{normalization constant} \quad (6) \]

with \( AID(h') \): normalized surface area density at \( h' \)
- \( h' \): height above ground level divided by plant height
- \( a, c, z \): function parameters

Fig. 1 illustrates how the parameters \( a, c \) and \( z \) determine the shape of the curve. The normalization constant serves to fulfill constraint (4ii) and is accordingly given by
\[
\int_{h'=0}^{1} (-ah'^z + a + c) \, dh' = a \cdot (1 + \frac{c}{a} - \frac{1}{z+1}) = NC
\]  

(7)

As the form of the function as well as the parameter values are assumed to be constant during the growing season, the normalization constant is evaluated in the initial section of the program. The surface area index within a horizontal layer bounded by the relative heights \(h_1'\) and \(h_2'\) is calculated at every time step as

\[
TAI \cdot NC \cdot \int_{h_1'}^{h_2'} (a + c - ah'^z) \, dh' =
\]

\[
TAI \cdot NC \cdot a \cdot (A_1 \cdot (h_2' - h_1') - A_2 \cdot (h_2'^{z+1} - h_1'^{z+1}))
\]

(8)

where \(TAI\) is the total area index of the considered surface, \(NC\) is the normalization constant, and \(A_1 (= 1 + c/a)\) and \(A_2 (= 1/(z+1))\) are auxiliary variables calculated in the initial section of the program.

The function \(AID\) is assumed to characterize the distribution of total leaf area and total stem area respectively, encompassing the green as well as the yellow fraction. Thus a subdivision into a green and a yellow fraction of the surface area is necessary. For leaves as well as stems, it is assumed that the total yellow fraction is positioned below the total green fraction.

The ear area is assumed to be distributed as a homogeneous layer. This is equivalent to defining the vertical area density function (AID) as

\[
1/d \quad \text{for} \quad 1-d \leq h' \leq 1
\]

\[
AID(h') = \begin{cases} 
1/d & \text{for} \ 1-d \leq h' \leq 1 \\
0 & \text{otherwise}
\end{cases}
\]

where \(d\) is the thickness of the ear layer divided by the plant height. The yellow fraction of the ear area is assumed to be distributed vertically homogeneously within the ear layer.

3.3.2 Daily gross assimilation

**Principles**

The daily assimilation is obtained by a weighted summation (= numerical integration) of the instantaneous assimilation rates of selected time points.
during the day. The instantaneous assimilation rates are calculated from the instantaneous intensities of direct and diffuse light and accounting for the canopy architecture.

Module II.1: daylength and diffuse fraction of daily global radiation

The diffuse fraction of daily global radiation is derived from the measured global radiation according to Spitters et al. (1986).

Module II.2: instantaneous intensity and direct fraction of incoming light, sine of sun height

Given the calendar day, the latitude of the location and the diffuse fraction of daily global radiation, the instantaneous intensities of diffuse and direct visible radiation are estimated according to Spitters et al. (1986).

Module II.3: instantaneous rates of assimilation

The instantaneous assimilation rate of a competitor is derived from the instantaneous direct and diffuse light flux and the canopy structure. It is viewed as the sum of the rates performed by its different assimilating surfaces (leaf blades, stems + leaf sheaths, ears).

The instantaneous assimilation rate of a surface type (e.g. the leaves of one competitor) is derived by partitioning its total area into fractions each of which is exposed to an approximately uniform irradiation level. For each fraction, the instantaneous assimilation rate is obtained from the corresponding photosynthetic light response curve. This partitioning of the surface area belonging to one surface type is achieved by distributing it over the canopy layers (Module I.3). Within each layer, a sunlit and a shaded fraction are distinguished. This procedure can be formally summarized as

\[
A_c = \sum_{s=1}^{NST} \sum_{l=1}^{NCL} (A(s,l/\text{shaded}) + A(s,l/\text{sunlit})) \cdot l(c,s)
\]  

\[ (9) \]

\[ A_c : \text{instantaneous assimilation rate of competitor c} \]
\[ s: \text{subscript denoting the surface type} \]
\[ l: \text{subscript denoting the canopy layer} \]
\[ \text{NST: number of surface types} \]
\[ \text{NCL: number of canopy layers} \]
\[ A(s,l/\text{shaded}): \text{instantaneous assimilation rate performed by the shaded fraction of} \]
surface type s which is positioned in canopy layer 1
A(s, l/sunlit): instantaneous assimilation rate performed by the sunlit fraction of
surface type s which is positioned in canopy layer 1
l(c,s): switch function, having the value 1 if surface type s belongs to
competitor c and 0 otherwise.

We now present in some detail how the rates A(s, l/...) are calculated. The
basic task consists of coupling a submodel for vertical light distribution within
the canopy to a submodel for the distribution of absorption over the different
components within a canopy layer.

Several major steps are repeated for each canopy layer:
1) calculation of the diffuse and direct flux absorbed by the whole canopy layer,
2) calculation of absorption intensities for the sunlit and shaded parts of the
canopy layer,
3) calculation of absorption intensities for the sunlit and shaded parts of each
   of the different surface types present in the canopy layer,
4) calculation of assimilation rate of the sunlit and shaded parts of the
different surface types present in the canopy layer,

The thus obtained partial assimilation rates (A(s, l/...)) are then summed
according to (9).

ad 1:

Light entering the canopy is composed of 2 fluxes: a diffuse flux and a direct
flux.

Within the canopy the diffuse flux originates from 2 sources: light that has
entered the canopy as diffuse light and light that has entered the canopy as
direct light but that has been scattered within the canopy. To manage bookkeeping,
3 fluxes are discerned within the canopy:
a) diffuse light that had entered the canopy as diffuse light ("DIF")
b) light (diffuse and direct) that had entered the canopy as direct light ("DRF")
c) direct light ("DIR")
Note that flux DIR is part of flux DRF. These 3 fluxes are extincted exponentially
within the canopy. For each surface type s, the extinction coefficients differ for
the 3 fluxes: K_{dif}(s), K_{drf}(s), K_{dir}(s) for fluxes DIF, DRF, DIR, respectively.
The ratios between these 3 coefficients are approximately the same for all
surface types and only dependent on sun height (Goudriaan, 1982):

\[ K_{dir}(s) = CDIR \text{(sun height)} \times K_{dif}(s) \] (101)
K drf(s) = CDRF (sun height) * K dif(s) \hspace{1cm} (10ii)

This linearity facilitates compact algorithms for calculating the absorption within a canopy layer and the distribution of this absorption over the constituent surfaces.

Several auxiliary variables are defined. Let DIF_o, DRF_o and DIR_o denote the net downward fluxes of DIF, DRF and DIR at the top of the canopy. It holds

\[ \begin{align*}
DIF_o &= IRR(1.-FDIR) * (1.-REFLC_{dif}) \\
DRF_o &= IRR \cdot FDIR(1.-REFLC_{dir}) \\
DIR_o &= IRR \cdot FDIR
\end{align*} \hspace{1cm} (11i) \hspace{1cm} (11ii) \hspace{1cm} (11iii) \]

where IRR is the intensity and FDIR is the direct fraction of the light flux incident at top of the canopy and REFLC_{dif} and REFLC_{dir} are the reflection coefficients of the canopy for diffuse and direct light.

Let further FR_{dif}(x), FR_{drf}(x) and FR_{dir}(x) denote the fraction of DIF_o, DRF_o and DIR_o that penetrates to the height level x (cm) above the ground. By considering these auxiliary variables we only have to calculate the FR_{dif}-values for the layer boundaries in order to obtain readily the rates with which the layers absorb all 3 fluxes. This follows from equations (3) and (10i):

\[ \begin{align*}
FR_{dir}(x) &= \exp \left( - \sum_{s=1}^{NST} AI_{s}(x,x'(CT)) \cdot K_{dif}(s) \right) \\
&= \exp \left( - CDIR \cdot \sum_{s=1}^{NST} AI_{s}(x,x'(CT)) \cdot K_{dif}(s) \right) \\
&= (FR_{dif}(x))^{CDIR} \hspace{1cm} (12i)
\end{align*} \]

and, analogously,

\[ \begin{align*}
FR_{drf}(x) &= ... = (FR_{dif}(x))^{CDRF} \hspace{1cm} (12ii)
\end{align*} \]

Here x'(CT) denotes the height of the canopy top.

Defining as further auxiliary variable the "extinction capacity of a layer 1 for diffuse light"

\[ ECDIF(1) = \sum_{s=1}^{NST} AI_{s,1} \cdot K_{dif}(s) \hspace{1cm} (13) \]
we describe the 3 parallel absorption processes using the single loop structure:

\[
\text{FR}_{\text{dif}}^u = 1
\]

DO 1000 1 = 1,NCL

\[
\text{FR}_{\text{dif}}^d = \text{FR}_{\text{dif}}^u \cdot \exp(-\text{EC}_{\text{dif}}(1))
\]

\[
\text{AFR}_{\text{dif}} = \text{FR}_{\text{dif}}^u - \text{FR}_{\text{dif}}^d
\]

\[
\text{AFR}_{\text{drf}} = (\text{FR}_{\text{dif}}^u)^{\text{CDRF}} - (\text{FR}_{\text{dif}}^d)^{\text{CDRF}}
\]

\[
\text{AFR}_{\text{dir}} = (\text{FR}_{\text{dif}}^u)^{\text{CDIR}} - (\text{FR}_{\text{dif}}^d)^{\text{CDIR}}
\]

1000 CONTINUE \hspace{1cm} (14)

where NCL denotes the number of canopy layers, the superscripts u and d relate the function value to the upper and lower layer boundary, and AFR dir, drf, dir is the absorbed fraction of DIF o, DRF o, DIR o, respectively.

The layer absorbs direct (LABS dir) and diffuse (LABS dif) light with the rates

\[
\text{LABS}_{\text{dir}} = \text{DIR}_o \cdot \text{AFR}_{\text{dir}} \hspace{1cm} \text{(15i)}
\]

\[
\text{LABS}_{\text{dif}} = \text{DIF}_o \cdot \text{AFR}_{\text{dif}} + \text{DRF}_o \cdot \text{AFR}_{\text{drf}} - \text{LABS}_{\text{dir}} \hspace{1cm} \text{(15ii)}
\]

From AFR dir, the absorbed fraction of direct light, the sunlit fraction of the canopy layer (SLLA) can be derived (Goudriaan, 1982) approximately as

\[
\text{SLLA} = \text{AFR}_{\text{dir}} / (\text{KDIR} \cdot \text{TCLAI}) \cdot \text{KDIF} / \sqrt{1-\text{SCV}} / 0.8 \hspace{1cm} \text{(16)}
\]

with TCLAI denoting the summed area index of all surfaces present in the layer, KDIR, KDIF the area-weighted average of their extinction coefficients for diffuse, direct light and SCV the scattering coefficient.
The light absorption performed by the shaded part \( \text{LABS}_{\text{sh}} \) of the canopy layer is

\[
\text{LABS}_{\text{sh}} = \text{LABS}_{\text{dif}} \times (1 - \text{SLLA})
\]  

(17i)

and the rate of light absorption performed by the sunlit part \( \text{LABS}_{\text{su}} \) is

\[
\text{LABS}_{\text{su}} = \text{LABS}_{\text{dif}} \times \text{SLLA} + \text{LABS}_{\text{dir}}
\]

(17ii)

\textit{ad 3:}

From the light absorption by the shaded and by the sunlit part of the whole layer, the absorption rates of the sunlit and shaded parts of every surface type separately are calculated. The basic assumption is that the sunlit fraction of the total canopy layer is equal to the sunlit fraction of every single surface type. We thus obtain immediately (compare concept 3.1 d) the absorption rate per surface area of the shaded part of the surface type \( s \) positioned in layer 1:

\[
\text{SABS}(s,1/\text{shaded}) = \frac{(1 - \text{SLLA}_1) \cdot \text{AI}_{s,1} \cdot K_{\text{dif}}(s)}{\sum_{s' = 1}^{\text{NST}} \text{AI}_{s',L} \cdot (1 - \text{SLLA}_1) \cdot K_{\text{dif}}(s')}} \times \frac{1}{(1 - \text{SLLA}_1) \cdot \text{AI}_{s,1}}
\]

(18)

where \( \text{ECDIF} \) is again the extinction capacity of the canopy layer defined by (13).

From the linear relationship between \( K_{\text{dif}}, K_{\text{dir}} \) and \( K_{\text{drf}} \) (10i, 10ii) it follows that the absorption rate per surface area of the sunlit part of surface type \( s \) positioned in canopy layer 1 can be formulated analogously

\[
\text{SABS}(s,1/\text{sunlit}) = \frac{1}{\text{ECDIF}(1) \cdot (1 - \text{SLLA}_1)} \cdot K_{\text{dif}}(s)
\]

(19)

The compactness of the distribution algorithm is emphasized: two layer specific auxiliary variables \( 1/(\text{ECDIF} * \text{SLLA}) \) and \( 1/(\text{ECDIF} *(1 - \text{SLLA})) \) only have to be multiplied with a surface type specific constant \( K_{\text{dif}}(s) \).
ad 4:

Using the photosynthetic light response functions, from the absorption rates per surface area the corresponding assimilation rates per surface area are derived. For obtaining the assimilation rates per ground area \( (A(s,1/...)) \) in (9)), these rates per surface area are multiplied by the respective surface area index. For the sunlit and shaded part of the surface this is the layer specific surface area index \((A_l,s,1))\) multiplied by SLLA and \((1.-SLLA)\) respectively.

Module II.4: Integration of the instantaneous assimilation rate over the day

Following Goudriaan (1986), daily assimilation \((DA)\) is calculated by a 3-point Gaussian integration of the instantaneous assimilation rate \((A)\):

\[
DA = \sum_{i=1}^{3} A(t_i) \times W_i
\]

where \(t_{1,2,3}\) and \(W_{1,2,3}\) are being appropriate time points and weighting factors.

3.3.3 Dry matter increment

Module III.1: Maintenance respiration

The rate of maintenance respiration is obtained by calculating its value for a standard temperature \((15^\circ C)\) and multiplying this with the factor

\[
Q10 ** (0.1 \times T - 1.5)
\]

where \(T\) denotes the actual air temperature \((^\circ C)\) and \(Q10\) the increase of the respiration rate caused by a temperature increase of \(10^\circ C\).

The rate of maintenance respiration at the standard temperature is the sum of the rates of the different organs: leaves, stems, roots and ears. These rates are calculated as the dry matter weight of living organ tissue multiplied by an organ specific relative rate of respiration \((kg \text{ CH}_2O/kg \text{ DM/d})\). For leaves, this relative rate is described as a function of developmental state. The relative rates of the other organs are invariant parameters.
Module III.2: Allocation of net production and resulting rates of biosynthesis; dying process of organ tissues

Daily net production is distributed over the organs, leaves, stems, roots and ears according to allocation factors. These factors are formulated as functions of the developmental state. The transformation of allocated net production (kg CH\textsubscript{2}O) into new dry matter (kg biomass) is performed with organ specific efficiencies.

Parallel to biosynthesis, a dying process changes the weight of living organ tissues. The daily transformation of living into dead biomass is calculated by multiplying the live organ weight with an organ specific relative dying rate (kg/kg/d). These relative rates are formulated as functions of the number of days since emergence.

4. PERFORMANCE OF THE MODEL

The model has been applied to simulate field experiments with 12 spring wheat cultivars (Rennau & Spitters, in prep.). Monocultures and mixtures were grown at a range of plant densities. For experimental details and further results see Kramer (1984) and Spitters & Kramer (1986).

The model representation of inter-cultivar variation was restricted by the availability of data. It concerned the following 4 attributes: initial weight and leaf area (22 days after emergence), dry matter allocation to leaves as fraction of the allocation to the shoot, plant height and "dying" rates of leaves and grains.

A more detailed discussion of the model performance will be given in Rennau & Spitters (in prep.). Here we only present the performance of the model to simulate the biomass relations between the cultivars when growing in mixture. For this, a measure \( \Delta \ln \) is defined for the productivity of a cultivar relative to the average productivity level:

\[
\Delta \ln_i = \ln(W_i) - \ln(W) \approx \ln \left( \frac{W_i}{W} \right)
\]  

(21)

where \( W_i \) is the aboveground biomass of genotype \( i \), \( W \) and \( \ln(W) \) denote the average of \( W_i \) and \( \ln(W_i) \) over all genotypes, and \( \ln \) points to the natural logarithm.

Mixtures have been grown at total plant densities of 25, 44, 100 and 400 plants/m\textsuperscript{2}. For these experiments, the measured and simulated LN-values, averaged over the 4 densities, are shown in Fig. 2. Given the incomplete knowledge about the genetic variation of physiological and morphological attributes, we judge the model performance to be satisfactory.
5. GENERAL DISCUSSION

The model presented in this paper describes the growth of competing populations. As pointed out in the introduction, competition can be viewed as a special case of the general situation that the canopy description has to account for more than one type of light absorbing and photosynthesizing surface.

The model is an attempt to realize a modular structure directed towards representing a family of systems - heterogeneous canopies - rather than a specific system - competing genotypes. We do not claim that the modelling of another system of this family does not demand structural changes, but the modular structure confines the adjustments to few, exchangeable subunits of the program (subroutines). This principle will be illustrated by briefly sketching the "use" of the model for a quite different system with a heterogeneous canopy.

Consider a system consisting of a wheat crop and a pathogen covering a fraction of its leaves with variable density. It is assumed that the initial light use efficiency and the AMAX-value are reduced by the pathogen and the relationships between these reductions and the pathogen density are known quantitatively.

Evidently the canopy can be viewed as consisting of n surface types - leaves with different classes of pathogen density. These surface types differ with respect to their photosynthetic parameters. An appropriate approach for describing the vertical distribution of these surface types is first to distribute the total leaf area and to subdistribute this subsequently over the leaf classes.

For the first step the model offers a general implementation which is independent from the specific choice of a vertical area density function. A rather flexible 3-parametric function is used, but this can easily be replaced by an alternative without sacrificing the general distribution algorithm (subroutine VERDI). To implement the second step, a new subroutine has to be written which is called after the distribution of the total leaf area. This two step procedure runs analogously to the subdistribution of total surface area into its green and yellow fraction which is performed in the present model version.

Considering the local character of the adjustments this example may serve to illustrate the economy achieved by a modular approach in the longer run.
Acknowledgements

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REFERENCES


Fig. 1: Shape of the unnormalized leaf area density function $AIDun := -a h'^2 + a + c$ for different values of the parameter $z$; $h'$ denotes the height above the ground divided by the plant height; the function values for $h' = 0$ and $h' = 1$ are $c+a$ and $c$, respectively.

Simulated $\ln \left( \frac{W_i}{\bar{W}} \right)$

$\text{r} = 0.78$

Fig. 2. Performance of the model to fit the relative biomass production of 12 spring wheat cultivars grown in mixture. The aboveground biomass ($W_i$) of cultivar $i$ was expressed relative to the population mean ($\bar{W}$) and represented by the natural logarithm $\ln \left( \frac{W_i}{\bar{W}} \right)$. Each point represents the value of one cultivar, averaged over the 4 plant densities (25, 44, 100 and 400 plants/m²) at which the mixtures were grown.
Component layout

F : function
GA : array; i-th component → genotype with actual reference i
GL : array; i-th component → genotype with library reference i
C : array, i-th component → canopy layer i, counted from the top
CG : array; component (i-1) + j +
    canopy layer i, counted from the top,
    and genotype with the actual reference j
Gn : array; first n components → genotype with library reference 1,
    next n components → genotype with library reference 2, etc.
S : scalar (no array)
Appendix A: Listing of the model

TITLE COMPETITION BETWEEN WHEAT GENOTYPES
/ DIMENSION EARATA(27)
/ DIMENSION EAI(27)
/ DIMENSION FCHN(27)
/ DIMENSION HEI(27)
/ DIMENSION OGBM(27)
STORAGE SAI(27), YFST(27), KLSTEM(27), KLEAR(27)
STORAGE AGE(27), LAI(27), GASSP(27), STORE(144)
STORAGE VEARSUR(27), LAID(144), SAID(144), EAID(144)
STORAGE ULC(25), KL(27), FKL(27), EFF(27), EEFF(27), SEFF(27)
STORAGE YFLVS(27), LAIL(25), ECDIF(25)
STORAGE COR(27), DISPA1(200), DISPA2(200), DISPA3(200)
STORAGE CULTP(27), DVS(27), EAMAX(27), AMAX(27), pAMAX(27), SAMAX(27)
STORAGE OGBMPP(27), YFEAR(27)
STORAGE IWLVS(27), IWST(27), IDVSV(27)
STORAGE EMERG(27), EXIST(27), APPEAR(27), PLOP(27)
STORAGE LNDVBM(27), XEAI(20)
FIXED DNSP, V, NSP, NCL, I, L, K, A, G
FIXED STPSWI, EAPSWI, C, COMIND, AUXINT

*******************************************************************
INITIALIZATION
*******************************************************************
INITIAL NOSORT

*** BASIC SPECIFICATIONS

* NUMBER OF GENOTYPES DESCRIBED IN THE PARAMETER SET
PARAM DNSP = 12

* NUMBER OF COMPETING GENOTYPES SIMULATED IN THE PRESENT CASE
PARAM NSP = 12

*** LATITUDE OF LOCATION ***
PARAM LAT = 52.

*** SWITCH PARAMETERS FOR CHOOSING FROM ALTERNATIVE ALGORITHMS

* THE LEAF AREA INDEX CAN BE INTRODUCED AS A FORCING FUNCTION BY
* ASSIGNING TO THE SWITCH PARAMETER "LAISWI" THE VALUE 1
* INSTEAD OF 0
PARAM LAISWI = 0.

* SWITCH PARAMETER FOR DECIDING WHETHER THE ABBRSORPTION
* OF STEMS IS ACCOUNTED FOR WHEN MODELLING THE EXTINCTION
* OF LIGHT WITHIN THE CANOPY
PARAM STASWI = 1.

* SWITCH PARAMETER FOR DECIDING WHETHER THE PHOTOSYNTHESIS
* OF STEMS IS ACCOUNTED FOR WHEN CALCULATING THE DAILY
* ASSIMILATION (NOTE THAT IN THIS CASE ALSO THE ABSORPTION OF STEMS
* MUST BE ACCOUNTED FOR, THAT IS "STASWI = 1")
PARAM STPSWI = 1

* SWITCH PARAMETER FOR DECIDING WHETHER THE ABBRSORPTION
* OF EARS IS ACCOUNTED FOR WHEN CALCULATING THE EXTINCTION
* OF LIGHT WITHIN THE CANOPY
PARAM EAASWI = 1.

* SWITCH PARAMETER FOR DECIDING WHETHER THE PHOTOSYNTHESIS
* OF EARS IS ACCOUNTED FOR WHEN CALCULATING THE DAILY
* ASSIMILATION (NOTE THAT IN THIS CASE ALSO THE ABSORPTION OF EARS
* MUST BE CONSIDERED, THAT IS EAASWI = 1)
PARAM EAPSWI = 1
*** SIMULATION PROJECT SPECIFIC INPUT

*** INITIAL STATE OF THE POPULATIONS

TITLE SIMULATION PROJECT: REMIX 15 X 15
LABEL SIMULATION PROJECT: REMIX 15 X 15

* WEIGHTS OF LEAVES, STEMS, ROOTS;
  * (KG/HA / (FREQUENCY OF THE GENOTYPE) / "DENSITY FACTOR")
  * (EXPLANATION OF "DENSITY FACTOR": SEE BELOW)

| TABLE IWLVS (1-12)     | 1.273, 1.460, 1.666, 1.079, 1.323, 1.623,... |
|                        | 1.226, 1.196, 1.365, 1.296, 1.359, 1.219 |
| TABLE IWST (1-12)      | 0.569, 0.596, 0.703, 0.493, 0.594, 0.783,... |
|                        | 0.597, 0.487, 0.570, 0.499, 0.619, 0.483 |
| TABLE IWRT (1-12)      | 1.228, 1.371, 1.579, 1.048, 1.278, 1.604,... |
|                        | 1.215, 1.122, 1.290, 1.196, 1.319, 1.135 |

* LEAF AREA
  * (M**2/HA / (FREQUENCY OF THE GENOTYPE) / "DENSITY FACTOR")

| TABLE IARLF (1-12)     | 25.533, 28.759, 33.867, 28.567, 27.978, 34.030,... |
|                        | 26.267, 24.452, 27.619, 28.989, 26.174, 26.037 |

* "DENSITY FACTOR" WITH WHICH THE PARAMETER VALUES FOR INITIAL
  * WEIGHTS AND THE INITIAL LEAF AREA ARE MULTIPLIED AT THE
  * INITIALIZATION OF THE POPULATION
  * (INTRODUCTION OF THIS PARAMETER SPARES THE NECESSITY OF
  * REWRITING THE ARRAYS WITH INITIAL WEIGHTS AND LEAF AREAS
  * WHEN DIFFERENT PLANT DENSITIES ARE ASSUMED)

PARAM DFAC = 106.

* DEVELOPMENTAL STATE

| TABLE IDVSV (1-12)     | 0.21345, 0.22085, 0.22485, 0.21010, ... |
|                        | 0.21717, 0.20662, 0.21345, 0.20339, ... |
|                        | 0.20339, 0.20026, 0.20026, 0.20662 |

* TIME COURSE OF LN (LEAF AREA(M**2/HA))
  * (FOR THE INTRODUCTION OF THE LEAF AREA AS FORCING FUNCTION)

FUNCTION LNLAT,1. = 0., 6.60719, 22., 8.06840, 29., 9.0655,...

FUNCTION LNLAT,12. = 0., 6.60719, 22., 8.06840, 29., 9.0655,...

