Ch. 10: Vegetation models

Table of Contents

10 Vegetation models

10.1 Vegetation model overview

Daisy contains three main vegetation models, of which the vegetation model *crops* is the default and the most used model. It is also possible to define a *permanent* vegetation with constant height, root system and a specified leaf area index (LAI) over time, and a type called *afforestation* that is more dynamic than *permanent*, but still with pre-defined LAI (and in addition, pre-defined litterfall and rhizodeposition). The *permanent* vegetation and the *afforestation* option is described in the following two sections, while the *crops*-model, which is the commonly used option, is described in section 10.2 and onwards.

All vegetation types share the parameter *EpInterchange* that redistributes part of the unused soil evaporation to transpiration (β in eq. (3.39), see Chapter 3.3).

10.1.1 The vegetation option *permanent*

The *permanent* vegetation model uses the canopy description *CanopySimple*. A *permanent* vegetation does not have active photosynthesis and thus it does not grow but it still evaporates, and it still influences radiation, so the amount of radiation below the permanent vegetation is calculated. When LAI is reduced at the end of the season, the material becomes litter, which moves into the soil organic matter cycle.

Because the plant does not grow, it has a pre-defined height (default 80 cm) and a pre-defined amount of root dry matter (default 2 Mg DM h^{-1}]. The root functions as other roots with respect to water and N-uptake, and the root depth is set to MaxPen (default 100 cm) in the specification of the roots. LAI is specified as a plf, with a Julian day and the corresponding LAI (*LAIvsDay*). This is used every year, or combined with a year (*YearlyLAI*), so measured sequences in consecutive years can be simulated. For easy scaling of the LAI-values, a LAI factor can be specified (by default = 1).

To keep track of the biomass and N-content in the canopy, a DM- and a N-content per LAI-unit and area is specified by the user. The N-content is used to calculate the potential N-content (N-content/LAI ·LAI) and the N-demand in a timestep is then (N_{pot}-N_{act}) and uptake is calculated as described in Chapter 7. When LAI and thus the biomass in the vegetation is reduced towards the end of the season, the loss in LAI dry matter becomes litter, with the associated N-content. Turn-over parameters for the litter must thus be specified (by default AOM-SLOW and AOM-FAST), see Chapter 9.

An *Albedo* (default = 0.2) is specified for the permanent vegetation. The parameter is used for calculation of net radiation.

The *CanopySimple* model used by the *permanent* vegetation contains parameters for reflection and extinction of photosynthetically active radiation (*PARref* and *PARext*, see section 10.5.3), which in this case are mainly relevant if a crop is grown below the permanent cover, and thus require light. Similar, parameters are specified for near-infrared light (*NIRref* (Ross, 1975) and *NIRext* (Jones, 1983). While a calculation similar to PAR can be done for NIR, and the values can be logged, those values are not used in the standard SVAT model. The Sun-Shade-Open Canopy (SSOC) SVAT model applies other parameters (see Chapter 2 and Appendix 2.4). The parameters *EPext* (K_l in eq. (3.35)), *EpFac* ($k_{c,canopy}$ in eq. (3.36)), *EpFacWet* (potential evapotranspiration factor for wet surface, by default = *EpFac*)and *EpFacDS* (a DS-dependent scaling factor for *EpFac*) are used for the calculation of actual evapotranspiration (Chapter 3). The interception capacity of the leaves (*IntcpCap* = C_i in eq. (3.19)) is specified here too.

Furthermore, the parameters *rs_min* and *rs_max* [s m^{-1}], is specified, defining the minimum and maximum transpiration resistance. *rs_min* represents the stomatal resistance of a single leaf under well-watered conditions (default 100 [s m^{-1}] (Allen et al., 1998)) and is used if the pet-model *PM* is selected (see appendix 2.1). *rs_max* is not currently used anywhere in Daisy (default 100000 [s m^{-1}]).

It is in any case not appropriate to combine a simple canopy model with a very advanced SVAT-model as SSOC. However, some SSOC-relevant parameters are included here anyway.. The parameter *leaf_width* is a plf that specifies leaf width as a function of DS. As default, it is always 3 cm. It is used by the SSOC-model for calculation of boundary layer conductance of sunlit and shaded leaves, as well as for calculation of soil aerodynamic conductance.

Four types of permanent vegetation (bush, coniferous, grass and hardwood) are parameterised in the file *vegetation.dai*, distributed with the model.

10.1.2 The vegetation option *afforestation*

The *afforestation* option is slightly more dynamic than permanent vegetation, as it is supposed to describe a growing forest. A planting time is thus required for the simulation. The canopy height is not constant, but described with a plf, specifying height [cm] as a function of years after planting. The root is described exactly as for *permanent* vegetation. It is possible to specify a parameter (*root_depth*), where depth of the effective root zone is specified as a function of years after planting, but this function is not currently active in the model.

LAI is parameterised using a shape function (*LAI_shape*, plf), where LAI is expressed as a function of Julian day. The value "1" represents *LAI_min* and the value 5 represents *LAI_max* for the specific year. *LAI_min* and *LAI_max* are also plfs, specifying minimum and maximum values of LAI, respectively, as function of year.

To describe the N-content, the *N_per_LAI* [kg N ha^{-1}] must be specified. This N-amount will vary over the year, as a function of LAI. *N_nonleaves* describes the amount of nitrogen in the plants not accounted for by seasonal LAI variation. This is a function (plf) of years after planting [y -> kg N ha^{-1}].

As for permanent vegetation, the plants may drop leaves as litter. The total litterfall is described as a plf, where litterfall [Mg DM ha^{-1}] is specified as a function of year after planting. The distribution of litterfall over the year is described by the function *litterfall_shape*, where the relative speed of litterfall is given as a function of Julian day. This function is integrated over a year, and the litterfall in a specific period is then the integration of this parameter over the period, divided by the integration of this function over a year, multiplied with the total litterfall for that year. The quality of the litterfall is described with parameters for the C-content in dry matter (default = 0.42) and the C/N ratio of the litter. Turn-over parameters for the litter are described similarly to for *permanent* vegetation.

Rhizodeposition is described exactly as litterfall, with a year-dependent total deposition, a shape function, the C-content in dry matter and the C/N-ratio of the material. Turn-over parameters for the root are by default identical to the ones for litter.

An *Albedo* (default = 0.2) is specified for *afforestation*, similarly to the *permanent* vegetation.

The *afforestation* option uses *CanopySimple*, which is equipped with the parameters described for *permanent* vegetation, section 10.1.1.

The afforestation option has never been tested at should only be used in consultation with the Daisy group.

10.1.3 The vegetation option *crops*

For the vegetation model *crops*, almost all functions are further described under the *crop* component, which is outlined in section 10.2. The only parameter not handled there is the *ForcedLAI* submodel which allows the user to substitute the simulated LAI by measured values of LAI for part of (or all) the simulation time. In this option, the albedo is hard-coded to 0.23, which is the value for a reference crop given by (Allen et al