FUNCTION YFRLVT,1. = 0., 0., 49., 0.
FUNCTION YFRLVT,12. = 0., 0., 49., 0.

* PLANTS/M2

PARAM FS = 400.

*** TIME SPECIFICATIONS

* DAY OF EMERGENCE

| TABLE EMERG (1-12)     | 12 * 107. |

* FIRST DAY OF SIMULATED GROWTH (NOT NECESSARILY THE DAY OF
  * EMERGENCE)

| TABLE APPEAR (1-12)    | 12 * 129. |

* FIRST DAY OF SIMULATION (HAS TO BE AT LEAST
  * 1 DAY BEFORE GROWTH SIMULATION STARTS)

PARAM START = 106.

* LAST DAY OF SIMULATION

PARAM STOP = 231.
FINISH TIME = STOP
PARAMETRIC CHARACTERIZATION OF THE VERTICAL DISTRIBUTION OF LEAVES, STEMS AND EARS

* 3 PARAMETERS USE FOR CHARACTERIZING THE VERTICAL DISTRIBUTION * OF THE LEAF AREA
  * (THE UNNORMALIZED LEAF AREA DENSITY FUNCTION (M**2/M**3)
  * IS ASSUMED TO HAVE THE FORM:
  * \( Y = A - A * H^Z + C \)
  * WITH A, C AND Z PARAMETERS AND H: HEIGHT ABOVE GROUND/PLANT HEIGHT)
  PARAM LA = 1., LC = 0., LZ = 50.
  DISP1,DUM = VPRE1 (DNSP,LA,LC,LZ)

* 3 PARAMETERS USE FOR CHARACTERIZING THE VERTICAL DISTRIBUTION * OF THE STEM AREA
  * (THE UNNORMALIZED STEM AREA DENSITY FUNCTION (M**2/M**3)
  * IS ASSUMED TO HAVE THE FORM:
  * \( Y = A - A * H^Z + C \)
  * WITH A, C AND Z PARAMETERS AND H: HEIGHT ABOVE GROUND/PLANT HEIGHT)
  PARAM SA = 1., SC = 0., SZ = 50.
  DISP2,DUM = VPRE1 (DNSP,SA,SC,SZ)

* 1 PARAMETER USED FOR CHARACTERIZING THE VERTICAL DISTRIBUTION OF EARS
  * (IT IS ASSUMED THAT THE EARS OF A GIVEN GENOTYPE ARE DISTRIBUTED
  * IN A HOMONEGEOUS LAYER THAT EXTENDS FROM THE PLANT TOP
  * TO A DISTANCE BELOW (CM) GIVEN BY THE PARAMETER "VEEL")
  PARAM VEEL = 20.
  DISP3,DUM = VPRE2 (DNSP,VEEL)

THE WHO-IS-WHO OF COMPETING GENOTYPES

* THE GENOTYPES SIMULATED IN THE PRESENT CASE ARE
* NUMBERED FROM 1 TO NSP; THE ARRAY V LINKS THIS ACTUAL
* REFERENCES ("A") TO THE NUMBERS USED IN THE PARAMETER
* LIBRARY (LIBRARY REFERENCE = "L")

* EXAMPLE:
  "TABLE V (1-12) = 2, 5, 8, 9 * 11"
  PRODUCES - DEPENDENT ON THE PARAMETER "NSP" -
  THE FOLLOWING MIXTURE COMPOSITIONS:
  "NSP=1" - MONOCULTURE OF VARIETY 2
  "NSP=2" - BINARY MIXTURE WITH THE VARIETIES 2 AND 5
  "NSP=3" - MIXTURE WITH THE VARIETIES 2, 5, 8
  AND SO ON
  TABLE V(1-12) = 12 * 1

* GENOTYPE FREQUENCIES
  (SUM OVER THE NSP GENOTYPES PRESENTLY SIMULATED MUST BE 1 !)
  TABLE COR (1-12) = 12 * 8.33333333E-2

SOME TECHNICAL PREPARATIONS

* FOR USE OF THE RERUN-FACILITIES SOME VARIABLES
* HAVE TO BE SET ZERO

    DO 737 A = 1,NSP
    GASSP(A) = 0.
    FCNM(A) = 0.
    LA(A) = 0.
    YFVS(A) = 0.
    SAI(A) = 0.
    YFST(A) = 0.
DVS(A) = 0.
DVRV(A) = 0.
DVR(R) = 0.
EARATA(A) = 0.
OGBM(A) = 0.
OGBMPP(A) = 0.
LNDVBM(A) = 0.
GRLVS(A) = 0.
GRST(A) = 0.
GRST = 0.
GRRT(A) = 0.
GRGR(A) = 0.

737 CONTINUE

AUXINT = MAXCL * NSP
DO 738 A = 1, AUXINT
    LAID(A) = 0.
    SAID(A) = 0.
    EAID(A) = 0.
738 CONTINUE

***********************************************************************
*** SYSTEM DYNAMICS ***
***********************************************************************
DYNAMIC
NOSORT
*** CHECKING THE NECESSITY TO MODEL GROWTH PROCESSES
*** ON THE PRESENT DAY

DAY = TIME

* ARE PLANTS PRESENT OR EXPECTED TO APPEAR ON THE FOLLOWING DAY?
* (TO KNOW THIS MAY SAVE THE COMPUTER LOTS OF CALCULATIONS)
DO 719 A = 1, NSP
    L = V(A)
    PLOP(A) = INSW(APPEAR(L) - 0.9 - TIME, 0., 1.) * ...
    INSW(TIME - APPEAR(L) + 1.1, 0., 1.)
    EXIST(A) = INSW(DAY-APPEAR(L) + 1.E-8, 0., 1.)
719 CONTINUE

XEXIST = 0.
XPLOP = 0.
DO 865 A = 1, NSP
    XEXIST = XEXIST + EXIST(A)
    XPLOP = XPLOP + PLOP(A)
865 CONTINUE

GROWTH = INSW(XEXIST-.1, 0., 1.)
ARRIVE = INSW(XPLOP -.1, 0., 1.)
IF ((GROWTH + ARRIVE).LE.0.) GOTO 7020

***********************************************************************
* WEATHER DATA *
***********************************************************************

* DAILY GLOBAL RADIATION (J / M**2 / D)
   DTR = AFGEN (DTRT, DAY) * 1.E4

* AVERAGE AIR TEMPERATURE (DEGREES C)
   TMPA = (AFGEN (MXTT, DAY) + AFGEN (MNTT, DAY)) * 0.5

* AVERAGE AIR TEMPERATURE DURING DAYLIGHT PERIOD
   EVE = AFGEN (MXTT, DAY) - 0.25 * (AFGEN (MXTT, DAY) - ...
       AFGEN (MNTT, DAY))
DEVELOPMENT

PRE- AND POST-ANTHESIS DEVELOPMENTAL RATES
(EQUATIONS ACCORDING TO VAN KEULEN(85));
TIME SINCE EMERGENCE

DO 8100 A = 1, NSP.
L = V(A)
XD1 = CULTP(L) * AMAX1 (0., 0.00094 * TMPA -0.00046)...
* INSW (DVS(A) -1., 1., 0.)
DVRV(A) = XD1 * EXIST(A) + PLOP(A) * IDVSV(L)
XD2 = AMAX1(0., 0.000913 * TMPA + 0.003572 )
DVRR(A) = XD2 * INSW (DVS(A)-1.,0.,1.) * EXIST(A)
AGE(A) = AMAX1(0.,DAY-EMERG(L))
8100 CONTINUE

DVS = INTGRL (0., DVRV, 12)
DVS = INTGRL (0., DVRR, 12)
DO 9000 A = 1, NSP
DVS (A) = AMIN1 (1., 0.5 * (DVS(A) + DVSR(A)))
9000 CONTINUE
IF (GROWTH.LE.0.5) GOTO 20000

VERTICAL DISTRIBUTION OF LIGHT ABSORBING SURFACES

** AREA INDICES **

DECISION WHETHER LEAF AREA DEVELOPMENT IS MODELLED
DYNAMICALLY OR INTRODUCED AS A FORCING FUNCTION
IF (LAISWI.GT.0.5) GOTO 1011

LEAF AREA DEVELOPMENT IS MODELLED DYNAMICALLY AND NOT INTRODUCED
AS A FORCING FUNCTION
DO 1002 A = 1,NSP
IF (EXIST(A).LT.0.5) GOTO 1002
SLA = TWOVAR(SLATB,DVS(A),LR) * 1.E-4
LAI(A) = (WLVS(A) + WDLVS(A)) * SLA
IF (LAI(A).LT.1.E-6) THEN
TYPE 4999,A
4999 FORMAT (' SPECIES ',',15,' WITH LAI = 0 ')
GOTO 1002
ENDIF
YFLVS(A)= WDLVS(A) / (WDLVS(A) + WLVS(A))
1002 CONTINUE
GOTO 1012
1011 CONTINUE

DEVELOPMENT OF LEAF AREA IS INTRODUCED AS A FORCING FUNCTION
DO 1005 A = 1,NSP
IF (EXIST(A).LT.0.5) GOTO 1005
L = V(A)
LR = V(A)
XLNL = TWOVAR (LNALT,AGE(A),LR)
LAI(A) = EXP(XLNL) * 1.E-4
YFLVS(A)= TWOVAR (YFRLVT, AGE(A), LR)
1005 CONTINUE
1012 CONTINUE
*** STEM AREA ***

DO 950 A = 1, NSP
IF (EXIST(A).LT.0.5) GOTO 950
SAI(A) = (WST(A) + W_DST(A)) * SSTA * 1.E-4
IF (SAI(A).LT.1.E-6) THEN
  TYPE 5001, A
  FORMAT ( 'SPECIES ',IS,' WITH SAI = 0' )
GOTO 950
ENDIF
YFST(A) = WDST(A) / (WDST(A) + WST(A))
950 CONTINUE

*** EAR AREA ***

* EAR AREA INDEX (Determined by the aboveground biomass at anthesis)
DO 148 A = 1, NSP
  L = V(A)
  LR = V(A)
  IF (EXIST(A).LT.0.5) GOTO 148
  IF (EARATA(A).GT.1.E-6) GOTO 149
  IF (DVS(A).LT.0.5) GOTO 148
  EARATA(A) = EARSUR(L) * OGBM(A) * 1.E-5
149 CONTINUE
  SAI(A) = EARATA(A) * AFGEM(EARGRT,DVS(A))
  YFEAR(A) = 1. - TWOVAR(GFET,AGE(A),LR)
148 CONTINUE

*** ----------------------------------- ***
*** BOUNDARY HEIGHTS SEPARATING ***
*** THE CANOPY LAYERS ***
*** ----------------------------------- ***

*** NUMBER OF DISTINGUISHED CANOPY LAYERS

PARAM CLPERL = 12., MINCL = 12., MAXCL = 12.

XLAIT = 0.
DO 8000 A = 1, NSP
  XLAIT = XLAIT + LAI(A)
8000 CONTINUE
  XNCL = LIMIT (MINCL, MAXCL, XLAIT * CLPERL)
NCL = XNCL

*** BOUNDARIES OF CANOPY LAYERS

* HEIGHT DEVELOPMENT IS INTRODUCED AS A FORCING FUNCTION ("HEITB")
MAXHEI = 0.
DO 7000 A = 1, NSP
  LR = V(A)
  HEI (A) = TWOVAR (HEITB, AGE(A), LR)
  IF (HEI(A).GT.MAXHEI) MAXHEI = HEI (A)
7000 CONTINUE
  IF (MAXHEI.LT.1.E-3) THEN
    TYPE 4997, MAXHEI
    4997 FORMAT (' MAXHEI = ',F10.4)
    MAXHEI = 1.E-3
  ENDIF

* UPPER LIMITS ("ULCL") OF THE NCL CANOPY LAYERS (CM above the ground);
* THE CHOSEN LAYERS HAVE IDENTICAL THICKNESS

CALL STRATA (MAXHEI, NCL, ULCL)
* THE POTENTIAL EXTINCTION COEFFICIENT OF LEAVES IS CORRECTED
* TO ACCOUNT FOR THE STRONG CLUSTERING OF LEAVES THAT YOUNG
* PLANT EXHIBIT

DO 530 A = 1,NSP
   L = V(A)
   KL(L) = PKL(L) * AFGEN(KLREDT,DVS(A))
530 CONTINUE

DO 981 K = 1,NCL
   LAIL(K) = 0.
   ECDIF(K) = 0.
981 CONTINUE

*** DISTRIBUTION OF THE TOTAL LEAF AREA
CALL VERDII (NSP,DNSP,V,EXIST,...
   NCL,HEI,ULCL,...
   LAI,KL,DISPA1,...
   LAID,LAIL,ECDIF,...
   CHECK1,CHECK2,CHECK3)

* DERIVED DISTRIBUTION OF THE GREEN LEAF AREA
CALL YELDI2 (NSP,NCL,LAI,LAID,YFLVS)

*** DISTRIBUTION OF STEM AREA

CALL VERDII (NSP,DNSP,V,EXIST,...
   NCL,HEI,ULCL,...
   SAI,KLSTEM,DISPA2,...
   SAID,LAIL,ECDIF,...
   CHECK4,CHECK5,CHECK6)

* DERIVED DISTRIBUTION OF THE GREEN STEM AREA
CALL YELDI2 (NSP,NCL,SAI,SAID,YFST)

IF (EAASWI.LT.0.5) GOTO 9876

*** DISTRIBUTION OF EAR AREA

CALL VERDII (NSP,DNSP,V,EXIST,...
   NCL,HEI,ULCL,...
   EAI,KLEAR,DISPA3,...
   EAID,LAIL,ECDIF,...
   CHECK7,CHECK8,CHECK9)

* DERIVED DISTRIBUTION OF THE GREEN EAR AREA
CALL YELDI2 (NSP,NCL,EAID,YFEAR)

DO 4869 A = 1,NSP
   XEAI(A) = EAI(A)
4869 CONTINUE

DO 4870 A = 1,NSP*NCL
   STORE(A) = EAID(A)
4870 CONTINUE

***********************************************************************
* DAILY GROSS PRODUCTION *
***********************************************************************

9876 CONTINUE

*** ACTUAL VALUES OF AMAX
TRAMAX = AFGEN (TRAMAT,EAVT)
DO 1710 A=1,NSP
L = V(A)
SRAMAX = AFGEN (SRAMAT,DVS(A))
AMAX(L) = PAMAX(L) * TRAMAX * SRMAX
1710 CONTINUE

*** DAILY GROSS PRODUCTION ***
GASSP,DUM, DAYL, IRR, INST1, FRDPE, FRDR = ...
DAYASS (DAY, DTR, LAT, NCL, NSP, DNSP, V, STPSW, EAPSW, ...)
LAI, SAID, EAI, LAIL, ECDF, KL, KLSTEM, KLEAR, ...
AMAX, SAMAX, EAMAX, EFF, SEFF, EEFF)

***********************************************************************
* DYNAMICS OF DRY MATTER *
***********************************************************************

*** MAINTENANCE RESPIRATION ***

MAINTENANCE RESPIRATION IS SUBTRACTED FROM THE GROSS PRODUCTION

TEMR = Q10 * (0.1 * TMPA - 1.5)
DO 5000 A = 1, NSP
XMR0 = WLVS(A) * BMRCLV * AFGEN (LVRRT, DVS(A)) + ...
WST(A) * BMRCST + ...
WRT(A) * BMRCRT + ...
WGR(A) * BMRCGR + ...
RMNT = AMIN1 (TEMR * XMR0, GASSP(A))
FCHN (A) = GASSP (A) - RMNT
5000 CONTINUE
20000 CONTINUE
IF ((GROWTH+ARRIVE).LT.0.5) GOTO 7020

*** ALLOCATION OF NET PRODUCTION ***
*** TO THE DIFFERENT ORGANS AND ***
*** ITS TRANSFORMATION INTO ***
*** DRY MATTER; ***
*** TRANSFORMATION OF LIVE INTO ***
*** DEAD DRY MATTER ***

*** RATES DRY MATTER ACCUMULATION IN LEAVES, STEMS, GRAINS, ROOTS ***
DO 70 A = 1, NSP
L = V(A)
LR = V(A)
IF (DAY.LE.APPEAR(L)-2) GOTO 70

*** ROOTS AND SHOOT ***

FSH = TWOVAR (FSHTB, DVS(A), LR)
XGRRT = FCHN(A) * (1.- FSH) * EFCHRT + ...
PLOP(A) * IWR(L) * COR(A) * DFAC
DRRT = WRT(A) * AFGEN(DRRTB, AGE(A))
GRRT(A) = XGRRT - DRRT
WRT = INTGRL (0., GRRT, 12)
GSHOOT = FCHN(A) * FSH

*** LEAVES ***

FLVS = TWOVAR (FLVST, DVS(A), LR)
XGRLVS = GSHOOT * FLVS * EFCLVS + ...
PLOP(A) * IWLVS(L) * COR(A) * DFAC
DRLVS(A) = WLVS(A) * TWOVAR(DRLVTB, AGE(A), LR)
GRLVS (A) = XGRLVS - DRLVS (A)
WLVS = INTGRL (0., GRLVS, 12)
WDLVS = INTGRL (0., DRLVS, 12)

*** STEMS ***
FST = TWOVAR (FSTT, DVS(A), LR)
XGRST = GSHOOT * FST * EFCST +...
PLOP(A) * IWS(L) * COR(A) * DFAC
DRST(A) = WST(A) * AFGEN (DRSTTB,AGE(A))
GRST(A) = XGRST - DRST(A)
WST = INTGRL (0., GRST, 12)
WDST = INTGRL (0., DRST, 12)

*** GRAINS ***
FGR = 1. - FLVS - FST
GRGR (A) = GSHOOT * FGR * EFCGR
70 CONTINUE
WGR = INTGRL (0, GRGR, 12)

***************************************************************
* GROWTH RECORDING *
***************************************************************
IF (GROWTH.LE.0.5) GOTO 7020
*
ABOVEGROUND BIOMASS ( KG/HA), G/PLANT )
DO 7010 A = 1,NSP
OGBM(A) = WLVS(A) + WDLVS(A) + WST(A) + WDST(A) + WGR(A)
IF (COR(A).LT.1.E-6) THEN
TYPE 5002,A
5002 FORMAT (' SPECIES ',IS,' WITH COR • 0 ')
GOTO 7010
END IF
OGBMPP(A) = OGBM(A) / ( 10. * PSM * COR(A))
7010 CONTINUE
*
AVERAGE, VARIANCE AND COEFFICIENT OF VARIATION OF ABOVEGROUND
Biomass per plant
AV,VAR,CV = EVAL1 (NSP,OGBMPP,COR)
*
DELTA - LN - VALUES
LNDVBM,DUM = LNDCAL (NSP,OGBMPP,COR)
7020 CONTINUE

*****************************************************************
* PARAMETER LIBRARY *
*****************************************************************

*** PHYSIOLOGICAL PARAMETERS USED FOR DESCRIBING THE GROWTH
OF 12 SPRING WHEAT VARIETIES
*** DEVELOPMENTAL RATE ***
* VARIETY SPECIFIC FACTOR USED FOR DESCRIBING THE PREANTHESIS
* DEVELOPMENTAL RATE (OBTAINED BY FITTING THE EQUATION GIVEN BY
* VAN KEULEN(85) TO OBSERVED DURATIONS UNTIL ANTHESIS)
TABLE CULTP (1-12) = 1.4066, 1.4554, 1.4817, 1.3845, ...
1.4311, 1.3616, 1.4066, 1.3403, ...
1.3403, 1.3197, 1.3197, 1.3616

*** OPTICAL PROPERTIES ***
* EXTINCTION COEFFICIENT OF EARS AND STEMS
* (ESTIMATION ACCORDING TO DE GROOT (85) (PERS. COMMUNICATION)
TABLE KLEAR (1-12) = 12 * 0.4
TABLE KLSTEM (1-12) = 12 * 0.4
* POTENTIAL EXTINCTION COEFFICIENT OF LEAVES
  * (NOT FULLY REALIZED DURING THE FIRST DAYS OF GROWTH)
  
  **TABLE PKL (1-12)**
  \[
  \begin{array}{c}
  \text{PKL (1-12)} \\
  \text{0.60}
  \end{array}
  \]

* REDUCTION FACTOR FOR THE EXTINCTION COEFFICIENT OF LEAVES,
  * ACCOUNTING FOR THE LEAF CLUSTERING EXHIBITED BY YOUNG PLANTS
  **FUNCTION KREDT**
  \[
  \begin{array}{c}
  \text{KREDT (0.6, 0.1, 1, 1.1, 1.1, 1.1)}
  \end{array}
  \]

*** PHOTOSYNTHETIC CHARACTERISTICS ***

* POTENTIAL AMAX (KG CO2 / HA / H) AND LIGHT USE EFFICIENCY
  * (KG CO2 / HA / H / (J / M2 / S) OF LEAVES
  **TABLE PAMAX (1-12)**
  \[
  \begin{array}{c}
  \text{PAMAX (1-12)} \times 40.
  \end{array}
  \]

  **TABLE EFF (1-12)**
  \[
  \begin{array}{c}
  \text{EFF (1-12)} \times 0.45
  \end{array}
  \]

* REDUCTION FACTOR OF AMAX ACCOUNTING FOR THE EFFECT
  * OF SENESCENCE; VALUES AS FUNCTION OF THE DEVELOPMENTAL STATE
  **FUNCTION SRAMAT**
  \[
  \begin{array}{c}
  \text{SRAMAT (0.1, 0.5, 1, 1.1, 1.1, 0.5)}
  \end{array}
  \]

* REDUCTION FACTOR OF AMAX ACCOUNTING
  * FOR THE EFFECT OF TEMPERATURE; VALUES AS FUNCTION OF
  * THE AVERAGE TEMPERATURE (°C) DURING DAYLIGHT PERIOD
  **FUNCTION TRAMAT**
  \[
  \begin{array}{c}
  \text{TRAMAT (0, 0.1, 10, 1, 25, 1, 35, 0.01)}
  \end{array}
  \]

* AMAX (KG CO2 / HA / H) OF STEMS
  **TABLE SAMAX (1-12)**
  \[
  \begin{array}{c}
  \text{SAMAX (1-12)} \times 20.
  \end{array}
  \]

* INITIAL LIGHT USE EFFICIENCY OF STEMS
  * (KG CO2 / HA / H / (J/S/CM**2)
  **TABLE SEFF (1-12)**
  \[
  \begin{array}{c}
  \text{SEFF (1-12)} \times 0.45
  \end{array}
  \]

* AMAX (KG CO2 / HA / H) OF EARS
  **TABLE EAHAX (1-12)**
  \[
  \begin{array}{c}
  \text{EAHAX (1-12)} \times 20.
  \end{array}
  \]

* INITIAL LIGHT USE EFFICIENCY OF EARS
  * (KG CO2 / HA / H / (J/S/CM**2)
  **TABLE EEFF (1-12)**
  \[
  \begin{array}{c}
  \text{EEFF (1-12)} \times 0.22
  \end{array}
  \]

*** DEVELOPMENT OF THE EAR AREA ***

* EAR SURFACE AT ANTHESIS DIVIDED BY ABOVEGROUND BIOMASS AT
  * ANTHESIS (CM**2 / G)
  * (LARGE VALUES BELONG TO GENOTYPES WITH AWNS, SMALL TO
  * GENOTYPES WITHOUT AWNS)
  **TABLE EARSUR (1-12)**
  \[
  \begin{array}{c}
  \text{EARSUR (1-12)} \times 8.64, 8.64, 15.98, 15.98, 8.64, 8.64, \ldots
  \end{array}
  \]

* GROWTH OF THE EAR AREA ((EARSURFACE/PLANT) / (EARSURFACE/PLANT AT
  * ANTHESIS) AS FUNCTION OF THE DEVELOPMENT STATE
  **FUNCTION EARGRT**
  \[
  \begin{array}{c}
  \text{EARGRT (0, 0.1, 0.4999, 0.1, 0.5, 1, 1.1, 1.1, 1.1, 1.1)}
  \end{array}
  \]

* THICKNESS OF THE EAR LAYER BELONGING
  * TO A SINGLE GENOTYPE (CM)
  **PARAM VEEL**
  \[
  \begin{array}{c}
  \text{VEEL = 20.}
  \end{array}
  \]

*** GREEN FRACTION OF THE EAR AREA ***

* VALUES AS FUNCTION OF THE NUMBER OF DAYS AFTER EMERGENCE
  **FUNCTION GFET, 1**
  \[
  \begin{array}{c}
  \text{GFET, 1 (1-1, 0.1, 0.000, 0.200, 0.125, \ldots}
  \end{array}
  \]

  **FUNCTION GFET, 2**
  \[
  \begin{array}{c}
  \text{GFET, 2 (0, 0.1, 0.050, 0.250, 0.138, \ldots}
  \end{array}
  \]

  **FUNCTION GFET, 3**
  \[
  \begin{array}{c}
  \text{GFET, 3 (0, 0.1, 0.029, 0.327, 0.319, \ldots}
  \end{array}
  \]

  **FUNCTION GFET, 4**
  \[
  \begin{array}{c}
  \text{GFET, 4 (0, 0.1, 0.039, 0.422, 0.352, \ldots}
  \end{array}
  \]
FUNCTION GFET, 5. = 0., 1., 66.1.000, 103.0.263, 107.0.163, ...
112.0.050, 117.0.050, 130.0., 131.0.
112.0.050, 117.0.000, 130.0., 131.0.
FUNCTION GFET, 6. = 0., 1., 69.1.000, 103.0.200, 107.0.150, ...
FUNCTION GFET, 7. = 0., 1., 67.1.000, 103.0.200, 107.0.138, ...
112.0.050, 117.0.000, 130.0., 131.0.
FUNCTION GFET, 8. = 0., 1., 70.1.000, 103.0.225, 107.0.150, ...
112.0.050, 117.0.000, 130.0., 131.0.
FUNCTION GFET, 9. = 0., 1., 67.1.000, 103.0.509, 107.0.375, ...
112.0.118, 117.0.000, 130.0., 131.0.
FUNCTION GFET, 10. = 0., 1., 71.1.000, 103.0.288, 107.0.188, ...
112.0.113, 117.0.000, 130.0., 131.0.
FUNCTION GFET, 11. = 0., 1., 69.1.000, 103.0.238, 107.0.163, ...
112.0.100, 117.0.000, 130.0., 131.0.

*** RELATIVE DYING RATES OF LEAVES ***
* VALUES AS FUNCTION OF THE NUMBER OF DAYS AFTER EMERGENCE
FUNCTION DRLVBT, 1. = 0., 0., 66., 0., 67., 0.024, 102., 0.024, ...
103., 0.038, 106., 0.038, 107., 0.197, 111., 0.197, ...
112., 0.392, 116., 0.392, 117., 0.452, 131., 0.452
FUNCTION DRLVBT, 2. = 0., 0., 64., 0., 65., 0.033, 102., 0.033, ...
103., 0.092, 106., 0.092, 107., 0.234, 111., 0.234, ...
112., 0.818, 116., 0.818, 117., 0.818, 131., 0.818
FUNCTION DRLVBT, 3. = 0., 0., 63., 0., 64., 0.045, 102., 0.045, ...
103., 0.045, 106., 0.045, 107., 0.156, 111., 0.156, ...
112., 0.197, 116., 0.197, 117., 0.443, 131., 0.443
FUNCTION DRLVBT, 4. = 0., 0., 67., 0., 68., 0.038, 102., 0.038, ...
103., 0.075, 106., 0.075, 107., 0.139, 111., 0.139, ...
112., 0.838, 116., 0.838, 117., 0.838, 131., 0.838
FUNCTION DRLVBT, 5. = 0., 0., 65., 0., 66., 0.030, 102., 0.030, ...
103., 0.077, 106., 0.077, 107., 0.178, 111., 0.178, ...
112., 0.356, 116., 0.356, 117., 0.412, 131., 0.412
FUNCTION DRLVBT, 6. = 0., 0., 68., 0., 69., 0.033, 102., 0.033, ...
103., 0.111, 106., 0.111, 107., 0.189, 111., 0.189, ...
112., 0.830, 116., 0.830, 117., 0.830, 131., 0.830
FUNCTION DRLVBT, 7. = 0., 0., 66., 0., 67., 0.038, 102., 0.038, ...
103., 0.168, 106., 0.168, 107., 0.197, 111., 0.197, ...
112., 0.810, 116., 0.810, 117., 0.810, 131., 0.810
FUNCTION DRLVBT, 8. = 0., 0., 69., 0., 70., 0.033, 102., 0.033, ...
103., 0.118, 106., 0.118, 107., 0.189, 111., 0.189, ...
112., 0.830, 116., 0.830, 117., 0.830, 131., 0.830
FUNCTION DRLVBT, 9. = 0., 0., 69., 0., 70., 0.022, 102., 0.022, ...
103., 0.134, 106., 0.134, 107., 0.164, 111., 0.164, ...
112., 0.381, 116., 0.381, 117., 0.412, 131., 0.412
FUNCTION DRLVBT, 10. = 0., 0., 70., 0., 71., 0.024, 102., 0.024, ...
103., 0.087, 106., 0.087, 107., 0.165, 111., 0.165, ...
112., 0.850, 116., 0.850, 117., 0.850, 131., 0.850
FUNCTION DRLVBT, 11. = 0., 0., 70., 0., 71., 0.027, 102., 0.027, ...
103., 0.105, 106., 0.105, 107., 0.140, 111., 0.140, ...
112., 0.140, 116., 0.140, 117., 0.488, 131., 0.488
FUNCTION DRLVBT, 12. = 0., 0., 68., 0., 69., 0.030, 102., 0.030, ...
103., 0.148, 106., 0.148, 107., 0.234, 111., 0.234, ...
112., 0.818, 116., 0.818, 117., 0.818, 131., 0.818

*** RELATIVE DYING RATE OF ROOTS ***
* VALUES AS FUNCTION OF THE NUMBER OF DAYS AFTER EMERGENCE
FUNCTION DRRTB = 0., 0., 67., 0., 68., 0.0061, 102., 0.0061, ...
103., 0.0206, 106., 0.0206, 107., 0.037, 111., 0.037, ...
112., 0.073, 131., 0.073

*** RELATIVE DYING RATE OF STEMS ***
* VALUES AS FUNCTION OF THE NUMBER OF DAYS AFTER EMERGENCE
FUNCTION DRSTTB = 0., 0., 67., 0., 68., 0.0076, 102., 0.0076, ...
103., 0.0258, 106., 0.0258, 107., 0.047, 111., 0.047, ...
112., 0.091, 131., 0.091
*** DEVELOPMENT OF PLANT HEIGHT ***

* VALUES AS FUNCTION OF THE NUMBER OF DAYS AFTER EMERGENCE

FUNCTION HEITB, 1. = 0., 5., 40., 34., 55., 64., 72., 89., 130., 73.

FUNCTION HEITB, 2. = 0., 5., 40., 30., 55., 56., 72., 81., 130., 63.


FUNCTION HEITB, 4. = 0., 5., 40., 32., 55., 54., 72., 81., 130., 66.

FUNCTION HEITB, 5. = 0., 5., 40., 32., 55., 58., 72., 81., 130., 70.

FUNCTION HEITB, 6. = 0., 5., 40., 31., 55., 58., 72., 97., 130., 82.

FUNCTION HEITB, 7. = 0., 5., 40., 34., 55., 58., 72., 82., 130., 70.

FUNCTION HEITB, 8. = 0., 5., 40., 26., 55., 58., 72., 97., 130., 63.


FUNCTION HEITB, 10. = 0., 5., 40., 30., 55., 55., 72., 89., 130., 69.


FUNCTION HEITB, 12. = 0., 5., 40., 27., 55., 58., 72., 93., 130., 79.

*** MAINTENANCE RESPIRATION ***

* "Q10-PARAMTER"

PARAM Q10 = 2.

*** RELATIVE RESPIRATION RATES OF LEAVES, STEMS, ROOTS, GRAINS ***

PARAM BMRCLV = 0.03, BMRCST = 0.015, BMRCRT = 0.01, BMRCGR = 0.01

* REDUCTION FACTOR ACCOUNTING FOR THE EFFECT OF SENESCENCE ON THE

* RESPIRATION RATE OF LEAVES; VALUES AS FUNCTION OF THE

* DEVELOPMENTAL STATE

FUNCTION LVRRT = 0., 1., 0.5, 1., 0.5001, 0.5, 1.1, 0.5

*** GROWTH EFFICIENCY ***

PARAM EFCLVS = 0.68, EFCST = 0.66, EFCRT = 0.69, EFCGR = 0.70

*** DRY MATTER ALLOCATION ***

* FRACTION OF NET ASSIMILATION ALLOCATED TO THE LEAVES,

* DIVIDED BY THE FRACTION ALLOCATED TO THE SHOOT

VALUES AS FUNCTION OF THE DEVELOPMENTAL STATE

FUNCTION FLVST, 1. = 0., 0.61, 0.10671, 0.61, ...

0.10672, 0.65, 0.14982, 0.65, 0.14982, 0.54, 0.22581, 0.54, ...

0.22582, 0.47, 0.26922, 0.47, 0.26922, 0.32, 0.31265, 0.32, ...

0.40000, 0.04, 0.50001, 0., 1.0.

FUNCTION FLVST, 2. = 0., 0.65, 0.11042, 0.65, ...

0.11042, 0.66, 0.15501, 0.66, 0.15502, 0.56, 0.23361, 0.56, ...

0.23362, 0.42, 0.27851, 0.42, 0.27852, 0.32, 0.32350, 0.32, ...

0.40000, 0.04, 0.50001, 0., 1.0.

FUNCTION FLVST, 3. = 0., 0.64, 0.11241, 0.64, ...

0.11242, 0.58, 0.15781, 0.58, 0.15782, 0.54, 0.23781, 0.54, ...

0.23782, 0.42, 0.28361, 0.42, 0.28362, 0.32, 0.32394, 0.32, ...

0.40000, 0.04, 0.50001, 0., 1.0.

FUNCTION FLVST, 4. = 0., 0.59, 0.10511, 0.59, ...

0.10512, 0.65, 0.14741, 0.65, 0.14742, 0.56, 0.22221, 0.56, ...

0.22222, 0.55, 0.26501, 0.55, 0.26502, 0.32, 0.30774, 0.32, ...

0.40000, 0.04, 0.50001, 0., 1.0.

FUNCTION FLVST, 5. = 0., 0.62, 0.10861, 0.62, ...

0.10862, 0.63, 0.15241, 0.63, 0.15242, 0.53, 0.22971, 0.53, ...

0.22972, 0.42, 0.27391, 0.42, 0.27392, 0.32, 0.31810, 0.32, ...

0.40000, 0.04, 0.50001, 0., 1.0.

FUNCTION FLVST, 6. = 0., 0.60, 0.10331, 0.60, ...

0.10332, 0.65, 0.14501, 0.65, 0.14502, 0.54, 0.21851, 0.54, ...

0.21852, 0.46, 0.26061, 0.44, 0.26062, 0.32, 0.30265, 0.32, ...

0.40000, 0.04, 0.50001, 0., 1.0.
FUNCTION FLVST, 7.
= 0.0.60, 0.10671,0.60, ...
0.10672,0.62, 0.14981,0.62, 0.14982,0.51, 0.22581,0.51, ...
0.22582,0.57, 0.26921,0.57, 0.26922,0.32, 0.31265,0.32, ...
0.40000,0.04, 0.50001,0., 1.0.

FUNCTION FLVST, 8.
= 0.0.65, 0.10171,0.65, ...
0.10172,0.68, 0.14271,0.68, 0.14272,0.59, 0.21511,0.59, ...
0.21512,0.53, 0.25651,0.53, 0.25652,0.32, 0.29792,0.32, ...
0.40000,0.04, 0.50001,0., 1.0.

FUNCTION FLVST, 9.
= 0.0.64, 0.10672,0.64, ...
0.10673,0.66, 0.14272,0.66, 0.14273,0.55, 0.21512,0.55, ...
0.21513,0.57, 0.25652,0.57, 0.25653,0.32, 0.29793,0.32, ...
0.40000,0.04, 0.50001,0., 1.0.

FUNCTION FLVST, 10.
= 0.0.65, 0.10172,0.65, ...
0.10173,0.68, 0.14272,0.68, 0.14273,0.56, 0.21512,0.56, ...
0.21513,0.59, 0.25653,0.59, 0.25654,0.32, 0.29794,0.32, ...
0.40000,0.04, 0.50001,0., 1.0.

FUNCTION FLVST, 11.
= 0.0.62, 0.10011,0.62, ...
0.10012,0.71, 0.14052,0.71, 0.14053,0.61, 0.21181,0.61, ...
0.21182,0.46, 0.25261,0.46, 0.25262,0.32, 0.29334,0.32, ...
0.40000,0.04, 0.50001,0., 1.0.

FUNCTION FLVST, 12.
= 0.0.64, 0.10331,0.64, ...
0.10332,0.67, 0.14502,0.67, 0.14503,0.57, 0.21851,0.57, ...
0.21852,0.43, 0.26061,0.43, 0.26062,0.32, 0.30265,0.32, ...
0.40000,0.04, 0.50001,0., 1.0.

* FRACTION OF NET ASSIMILATION ALLOCATED TO THE STEMS, *
* DIVIDED BY THE FRACTION ALLOCATED TO THE SHOOT *
* VALUES AS FUNCTION OF THE DEVELOPMENTAL STATE *
FUNCTION FSTT, 11 = 0.10012, 0.29, 0.21182, 0.52, 0.40000, 0.96, ...
FUNCTION FSTT, 12 = 0.10332, 0.33, 0.21852, 0.57, 0.40000, 0.96, ...

FUNCTION FSHTB, 1 = 0., 0.38, 0.10011, 0.38, 0.14051, 0.29, 0.14052, 0.39, 0.25261, 0.52, 0.25262, 0.68, 0.50000, 0., 1., 1., 1., 1.
FUNCTION FSHTB, 12 = 0., 0.36, 0.10331, 0.36, 0.14501, 0.33, 0.14502, 0.43, 0.26061, 0.57, 0.26062, 0.68, 0.50000, 0., 1., 1., 1., 1.

*** SPECIFIC LEAF AREA ***
* VALUES AS FUNCTION OF THE DEVELOPMENTAL STATE *
* (M**2 / KG)
FUNCTION SLATB, 1 = 0., 21.570, 1., 21.570
FUNCTION SLATB, 2 = 0., 21.848, 1., 21.848
FUNCTION SLATB, 3 = 0., 20.786, 1., 20.786
FUNCTION SLATB, 4 = 0., 23.348, 1., 23.348
FUNCTION SLATB, 5 = 0., 22.227, 1., 22.227
FUNCTION SLATB, 6 = 0., 22.457, 1., 22.457
FUNCTION SLATB, 7 = 0., 22.041, 1., 22.041
FUNCTION SLATB, 8 = 0., 22.124, 1., 22.124
FUNCTION SLATB, 9 = 0., 22.758, 1., 22.758

*** SPECIFIC STEM AREA ***
* (M**2 / KG)
PARAM SSTA = 2.5

METHOD RECT

WEATHER DATA

DAILY GLOBAL RADIATION (J/CM**2/D)
FUNCTION DTRT = 96., 1873., 97., 1593., 98., 834., 99., 902., 100., 0., ...
111., 1631., 112., 2159., 113., 959., 114., 2097., 115., 1341., ...
126., 2589., 127., 1695., 128., 1363., 129., 957., 130., 2486., ...
131., 2774., 132., 2701., 133., 2627., 134., 2691., 135., 2767., ...
136., 2656., 137., 2089., 138., 2233., 139., 1998., 140., 2601., ...
141., 2004., 142., 2567., 143., 2778., 144., 1943., 145., 833., ...
146., 1580., 147., 2040., 148., 1671., 149., 1623., 150., 1326., ...
151., 2310., 152., 1336., 153., 1319., 154., 2324., 155., 628., ...
156., 1737., 157., 2798., 158., 2594., 159., 970., 160., 1885., ...
161., 2365., 162., 949., 163., 2053., 164., 2584., 165., 2214., ...
166., 1707., 167., 1485., 168., 870., 169., 1383., 170., 1147., ...
171., 667., 172., 1521., 173., 1369., 174., 1398., 175., 1543., ...
176., 1355., 177., 1892., 178., 1720., 179., 1735., 180., 799., ...
181., 1573., 182., 2212., 183., 1065., 184., 1542., 185., 1652., ...
186., 878., 187., 1329., 188., 2219., 189., 1007., 190., 635., ...
191., 779., 192., 428., 193., 618., 194., 1194., 195., 1348., ...
196., 1017., 197., 1735., 198., 1031., 199., 1263., 200., 753., ...
201., 389., 202., 655., 203., 540., 204., 2615., 205., 2592., ...
206., 2141., 207., 2414., 208., 2153., 209., 1667., 210., 1700., ...
<table>
<thead>
<tr>
<th>Day</th>
<th>Temperature Maxima (°C)</th>
<th>Day</th>
<th>Temperature Minima (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>211</td>
<td>2282.2, 212.5, 556.2, 213, 2290.4, 214, 2044, 215, 2073, ...</td>
<td>216</td>
<td>1507.2, 217, 1480.2, 218, 1393.2, 219, 1296, 220, 1455, ...</td>
</tr>
<tr>
<td>221</td>
<td>1799.2, 222, 1814.2, 223, 1563.2, 224, 1264.2, 225, 1238, ...</td>
<td>226</td>
<td>1164.2, 227, 724, 228, 1989, 229, 928, 230, 1705, ...</td>
</tr>
<tr>
<td>231</td>
<td>1045.2, 232, 1372, 233, 1115, 234, 1364, 235, 1229, ...</td>
<td>236</td>
<td>1073, 237, 579, 238, 1895, 239, 2087, 240, 1819, ...</td>
</tr>
<tr>
<td>241</td>
<td>704, 242, 928, 243, 820, 244, 779, 245, 1572, ...</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* DAILY TEMPERATURE MAXIMA (°C)

* DAILY TEMPERATURE MINIMA (°C)

********************************************************************
*************** OUTPUT AND RUN CONTROL ***************************
********************************************************************
NOSORT
TIMER FINTIM = 231., TIME = 126., DELT=1., PRDEL=1., OUTDEL=1.
PRINT OGBMPP(1-12)
END
STOP

********************************************************************
***** SUBROUTINES CALLED FROM DYNAMIC *****
********************************************************************

SUBROUTINE STRATA (MAXHEI,NCL,ULCL)
SUBROUTINE CALCULATING THE BOUNDARY HEIGHTS SEPERATING THE CANOPY LAYERS; THE LAYERS HAVE EQUAL THICKNESS

INPUT PARAMETERS:
- MAXHEI : CANOPY HEIGHT [CM]
- NCL : NUMBER OF CANOPY LAYERS

OUTPUT PARAMETERS:
- ULCL : UPPER LIMITS OF CANOPY LAYERS [CM]

IMPLICIT REAL(A-Z)
INTEGER NCL,K
DIMENSION ULCL (NCL+1)
THK = MAXHEI / NCL
DO 10 K = 1,NCL
   ULCL(K) = MAXHEI - (K-1) * THK
10 CONTINUE
ULCL(NCL+1) = 0.
RETURN
END

SUBROUTINE VPREI (DNSP,A,C,Z,DISPA,DUM)
SUBROUTINE WRITING AN ARRAY CONTAINING PARAMETERS AND/OR AUXILIARY VARIABLES USED FOR THE VERTICAL DISTRIBUTION OF A SURFACE TYPE; THE ARRAY PRODUCED BY "VPREI" REFLECTS THE SITUATION THAT FOR ALL DESCRIBED GENOTYPES THE VERTICAL AREA DENSITY FUNCTION IS GIVEN BY Y = ( A * X**Z + A + C) / NORMALIZATION CONSTANT AND THAT ITS 3 PARAMETERS (A,C,Z) ARE IDENTICAL FOR ALL GENOTYPES

INPUT PARAMETERS:
- DNSP : DESCRIBED NUMBER OF GENOTYPES
- A,C,Z : PARAMETERS CHARACTERIZING THE VERTICAL AREA DENSITY FUNCTION

OUTPUT PARAMETERS:
- DISPA : ARRAY CONTAINING PARAMETERS AND/OR AUXILIARY VARIABLES USED FOR THE VERTICAL DISTRIBUTION OF A SURFACE TYPE

IMPLICIT REAL(A-Z)
INTEGER DNSP,K
DIMENSION DISPA (DNSP),DUM (DNSP)
DO 10 K = 1,DNSP
   DISPA(K) = A * X**Z + A + C
10 CONTINUE
RETURN
END
SUBROUTINE VPRE2 (DNSP,D,DISPA,DUM)

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C SUBROUTINE WRITING AN ARRAY CONTAINING PARAMETERS AND/OR AUXILIARY C
C VARIABLES USED FOR THE VERTICAL DISTRIBUTION OF A SURFACE TYPE; C
C THE ARRAY PRODUCED BY "VPRE2" REFLECTS THE SITUATION THAT FOR ALL C
C DESCRIBED GENOTYPES THE VERTICAL AREA DENSITY FUNCTION OF THE C
C SURFACE IS GIVEN BY C
C
C Y = 1 / D, 1-D - X = 1 C
C
C AND THAT ITS PARAMETER (D) IS IDENTICAL FOR ALL GENOTYPES C

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C INPUT PARAMETERS:
C DNOSP : DESCRIBED NUMBER OF GENOTYPES C
C D : PARAMETER CHARACTERIZING THE VERTICAL AREA DENSITY C
C FUNCTION C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C OUTPUT PARAMETERS:
C DISPA : ARRAY CONTAINING PARAMETERS AND/OR AUXILIARY VARIABLES C
C USED FOR THE VERTICAL DISTRIBUTION OF A SURFACE TYPE C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
IMPLICIT REAL (A-Z)
INTEGER A,G,COUNT,DNSP
DIMENSION X(6)
DIMENSION DISPA (72)

COUNT = 0
DO 128 G = 3,6
X(G) = 0.
128 CONTINUE
COUNT = 0
DNOSP = 1
DO 698 G = 1,6
DISPA(COUNT) = X(G)
698 CONTINUE
RETURN
END
SUBROUTINE CLFRAC (DISPA,L,LOWLIM,UPLIM,HEIGHT,TAI,CLAI)

SUBROUTINE CALCULATING THE AREA INDEX OF THAT FRACTION OF A SURFACE TYPE WHICH IS POSITIONED IN A CANOPY LAYER

INPUT PARAMETERS:

DISPA : ARRAY CONTAINING PARAMETERS AND/OR AUXILIARY VARIABLES
L : LIBRARY REFERENCE OF THE GENOTYPE
LOWLIM : LOWER BOUNDARY HEIGHT OF THE CONSIDERED CANOPY LAYER [CM]
UPLIM : UPPER BOUNDARY HEIGHT OF THE CONSIDERED CANOPY LAYER [CM]
HEIGHT : PLANT HEIGHT OF THE GENOTYPE
TAI : TOTAL AREA INDEX OF THE SURFACE TYPE

OUTPUT PARAMETERS:

CLAI : AREA INDEX OF THAT FRACTION OF THE SURFACE TYPE WHICH IS POSITIONED IN THE CANOPY LAYER

IMPLICIT REAL(A-Z)
INTEGER L,XADRES,XFUNC
DIMENSION DISPA (72)

CHOOSE THE DISTRIBUTION FUNCTION
XADRES = (L-1) * 6 + 1
XFUNC = DISPA(XADRES)
IF (XFUNC.EQ.1) GOTO 88877

DISTRIBUTION FUNCTION:
Y = A - A * X**Z + C
LOW = AMAX1 (0.,LOWLIM / HEIGHT)
UP = AMIN1 (1.,UPLIM / HEIGHT)
IF (LOWLIM.GE.HEIGHT. OR. UP.LE.1.E-5 ) THEN
    CLAI = 0.
ELSE
    XO = DISPA(XADRES+4)
    X1 = DISPA(XADRES+1) * (UP-LOW)
    X2 = DISPA(XADRES+2) * ( UP ** XO - LOW ** XO )
    CLAI = (X1 - X2) / DISPA(XADRES+3) * TAI
ENDIF
GOTO 90909

88877 CONTINUE

DISTRIBUTION FUNCTION:

Y = 1 / D , 1-D = X = 1

LIM1 = AMAX1 (0.,HEIGHT - DISPA (XADRES+1))
LIM2 = AMAX1 (0.,HEIGHT - DISPA (XADRES+2))
THICK = LIM2 - LIM1
IF (TAI. LE. 1.E-6. OR. THICK.LE. 1.E-6. OR. UPLIM.LE. LIM1. OR. LOWLIM.GE.LIM2) THEN
    CLAI = 0.
ELSE
    XU = AMIN1 (UPLIM, LIM2)
    XL = AMAX1 (LOWLIM,LIM1)
    CLAI = (XU - XL) / THICK * TAI
ENDIF

90909 CONTINUE
RETURN
END

SUBROUTINE VERDI2 (NSP,DNSP,V,EXIST, NCL,HEI,ULCL, AI,ECOF,DISPA, AID,LAIL,ECDIF, CHECK1,CHECK2,CHECK3)
SUBROUTINE DISTRIBUTING THE AREA INDEX OF A SURFACE TYPE OVER THE CANOPY LAYERS; FOR EACH CANOPY LAYER, THE EXTINCTION CAPACITY AND THE TOTAL AREA INDEX OF ALL CONTAINED SURFACES IS ENHANCED CORRESPONDINGLY TO THE CONTRIBUTION OF THIS SURFACE TYPE TO THE VARIOUS GENOTYPES.

INPUT PARAMETERS:
- NSP: NUMBER OF GENOTYPES
- DNSP: DESCRIBED NUMBER OF GENOTYPES
- V: ARRAY LINKING THE ACTUAL REFERENCES OF THE GENOTYPES TO THEIR LIBRARY REFERENCES
- NCL: NUMBER OF CANOPY LAYERS
- HEI: PLANT HEIGHTS OF THE GENOTYPES
- ULCL: BOUNDARY HEIGHTS SEPARATING THE CANOPY LAYERS
- AI: AREA INDICES OF THE VARIOUS GENOTYPES
- ECOF: EXTINCTION COEFFICIENTS OF THIS SURFACE TYPE BELONGING TO THE VARIOUS GENOTYPES
- DISPA: ARRAY CONTAINING PARAMETERS AND/OR AUXILIARY VARIABLES USED FOR THE VERTICAL DISTRIBUTION OF A SURFACE TYPE
- LAIL: CONTAINS FOR EACH OF THE NCL CANOPY LAYERS THE SUM OF AREA INDICES BELONGING TO ABSORBING SURFACES (LEAVES, STEMS, EARS...) POSITIONED IN IT [HA/HA]
- ECDIF: AS LAIL, BUT THE CONTRIBUTING AREA INDICES ARE MULTIPLIED BY THE CORRESPONDING EXTINCTION COEFFICIENTS FOR DIFFUSE LIGHT [HA/HA]

OUTPUT PARAMETERS:
- AID: DISTRIBUTION OF THE TOTAL AREA INDEX OF THE CONSIDERED SURFACE TYPE OVER CANOPY LAYERS AND COMPETITORS
- LAIL: CONTAINS FOR EACH OF THE NCL CANOPY LAYERS THE SUM OF AREA INDICES BELONGING TO ABSORBING SURFACES (LEAVES, STEMS, EARS...) POSITIONED IN IT [HA/HA]
- ECDIF: AS LAIL, BUT THE CONTRIBUTING AREA INDICES ARE MULTIPLIED BY THE CORRESPONDING EXTINCTION COEFFICIENTS FOR DIFFUSE LIGHT [HA/HA]

IMPLICIT REAL (A-Z)
INTEGER V,K,A,C,NSP,DNSP,NCL,L
DIMENSION V (NSP)
DIMENSION EXIST (NSP)
DIMENSION HEI (NSP)
DIMENSION ULCL (NCL+1)
DIMENSION AI (NSP)
DIMENSION ECOF (DNSP)
DIMENSION DISPA (72)
DIMENSION AID (NSP*NCL)
DIMENSION LAIL (NCL)
DIMENSION ECDIF (NCL)
C = 0
CHECK1 = 0.
DO 565 K = 1,NCL
LOWLIM = ULCL(K+1)
UPLIM = ULCL(K)
   DO 566 A = 1,NSP
      L = V(A)
      XAI = AI(A)
      XHEI= HEI(A)
      CALL CLFRAC (DISPA,L,LOWLIM,UPLIM,XHEI,XAI,CLAI)
      CHECK1 = CHECK1 + CLAI
      AID (C) = CLAI
      LAIL (K) = LAIL (K) + CLAI
      ECDIF (K) = ECDIF (K) + CLAI * ECOF(L)
   CONTINUE
566   CONTINUE
565   CONTINUE
CHECK2 = 0.
DO 1729 A = 1,NSP
   CHECK2 = CHECK2 + AI(A)
1729 CONTINUE
CHECKING THE CORRECT DISTRIBUTION
IF (CHECK2.LT.1.E-5) THEN
  CHECK3 = CHECK1
ELSE
  CHECK3 = ABS(CHECK1-CHECK2) / CHECK2
ENDIF

IF (CHECK3.GT.0.01) THEN
  TYPE 88661 - 40 - 88661
  FORMAT ('INCORRECT DISTRIBUTION ALGORITHM')
  RETURN
END

SUBROUTINE YELDIl (NSP,NCL,AI,GAIID,YFRAC)

C SUBROUTINE DERIVING THE DISTRIBUTION OF THE GREEN FRACTION OF A SURFACE TYPE OVER CANOPY LAYERS AND COMPETITORS FROM THE CORRESPONDING DISTRIBUTION OF THE TOTAL SURFACE AREA; THE DERIVATION REFLECTS THE SITUATION THAT THE TOTAL GREEN FRACTION IS POSITIONED ABOVE THE TOTAL YELLOW FRACTION

C INPUT PARAMETERS:
C  NSP : NUMBER OF GENOTYPES
C  NCL : NUMBER OF CANOPY LAYERS
C  AI : TOTAL AREA INDICES OF THE VARIOUS GENOTYPES
C  YFRAC : YELLOW FRACTIONS OF THE TOTAL AREA INDICES BELONGING TO THE VARIOUS GENOTYPES

C OUTPUT PARAMETERS:
C  GAID : DISTRIBUTION OF THE GREEN AREA INDEX OF THE CONSIDERED SURFACE TYPE OVER CANOPY LAYERS AND COMPETITORS

C IMPLICIT REAL (A-Z)
C INTEGER NSP,NCL,A,K
C DIMENSION AI (NSP)
C DIMENSION GAID (NSP*NCL)
C DIMENSION YFRAC (NSP)
C DO 1914 A = 1,NSP
    XGAI = AI(A) * (1.-YFRAC(A))
    DO 1915 K = A, (NCL-1) * NSP + A, NSP
        GAIID (K) = LIMIT (0.,GAID(K), XGAI - XCUMGR)
        XCUMGR = XCUMGR + GAID(K)
1915 CONTINUE
1914 CONTINUE
RETURN
END

SUBROUTINE YELDII2 (NSP,NCL,GAIID,YFRAC)

C SUBROUTINE DERIVING THE DISTRIBUTION OF THE GREEN FRACTION OF A SURFACE TYPE OVER CANOPY LAYERS AND COMPETITORS FROM THE CORRESPONDING DISTRIBUTION OF THE TOTAL SURFACE AREA; THE DERIVATION REFLECTS THE SITUATION THAT THE GREEN FRACTION IS DISTRIBUTED UNIFORMLY FROM GROUND TO PLANT TOP IS POSITIONED ABOVE THE TOTAL YELLOW FRACTION

C INPUT PARAMETERS:
C  NSP : NUMBER OF GENOTYPES
C  NCL : NUMBER OF CANOPY LAYERS
C  YFRAC : YELLOW FRACTIONS OF THE TOTAL AREA INDICES BELONGING TO THE VARIOUS GENOTYPES

C OUTPUT PARAMETERS:
C  GAID : DISTRIBUTION OF THE GREEN AREA INDEX OF THE CONSIDERED SURFACE TYPE OVER CANOPY LAYERS AND COMPETITORS

C IMPLICIT REAL (A-Z)
C INTEGER NSP,NCL,A,K
C DIMENSION AI (NSP)
C DIMENSION GAID (NSP*NCL)
C DIMENSION YFRAC (NSP)
C DO 1914 A = 1,NSP
    XGAI = AI(A) * (1.-YFRAC(A))
    DO 1915 K = A, (NCL-1) * NSP + A, NSP
        GAIID (K) = LIMIT (0.,GAID(K), XGAI - XCUMGR)
        XCUMGR = XCUMGR + GAID(K)
1915 CONTINUE
1914 CONTINUE
RETURN
END
IMPLICIT REAL (A-Z)
INTEGER NSP,NCL,A,K
DIMENSION GAID (NSP * NCL)
DIMENSION YFRAC (NSP)
DO 8001 A = 1,NSP
   DO 8002 K = A, (NCL-1) * NSP + A, NSP
      GAID (K) = GAID (K) * (1. - YFRAC(A))
8002 CONTINUE
8001 CONTINUE
RETURN
END

SUBROUTINE ASTRO(DAY,LAT,DTR,DAYL,SININT,$
   $ SINLD,COSLD)
   C SUBROUTINE CALCULATING THE DAYLENGTH [H] AND 3 AUXILIARY VARIABLES C
   C NEEDED FOR DESCRIBING THE INSTANTANEOUS RADIATION FOR A GIVEN C
   C TIMEPOINT OF THE DAY C
   C INPUT PARAMETERS:
   C · DAY : NUMBER OF CALENDAR DAY
   C · LAT : LATITUDE OF LOCATION
   C OUTPUT PARAMETERS:
   C · DAYL : DAYLENGTH [H]
   C · SINLD : AUXILIARY VARIABLE
   C · COSLD : AUXILIARY VARIABLE
   C · SININT : AUXILIARY VARIABLE
   IMPLICIT REAL (A-Z)
   PI=3.1415926
   RAD=PI/180.
   DEC=-23.45*COS(2*PI*(DAY+10.)/365.)
   SINLD=SIN(RAD*LAT)*SIN(RAD*DEC)
   COSLD=COS(RAD*LAT)*COS(RAD*DEC)
   AOB=SINLD/COSLD
   DAYL=12.0*(1.0+2.0*ASIN(AOB)/PI)
   SININT=DAYL*(SINLD+0.4*(SINLD*SINLD+COSLD*COSLD*0.5) ) +$
   $12.0*COSLD*(2.0+3.0*0.4*SINLD)*SQRT(1.0-AOB*AOB)/PI
   RETURN
END

SUBROUTINE FRADIF (DAY,DTR,DAYL,SINLD,COSLD,FRDFD)
   C SUBROUTINE CALCULATING THE DIFFUSE FRACTION OF DAILY VISIBLE C
   C RADIATION C
   C INPUT PARAMETERS:
   C · DAY : NUMBER OF CALENDAR DAY
   C · DTR : DAILY GLOBAL RADIATION [J/M**2/D]
   C · DAYL : DAYLENGTH [H]
   C · SINLD : AUXILIARY VARIABLE
   C · COSLD : AUXILIARY VARIABLE
   C OUTPUT PARAMETERS:
   C · FRDFD : DIFFUSE FRACTION OF DAILY VISIBLE RADIATION
   IMPLICIT REAL (A-Z)
   PI=3.1415926
   SC = 1370.
   SCACT = SC * (1. + 0.033 * COS(360.*DAY/365.))
   INTBET= 3600. * (DAYL * SINLD + 24./PI * COSLD *$
   $ SQRT(1.-(SINLD/COSLD)**2))
   EXTRF= INTBET * SCACT
   ATD = DTR / EXTRF
   RETURN
END
C  FRACTION DIFFUSE LIGHT ON DAY BASIS
IF (ATD.GE.0.35) FRDF = 1.33 - 1.46 * ATD
IF (ATD.LT.0.35) FRDF = 1. - 2.3 * (ATD-0.07)**2
FRDFD = LIMIT(0.23,1.,FRDF)
RETURN
END

SUBROUTINE INSTIR (DAYL,HOUR,DTR,FRDFD,SINLD,COSLD,SININT, $
IRR,SINB,FRDR)

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C SUBROUTINE CALCULATING THE SINE OF SUN HEIGHT AND THE INTENSITY .C
C [J/M**2/S] AND DIRECT FRACTION OF INSTANTANEOUS VISIBLE .C
C RADIATION .C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C INPUT PARAMETERS: C
C DAYL : DAYLENGTH [H] C
C HOUR : ACTUAL HOUR OF THE DAY C
C DTR : DAILY GLOBAL RADIATION [J/M**2/D] C
C FRDFD : DIFFUSE FRACTION OF DAILY VISIBLE RADIATION C
C SINLD : AUXILIARY VARIABLE C
C COSLD : AUXILIARY VARIABLE C
C SININT : AUXILIARY VARIABLE C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C OUTPUT PARAMETERS: C
C IRR : INTENSITY OF INSTANTANEOUS VISIBLE RADIATION [J/M**2/S] C
C FRDR : DIRECT FRACTION OF VISIBLE RADIATION C
C SINB : SINE OF SUN HEIGHT C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
IMPLICIT REAL (A-Z)
PI • 3.1415926
SINB = AMAX(0.,SINLD + COSLD * COS(2. * PI * (HOUR+12.)/24.))
1 SFF = SINB * (1. + 0.4 * SINB)
1 IRR = SFF * DTR * 0.5 / (SININT * 3600.)
1 AUXFRD• (1. - FRDFD) * (1.08 - 0.0095 * EXP (4.6 * (HOUR-12.) / (0.5*DAYL)))
$ FRDR = LIMIT(0.1.,AUXFRD)
3000 CONTINUE
RETURN
END

SUBROUTINE PHOTOC (NCL, NSP, DNSP, V, STESWI, EARSWI, 1 LAIFIX,SAIFIX, RAIFIX, LAIL, ECDFI, 1 KL, KLSTEM, KLEAR, 1 AMAX,SAMAX,EAMAX, EFF, SEFF, EEFF, 1 IRR, FRDR, SINB, PROD)

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C SUBROUTINE CALCULATING C
C I N S T A N T A N E O U S RATES OF GROSS ASSIMILATION [KGIHAIH] C
C OF NSP COMPETITORS FORMING A CANOPY DESCRIBED IN TERMS OF NCL C
C CANOPY LAYERS; OPTIONALLY, THE PHOTOSYNTHESIS OF STEMS AND EARS C
C CAN BE INCLUDED C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C INPUT PARAMETERS: C
C IRR : INTENSITY OF VISIBLE RADIATION [J/M**2/S] C
C FRDR : DIRECT FRACTION OF VISIBLE RADIATION C
C SINB : SINE OF SUN HEIGHT C
C THE OTHER INPUT PARAMETERS ARE EXPLAINED IN THE HEAD PART OF C
C THE SUBROUTINE D A Y A S S C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C OUTPUT PARAMETERS: C
C PROD : INSTANTANEOUS ASSIMILATION RATES OF THE NSP SPECIES C
[KG/HA/H] C
IMPLICIT REAL (A-Z)
INTEGER G,K,A,DNSP,NSP,V,NCL,C,STESWI,EARSWI
DIMENSION LAIFIX (NCL*NSP)
DIMENSION SAIFIX (NCL*NSP)
DIMENSION EAIFIX (NCL*NSP)
DIMENSION LAIL (NCL)
DIMENSION ECDIF (NCL)
DIMENSION KL (DNSP)
DIMENSION KLSTEM (DNSP)
DIMENSION KL (DNSP)
DIMENSION EAMAX (DNSP)
DIMENSION SEFF (DNSP)
DIMENSION EAMAX (DNSP)
DIMENSION SEFF (DNSP)
DIMENSION PROD (NSP)

C SCATTERING COEFFICIENT (ASSUMED TO BE EQUAL FOR ALL LIGHT ABSORBING STRUCTURES)
SCV = 0.2
C AN AUXILIARY VARIABLE ("SQV")
SQV = SQRT (1. - SCV)
C REFLECTION COEFFICIENT OF THE CANOPY
REFLC = (1. - SQV) / (1. + SQV)
C INTENSITIES (J/CM**2/S) OF DIRECT LIGHT ("DIR") AND OF INDIRECT LIGHT ("DIF") ABOVE THE CANOPY AT THE CONSIDERED TIMEPOINT
DIF = IRR * (1.- FRDR) * (1. - REFLC)
DIR = IRR * FRDR
DO 4 A = 1,NSP
PROD(A) = 0.
4 CONTINUE
C MULTIPLICATION FACTORS FOR CONVERTING THE EXTINCTION OF DIFFUSE LIGHT INTO THE EXTINCTION OF LIGHT INTENSITY WHEN THE INCOMING RADIATION IS DIRECT ("CONDRF") AND INTO THE EXTINCTION OF THE DIRECT COMPONENT OF INCOMING DIRECT RADIATION ("CONDIR")
CONDIR = 0.5 / (SINB * SQV * 0.8)
CONDRF = CONDIR * SQV
C FRACTIONS OF DIFFUSE LIGHT ENTERING (DIFIN) AND LEAVING (DIFOUT) THE CONSIDERED LEAF LAYER
DIFIN = DIFOUT = 1.
C LOOP ACCOUNTING FOR THE DIFFERENT LEAF LAYERS
DO 2 K = 1,NCL
C KDIF AND KDIR OF THE COMPOSITE LEAF LAYER, OBTAINED BY AVERAGING THE LAI-WEIGHTED VALUES OF THE CONTRIBUTING SPECIES (USED FOR CALCULATING THE SUNLIT LEAF AREA)
IF (LAIL(K).LT.1.E-4) THEN
TYPE 5011,K
FORMAT (' CANOPY LAYER ',I5,' WITH LAIL = 0 ')
GOTO 2
END IF
IF (ECDIF(K).LT.1.E-4) THEN
TYPE 5012,K
FORMAT (' CANOPY LAYER',I5,' WITH ECDIF = 0 ')
GOTO 2
ENDIF
2 CONTINUE
C FRACTIONS OF DIFFUSE LIGHT ENTERING (DIFIN) AND LEAVING (DIFOUT) THE CONSIDERED LEAF LAYER
DIFIN = DIFOUT = 1.
C FRACTION OF DIFFUSE LIGHT ABSORBED IN THE LAYER ("ADIF"), OF DIRECT LIGHT ABSORBED IN THE LAYER AS DIRECT LIGHT ("ADDIR") AND OF DIRECT LIGHT ABSORBED IN THE LAYER AS DIRECT OR...
C INDIRECT LIGHT ("ATDIR") (1/S)
ADIF = DIFIN - DIFOUT
EDDIR = DIFIN**CONDIR - DIFOUT**CONDIR
ADDIR = EDDIR * (1.-SCV)
ATDIR = (DIFIN**CONDRF - DIFOUT**CONDRF) * (1.-REFLC)
C FRACTION OF SUNLIT LEAF AREA IN THE LAYER
SLLA = EDDIR / (KDIR*LAIL(K)) * KDIF/SQV/0.8
IF (SLLA.LT.1.E-10) THEN
  TYPE 5020
  5020 FORMAT (' SLLA = 0 ')
  GOTO 2
END IF
C ABSORPTION RATE (J/S) OF THE SUNLIT PART OF THE LEAF LAYER ("SUNA")
C AND OF THE SHADOWED PART ("SHAA") (1/S)
SUMDIF = DIF * ADIF + DIR * (ATDIR-ADDIR)
SHAA = SUMDIF * (1. - SLLA)
SUNA = SLLA * SUMDIF + DIR * ADDIR
C *** ASSIMILATION PERFORMED BY LEAVES ***
DO 3 A = 1,NSP
  L = V(A)
  C = (K-1) * NSP + A
  LEAFAR = LAIFIX (C)
C ABSORPTION RATE (J/CM**2 LEAF/S) OF SUNLIT LEAVES ("ABSDIR")
C AND OF SHADOWED LEAVES ("ABSDIF")
  ABSDIR = SUNA * KL(L)/(ECDIF(K) * SLLA)
  ABSdif = SHAA * KL(L)/(ECDIF(K) * (1. - SLLA))
C THE ASSIMILATION OF SUNLIT AND SHADOWED LEAF AREA IS
C ADDED TO THE OVERALL PRODUCTION OF THE SPECIES WITHIN
C THE CONSIDERED LEAF LAYER
IF (AMAX(L).LT.1.E-3) THEN
  TYPE 5014,L
  5014 FORMAT (' SPECIES ',IS,' WITH AMAX = 0 ! ')
  GOTO 3
END IF
PROD1 = AMAX(L) * (1. - EXP(-EFF(L)*ABSDIF/AMAX(L)))
PROD2 = AMAX(L) * (1. - EXP(-EFF(L)*ABSDIR/AMAX(L)))
PROD(A) = PROD(A) + LEAFAR * (SLLA*PROD2 + (1. - SLLA) * PROD1)
3 CONTINUE
IF (ESTESWI.EQ.0) GOTO 80
C *** ASSIMILATION PERFORMED BY STEMS ***
C ABSORPTION RATE (J/CM**2 STEM/S) OF SUNLIT STEM AREA ("STADIR")
C AND OF SHADOWED STEM AREA ("STADIF")
STADIR = SUNA * KLSTEM(L)/(ECDIF(K) * SLLA)
STADIF = SHAA * KLSTEM(L)/(ECDIF(K) * (1. - SLLA))
C THE ASSIMILATION OF SUNLIT AND SHADOWED STEM AREA IS
C ADDED TO THE OVERALL PRODUCTION OF THE SPECIES WITHIN
C THE CONSIDERED LEAF LAYER
DO 70 A = 1, NSP
  L = V(A)
  C = (K-1) * NSP + A
  STEMAR = SAIFIX (C)
IF (SAMAX(L).LT.1.E-3) THEN
  TYPE 5015,L
  5015 FORMAT (' SPECIES ',IS,' WITH SAMAX = 0 ! ')
  GOTO 70
END IF
PROD1 = SAMAX(L)*(1. - EXP(-SEFF(L) * STADIF/SAMAX(L)))
PROD2 = SAMAX(L)*(1. - EXP(-SEFF(L) * STADIR/SAMAX(L)))
PROD(A) = PROD(A) + STEMAR * (SLLA * PROD2 + (1. - SLLA) * PROD1)
70 CONTINUE
80 IF (EARSWI.EQ.0) GOTO 2
ASSIMILATION PERFORMED BY EARS

Absorption rate (J/m**2 ear/s) of sunlit eararea ("EARDIR") and of shaded eararea ("EARDIF")

\[
\text{EARDIR} = \text{SUMA} \times \text{KLEAR}(L) / (\text{ECDIF}(K) \times \text{SLLA})
\]
\[
\text{EARDIF} = \text{SHAA} \times \text{KLEAR}(L) / (\text{ECDIF}(K) \times (1. - \text{SLLA}))
\]

The assimilation of sunlit and shaded eararea is added to the overall production of the species within the considered leaf layer.

\[
\text{PROD1} = \text{EAMAX}(L) \times (1. - \exp(-\text{EEFF}(L) \times \text{EARDIF} / \text{EAMAX}(L)))
\]
\[
\text{PROD2} = \text{EAMAX}(L) \times (1. - \exp(-\text{EEFF}(L) \times \text{EARDIR} / \text{EAMAX}(L)))
\]
\[
\text{PROD}(A) = \text{PROD}(A) + \text{EARAR} \times (\text{SLLA} \times \text{PROD2} + (1. - \text{SLLA}) \times \text{PROD1})
\]

Now the loop has gone through all leaf layers and all competitors.

\[
\text{PROD}(A) = \text{PROD}(A) \times 30. / 44.
\]

RETURN

END

SUBROUTINE CALCULATING THE DAILY GROSS ASSIMILATION [KG/HA/D]

INPUT PARAMETERS:

DAY : NUMBER OF CALENDAR DAY
DTR : DAILY GLOBAL RADIATION [J/m**2/D]
LAT : LATITUDE OF LOCATION
NCL : NUMBER OF DESCRIPTED CANOPY LAYERS
NSP : NUMBER OF SPECIES MODELLED IN THE PRESENT CASE
DNSP : NUMBER OF SPECIES DESCRIBED IN THE PARAMETER SECTION OF THE MAIN PROGRAM
V : ARRAY RELATING THE NUMBER USED TO DENOTE A SPECIES IN THE PARAMETER SECTION OF THE MAIN PROGRAM TO THE NUMBER USED IN THE ACTUAL RUN
STESWI, EARSWI : SWITCH PARAMETERS DETERMINING IF PHOTOSYNTHESIS OF STEMS (EARS) IS TO BE INCLUDED
LAID : DISTRIBUTION OF LAI (GREEN LEAVES ONLY) OVER SPECIES AND LEAF LAYER [HA/HA]
SAID : AS LAIFIX, BUT FOR GREEN STEM AND GREEN EAR AREA [HA/HA]
(If photosynthesis of stems (ears) is to be neglected, saifix (eaifix) may be any dummy array with a dimension greater or equal "NSP+NCL" (thus for example "laifix") contains for each of the ncl canopy layers the sum of area indices belonging to absorbing surfaces (leaves, stems, ears... ) positioned in it [HA/HA].
ECDIS : As laid, but the contributing area indices are multiplied by the corresponding extinction coefficients for diffuse light [HA/HA].
C KL,
C KLSTEM,
C KLEAR : EXTINCTION COEFFICIENTS FOR DIFFUSE LIGHT OF LEAVES
C STEMS, EARS
C AMAX,
C SAMAX,
C EAMAX : AMAX VALUES OF LEAVES, STEMS, EARS [KG/HA/D]
C EFF,
C SEFF,
C EEFF : LIGHT USE EFFICIENCY OF LEAVES, STEMS, EARS [KG/HA/D/(J/S/M**2)]
C GASSP : GROSS ASSIMILATION OF THE NSP SPECIES [KG/HA/D]
C DUM : DUMMY PARAMETER
C

IMPLICIT REAL (A-Z)
IMPLICIT INTEGER

INTEGER G,K,A,DNSP,NSP,V,NCL,C,STESWI,EARSWI
DIMENSION LAID (NCL*NSP)
DIMENSION SAID (NCL*NSP)
DIMENSION EAID (NCL*NSP)
DIMENSION LAIL (NCL)
DIMENSION ECDIF (NCL)
DIMENSION V (NSP)
DIMENSION KL (DNSP)
DIMENSION KLSTEM (DNSP)
DIMENSION KLEAR (DNSP)
DIMENSION AMAX (DNSP)
DIMENSION SAMAX (DNSP)
DIMENSION EAMAX (DNSP)
DIMENSION EFF (DNSP)
DIMENSION SEFF (DNSP)
DIMENSION EEFF (DNSP)
DIMENSION GASSP (NSP)
DIMENSION INSTAS (27)
DIMENSION WEIGHT (3)
DIMENSION DIR (3)
DIMENSION INTENS (3)
DIMENSION SNUS (3)

C CALCULATE DAYLENGTH AND 3 AUXILIARY VARIABLES WHICH
C ARE NEEDED FOR DESCRIBING INSTANTANEOUS IRRADIATION
CALL ASTRO (DAY,LAT,DTR,
1 DAYL,SININT,SINLD,COSLD)
C CALCULATE THE DIFFUSE FRACTION OF DAILY IRRADIATION
CALL FRADIF(DAY,DTR,DAYL,SINLD,COSLD,
1 FRDFD)
C WEIGHTING FACTORS USED IN THE 3-POINT GAUSS INTEGRATION
WEIGHT(1) = 1.
WEIGHT(2) = 1.6
WEIGHT(3) = 1.
XGAUS = SQRT (0.15)
DO 445 A = 1,NSP
        GASSP(A) = 0.
445 CONTINUE
DO 6000 G=1,3
C SELECT TIMEPOINT DURING THE DAY
HOUR = 12. + DAYL * 0.5 * (0.5 + (G-2.) * XGAUS)
C DESCRIBE INSTANTANEOUS IRRADIATION (INTENSITY, DIRECT
C FRACTION AND SINUS OF SUN HEIGHT)
CALL INSTIR (DAYL,HOUR,DTR,FRDFD,SINLD,COSLD,SININT,
1 IRR,SINB,FRDR)
        DIR(G) = FRDR
        INTENS(G) = IRR
        SNUS (G) = SINB
CALCULATE INSTANTANEOUS ASSIMILATION RATES OF THE NSP COMPETITORS

CALL PHOTOC (NCL,NSP,DNSP,V,STESWI,EARSWI,LAID,SAID,EAID, 
1       LAIL,ECDIF,KL,KLSTEM,KLEAR,AMAX,SAMAX,EAMAX,EFF,SEFF, 
1       INSTAS)

INST1 = INSTAS(1)

WEIGHTED SUMMATION OF INSTANTANEOUS ASSIMILATION RATES
DO 5 A = 1,NSP
   GASSP(A) = GASSP(A) + INSTAS(A) * WEIGHT(C)
5 CONTINUE

WRITE (20,2620) FRDFD,DIR(1),DIR(2),DIR(3),INTENS(1), 
1       INTENS(2),INTENS(3),SNUS(1),SNUS(2),SNUS(3)

SUBROUTINE EVAL1 (DIM,ARR,PROB,EXVA,VAR,CV)

ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
C  SUBROUTINE CALCULATING EXPECTATION VALUE, VARIANCE AND THE COEFFICIENT C
C  OF VARIATION OF A CHANCE VARIABLE
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
C  INPUT PARAMETERS:
C    DIM  : NUMBER OF VALUES OF THE CHANCE VARIABLE
C    ARR  : VALUES OF THE CHANCE VARIABLE
C    PROB : PROBABILITIES ASSOCIATED WITH THE VALUES
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
C  OUTPUT PARAMETERS:
C    EXVA : EXPECTATION VALUE
C    VAR  : VARIANCE
C    CV   : COEFFICIENT OF VARIATION
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
IMPLICIT REAL (A-Z)
INTEGER DIM,J
DIMENSION ARR (DIM)
DIMENSION PROB(DIM)
IF (DIM.EQ.1 ) THEN
   EXVA = ARR(1)
   VAR  = 0.
ELSE
   SUMX = 0.
   SUMXX = 0.
   DO 851 J = 1,DIM
      SUMX = SUMX + ARR(J) * PROB(J)
      SUMXX = SUMXX + ARR(J)**2 * PROB(J)
851 CONTINUE
   EXVA = SUMX
   VAR = SUMXX - SUMX**2
ENDIF
IF (EXVA.LT.1.E-8) GOTO 9013
IF (VAR. LT.1.E-8) THEN
   CV = 0.
ELSE
   CV = SQRT(VAR) / EXVA
ENDIF
9013 CONTINUE
RETURN
END
SUBROUTINE LNDCAL (NSP, OGBMPP, PROB, LNDVBM, DUM)

C SUBROUTINE CALCULATING DELTA - LN - VALUES

C INPUT PARAMETERS:

C NSP : NUMBER OF GENOTYPES

C OGBMPP : ABOVE GROUND BIOMASS PER PLANT [G]

C PROB : FREQUENCIES OF THE GENOTYPES

C OUTPUT PARAMETERS:

C LNDVBM : DELTA - LN - VALUES

C DUM : DUMMY VARIABLE

IMPLICIT REAL (A-Z)
INTEGER NSP, A
DIMENSION OGBMPP(NSP)
DIMENSION PROB (NSP)
DIMENSION LNDVBM(NSP)

IF (NSP.EQ.1) GOTO 7020
SUMLN = 0.
DO 851 A = 1, NSP
  IF (OGBMPP(A).LT.1.E-3) GOTO 851
  SUMLN = SUMLN + ALOG(OGBMPP(A)) * PROB(A)
851 CONTINUE
AVLN = SUMLN
DO 852 A = 1, NSP
  LNDVBM(A) = ALOG(AMAX1(6.73795E-3, OGBMPP(A))) - AVLN
852 CONTINUE
7020 CONTINUE
RETURN
END
ENDJOB
<table>
<thead>
<tr>
<th>Name</th>
<th>Component</th>
<th>Definition</th>
<th>Dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>(S)</td>
<td>actual reference of a genotype (can be 1, ..., NSP)</td>
<td></td>
</tr>
<tr>
<td>AGE</td>
<td>(GA)</td>
<td>number of days since emergence</td>
<td></td>
</tr>
<tr>
<td>AMAX</td>
<td>(GL)</td>
<td>photosynthetic rate of leaves at light saturation</td>
<td>kg CO2/ha/h</td>
</tr>
<tr>
<td>APPEAR</td>
<td>(GL)</td>
<td>calendar day on which the population of the considered genotype is initialized</td>
<td></td>
</tr>
<tr>
<td>ARRIVE</td>
<td>(GA)</td>
<td>switch variable assuming the value 1 on days preceding a day of population initialization and the value 0 on other days</td>
<td></td>
</tr>
<tr>
<td>AV</td>
<td>(S)</td>
<td>average aboveground biomass per plant</td>
<td>g/plant</td>
</tr>
<tr>
<td>BMRCLV</td>
<td>(S)</td>
<td>relative rate of maintenance respiration of leaves at reference temperature</td>
<td>kg/kg/d</td>
</tr>
<tr>
<td>BMRGCR</td>
<td>(S)</td>
<td>relative rate of maintenance respiration of grains at reference temperature</td>
<td>kg/kg/d</td>
</tr>
<tr>
<td>BMRCRT</td>
<td>(S)</td>
<td>relative rate of maintenance respiration of roots at reference temperature</td>
<td>kg/kg/d</td>
</tr>
<tr>
<td>BMRCST</td>
<td>(S)</td>
<td>relative rate of maintenance respiration of stems at reference temperature</td>
<td>kg/kg/d</td>
</tr>
<tr>
<td>CLPERL</td>
<td>(S)</td>
<td>number of canopy layers which are defined per unit of the summed leaf area indices of all populations</td>
<td></td>
</tr>
<tr>
<td>CULTP</td>
<td>(GL)</td>
<td>parameter characterizing the dependence of DVRV on temperature</td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>(S)</td>
<td>coefficient of variation of aboveground biomass per plant</td>
<td></td>
</tr>
<tr>
<td>DAY</td>
<td>(S)</td>
<td>calendar day</td>
<td></td>
</tr>
<tr>
<td>DFAC</td>
<td>(S)</td>
<td>&quot;plant density factor&quot; with which the parameter values for the initial weights of leaves, stems and roots are multiplied at the initialization of the populations</td>
<td></td>
</tr>
<tr>
<td>DISPA1</td>
<td>(G6)</td>
<td>array containing auxiliary variables used for distributing the leaf area over the canopy layers</td>
<td></td>
</tr>
<tr>
<td>DISPA2</td>
<td>(G6)</td>
<td>array containing auxiliary variables used for distributing the stem area over the canopy layers</td>
<td></td>
</tr>
<tr>
<td>DISPA3</td>
<td>(G6)</td>
<td>array containing auxiliary variables used for distributing the ear area over the canopy layers</td>
<td></td>
</tr>
<tr>
<td>DNSP</td>
<td>(S)</td>
<td>number of genotypes described in the parameter library</td>
<td></td>
</tr>
<tr>
<td>DRLVS</td>
<td>(GA)</td>
<td>relative dying rate of leaves</td>
<td>kg/ha/d</td>
</tr>
<tr>
<td>DRLVTD</td>
<td>(F)</td>
<td>relative dying rate of leaves as function of the developmental state, dependent on the library reference of the genotype</td>
<td>kg/kg/d</td>
</tr>
<tr>
<td>DRRRT</td>
<td>(S)</td>
<td>dying rate of roots</td>
<td>kg/ha/d</td>
</tr>
<tr>
<td>DRRRTB</td>
<td>(F)</td>
<td>relative dying rate of roots as function of the developmental state</td>
<td>kg/kg/d</td>
</tr>
<tr>
<td>DRRST</td>
<td>(GA)</td>
<td>dying rate of stems</td>
<td>kg/ha/d</td>
</tr>
</tbody>
</table>
relative dying rate of stems as function of the developmental state

daily global radiation

DTR as function of the calendar day

rate of post-anthesis development

rate of pre-anthesis development

developmental state (0 at emergence, 1 at dead ripeness)

state of post-anthesis development (0 at anthesis, 1 at dead ripeness)

state of pre-anthesis development (0 at emergence, 1 at dead ripeness)

index of total ear area

index of the green ear area belonging to a considered genotype and positioned in a considered canopy layer

photosynthetic rate of ears at light saturation

ear area index at anthesis

ratio between the present ear area and the ear area at anthesis as function of the developmental state

total ear area index at anthesis

ratio of the ear area and the aboveground biomass at anthesis

"extinction capacity" of a canopy layer, defined as the sum of the products of area index and extinction coefficient of all contained surfaces

initial light use efficiency of ears

initial light use efficiency of leaves

calendar day on which the considered genotype emerges

efficiency of biosynthesis of grain tissue from carbohydrates

efficiency of biosynthesis of leaf tissue from carbohydrates

efficiency of biosynthesis of root tissue from carbohydrates

efficiency of biosynthesis of stem tissue from carbohydrates

switch variable assuming the value 0 before the initialization of the population and the value 1 from that timepoint on

daily net assimilation

fraction of net production allocated to the grains, divided by the fraction allocated to the shoot

fraction of net production allocated to the leaves, divided by the fraction allocated to the shoot

FLVS as function of the developmental state, dependent on the library reference of the genotype

fraction of net production allocated to the shoot

FSH as function of the developmental state, dependent on the library reference of the genotype

fraction of net production allocated to the stems, divided by the fraction allocated to the shoot

FST as function of the developmental state, dependent on the library reference of the genotype

daily gross assimilation

green fraction of the ear area as function of the number of days since emergence, dependent on the library reference of the genotype

growth rate of grains

net growth rate of living leaf tissue

switch variable assuming the value 0 before any population is initialized and the value 1 from the first initialization on

rate of assimilate allocation to the shoot

plant height

HEITB as function of the number of days since emergence, dependent on the library reference of the genotype

initial value of DVSV

initial dry weight of leaves, divided by the frequency of the genotype and the "density factor" DFAC
IWKT (GL) initial dry weight of roots, divided by the frequency of the genotype and the "density factor" DFAC kg/ha
IWST (GL) initial dry weight of stems, divided by the frequency of the genotype and the "density factor" DFAC kg/ha
KL (GL) extinction coefficient of leaves kg/ha
KLEAR (GL) extinction coefficient of ears kg/ha
KLREDT (F) reduction factor for the extinction coefficient of leaves, accounting for leaf clustering of young plants; values as function of the developmental state
KLSTEM (GL) extinction coefficient of stems kg/ha
L (S) library reference of a genotype (can be 1, ..., DNSP) ha/ha
LA, LC, LZ (S) parameters for characterizing the vertical area density function of leaf area ha/ha
LAI (GA) index of total leaf area ha/ha
LAID (CG) index of the green leaf area belonging to a given genotype and positioned in a given canopy layer ha/ha
LAIL (C) "total area index of a canopy layer": sum of the area indices of all surfaces contained in the considered canopy layer ha/ha
LAT (S) latitude of location
LC (S) see LA
LNDVBM (GA) defined as: LN(OGBMPP) - E (LN(OGBMPP)) (with E denoting the expectation value referring to the genotypes present in the mixed population) ha/ha
LNLAT (F) ln (leaf area) as function of the number of days since emergence, dependent on the library reference of the genotype
LVRRT (F) reduction factor for the maintenance respiration of leaves accounting for the effect of senescence; values as function of the developmental state
LZ (S) see LA
MAXCL (S) maximal number of canopy layers cm
MAXHEI (S) height of the canopy
MINCL (S) minimal number of canopy layers
NCL (S) number of canopy layers
NSP (S) number of genotypes competing in the actual simulation
OGBM (GA) aboveground biomass kg/ha
OGBMPP (GA) aboveground biomass g/plant
PAMAX (GL) potential photosynthetic rate of leaves at light saturation (possible reduction dependent on developmental state and temperature) kg CO2/ha/h
PKL (GL) potential extinction coefficient of leaves
PLOP (GA) switch variable assuming the value 1 on the day before the considered population is initialized; on other days the value is 0
PSM (S) total number of plants per m**2 m**2
RMNT (S) rate of maintenance respiration kg/ha/d
SA, SC, SZ (S) parameters for characterizing the vertical area density function of stem area
SAI (GA) index of total stem area ha/ha
SAID (CG) index of the green stem area belonging to a considered genotype and positioned in a considered canopy layer ha/ha
SC (S) see SA
SAMAX (GL) photosynthetic rate of stems at light saturation kg CO2/ha/h
SEFF (GL) initial light use efficiency of stems kg CO2/ha/h/(J/m**2/s)
SLA (S) specific leaf area m**2/kg
SLATB (F) SLA as function of the developmental state, dependent on the library reference of the genotype
SRAMAX (S) reduction factor of AMAX accounting for the effect of senescence m**2/kg
SRAMAT (F) SRAMAX as function of the developmental state
SSTA (S) specific stem area m**2/kg
START (S) calendar day on which the simulation starts
STOP (S) calendar day on which the simulation finishes
SWI... (S) switch parameter whose function is explained in the program listing (initial section)

SZ (S) see SA

TEMR (S) factor accounting for the effect of temperature on the rate of maintenance respiration

THK (S) thickness of the canopy layers

TRAMAX (S) reduction factor of AMAX accounting for the effect of temperature

TRAMAT (F) TRAMAX as function of the average temperature during daylight period (C)

ULCL (C) upper limit of a canopy layer

V (GA) array linking the actual references of the genotypes (A) to their library references (L)

VAR (S) variance of aboveground biomass per plant (referring to the genotypes present in the mixed population)

VEEL (S) thickness of the ear layer belonging to a single genotype

WDLVS (GA) dry weight of dead leaves

WGST (GA) dry weight of dead stems

WGR (GA) dry weight of grains

WLVS (GA) dry weight of living leaves

WRT (GA) dry weight of living roots

WST (GA) dry weight of living stems

X... (S) auxiliary variable

YFEAR (GA) yellow fraction of ear area

YFLVS (GA) yellow fraction of leaf area

YFST (GA) yellow fraction of stem area
Appendix A: Listing of the model

TITLE COMPETITION BETWEEN WHEAT GENOTYPES
/ DIMENSION EARATA(27)
/ DIMENSION EAI(27)
/ DIMENSION FCHN(27)
/ DIMENSION HRI(27)
/ DIMENSION OGBM(27)
STORAGE SAI(27), YFST(27), KLSTRM(27), KLEAR(27)
STORAGE AGC(27), LAI(27), GASSP(27), STORE(144)
STORAGE V(27), EARSUR(27), LAID(144), SAID(144), RAID(144)
STORAGE UCL25(25), KL(27), PKL(27), EFF27(27), SEFF(27)
STORAGE YFVS(27), LAIL25(25), ECDIF(25)
STORAGE COR(27), DISPAS1(200), DISPAS2(200), DISPAS3(200)
STORAGE CULTP(27), DVS(27), EAMAX(27), AMAX(27), PAMAX(27), SAMAX(27)
STORAGE OGBMPP(27), YFEAR(27)
STORAGE IWLVS(27), IYRST(27), IWRT(27), IARLF(27), IDVSV(27)
STORAGE EMERG(27), EXIST(27), APPEAR(27), PLOP(27)
STORAGE LNDVBM(27), XEAI(20)
FIXED DNSP, V, NSP, NCL, I, L, K, A, G
FIXED STPSWI, EAPSWI, C, COMIND, AUXINT

*******************************************************************
INITIALIZATION
*******************************************************************
INITIAL
NOSORT

*** BASIC SPECIFICATIONS

* NUMBER OF GENOTYPES DESCRIBED IN THE PARAMETER SET
PARAM DNSP = 12

* NUMBER OF COMPETING GENOTYPES SIMULATED IN THE PRESENT CASE
PARAM NSP = 12

*** LATITUDE OF LOCATION ***
PARAM LAT = 52.

*** SWITCH PARAMETERS FOR CHOOSING FROM ALTERNATIVE ALGORITHMS

* THE LEAF AREA INDEX CAN BE INTRODUCED AS A FORCING FUNCTION BY
* ASSIGNING TO THE SWITCH PARAMETER "LAISWI" THE VALUE 1
* INSTEAD OF 0
PARAM LAISWI = 0.

* SWITCH PARAMETER FOR DECIDING WHETHER THE ABSORPTION
* OF STEMS IS ACCOUNTED FOR WHEN MODELLING THE EXTINCTION
* OF LIGHT WITHIN THE CANOPY
PARAM STASWI = 1.

* SWITCH PARAMETER FOR DECIDING WHETHER THE PHOTOSYNTHESIS
* OF STEMS IS ACCOUNTED FOR WHEN CALCULATING THE DAILY
* ASSIMILATION (NOTE THAT IN THIS CASE ALSO THE ABSORPTION OF STEMS
* MUST BE ACCOUNTED FOR, THAT IS "STASWI = 1")
PARAM STPSWI = 1

* SWITCH PARAMETER FOR DECIDING WHETHER THE ABSORPTION
* OF EARS IS ACCOUNTED FOR WHEN CALCULATING THE EXTINCTION
* OF LIGHT WITHIN THE CANOPY
PARAM EAASWI = 1.

* SWITCH PARAMETER FOR DECIDING WHETHER THE PHOTOSYNTHESIS
* OF EARS IS ACCOUNTED FOR WHEN CALCULATING THE DAILY
* ASSIMILATION (NOTE THAT IN THIS CASE ALSO THE ABSORPTION OF EARS
* MUST BE CONSIDERED, THAT IS EAASWI = 1).
PARAM EAPSWI = 1
*** SIMULATION PROJECT SPECIFIC INPUT

*** INITIAL STATE OF THE POPULATIONS

TITLE SIMULATION PROJECT: REAMIX 15 X 15
LABEL SIMULATION PROJECT: REAMIX 15 X 15

* WEIGHTS OF LEAVES, STEMS, ROOTS;
* (KG/HA / (FREQUENCY OF THE GENOTYPE) / "DENSITY FACTOR")
* (EXPLANATION OF "DENSITY FACTOR" : SEE BELOW)

TABLE IWLVS (1-12) = 1.273, 1.460, 1.666, 1.079, 1.323, 1.623,
1.226, 1.196, 1.365, 1.296, 1.359, 1.219

TABLE IWST (1-12) = 0.569, 0.596, 0.703, 0.493, 0.594, 0.783,
0.597, 0.487, 0.570, 0.499, 0.619, 0.483

TABLE IWRT (1-12) = 1.228, 1.371, 1.579, 1.048, 1.278, 1.604,
1.215, 1.122, 1.290, 1.196, 1.319, 1.135

* LEAF AREA
* (M**2/HA / (FREQUENCY OF THE GENOTYPE) / "DENSITY FACTOR")

TABLE IARLF (1-12) = 25.533, 28.759, 33.867, 28.567, 27.978, 34.030,
26.267, 24.452, 27.619, 28.989, 26.174, 26.037

* "DENSITY FACTOR" WITH WHICH THE PARAMETER VALUES FOR INITIAL
* WEIGHTS AND THE INITIAL LEAF AREA ARE MULTIPLIED AT THE
* INITIALIZATION OF THE POPULATION
* (INTRODUCTION OF THIS PARAMETER SPARES THE NECESSITY OF
* REWRITING THE ARRAYS WITH INITIAL WEIGHTS AND LEAF AREAS
* WHEN DIFFERENT PLANT DENSITIES ARE ASSUMED)

PARAM DFAC = 108.

* DEVELOPMENTAL STATE

TABLE IDVSV (1-12) = 0.21345, 0.22085, 0.22485, 0.21010,
0.21717, 0.20662, 0.21345, 0.20339,
0.20339, 0.20026, 0.20026, 0.20662

* TIME COURSE OF LN (LEAF AREA(M**2/HA))
* (FOR THE INTRODUCTION OF THE LEAF AREA AS FORCING FUNCTION)

FUNCTION LNLAT,1. = 0., 6.60719, 22., 8.06840, 29., 9.0655,

FUNCTION LNLAT,12. = 0., 6.60719, 22., 8.06840, 29., 9.0655,

FUNCTION YFRLVT,1. = 0., 0., 49., 0.

FUNCTION YFRLVT,12. = 0., 0., 49., 0.

* PLANTS/M2

PARAM PSM = 400.

*** TIME SPECIFICATIONS

* DAY OF EMERGENCE

TABLE EMERG (1-12) = 12 * 107.

* FIRST DAY OF SIMULATED GROWTH (NOT NECESSARILY THE DAY OF
* EMERGENCE)

TABLE APPEAR (1-12) = 12 * 129.

* FIRST DAY OF SIMULATION (HAS TO BE AT LEAST
* 1 DAY BEFORE GROWTH SIMULATION STARTS)

PARAM START = 106.

* LAST DAY OF SIMULATION

PARAM STOP = 231.

FINISH TIME = STOP
*** PARAMETRIC CHARACTERIZATION OF THE VERTICAL DISTRIBUTION OF ***
*** LEAVES, STEMS AND EARS ***

* 3 PARAMETERS USE FOR CHARACTERIZING THE VERTICAL DISTRIBUTION
* OF THE LEAF AREA
* (THE UNNORMALIZED LEAF AREA DENSITY FUNCTION (M**2/M**3)
* IS ASSUMED TO HAVE THE FORM:
  * \( Y = A - A * H^K + C \)
  * WITH A, C AND Z PARAMETERS AND H := HEIGHT ABOVE GROUND/PLANT HEIGHT)
PARAM LA = 1., LC = 0., LZ = 50.

DISPA1,DUM = VPRE1 (DNSP,LA,LC,LZ)

* 3 PARAMETERS USE FOR CHARACTERIZING THE VERTICAL DISTRIBUTION
* OF THE STEM AREA
* (THE UNNORMALIZED STEM AREA DENSITY FUNCTION (M**2/M**3)
* IS ASSUMED TO HAVE THE FORM:
  * \( Y = A - A * H^K + C \)
  * WITH A, C AND Z PARAMETERS AND H := HEIGHT ABOVE GROUND/PLANT HEIGHT)
PARAM SA = 1., SC = 0., SZ = 50.

DISPA2,DUM = VPRE1 (DNSP,SA,SC,SZ)

* 1 PARAMETER USED FOR CHARACTERIZING THE VERTICAL DISTRIBUTION OF EARS
* (IT IS ASSUMED THAT THE EARS OF A GIVEN GENOTYPE ARE DISTRIBUTED
* IN A HOMONEGEOUS LAYER THAT EXTENDS FROM THE PLANT TOP
* TO A DISTANCE BELOW (CM) GIVEN BY THE PARAMETER "VEEL")
PARAM VEEL = 20.

DISPA3,DUM = VPRE2 (DNSP,VEEL)

*** THE WHO-IS-WHO OF COMPETING GENOTYPES

* THE GENOTYPES SIMULATED IN THE PRESENT CASE ARE
* NUMBERED FROM 1 TO NSP; THE ARRAY V LINKS THIS ACTUAL
* REFERENCES ("A") TO THE NUMBERS USED IN THE PARAMETER
* LIBRARY (LIBRARY REFERENCE - "L")

* EXAMPLE:
  * "TABLE V (1-12) = 2, 5, 8, 9 * 11"
  * PRODUCES - DEPENDENT ON THE PARAMETER "NSP" -
  * THE FOLLOWING MIXTURE COMPOSITIONS:
    * "NSP=1" =" " MONOCULTURE OF VARIETY 2
    * "NSP=2" =" " BINARY MIXTURE WITH THE VARIETIES 2 AND 5
    * "NSP=3" =" " MIXTURE WITH THE VARIETIES 2, 5, 8
  * AND SO ON
TABLE V(1-12) = 12 * 1

* GENOTYPE FREQUENCIES
* (SUM OVER THE NSP GENOTYPES PRESENTLY SIMULATED MUST BE 1 1)
TABLE COR (1-12) = 12 * 8.333333333E-2

*** SOME TECHNICAL PREPARATIONS

* FOR USE OF THE RERUN-FACILITIES SOME VARIABLES
* HAVE TO BE SET ZERO

DO 737 A = 1,NSP
GASSP(A) = 0.
FCHM(A) = 0.
LAI(A) = 0.
YFLVS(A) = 0.
SAI(A) = 0.
YFST(A) = 0.
DVS(A) = 0.
DVRV(A) = 0.
DVBR(A) = 0.
EARATA(A) = 0.
OGBM(A) = 0.
OGBMPP(A) = 0.
LNDVBM(A) = 0.
GRLVS(A) = 0.
GRLVS(A) = 0.
GRST (A) = 0.
DRST (A) = 0.
GRRT (A) = 0.
GRGR (A) = 0.

CONTINUE

AUXINT = MAXCL * NSP
DO 738 A = 1, AUXINT
LAID(A) = 0.
SAID(A) = 0.
EAID(A) = 0.
CONTINUE

737

***********************************************************************
*** SYSTEM DYNAMICS ***
***********************************************************************
DYNAMIC NO SORT
*** CHECKING THE NECESSITY TO MODEL GROWTH PROCESSES
*** ON THE PRESENT DAY

DAY = TIME

* ARE PLANTS PRESENT OR EXPECTED TO APPEAR ON THE FOLLOWING DAY?
* (TO KNOW THIS MAY SAVE THE COMPUTER LOTS OF CALCULATIONS)
DO 719 A = 1, NSP
L = V(A)
PLOP(A) = INSW(APPEAR(L) - 0.9 - TIME, 0., 1.) * ... 
INSW(TIME - APPEAR(L) + 1.1, 0., 1.)
EXIST(A) = INSW(DAY - APPEAR(L) + 1.E-8, 0., 1.)
CONTINUE
XEXIST = 0.
XPLOP = 0.
DO 865 A = 1, NSP
XEXIST = XEXIST + EXIST(A)
XPLOP = XPLOP + PLOP(A)
CONTINUE
GROWTH = INSW(XEXIST-.1, 0., 1.)
ARRIVE = INSW(XPLOP-.1, 0., 1.)
IF ((GROWTH + ARRIVE).LE.0.) GOTO 7020

865

***********************************************************************
* WEATHER DATA *
***********************************************************************

* DAILY GLOBAL RADIATION (J / M**2 / D)
DTR = AFGEN (DTRT, DAY) * 1.E4

* AVERAGE AIR TEMPERATURE (DEGREES C)
TMPA = (AFGEN (MXTT, DAY) + AFGEN (MNTT, DAY)) * 0.5

* AVERAGE AIR TEMPERATURE DURING DAYLIGHT PERIOD
EAVT = AFGEN (MXTT, DAY) - 0.25 * (AFGEN (MXTT, DAY) - ... 
AFGEN (MNTT, DAY))
**DEVELOPMENT**

* PRE- AND POST-A NTHESIS DEVELOPMENTAL RATES
* (EQUATIONS ACCORDING TO VAN KEULEN(85));
* TIME SINCE EMERGENCE

DO 8100 A = 1, NSP
  L = V(A)
  XD1 = CULTP(L) * AMAX1 (0., 0.00094 * TMPA -0.00046) ...
  * INSW (DVSV(A) -1., 1., 0.)
  DVRV(A) = XD1 * EXIST(A) + PLOP(A) * IDVSV(L)
  XD2 = AMAX1(0., 0.000913 * TMPA + 0.003572 )
  DVRR(A) = XD2 * INSW (DVSV(A) -1., 0., 1.) * EXIST(A)
  AGE(A) = AMAX1(0., DAY - EMERG(L))

8100 CONTINUE

DVSV = INTGRL (0, DVRV, 12)
DVSR = INTGRL (0., DVRR, 12)
DO 9000 A = 1, NSP
  DVS(A) = AMINI (1., 0.5 * (DVSV(A) + DVSR(A)))
9000 CONTINUE

IF (GROWTH.LE.0.5) GOTO 20000

**VERTICAL DISTRIBUTION OF LIGHT ABSORBING SURFACES**

*** ================ ***
*** AREA INDICES ***
*** ================ ***

*** LEAF AREA ***

* DECISION WHETHER LEAF AREA DEVELOPMENT IS MODELED
* DYNAMICALLY OR INTRODUCED AS A FORCING FUNCTION
IF (LAIISWI.GT.0.5) GOTO 1011

* LEAF AREA DEVELOPMENT IS MODELED DYNAMICALLY AND NOT INTRODUCED
* AS A FORCING FUNCTION
DO 1002 A = 1,NSP
  IF (EXIST(A).LT.0.5) GOTO 1002
  LR = V(A)
  SLA = TWOVAR(SLATB,DVS(A),LR) * 1.E-4
  LAI(A) = (WLVS(A) + WDLVS(A)) * SLA
  IF (LAI(A).LT.1.E-6) THEN
    TYPE 4999,A
    4999 FORMAT (' SPECIES ',IS,' WITH LAI = 0 ')
    GOTO 1002
  END IF
  YFLVS(A) = WDLVS(A) / (WDLVS(A) + WLVS(A))
1002 CONTINUE
1011 CONTINUE

* DEVELOPMENT OF LEAF AREA IS INTRODUCED AS A FORCING FUNCTION
DO 1005 A = 1,NSP
  IF (EXIST(A).LT.0.5) GOTO 1005
  L = V(A)
  LR = V(A)
  XLNLA = TWOVAR (LNLAT,AGE(A),LR)
  LAI(A) = EXP(XLNLA) * 1.E-4
  YFLVS(A) = TWOVAR (YFRLVT, AGE(A), LR)
1005 CONTINUE
1012 CONTINUE
*** STEM AREA ***

DO 950 A = 1, NSP
   IF (EXIST(A).LT.0.5) GOTO 950
   SAI(A) = (WST(A) + WDST(A)) * SSTA * 1.E-4
   IF (SAI(A).LT.1.E-6) THEN
      TYPE 5001,A
   ENDIF
      FORMAT (' SPECIES ',I5,' WITH SAI = 0 ')
      GOTO 950
END IF
YFST(A) = WDST(A) / (WDST(A) + WST(A))
CONTINUE

*** EAR AREA ***

* EAR AREA INDEX (DETERMINED BY THE ABOVEGROUND BIOMASS AT ANTHESIS)

DO 148 A = 1, NSP
   L = V(A)
   LR = V(A)
   IF (EXIST(A).LT.0.5) GOTO 148
   IF (EARATA(A).GT.1.E-6) GOTO 149
   IF (DVS(A).LT.0.5) GOTO 148
   EARATA(A) = EARSUR(L) * OGBM(A) * 1.E-5
   CONTINUE
   EAI(A) = EARATA(A) * AFGEN(EARGRT,DVS(A))
   YFEAR(A) = 1. - TWOVAR(GFET,AGE(A),LR)
CONTINUE

*** BOUNDARY HEIGHTS SEPARATING THE CANOPY LAYERS ***

*** NUMBER OF DISTINGUISHED CANOPY LAYERS

PARAM CLPERL = 12., MINCL = 12., MAXCL = 12.

     XLAIT = 0.
     DO 8000 A = 1, NSP
        XLAIT = XLAIT + LAI(A)
     CONTINUE
     8000 CONTINUE
     XNCL = LIMIT (MINCL,MACL,XLAIT * CLPERL)
     NCL = XNCL

*** BOUNDARIES OF CANOPY LAYERS

* HEIGHT DEVELOPMENT IS INTRODUCED AS A FORCING FUNCTION ("HEITB")

MAXHEI = 0.
     DO 7000 A = 1, NSP
        LR = V(A)
        HEI (A) = TWOVAR (HEITB,AGE(A), LR)
        IF (HEI(A).GT.MAXHEI) MAXHEI = HEI (A)
     CONTINUE
     IF (MAXHEI.LT.1.E-3) THEN
        TYPE 4997,MACL
        4997 FORMAT (' MAXHEI = ',F10.4 )
        MAXHEI = 1.E-3
     ENDF

* UPPER LIMITS ("ULCL") OF THE NCL CANOPY LAYERS (CM ABOVE THE GROUND);
* THE CHOSEN LAYERS HAVE IDENTICAL THICKNESS

     CALL STRATA (MAXHEI,NCL,ULCL)
THE POTENTIAL EXTINCTION COEFFICIENT OF LEAVES IS CORRECTED TO ACCOUNT FOR THE STRONG CLUSTERING OF LEAVES THAT YOUNG PLANT EXHIBIT

```
DO 530 A = 1,NSP
   KL(L) = PKL(L) * AFGEN(KLREDT,DVS(A))
530 CONTINUE
DO 981 K = 1,NCL
   LAIL(K) = 0.
   ECDFI(K)= 0.
981 CONTINUE

* DISTRIBUTION OF LEAF AREA
* DISTRIBUTION OF THE TOTAL LEAF AREA
CALL VERD2 (NSP,DNSP,V,EXIST,...
   NCL,HEI,ULCL,...
   LAI,KL,DISPA1,...
   LAID,LAIL,ECDFI,...
   CHECK1,CHECK2,CHECK3)

* DERIVED DISTRIBUTION OF THE GREEN LEAF AREA
CALL YELDII (NSP,NCL,LAI,LAID,YFLVS)

* DISTRIBUTION OF STEM AREA
* DISTRIBUTION OF THE TOTAL STEM AREA
CALL VERD2 (NSP,DNSP,V,EXIST,...
   NCL,HEI,ULCL,...
   SAI,KLSTEM,DISPA2,...
   SAID,LAIL,ECDFI,...
   CHECK4,CHECK5,CHECK6)

* DERIVED DISTRIBUTION OF THE GREEN STEM AREA
CALL YELDII (NSP,NCL,SAI,SAID, YFST)
IF (EAASWI.LT.0.5) GOTO 9876

* DISTRIBUTION OF EAR AREA
* DISTRIBUTION OF THE TOTAL EAR AREA
CALL VERD2 (NSP,DNSP,V,EXIST,...
   NCL,HEI,ULCL,...
   EAI,KLEAR,DISPA3,...
   EAID,LAIL,ECDFI,...
   CHECK7,CHECK8,CHECK9)

* DERIVED DISTRIBUTION OF THE GREEN EAR AREA
CALL YELDII (NSP,NCL,EAID,YFEAR)

DO 4869 A = 1,NSP
   XEAI(A) = EAI(A)
4869 CONTINUE
DO 4870 A = 1,NSP*NCL
   STORE(A) = EAID(A)
4870 CONTINUE
```

** DAILY GROSS PRODUCTION **

9876 CONTINUE

*** ACTUAL VALUES OF AMAX ***

- 27 -
TRAMAX = AFGEN (TRAMAT,EAVT)
DO 1710 A=1,NSP
  L = V(A)
SRAMAX = AFGEN (SRAMAT,DVS(A))
AMAX(L) = PAMAX(L) * TRAMAX * SRAMAX
1710 CONTINUE

*** DAILY GROSS PRODUCTION ***

GASSP,DUM, DAYL, IRR, INSTI, PRDFD, FRDR = ... 
DAYASS (DAY, DTR, LAT, NCL, NSP, DNSP, V, STPSWI, EAPSWI, ...
  LAID, SAID, HAIL, LAIL, ECDIF, KL, KLSTEM, KLEAR, ...
  AMAX, SAMAX, EAMAX, EFF, SEFF, EEFF)

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

* DYNAMICS OF DRY MATTER *

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

*** MAINTENANCE RESPIRATION ***

MAINTENANCE RESPIRATION IS SUBTRACTED FROM THE GROSS PRODUCTION

TEMR = Q10 ** (0.1 * TMPA - 1.5)
DO 5000 A = 1, NSP
  XMRO = WLVS(A) * BMRCST * AFGEN (LVRT, DVS(A)) + ...
       WST(A) * BNRCST + ...
       WRT(A) * BMRCRT + ...
       WGR(A) * BMRCGR
RMNT = AHINT (TEMR * XMRO, GASSP(A))
FCHN(A) = GASSP(A) - RMNT
5000 CONTINUE
20000 CONTINUE
IF ((GROWTH+ARRIVE).LT.0.5) GOTO 7020

*** ALLOCATION OF NET PRODUCTION ***

TO THE DIFFERENT ORGANS AND DRY MATTER;

TRANSFORMATION OF LIVE INTO DEAD DRY MATTER

RATES DRY MATTER ACCUMULATION IN LEAVES, STEMS, GRAINS, ROOTS
DO 70 A = 1, NSP
  L = V(A)
  LR = V(A)
  IF (DAY.LE.APPEAR(L)-2) GOTO 70

*** ROOTS AND SHOOT ***

FSH = TWOVAR (FSHTB, DVS(A), LR)
XGRT = FCHN(A) * (1. - FSH) * EFCRT + ...
PLOP(A) * IWRT(L) * COR(A) * DFAC
DRRT = WRT(A) * AFGEN(DRRTB, AGE(A))
GRRT(A) = XGRT - DRRT
WRT = INTGRL (0., GRRT, 12)
GSHOOT = FCHN(A) * FSH

*** LEAVES ***

FLVS = TWOVAR (FLVST, DVS(A), LR)
XGRLVS = GSHOOT * FLVS * EFCRLVS + ...
PLOP(A) * IWLVS(L) * COR(A) * DFAC
DRLVS(A) = WLVS(A) * TWOVAR (DRLVTB, AGE(A), LR)
GRLVS(A) = XGRLVS - DRLVS(A)
**STems**

FST = TWOVAR (FSTT, DVS(A), LR)
XGRST = GSHOOT * FST * EFCST + ...
PLOP(A) * IWST(L) * COR(A) * DFAC
DRST(A) = WST(A) * AGFEN (DRESSTB, AGE(A))
GRST(A) = XGRST - DRST(A)

**Grains**

FGR = 1. - FLVS - FST
GRGR (A) = GSHOOT * FGR * EFCGR

**Growth Recording**

IF (GROWTH.LE.0.5) GOTO 7020

* ABOVEGROUND BIOMASS (KG/HA), G/PLANT *
DO 7010 A = 1,NSP
OGBM(A) = WLVS(A) + WDLVS(A) + WST(A) + WDST(A)+ WGR(A)
IF (COR(A).LT.1.E-6) THEN
TYPE 5002,A
5002 FORMAT (' SPECIES ',IS,' WITH COR = 0 ')
GOTO 7010
ENDIF
OGBMPP(A) = OGBM(A) / ( 10. * PSM * COR(A))
7010 CONTINUE

* AVERAGE, VARIANCE AND COEFFICIENT OF VARIATION OF ABOVEGROUND *
* BIOMASS PER PLANT *
AV,VAR,CV = EVAL1 (NSP,OGBMPP,COR)

* DELTA - LN - VALUES *
LNDVBM,DUM = LNDCAL (NSP,OGBMPP,COR)
7020 CONTINUE

**Physiological Parameters Library**

*** Developmental Rate ***

** Variety Specific Factor Used For Describing The Preanthesis *
** Developmental Rate (Obtained By Fitting The Equation Given By *
** Van Keulen(85) To Observed Durations Until Anthesis) *
TABLE CULTP (1-12) = 1.4066, 1.4554, 1.4817, 1.3845, ...
1.4311, 1.3616, 1.4066, 1.3403, ...
1.3403, 1.3197, 1.3197, 1.3616

** Optical Properties **

* Extinction Coefficient of Ears and Stems *
* (Estimation According To De Groot (85) (Pers. Communication) *
TABLE KLEAR (1-12) = 12 * 0.4
TABLE KLSTEM (1-12) = 12 * 0.4
**Potential Extinction Coefficient of Leaves**

* (not fully realized during the first days of growth)

Table PKL (1-12) = 12 * 0.60

**Reduction Factor for the Extinction Coefficient of Leaves, Accounting for the Leaf Clustering Exhibited by Young Plants**

Function KLREDT = 0., 0.6, 0.1, 1., 1.1, 1.

*** Photosynthetic Characteristics ***

**Potential Amax (kg CO2 / ha / h) and Light Use Efficiency**

* (kg CO2 / ha / h / (J/m2/s) of leaves

Table PAMAX (1-12) = 12 * 40.

Table EFF (1-12) = 12 * .45

**Reduction Factor of Amax Accounting for the Effect**

* of senescence; values as function of the developmental state

Function SRAMAT = 0., 1., 0.5, 1., 1.0, 0.5

**Reduction Factor of Amax Accounting**

* for the effect of temperature; values as function of

* the average temperature (°C) during daylight period

Function TRAMAT = 0., 0., 10., 1., 25., 1., 35., 0.01

**Amax (kg CO2 / ha / h) of Stems**

Table SAMAX (1-12) = 12 * 20.

**Initial Light Use Efficiency of Stems**

* (kg CO2 / ha / h / (J/m2/cm*2)

Table SEFF (1-12) = 12 * 0.45

**Amax (kg CO2 / ha / h) of Ears**

Table EAMAX (1-12) = 12 * 20.

**Initial Light Use Efficiency of Ears**

* (kg CO2 / ha / h / (J/m2/cm*2)

Table EEFF (1-12) = 12 * 0.22

*** Development of the Ear Area ***

**Ear Surface at Anthesis Divided by Aboveground Biomass at**

**Anthesis (cm*2 / c)**

* (large values belong to genotypes with awns, small to

* genotypes without awns)

Table EARSUR (1-12) = 8.64, 8.64, 15.98, 15.98, 8.64, 8.64, 8.64, 8.64, 8.64, 8.64, 15.98, 8.64, 8.64

**Growth of the Ear Area (Earsurface/Plant) / (Earsurface/Plant at**

**Anthesis) as Function of the Development State**

Function EARGRT = 0., 0., 0.4999, 0., 0.5, 1., 1.1, 1.

**Thickness of the Ear Layer Belonging**

* to a single genotype (cm)

Param VEEL = 20.

*** Green Fraction of the Ear Area ***

**Values as Function of the Number of Days After Emergence**

Function GFET, 1. = 0., 1., 67., 1.000, 103., 0.200, 107., 0.125, ...

112., 0.050, 117., 0.025, 130., 0., 131., 0.

Function GFET, 2. = 0., 1., 65., 1.000, 103., 0.250, 107., 0.138, ...

112., 0.050, 117., 0.000, 130., 0., 131., 0.

Function GFET, 3. = 0., 1., 64., 1.000, 103., 0.327, 107., 0.319, ...

112., 0.029, 117., 0.014, 130., 0., 131., 0.

Function GFET, 4. = 0., 1., 68., 1.000, 103., 0.422, 107., 0.352, ...

112., 0.205, 117., 0.000, 130., 0., 131., 0.

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FUNCTION GFET, 5. = 0., 1., 66., 1.000, 103., 0.263, 107., 0.163, ...
FUNCTION GFET, 6. = 0., 1., 69., 1.000, 103., 0.200, 107., 0.150, ...
FUNCTION GFET, 7. = 0., 1., 67., 1.000, 103., 0.200, 107., 0.138, ...
FUNCTION GFET, 8. = 0., 1., 70., 1.000, 103., 0.225, 107., 0.150, ...
FUNCTION GFET, 9. = 0., 1., 70., 1.000, 103., 0.309, 107., 0.375, ...
FUNCTION GFET, 10. = 0., 1., 71., 1.000, 103., 0.288, 107., 0.188, ...
FUNCTION GFET, 11. = 0., 1., 71., 1.000, 103., 0.375, 107., 0.213, ...
FUNCTION GFET, 12. = 0., 1., 69., 1.000, 103., 0.238, 107., 0.163, ...

*** RELATIVE DYING RATES OF LEAVES ***
* VALUES AS FUNCTION OF THE NUMBER OF DAYS AFTER EMERGENCE

FUNCTION DRLVTB, 1. = 0., 1., 66., 0., 67., 0.024, 102., 0.024, ...
103., 0.038, 106., 0.038, 107., 0.197, 111., 0.197, ...
112., 0.392, 116., 0.392, 117., 0.452, 131., 0.452

FUNCTION DRLVTB, 2. = 0., 1., 64., 0., 65., 0.033, 102., 0.033, ...
103., 0.092, 106., 0.092, 107., 0.234, 111., 0.234, ...
112., 0.818, 116., 0.818, 117., 0.818, 131., 0.818

FUNCTION DRLVTB, 3. = 0., 1., 63., 0., 64., 0.045, 102., 0.045, ...
103., 0.045, 106., 0.045, 107., 0.156, 111., 0.156, ...
112., 0.197, 116., 0.197, 117., 0.443, 131., 0.443

FUNCTION DRLVTB, 4. = 0., 1., 67., 0., 68., 0.038, 102., 0.038, ...
103., 0.075, 106., 0.075, 107., 0.139, 111., 0.139, ...
112., 0.838, 116., 0.838, 117., 0.838, 131., 0.838

FUNCTION DRLVTB, 5. = 0., 1., 65., 0., 66., 0.030, 102., 0.030, ...
103., 0.077, 106., 0.077, 107., 0.178, 111., 0.178, ...
112., 0.356, 116., 0.356, 117., 0.412, 131., 0.412

FUNCTION DRLVTB, 6. = 0., 1., 69., 0., 69., 0.033, 102., 0.033, ...
103., 0.111, 106., 0.111, 107., 0.189, 111., 0.189, ...
112., 0.830, 116., 0.830, 117., 0.830, 131., 0.830

FUNCTION DRLVTB, 7. = 0., 1., 66., 0., 67., 0.038, 102., 0.038, ...
103., 0.168, 106., 0.168, 107., 0.197, 111., 0.197, ...
112., 0.810, 116., 0.810, 117., 0.810, 131., 0.810

FUNCTION DRLVTB, 8. = 0., 1., 69., 0., 70., 0.033, 102., 0.033, ...
103., 0.118, 106., 0.118, 107., 0.189, 111., 0.189, ...
112., 0.830, 116., 0.830, 117., 0.830, 131., 0.830

FUNCTION DRLVTB, 9. = 0., 1., 69., 0., 70., 0.022, 102., 0.022, ...
103., 0.134, 106., 0.134, 107., 0.164, 111., 0.164, ...
112., 0.381, 116., 0.381, 117., 0.412, 131., 0.412

FUNCTION DRLVTB, 10. = 0., 1., 70., 0., 71., 0.024, 102., 0.024, ...
103., 0.087, 106., 0.087, 107., 0.165, 111., 0.165, ...
112., 0.850, 116., 0.850, 117., 0.850, 131., 0.850

FUNCTION DRLVTB, 11. = 0., 1., 70., 0., 71., 0.027, 102., 0.027, ...
103., 0.105, 106., 0.105, 107., 0.140, 111., 0.140, ...
112., 0.140, 116., 0.140, 117., 0.488, 131., 0.488

FUNCTION DRLVTB, 12. = 0., 1., 68., 0., 69., 0.030, 102., 0.030, ...
103., 0.148, 106., 0.148, 107., 0.234, 111., 0.234, ...
112., 0.818, 116., 0.818, 117., 0.818, 131., 0.818

*** RELATIVE DYING RATE OF ROOTS ***
* VALUES AS FUNCTION OF THE NUMBER OF DAYS AFTER EMERGENCE

FUNCTION DRRKB = 0., 1., 67., 0., 68., 0.0061, 102., 0.0061, ...
103., 0.0206, 106., 0.0206, 107., 0.037, 111., 0.037, ...
112., 0.073, 131., 0.073

*** RELATIVE DYING RATE OF STEMS ***
* VALUES AS FUNCTION OF THE NUMBER OF DAYS AFTER EMERGENCE

FUNCTION DRRSTB = 0., 1., 67., 0., 68., 0.0076, 102., 0.0076, ...
103., 0.0258, 106., 0.0258, 107., 0.047, 111., 0.047, ...
112., 0.091, 131., 0.091
*** DEVELOPMENT OF PLANT HEIGHT ***
* VALUES AS FUNCTION OF THE NUMBER OF DAYS AFTER EMERGENCE
FUNCTION HEITB, 1. = o., 5., 40., 34., 55., 64., 72., 69., 130., 73.
FUNCTION HEITB, 7. = o., 5., 40., 34., 55., 58., 72., 82., 130., 70.

*** MAINTENANCE RESPIRATION ***
* "Q10-PARAMETER"
PARAM Q10 = 2.

*** RELATIVE RESPIRATION RATES OF LEAVES, STEMS, ROOTS, GRAINS ***
PARAM BMRCLV = 0.03, BMRCST = 0.015, BMRCRT = 0.01, BMRCGR = 0.01

* REDUCTION FACTOR ACCOUNTING FOR THE EFFECT OF SENESCENCE ON THE RESPIRATION RATE OF LEAVES; VALUES AS FUNCTION OF THE DEVELOPMENTAL STATE
FUNCTION LVRRT = 0., 1., 0.5, 1., 0.5, 0.1, 1., 0.5

*** GROWTH EFFICIENCY ***
PARAM EFCLVS = 0.68, EFCST = 0.66, EFCRT = 0.69, EFCGR = 0.70

*** DRY MATTER ALLOCATION ***
* FRACTION OF NET ASSIMILATION ALLOCATED TO THE LEAVES,
* DIVIDED BY THE FRACTION ALLOCATED TO THE SHOOT
* VALUES AS FUNCTION OF THE DEVELOPMENTAL STATE
FUNCTION FLVST, 1. = 0.10672, 0.65, 0.10671, 0.01, 0.14982, 0.54, 0.22581, 0.54, 0.31265, 0.32, 0.40000, 0.04, 1.0, 0.
FUNCTION FLVST, 2. = 0.11042, 0.66, 0.11041, 0.01, 0.15502, 0.56, 0.23361, 0.56, 0.32350, 0.32, 0.40000, 0.04, 1.0, 0.
FUNCTION FLVST, 3. = 0.11242, 0.58, 0.11241, 0.01, 0.15782, 0.54, 0.23781, 0.54, 0.32394, 0.32, 0.40000, 0.04, 1.0, 0.
FUNCTION FLVST, 4. = 0.10512, 0.65, 0.10511, 0.01, 0.14742, 0.56, 0.22221, 0.56, 0.30774, 0.32, 0.40000, 0.04, 1.0, 0.
FUNCTION FLVST, 5. = 0.10862, 0.63, 0.10861, 0.01, 0.15242, 0.53, 0.22971, 0.53, 0.31810, 0.32, 0.40000, 0.04, 1.0, 0.
FUNCTION FLVST, 6. = 0.10332, 0.65, 0.10331, 0.01, 0.14502, 0.54, 0.21851, 0.54, 0.30265, 0.32, 0.40000, 0.04, 1.0, 0.
FUNCTION FLVST, 7. = 0., 0.60, 0.10671, 0.60, 0.14981, 0.60, 0.14982, 0.51, 0.22581, 0.51, 0.22582, 0.51, 0.26921, 0.57, 0.26922, 0.32, 0.31265, 0.32, 0.40000, 0.04, 0.50001, 0., 1., 0.

FUNCTION FLVST, 8. = 0., 0.65, 0.10171, 0.65, 0.14271, 0.68, 0.14272, 0.59, 0.21511, 0.59, 0.21512, 0.59, 0.25651, 0.53, 0.25652, 0.32, 0.29792, 0.32, 0.40000, 0.04, 0.50001, 0., 1., 0.

FUNCTION FLVST, 9. = 0., 0.64, 0.10171, 0.64, 0.14271, 0.64, 0.14272, 0.57, 0.21511, 0.57, 0.21512, 0.57, 0.25651, 0.36, 0.25652, 0.32, 0.29792, 0.32, 0.40000, 0.04, 0.50001, 0., 1., 0.

FUNCTION FLVST, 10. = 0., 0.65, 0.10011, 0.65, 0.14051, 0.70, 0.14052, 0.61, 0.25261, 0.68, 0.25262, 0.32, 0.30263, 0.32, 0.40000, 0.04, 0.50001, 0., 1., 0.

FUNCTION FLVST, 11. = 0., 0.60, 0.10011, 0.60, 0.14051, 0.71, 0.14052, 0.61, 0.25261, 0.64, 0.25262, 0.32, 0.30263, 0.32, 0.40000, 0.04, 0.50001, 0., 1., 0.

FUNCTION FLVST, 12. = 0., 0.67, 0.10331, 0.67, 0.14501, 0.67, 0.14502, 0.57, 0.26061, 0.46, 0.26062, 0.32, 0.32394, 0.32, 0.40000, 0.04, 0.50001, 0., 1., 0.

* FRACTION OF NET ASSIMILATION ALLOCATED TO THE STEM, DIVIDED BY THE FRACTION ALLOCATED TO THE SHOOT VALUES AS FUNCTION OF THE DEVELOPMENTAL STATE

FUNCTION FSTT, 1. = 0., 0.39, 0.10671, 0.39, 0.14981, 0.39, 0.14982, 0.35, 0.15241, 0.35, 0.15242, 0.37, 0.22971, 0.37, 0.22972, 0.38, 0.31265, 0.38, 0.40000, 0.96, 0.50001, 0., 1., 0.

FUNCTION FSTT, 2. = 0., 0.35, 0.11041, 0.35, 0.11042, 0.34, 0.14741, 0.34, 0.14742, 0.41, 0.22221, 0.41, 0.22222, 0.44, 0.30774, 0.44, 0.40000, 0.96, 0.50001, 0., 1., 0.

FUNCTION FSTT, 3. = 0., 0.36, 0.11241, 0.36, 0.11242, 0.42, 0.15781, 0.42, 0.15782, 0.46, 0.23781, 0.46, 0.23782, 0.58, 0.32350, 0.58, 0.40000, 0.96, 0.50001, 0., 1., 0.

FUNCTION FSTT, 4. = 0., 0.35, 0.10511, 0.35, 0.10512, 0.35, 0.14741, 0.35, 0.14742, 0.45, 0.21851, 0.45, 0.21852, 0.47, 0.29334, 0.47, 0.40000, 0.96, 0.50001, 0., 1., 0.

FUNCTION FSTT, 5. = 0., 0.38, 0.10861, 0.38, 0.10862, 0.37, 0.15241, 0.37, 0.15242, 0.47, 0.22971, 0.47, 0.22972, 0.58, 0.31810, 0.58, 0.40000, 0.96, 0.50001, 0., 1., 0.

FUNCTION FSTT, 6. = 0., 0.39, 0.10331, 0.39, 0.10332, 0.35, 0.14501, 0.35, 0.14502, 0.46, 0.21851, 0.46, 0.21852, 0.56, 0.30265, 0.56, 0.40000, 0.96, 0.50001, 0., 1., 0.

FUNCTION FSTT, 7. = 0., 0.40, 0.10671, 0.40, 0.14981, 0.40, 0.14982, 0.49, 0.22581, 0.49, 0.22582, 0.43, 0.26921, 0.43, 0.26922, 0.32, 0.31265, 0.32, 0.40000, 0.96, 0.50001, 0., 1., 0.

FUNCTION FSTT, 8. = 0., 0.35, 0.10171, 0.35, 0.10172, 0.32, 0.14271, 0.32, 0.14272, 0.41, 0.21511, 0.41, 0.21512, 0.47, 0.25651, 0.47, 0.25652, 0.68, 0.29792, 0.68, 0.40000, 0.96, 0.50001, 0., 1., 0.

FUNCTION FSTT, 9. = 0., 0.36, 0.10171, 0.36, 0.10172, 0.36, 0.14271, 0.36, 0.14272, 0.45, 0.21511, 0.45, 0.21512, 0.64, 0.25651, 0.64, 0.25652, 0.32, 0.29792, 0.32, 0.40000, 0.96, 0.50001, 0., 1., 0.

FUNCTION FSTT, 10. = 0., 0.35, 0.10011, 0.35, 0.10012, 0.30, 0.14051, 0.30, 0.14052, 0.39, 0.21181, 0.39, 0.21182, 0.54, 0.25261, 0.54, 0.25262, 0.68, 0.29334, 0.68, 0.40000, 0.96, 0.50001, 0., 1., 0.
FUNCTION FSTT, 11. = 0., 0.10012, 0.29, 0.21182, 0.52, 0.40000, 0.96, 0.50000, 1., 1., 1.
FUNCTION FSTT, 12. = 0.10332, 0.33, 0.21852, 0.57, 0.40000, 0.96, 0.50000, 1., 1., 1.,

* FRACTION OF NET ASSIMILATION ALLOCATED TO THE SHOOT, 
* DEPENDENT ON THE DEVELOPMENTAL STATE
FUNCTION FSHTB, 1. = 0., 0.5, 0.25, 0.8, 1., 1., 1.
FUNCTION FSHTB, 12. = 0., 0.5, 0.25, 0.8, 1., 1., 1.

*** SPECIFIC LEAF AREA ***
* VALUES AS FUNCTION OF THE DEVELOPMENTAL STATE
* (M**2 / KG)
FUNCTION SLATB, 1. = 0., 21.570, 21.848
FUNCTION SLATB, 2. = 0., 21.848
FUNCTION SLATB, 3. = 0., 20.786, 20.786
FUNCTION SLATB, 4. = 0., 23.348
FUNCTION SLATB, 5. = 0., 22.227, 22.227
FUNCTION SLATB, 6. = 0., 21.459, 21.459
FUNCTION SLATB, 7. = 0., 22.457
FUNCTION SLATB, 8. = 0., 22.041
FUNCTION SLATB, 9. = 0., 20.396
FUNCTION SLATB, 10. = 0., 21.124
FUNCTION SLATB, 11. = 0., 22.758
FUNCTION SLATB, 12. = 0., 22.758

*** SPECIFIC STEM AREA ***
* (M**2 / KG)
PARAM SSA = 2.5

METHOD RECT

**********************************************************************
* WEATHER DATA *
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</tbody>
</table>

*WAG1980
211.,17.0,212.,13.4,213.,12.5,214.,16.0,215.,12.6
216.,15.6,217.,13.7,218.,17.5,219.,15.8,220.,14.2
221.,11.2,222.,6.8,223.,10.6,224.,14.3,225.,15.1
226.,12.8,227.,16.0,228.,15.1,229.,15.5,230.,16.4
236.,9.4,237.,7.0,238.,3.0,239.,4.3,240.,6.4
246.,6.6,247.,10.5,248.,11.5,249.,11.5,250.,11.7

********************************************************************
***************
OUTPUT AND RUN CONTROL
***************************
********************************************************************

NOSORT
TIMER FINTIM = 231., TIME = 126., DELT = 1., PRDEL = 1., OUTDEL = 1.
PRINT OGBMPP(1-12)
END
STOP

********************************************************************
*****
SUBROUTINES CALLED FROM DYNAMIC
*****
********************************************************************

SUBROUTINE STRATA (MAXHEI,NCL,ULCL)
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
C SUBROUTINE CALCULATING THE BOUNDARY HEIGHTS SEPERATING THE C
C CANOPY LAYERS; THE LAYERS HAVE EQUAL THICKNESS C
C INPUT PARAMETERS: C
C MAXHEI : CANOPY HEIGHT [CM] C
C NCL : NUMBER OF CANOPY LAYERS C
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
C OUTPUT PARAMETERS: C
C ULCL : UPPER LIMITS OF CANOPY LAYERS [CM] C
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
IMPLICIT REAL(A-Z)
INTEGER NCL,K
DIMENSION ULCL(NCL+1)
THK = MAXHEI / NCL
DO 10 K = 1,NCL
  ULCL(K) = MAXHEI - (K-1) * THK
10 CONTINUE
ULCL(NCL+1) = 0.
RETURN
END

SUBROUTINE VPRE1 (DNSP,A,C,Z,DISPA,DUM)
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
C SUBROUTINE WRITING AN ARRAY CONTAINING PARAMETERS AND/OR AUXILIARY C
C VARIABLES USED FOR THE VERTICAL DISTRIBUTION OF A SURFACE TYPE; C
C THE ARRAY PRODUCED BY "VPRE1" REFLECTS THE SITUATION THAT FOR ALL C
C DESCRIBED GENOTYPES THE VERTICAL AREA DENSITY FUNCTION OF THE C
C SURFACE IS GIVEN BY C
C Y = ( A * X**Z + A + C ) / NORMALIZATION CONSTANT C
C AND THAT ITS 3 PARAMETERS (A,C,Z) ARE IDENTICAL FOR ALL GENOTYPES C
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
C INPUT PARAMETERS: C
C DNSP : DESCRIBED NUMBER OF GENOTYPES C
C A,C,Z : PARAMETERS CHARACTERIZING THE VERTICAL AREA DENSITY C
C FUNCTION C
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
C OUTPUT PARAMETERS: C
C DISPA : ARRAY CONTAINING PARAMETERS AND/OR AUXILIARY VARIABLES C
C USED FOR THE VERTICAL DISTRIBUTION OF A SURFACE TYPE C
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
IMPLICIT REAL (A-Z)
INTEGER DNSP,A,G,COUNT
DIMENSION DISPA (72)
DIMENSION X (6)
C X(1) = 0.
X(2) = 1. + C/A
X(3) = 1. / (Z+1.)
X(4) = X(2) - X(3)
X(5) = Z + 1.
X(6) = 0.
COUNT = 0
DO 15251 A = 1,DNSP
    DO 15252 G = 1,6
        COUNT = COUNT + 1
        DISPA(COUNT) = X(G)
    15252
CONTINUE
15251 CONTINUE
RETURN
END

SUBROUTINE VPRE2 (DNSP,D,DISPA,DUM)

C SUBROUTINE WRITING AN ARRAY CONTAINING PARAMETERS AND/OR AUXILIARY
C VARIABLES USED FOR THE VERTICAL DISTRIBUTION OF A SURFACE TYPE;
C THE ARRAY PRODUCED BY "VPRE2" REFLECTS THE SITUATION THAT FOR ALL
C DESCRIBED GENOTYPES THE VERTICAL AREA DENSITY FUNCTION OF THE
C SURFACE IS GIVEN BY
C
C     Y = 1 / D, 1-D <= X <= 1
C     0, OTHERWISE
C AND THAT ITS PARAMETER (D) IS IDENTICAL FOR ALL GENOTYPES
C
C INPUT PARAMETERS:
C DNSP : DESCRIBED NUMBER OF GENOTYPES
C D : PARAMETER CHARACTERIZING THE VERTICAL AREA DENSITY FUNCTION
C
C OUTPUT PARAMETERS:
C DISPA : ARRAY CONTAINING PARAMETERS AND/OR AUXILIARY VARIABLES USED FOR THE VERTICAL DISTRIBUTION OF A SURFACE TYPE

IMPLICIT REAL (A-Z)
INTEGER A,G,COUNT,DNSP
DIMENSION X(6)
DIMENSION DISPA (72)
X(1) = 1.
X(2) = D
DO 128 G = 3,6
    X(G) = 0.
128 CONTINUE
COUNT = 0
DO 698 A = 1,DNSP
    DO 699 G = 1,6
        COUNT = COUNT + 1
        DISPA(COUNT) = X(G)
    699 CONTINUE
698 CONTINUE
RETURN
END
SUBROUTINE CLFRAC (DISPA, L, LOWLIM, UPLIM, HEIGHT, TAI, CLAI)

C SUBROUTINE CALCULATING THE AREA INDEX OF THAT FRACTION OF A
C SURFACE TYPE WHICH IS POSITIONED IN A CANOPY LAYER
C
C INPUT PARAMETERS:
C
C DISPA : ARRAY CONTAINING PARAMETERS AND/OR AUXILIARY
C USED FOR DESCRIBING THE VERTICAL DISTRIBUTION OF A
C SURFACE TYPE
C
C L : LIBRARY REFERENCE OF THE GENOTYPE
C
C LOWLIM : LOWER BOUNDARY HEIGHT OF THE CONSIDERED CANOPY LAYER [CM]
C
C UPLIM : UPPER BOUNDARY HEIGHT OF THE CONSIDERED CANOPY LAYER [CM]
C
C HEIGHT : PLANT HEIGHT OF THE GENOTYPE
C
C TAI : TOTAL AREA INDEX OF THE SURFACE TYPE
C
C OUTPUT PARAMETERS:
C
C CLAI : AREA INDEX OF THAT FRACTION OF THE SURFACE TYPE
C WHICH IS POSITIONED IN THE CANOPY LAYER
C
C
C IMPLICIT REAL(A-Z)
INTEGER L, XADRES, XFUNC
DIMENSION DISPA (72)

CHOSE THE DISTRIBUTION FUNCTION
XADRES = (L-1) * 6 + 1
XFUNC = DISPA(XADRES)
IF (XFUNC.EQ.1) GOTO 88877

DISTRIBUTION FUNCTION :
C
Y = A - A * X**2 + C
LOW = AMAX1 (0., LOWLIM / HEIGHT)
UP = AMIN1 (1., UPLIM / HEIGHT)
IF (LOWLIM.GE.HEIGHT. OR.
1 UP.LE.1.E-5 ) THEN
  CLAI = 0.
ELSE
  X0 = DISPA(XADRES+4)
  X1 = DISPA(XADRES+1) * (UP-LOW)
  X2 = DISPA(XADRES+2) * (UP**X0 - LOW**X0)
  CLAI = (X1 - X2) / DISPA(XADRES+3) * TAI
ENDIF
GOTO 90909

88877 CONTINUE

DISTRIBUTION FUNCTION :
C
1 / D , 1-D = X = 1
C
Y = 0 , OTHERWISE
C
LIM1 = AMAX1 (0., HEIGHT - DISPA (XADRES+1))
LIM2 = AMAX1 (0., HEIGHT - DISPA (XADRES+2))
THICK = LIM2 - LIM1
IF (TAI.LE.1.E-6. OR.
1 THICK.LE.1.E-6. OR.
1 UPLIM.LE. LIM1. OR.
1 LOWLIM.GE.LIM2) THEN
  CLAI = 0.
ELSE
  XU = AMIN1 (UPLIM, LIM2)
  XL = AMAX1 (LOWLIM, LIM1)
  CLAI = (XU - XL) / THICK * TAI
ENDIF

90909 CONTINUE
RETURN
END

SUBROUTINE VERDI2 (NSP, DNSP, V, EXIST,
  CLAI, ECOF, DISPA,
  CHECK1, CHECK2, CHECK3)
SUBROUTINE DISTRIBUTING THE AREA INDEX OF A SURFACE TYPE OVER THE CANOPY LAYERS; FOR EACH CANOPY LAYER, THE EXTINCTION CAPACITY AND THE TOTAL AREA INDEX OF ALL CONTAINED SURFACES IS ENHANCED CORRESPONDINGLY TO THE CONTRIBUTION OF THIS SURFACE TYPE.

INPUT PARAMETERS:
- NSP: NUMBER OF GENOTYPES
- DNSP: DESCRIBED NUMBER OF GENOTYPES
- V: ARRAY LINKING THE ACTUAL REFERENCES OF THE GENOTYPES TO THEIR LIBRARY REFERENCES
- NCL: NUMBER OF CANOPY LAYERS
- HEI: PLANT HEIGHTS OF THE GENOTYPES
- ULCL: BOUNDARY HEIGHTS SEPARATING THE CANOPY LAYERS
- AI: AREA INDICES OF THE VARIOUS GENOTYPES
- ECOF: EXTINCTION COEFFICIENTS OF THIS SURFACE TYPE BELONGING TO THE VARIOUS GENOTYPES
- DISPA: ARRAY CONTAINING PARAMETERSAND/OR AUXILIARY VARIABLES USED FOR THE VERTICAL DISTRIBUTION OF A SURFACE TYPE
- LAIL: CONTAINS FOR EACH OF THE NCL CANOPY LAYERS THE SUM OF AREA INDICES BELONGING TO ABSORBING SURFACES (LEAVES, STEMS, EARS... ) POSITIONED IN IT [HA/HA]
- ECDIF: AS LAIL, BUT THE CONTRIBUTING AREA INDICES ARE MULTIPLIED BY THE CORRESPONDING EXTINCTION COEFFICIENTS FOR DIFFUSE LIGHT [HA/HA]

OUTPUT PARAMETERS:
- AID: DISTRIBUTION OF THE TOTAL AREA INDEX OF THE CONSIDERED SURFACE TYPE OVER CANOPY LAYERS AND COMPETITORS
- LAIL: CONTAINS FOR EACH OF THE NCL CANOPY LAYERS THE SUM OF AREA INDICES BELONGING TO ABSORBING SURFACES (LEAVES, STEMS, EARS... ) POSITIONED IN IT [HA/HA]
- ECDIF: AS LAIL, BUT THE CONTRIBUTING AREA INDICES ARE MULTIPLIED BY THE CORRESPONDING EXTINCTION COEFFICIENTS FOR DIFFUSE LIGHT [HA/HA]

IMPLICIT REAL (A-Z)
INTEGER V,K,A,C,NSP,DNSP,NCL,L
DIMENSION V (NSP)
DIMENSION EXIST (NSP)
DIMENSION HEI (NSP)
DIMENSION ULCL (NCL+1)
DIMENSION AI (NSP)
DIMENSION ECOF (DNSP)
DIMENSION DISPA (72)
DIMENSION AID (NSP*NCL)
DIMENSION LAIL (NCL)
DIMENSION ECDIF (NCL)
C = 0
CHECK1 = 0.
DO 565 K = 1,NCL
  LOWLIM = ULCL(K+1)
  UPLIM = ULCL(K)
  DO 566 A = 1,NSP
    L = V(A)
    XAI = AI(A)
    XHEI = HEI(A)
    CALL CLFRAC (DISPA,L,LOWLIM,UPLIM,XHEI,XAI,CLAI)
    CHECK1 = CHECK1 + CLAI
    AID (C) = CLAI
    LAIL (K)= LAIL (K) + CLAI
    ECDIF (K) = ECDIF (K) + CLAI * ECOF(L)
  566 CONTINUE
565 CONTINUE
CHECK2 = 0.
DO 1729 A = 1,NSP
  CHECK2 = CHECK2 + AI(A)
1729 CONTINUE
C CHECKING THE CORRECT DISTRIBUTION
IF (CHECK2.LT.1.E-5) THEN
  CHECK3 = CHECK1
ELSE
  CHECK3 = ABS(CHECK1-CHECK2) / CHECK2
ENDIF
IF (CHECK3.GT.0.01) TYPE 88661
88661 FORMAT (' INCORRECT DISTRIBUTION ALGORITHM ')
RETURN
END

SUBROUTINE YELDI1 (NSP,NCL,AI,GAID,YFRAC)
CCCccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
C SUBROUTINE DERIVING THE DISTRIBUTION OF THE GREEN FRACTION OF A
C SURFACE TYPE OVER CANOPY LAYERS AND COMPETITORS FROM THE
C CORRESPONDING DISTRIBUTION OF THE TOTAL SURFACE AREA;
C THE DERIVATION REFLECTS THE SITUATION THAT THE TOTAL GREEN FRACTION
C IS POSITIONED ABOVE THE TOTAL YELLOW FRACTION
CCCCCccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
C INPUT PARAMETERS:
C NSP : NUMBER OF GENOTYPES
C NCL : NUMBER OF CANOPY LAYERS
C AI : TOTAL AREA INDICES OF THE VARIOUS GENOTYPES
C YFRAC : YELLOW FRACTIONS OF THE TOTAL AREA INDICES
C BELONGING TO THE VARIOUS GENOTYPES
CCCCCccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
C OUTPUT PARAMETERS:
C GAID : DISTRIBUTION OF THE GREEN AREA INDEX OF THE CONSIDERED
C SURFACE TYPE OVER CANOPY LAYERS AND COMPETITORS
CCCCCccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
IMPLICIT REAL (A-Z)
INTEGER NSP,NCL,A,K
DIMENSION AI (NSP)
DIMENSION GAID (NSP*NCL)
DIMENSION YFRAC (NSP)
DO 1914 A = 1,NSP
  XCMGR = 0.
  XGRAI = AI(A) * (1.-YFRAC(A))
  DO 1915 K = A, (NCL-1) * NSP + A, NSP
    GAID (K) = LIMIT (0.,GAID(K),XGRAI - XCMGR)
    XCMGR = XCMGR + GAID(K)
  1915 CONTINUE
1914 CONTINUE
RETURN
END

SUBROUTINE YELDI2 (NSP,NCL,GAID,YFRAC)
CCCccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
C SUBROUTINE DERIVING THE DISTRIBUTION OF THE GREEN FRACTION OF A
C SURFACE TYPE OVER CANOPY LAYERS AND COMPETITORS FROM THE
C CORRESPONDING DISTRIBUTION OF THE TOTAL SURFACE AREA;
C THE DERIVATION REFLECTS THE SITUATION THAT THE GREEN FRACTION
C IS DISTRIBUTED UNIFORMLY FROM GROUND TO PLANT TOP
C IS POSITIONED ABOVE THE TOTAL YELLOW FRACTION
CCCCCccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
C INPUT PARAMETERS:
C NSP : NUMBER OF GENOTYPES
C NCL : NUMBER OF CANOPY LAYERS
C YFRAC : YELLOW FRACTIONS OF THE TOTAL AREA INDICES
C BELONGING TO THE VARIOUS GENOTYPES
CCCCCccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
C OUTPUT PARAMETERS:
C GAID : DISTRIBUTION OF THE GREEN AREA INDEX OF THE CONSIDERED
C SURFACE TYPE OVER CANOPY LAYERS AND COMPETITORS
CCCCCccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
IMPLICIT REAL (A-Z)
INTEGER NSP,NCL,A,K
DIMENSION GAID (NSP * NCL)
DIMENSION YFRAC (NSP)
DO 8001 A = 1,NSP
   DO 8002 K = A, (NCL-1) * NSP + A, NSP
      GAID (K) = GAID (K) * (1. - YFRAC(A))
   8002 CONTINUE
8001 CONTINUE
RETURN
END

SUBROUTINE ASTRO(DAY,LAT,DTR,DAYL,SININT,SINLD,COSLD)
    IMPLICIT REAL(A-Z)
    PI=3.1415926
    RAD=PI/180.
    DEC=-23.45*COS(2*PI*(DAY+10.)/365.)
    SINLD=SIN(RAD*LAT)*SIN(RAD*DEC)
    COSLD=COS(RAD*LAT)*COS(RAD*DEC)
    AOB=SINLD/COSLD
    DAYL=12.0*(1.0+2.0*ASIN(AOB)/PI)
    SININT=DAYL*(SINLD+0.4*(SINLD*SINLD+COSLD*COSLD*0.5)**0.5) +
    12.0*COSLD*(2.0+3.0*0.4*SINLD)*SQRT(1.0-AOB*AOB)/PI
RETURN
END

SUBROUTINE FRADIF (DAY,DTR,DAYL,SINLD,COSLD,FRDFD)
    IMPLICIT REAL(A-Z)
    PI=3.1415926
    SCACT = SC * (1. + 0.033 * COS(360.*DAY/365.))
    INTBET= 3600. * (DAYL * SINLD + 24./PI * COSLD +
    SQRT(1.-(SINLD/COSLD)**2))
    EXTEIR= INTBET * SCACT
    ATD = DTR / EXTEIR
RESOLUTION (H) AND 3 AUXILIARY VARIABLES
NEEDED FOR DESCRIBING THE INSTANTANEOUS RADIATION FOR A GIVEN
TIMEPOINT OF THE DAY
DAY : NUMBER OF CALENDAR DAY
LAT : LATITUDE OF LOCATION
SINLD : AUXILIARY VARIABLE
COSLD : AUXILIARY VARIABLE
SININT : AUXILIARY VARIABLE
FRDFD : DIFFUSE FRACTION OF DAILY VISIBLE RADIATION
INPUT PARAMETERS:
DAY : NUMBER OF CALENDAR DAY
DTR : DAILY GLOBAL RADIATION [J/M**2/D]
DAYL : DAYLENGTH [H]
SINLD : AUXILIARY VARIABLE
COSLD : AUXILIARY VARIABLE
INPUT PARAMETERS:
DAY : NUMBER OF CALENDAR DAY
DTR : DAILY GLOBAL RADIATION [J/M**2/D]
DAYL : DAYLENGTH [H]
SINLD : AUXILIARY VARIABLE
COSLD : AUXILIARY VARIABLE
INPUT PARAMETERS:
DAY : NUMBER OF CALENDAR DAY
DTR : DAILY GLOBAL RADIATION [J/M**2/D]
DAYL : DAYLENGTH [H]
SINLD : AUXILIARY VARIABLE
COSLD : AUXILIARY VARIABLE
OUTPUT PARAMETERS:
FRDFD : DIFFUSE FRACTION OF DAILY VISIBLE RADIATION
OUTPUT PARAMETERS:
FRDFD : DIFFUSE FRACTION OF DAILY VISIBLE RADIATION
OUTPUT PARAMETERS:
FRDFD : DIFFUSE FRACTION OF DAILY VISIBLE RADIATION
OUTPUT PARAMETERS:
FRDFD : DIFFUSE FRACTION OF DAILY VISIBLE RADIATION
OUTPUT PARAMETERS:
FRDFD : DIFFUSE FRACTION OF DAILY VISIBLE RADIATION
OUTPUT PARAMETERS:
FRACTION DIFFUSE LIGHT ON DAY BASIS
IF (ATD.GE.0.35) FRDF = 1.33 - 1.46 * ATD
IF (ATD.LT.0.35) FRDF = 1. - 2.3 * (ATD-0.07)**2
FRDFD = LIMIT(0.23,1.,FRDF)
RETURN
END

SUBROUTINE INSTIR (DAYL,HOUR,DTR,FRDFD,SINLD,COSLD,SININT,
IRR,SINB,FRDR)
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc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IMPLICIT REAL (A-Z)
INTEGER G,K,A,DNSP,NSP,V,NCL,C,STESWI,EARSWI
DIMENSION LAIFIX (NCL*NSP)
DIMENSION SAIFIX (NCL*NSP)
DIMENSION EAIFIX (NCL*NSP)
DIMENSION LAIL (NCL)
DIMENSION ECDIF (NCL)
DIMENSION V (NSP)
DIMENSION KL (DNSP)
DIMENSION KLSTEM (DNSP)
DIMENSION KLEAR (DNSP)
DIMENSION EMAX (DNSP)
DIMENSION EMAX2 (DNSP)
DIMENSION EFF (DNSP)
DIMENSION SEFF (DNSP)
DIMENSION EEFF (DNSP)
DIMENSION PROD (NSP)

C SCATTERING COEFFICIENT (ASSUMED TO BE EQUAL FOR ALL LIGHT
C ABSORBING STRUCTURES
SCV = 0.2
C AN AUXILIARY VARIABLE ("SQV")
SQV = SQRT (1. - SCV)
C REFLECTION COEFFICIENT OF THE CANOPY
REFLC = (1. - SQV) / (1. + SQV)
C INTENSITIES (J/CM**2/S) OF DIRECT LIGHT ("DIR") AND OF INDIRECT
C LIGHT ("DIF") ABOVE THE CANOPY AT THE CONSIDERED TIMEPOINT
DIF = IRR * (1.- FRDR) * (1. - REFLC)
DIR = IRR * FRDR
DO 4 A = 1,NSP
PROD(A) = 0.
4 CONTINUE
C MULTIPLICATION FACTORS FOR CONVERTING THE EXTINCTION OF DIFFUSE
C LIGHT INTO THE EXTINCTION INTENSITY WHEN THE INCOMING
C RADIATION IS DIRECT ("CONDRF") AND INTO THE EXTINCTION OF
C THE DIRECT COMPONENT OF INCOMING DIRECT RADIATION ("CONDIR")
C (CONDRF = KDRF/KDIR, CONDIR = KDIR/KDIF)
CONDIR = 0.5 / (SINB * SQV * 0.8)
CONDRF = CONDIR * SQV
C FRACTION OF LIGHT ENTERING THE CANOPY
DIFOUT = 1.
C LOOP ACCOUNTING FOR THE DIFFERENT CANOPY LAYERS
DO 2 K = 1,NCL
C KDIF AND KDIR OF THE COMPOSITE CANOPY LAYER, OBTAINED BY
C AVERAGING THE LAI-WEIGHTED VALUES OF THE CONTRIBUTING
C SPECIES (USED FOR CALCULATING THE SUNLIT LEAF AREA)
IF (LAIL(K).LT.1.E-4) THEN
TYPE 5011,K
5011 FORMAT (' CANOPY LAYER ',I5,' WITH LAIL = 0 ')
GOTO 2
ENDIF
IF (ECDIF(K).LT.1.E-4) THEN
TYPE 5012,K
5012 FORMAT (' CANOPY LAYER',I5,' WITH ECDIF = 0 ')
GOTO 2
ENDIF
KDIF = ECDIF(K) / LAIL(K)
KDIR = KDIF * CONDIR
C FRACTIONS OF DIFFUSE LIGHT ENTERING (DIFIN) AND LEAVING
C (DIFOUT) THE CONSIDERED LEAF LAYER
DIFIN = DIFOUT
DIFOUT = DIFIN * EXP(-ECDIF(K))
C FRACTION OF DIFFUSE LIGHT ABSORBED IN THE LAYER ("ADIF"),
C OF DIRECT LIGHT ABSORBED IN THE LAYER AS DIRECT LIGHT ("ADDIR")
C AND OF DIRECT LIGHT ABSORBED IN THE LAYER AS DIRECT OR
C INDIRECT LIGHT ("ATDIR") (1/S)
ADIF = DIFIN - DIFOUT
EDDIR = DIFIN*CONDIR - DIFOUT**CONDIR
ADDIR = EDDIR * (1.-SCV)
ATDIR = (DIFIN**CONDIR - DIFOUT**CONDIR) * (1.-REFLC)

C FRACTION OF SUNLIT LEAF AREA IN THE LAYER
SLLA = EDDIR / (KDIR*LAIL(K)) * KDIF/SQV/0.8
IF (SLLA.LT.1.E-10) THEN
  TYPE S020
  S020 FORMAT ('SLLA = 0 ')
  GOTO 2
END IF

C ABSORPTION RATE (J/S) OF THE SUNLIT PART OF THE LEAF LAYER ("SUNA")
C AND OF THE SHADOWED PART ("SHAA") (1/S)
SUMDIF = DIF * ADIF + DIR * (ATDIR-ADDIR)
SHAA = SUMDIF * (1. - SLLA)
SUNA = SLLA * SUMDIF + DIR * ADDIR

C *** ASSIMILATION PERFORMED BY LEAVES ***
DO 3 A = 1,NSP
  L = V(A)
  C = (K-1) * NSP + A
  LEAFAR = LAIFIX (C)
END DO

C ABSORPTION RATE (J/CM**2 LEAF/S) OF SUNLIT LEAVES ("ABSDIR")
C AND OF SHAD ED LEAVES ("ABSDIF")
ABSDIR = SUNA * KL(L)/(ECDIF(K) * SLLA)
ABSDIF = SHAA * KL(L)/(ECDIF(K) * (1. - SLLA))

C THE ASSIMILATION OF SUNLIT AND SHAD ED LEAFAREA IS
C ADDED TO THE OVERALL PRODUCTION OF THE SPECIES WITHIN
C THE CONSIDERED LEAF LAYER
IF (AMAX(L).LT.1.E-3) THEN
  TYPE S014,L
  S014 FORMAT('SPECIES ',IS,' WITH AMAX = 0 ! ')
  GOTO 3
END IF
PROD1 = AMAX(L) * (1. - EXP(-EFF(L)*ABSDIR/AMAX(L)))
PROD2 = AMAX(L) * (1. - EXP(-EFF(L)*ABSDIF/AMAX(L)))
PROD(A) = PROD(A) + LEAFAR * (SLLA*PROD2 + (1. - SLLA) * PROD1)

3 CONTINUE
IF (STESWI.EQ.0) GOTO 80
C *** ASSIMILATION PERFORMED BY STEMS ***
C ABSORPTION RATE (J/CM**2 STEM/S) OF SUNLIT STEMAREA ("STADIR")
C AND OF SHAD ED STEMAREA ("STADIF")
STADIR = SUNA * KLSTEM(L)/(ECDIF(K) * SLLA)
STADIF = SHAA * KLSTEM(L)/(ECDIF(K) * (1. - SLLA))

C THE ASSIMILATION OF SUNLIT AND SHAD ED STEMAREA IS
C ADDED TO THE OVERALL PRODUCTION OF THE SPECIES WITHIN
C THE CONSIDERED LEAF LAYER
DO 70 A = 1,NSP
  L = V(A)
  C = (K-1) * NSP + A
  STEMAR = SAIFIX (C)
  IF (SAMAX(L).LT.1.E-3) THEN
    TYPE S015,L
    S015 FORMAT('SPECIES ',IS,' WITH SAMAX = 0 ! ')
    GOTO 70
  END IF
  PROD1 = SAMAX(L)*(1. - EXP(-SEFF(L)*STADIR/SAMAX(L)))
  PROD2 = SAMAX(L)*(1. - EXP(-SEFF(L)*STADIF/SAMAX(L)))
  PROD(A) = PROD(A) + STEMAR * (SLLA*PROD2 + (1. - SLLA) * PROD1)
70 CONTINUE
IF (RARSWI.EQ.0) GOTO 2
INDIRECT LIGHT ("ATDIR") (1/S)
ADIF = DIFIN - DIFOUT
EDDIR = DIFIN**CONDIR - DIFOUT**CONDIR
ADDIR = EDDIR * (1.-SCV)
ATDIR = (DIFIN**CONDRF - DIFOUT**CONDRF) * (1.-REFLC)

FRACTION OF SUNLIT LEAF AREA IN THE LAYER
SLLA = EDDIR / (KDIF/SQV/0.8)
IF (SLLA.LT.1.E-10) THEN
  TYPE 5020
  FORMAT (' SLLA = 0 ')
  GOTO 2
END IF

ABSORPTION RATE (J/S) OF THE SUNLIT PART OF THE LEAF LAYER ("SUNA")
AND OF THE SHADOWED PART ("SHAA") (1/S)
SUMDIF = DIF * ADIF + DIR * (ATDIR-ADDIR)
SHAA = SUMDIF * (1. - SLLA)
SUNA = SLLA * SUMDIF + DIR * ADDIR

ASSIMILATION PERFORMED BY LEAVES

DO 3 A = 1,NSP
  L = V(A)
  C = (K-1) * NSP + A
  LEAFAR = LAIFIX (C)
STADIR = SUNA * KLSTEM(L)/(ECDIF(K) * SLLA)
STADIF = SHAA * KLSTEM(L)/(ECDIF(K) * (1. - SLLA))
THE ASSIMILATION OF SUNLIT AND SHADOWED STEMAREA IS
ADDED TO THE OVERALL PRODUCTION OF THE SPECIES WITHIN
THE CONSIDERED LEAF LAYER
IF (AMAX(L).LT.1.E-3) THEN
  TYPE 5014,L
  FORMAT (' SPECIES ',IS,' WITH AMAX = 0 ! ')
  GOTO 3
END IF
PROD1 = AMAX(L) * (1. - EXP(-EFF(L)*ABSDIF/AMAX(L)))
PROD2 = AMAX(L) * (1. - EXP(-EFF(L)*ABSDIR/AMAX(L)))
PROD(A) = PROD(A) + LEAFAR * (SLLA*PROD2 + (1. - SLLA) * PROD1)
3 CONTINUE

ASSIMILATION PERFORMED BY STEMS

DO 70 A = 1,NSP
  L = V(A)
  C = (K-1) * NSP + A
  STEMAR = SAIFIX (C)
IF (SAMAX(L).LT.1.E-3) THEN
  TYPE 5015,L
  FORMAT (' SPECIES ',IS,' WITH SAMAX = 0 ! ')
  GOTO 70
END IF
PROD1 = SAMAX(L)*(1. - EXP{-SEFF{L)*STADIF/SAMAX(L)})
PROD2 = SAMAX(L)*(1. - EXP(-SEFF(L)*STADIR/SAMAX(L)))
PROD(A) = PROD(A) + STEMAR * (SLLA*PROD2 + (1. - SLLA) * PROD1)
70 CONTINUE

IF (STESWI.EQ.O) GOTO 80

ASSIMILATION PERFORMED BY STEMS

DO 70 A = 1,NSP
  L = V(A)
  C = (K-1) * NSP + A
  STADIR = SUNA * KLSTEM(L)/(ECDIF(K) * SLLA)
  STADIF = SHAA * KLSTEM(L)/(ECDIF(K) * (1. - SLLA))
THE ASSIMILATION OF SUNLIT AND SHADOWED STEMAREA IS
ADDED TO THE OVERALL PRODUCTION OF THE SPECIES WITHIN
THE CONSIDERED LEAF LAYER
IF (AMAX(L).LT.1.E-3) THEN
  TYPE 5015,L
  FORMAT (' SPECIES ',IS,' WITH AMAX = 0 ! ')
  GOTO 70
END IF
PROD1 = AMAX(L) * (1. - EXP(-EFF(L)*STADIF/AMAX(L)))
PROD2 = AMAX(L) * (1. - EXP(-EFF(L)*STADIR/AMAX(L)))
PROD(A) = PROD(A) + STEMAR * (SLLA*PROD2 + (1. - SLLA) * PROD1)
70 CONTINUE

IF (EARSWI.EQ.O) GOTO 2
INDIRECT LIGHT ("ATDIR") \((1/\text{S})\)

\[
\begin{align*}
\text{ADIF} &= \text{DIFIN} - \text{DIFOUT} \\
\text{EDDIR} &= \text{DIFIN} \times \text{CONDIR} - \text{DIFOUT} \times \text{CONDIR} \\
\text{ADDIR} &= \text{EDDIR} \times (1. - \text{SCV}) \\
\text{ATDIR} &= (\text{DIFIN} \times \text{CONDRF} - \text{DIFOUT} \times \text{CONDRF}) \times (1. - \text{REFLC})
\end{align*}
\]

FRACTION OF SUNLIT LEAF AREA IN THE LAYER

\[
\text{SLLA} = \frac{\text{EDDIR}}{(\text{KDIR} \times \text{LAIL(K)}) \times \text{KDIF}/\text{SQV}/0.8}
\]

IF \((\text{SLLA} < 1. \times 10^{-10})\) THEN

\[
\text{TYPE S020} \\
\text{FORMAT (' SLLA = 0 ') GOTO 2}
\]

END IF

ABSORPTION RATE \((\text{J/}\text{S})\) OF THE SUNLIT PART OF THE LEAF LAYER ("SUNA")

\[
\text{SUMDIF} = \text{DIF} \times \text{ADIF} + \text{DIR} \times (\text{ATDIR} - \text{ADDIR})
\]

\[
\text{SUNA} = \text{SLLA} \times \text{SUMDIF} + \text{DIR} \times \text{ADDIR}
\]

*** ASSIMILATION PERFORMED BY LEAVES ***

DO 3 A = 1, NSP

\[
\begin{align*}
\text{L} &= \text{V(A)} \\
\text{C} &= (K-1) \times \text{NSP} + A \\
\text{LEAFAR} &= \text{LAFIX (C)}
\end{align*}
\]

ABSORPTION RATE \((\text{J/cm}^{2}\text{/leaf}/\text{S})\) OF SUNLIT LEAVES ("ABSDIR")

\[
\begin{align*}
\text{ABSDIR} &= \text{SUNA} \times \text{KLSTEM(L)}/(\text{ECDF(K)} \times \text{SLLA}) \\
\text{ABSDIF} &= \text{SHAA} \times \text{KLSTEM(L)}/(\text{ECDF(K)} \times (1. - \text{SLLA}))
\end{align*}
\]

THE ASSIMILATION OF SUNLIT AND SHADED LEAF AREA IS ADDED TO THE OVERALL PRODUCTION OF THE SPECIES WITHIN THE CONSIDERED LEAF LAYER

IF \((\text{AMAX(L)} < 1. \times 10^{-3})\) THEN

\[
\text{TYPE S01S,L} \\
\text{FORMAT(' SPECIES ',IS,' WITH SAMAX = 0.01 ') GOTO 70}
\]

END IF

\[
\text{PROD1} = \text{AMAX(L)} \times (1. - \text{EXP(-SEFF(L) \times \text{ABSDIF}/\text{AMAX(L)}))} \\
\text{PROD2} = \text{AMAX(L)} \times (1. - \text{EXP(-SEFF(L) \times \text{ABSDIR}/\text{AMAX(L)}))} \\
\text{PROD(A)} = \text{PROD(A)} + \text{LEAFAR} \times (\text{SLLA} \times \text{PROD2} + (1. - \text{SLLA}) \times \text{PROD1})
\]

CONTINUE IF \((\text{STESWI} \neq 0)\) GOTO 80

END IF

PROD1 = \text{SAMAX(L)} \times (1. - \text{EXP(-SEFF(L) \times \text{STADIF}/\text{SAMAX(L)}))} \\
PROD2 = \text{SAMAX(L)} \times (1. - \text{EXP(-SEFF(L) \times \text{STADIR}/\text{SAMAX(L)}))} \\
PROD(A) = \text{PROD(A)} + \text{STEMAR} \times (\text{SLLA} \times \text{PROD2} + (1. - \text{SLLA}) \times \text{PROD1})

CONTINUE

IF \((\text{EARSWI.EQ.0})\) GOTO 2
SUBROUTINE LNDCAL (NSP,OGBMPP,PROB,LNDVBM,DUM)
ccc...CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C SUBROUTINE CALCULATING DELTA - LN - VALUES C
ccc...CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C INPUT PARAMETERS: C
C NSP : NUMBER OF GENOTYPES C
C OGBMPP : ABOVE GROUND BIOMASS PER PLANT [G] C
C PROB : FREQUENCIES OF THE GENOTYPES C
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
C OUTPUT PARAMETERS: C
C LNDVBM : DELTA - LN - VALUES C
C DUM : DUMMY VARIABLE C
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
IMPLICIT REAL (A-Z)
INTEGER NSP,A
DIMENSION OGBMPP(NSP)
DIMENSION PROB (NSP)
DIMENSION LNDVBM(NSP)
IF (NSP.EQ.1) GOTO 7020
SUMLN = 0.
DO 851 A = 1,NSP
IF (OGBMPP(A).LT.1.E-3) GOTO 851
SUMLN = SUMLN + ALOG(OGBMPP(A)) * PROB(A)
851 CONTINUE
AVLN = SUMLN
DO 852 A = 1,NSP
LNDVBM(A) = ALOG(AMAX1(6.73795E-3, OGBMPP(A))) - AVLN
852 CONTINUE
7020 CONTINUE
RETURN
END
ENDJOB
C CALCULATE INSTANTANEOUS ASSIMILATION RATES OF THE NSP COMPETITORS
C (KG CHO / HA / HA)
CALL PHOTOC (NCL, NSP, DNSP, V, STESWI, EARSWI, LAID, SAID, EAID,
1 LAIL, ECDIF, KL, KLSTEM, KLEAR, AMAX, SAMAX, EAMAX, EFF, SHEF,
1 INSTAS)
INST1 = INSTAS(1)
C WEIGHTED SUMMATION OF INSTANTANEOUS ASSIMILATION RATES
DO 5 A = 1, NSP
  GASSP(A) = GASSP(A) + INSTAS(A) * WEIGHT(G)
5 CONTINUE
6000 CONTINUE
WRITE (20, 2620) FRDFD, DIR(1), DIR(2), DIR(3), INTENS(1),
1 INTENS(2), INTENS(3), SNUS(1), SNUS(2), SNUS(3)
2620 FORMAT (10(F11.5))
C FINISHING THE INTEGRATION PROCEDURE
DO 6 A = 1, NSP
  GASSP(A) = GASSP(A) / 3.6 * DAYL
6 CONTINUE
RETURN
END
SUBROUTINE EVAL1 (DIM, ARR, PROB, EXVA, VAR, CV)
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
C SUBROUTINE CALCULATING EXPECTATION VALUE, VARIANCE AND THE
C COEFFICIENT OF VARIATION OF A CHANCE VARIABLE
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
C INPUT PARAMETERS:
C DIM : NUMBER OF VALUES OF THE CHANCE VARIABLE
C ARR : VALUES OF THE CHANCE VARIABLE
C PROB : PROBABILITIES ASSOCIATED WITH THE VALUES
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
C OUTPUT PARAMETERS:
C EXVA : EXPECTATION VALUE
C VAR : VARIANCE
C CV : COEFFICIENT OF VARIATION
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
IMPLICIT REAL (A-Z)
INTEGER DIM, J
DIMENSION ARR (DIM)
DIMENSION PROB(DIM)
IF (DIM.EQ.1 ) THEN
  EXVA = ARR(1)
  VAR = 0.
ELSE
  SUMX = 0.
  SUMXX = 0.
  DO 851 J = 1, DIM
    SUMX = SUMX + ARR(J) * PROB(J)
    SUMXX = SUMXX + ARR(J)**2 * PROB(J)
 851 CONTINUE
  EXVA = SUMX
  VAR = SUMXX - SUMX**2
ENDIF
IF (EXVA.LT.1.E-8) GOTO 9013
IF (VAR. LT.1.E-8) THEN
  CV = 0.
ELSE
  CV = SQRT(VAR) / EXVA
ENDIF
9013 CONTINUE
RETURN
END
*** ASSIMILATION PERFORMED BY EARS ***

**ABSORPTION RATE \((J/cm^2 \cdot 2 \cdot \text{Ear} / \text{S})\) OF SUNLIT EAR AREA \("\text{EARDIR}\)"

\[
\text{EARDIR} = \text{Suna} \cdot \text{Klear}(L) / (\text{ECDIF}(K) \cdot \text{Slla})
\]

**AND OF SHADED EAR AREA \("\text{EARDIF}\)"

\[
\text{EARDIF} = \text{Shaa} \cdot \text{Klear}(L) / (\text{ECDIF}(K) \cdot (1. - \text{Slla}))
\]

**THE ASSIMILATION OF SUNLIT AND SHADED EAR AREA IS ADDED TO THE OVERALL PRODUCTION OF THE SPECIES WITHIN THE CONSIDERED LEAF LAYER**

\[
\begin{align*}
\text{DO} & \ 75 \ A = 1, \text{NSP} \\
L & = V(A) \\
C & = (K-1) \cdot \text{NSP} + A \\
\text{EARAR} & = \text{EAIFIX}(C) \\
\text{IF} (\text{EAMAX}(L).LT.1.E-3) \text{ THEN} \\
\text{TYPE} & = 5016, L \\
5016 & \text{ FORMAT (' \text{SPECIES },IS,', 'WITH EAMAX = 0 ! ') GOTO 75 END IF} \\
\end{align*}
\]

\[
\begin{align*}
\text{PROD1} & = \text{EAMAX}(L) \cdot (1. - \exp(-\text{EFF}(L) \cdot \text{EARDIF}/\text{EAMAX}(L))) \\
\text{PROD2} & = \text{EAMAX}(L) \cdot (1. - \exp(-\text{EFF}(L) \cdot \text{EARDIR}/\text{EAMAX}(L))) \\
\text{PROD}(A) & = \text{PROD}(A) + \text{EARAR} \cdot (\text{Slla} \cdot \text{PROD2} + (1. - \text{Slla}) \cdot \text{PROD1}) \\
\end{align*}
\]

75 CONTINUE

2 CONTINUE

C NOW THE LOOP HAS GONE THROUGH ALL LEAF LAYERS AND ALL COMPETITORS

\[
\begin{align*}
\text{DO} & \ 85 \ A = 1, \text{NSP} \\
\text{PROD}(A) & = \text{PROD}(A) \cdot 30. / 44. \\
\end{align*}
\]

85 CONTINUE

RETURN

END

**SUBROUTINE DAYASS \((\text{DAY}, \text{DTR}, \text{LAT}, \text{NCL}, \text{NSP}, \text{DNSP}, \text{V}, \text{STESWI}, \text{EARSWI}, \text{LAID}, \text{SAID}, \text{EAID}, \text{LAIL}, \text{ECDIF})\)**

C SUBROUTINE CALCULATING THE DAILY GROSS ASSIMILATION \([\text{KG/HA/D}]\)

C OF NSP COMPETITORS FORMING A CANOPY DESCRIBED IN TERMS OF NCL CANOPY LAYERS; OPTIONALLY, THE PHOTOSYNTHESIS OF STEMS AND EARS CAN BE INCLUDED

C INPUT PARAMETERS:

C \text{DAY} : \text{NUMBER OF CALENDAR DAY} \[\text{J/M**2/D}]\n
C \text{DTR} : \text{DAILY GLOBAL RADIATION} \[\text{J/M**2/D}]\n
C \text{LAT} : \text{LATITUDE OF LOCATION} \[\text{DEG}]

C \text{NCL} : \text{NUMBER OF DESCRIBED CANOPY LAYERS} \[\text{N}]

C \text{NSP} : \text{NUMBER OF SPECIES MODELLED IN THE PRESENT CASE} \[\text{N}]

C \text{DNSP} : \text{NUMBER OF SPECIES DESCRIBED IN THE PARAMETER SECTION OF THE MAIN PROGRAMM} \[\text{N}]

C \text{V} : \text{ARRAY RELATING THE NUMBER USED TO DENOTE A SPECIES IN THE PARAMETER SECTION OF THE MAIN PROGRAM TO THE NUMBER USED IN THE ACTUAL RUN} \[\text{N}]

C \text{STESWI} : \text{SWITCH PARAMETERS DETERMINING IF PHOTOSYNTHESIS OF STEMS (EARS) IS TO BE INCLUDED} \[\text{L}]

C \text{EARSWI} : \text{DISTRIBUTION OF LAI (GREEN LEAVES ONLY) OVER SPECIES AND LAIFIX LAYER} \[\text{HA/HA}]

C \text{EAID} : \text{AS LAIFIX, BUT FOR GREEN STEM AND GREEN EAR AREA} \[\text{HA/HA}]

C \text{IF PHOTOSYNTHESIS OF STEMS (EARS) IS TO BE NEGLECTED, SAIFIX (EAIFIX) MAY BE ANY DUMMY ARRAY WITH A DIMENSION GREATER OR EQUAL "NSP*NCL" (THUS FOR EXAMPLE "LAIFIX")}

C \text{LAIL} : \text{CONTAINS FOR EACH OF THE NCL CANOPY LAYERS THE SUM OF AREA INDICES BELONGING TO ABSORBING SURFACES (LEAVES, STEMS, EARS... \ POSITIONED IN IT} \[\text{HA/HA}]

C \text{ECDIF} : \text{AS LAIFIX, BUT THE CONTRIBUTING AREA INDICES ARE MULTIPLIED BY THE CORRESPONDING AREA INDICES} \[\text{HA/HA}]

C \text{COEFFICIENTS FOR DIFFUSE LIGHT} \[\text{HA/HA}]\n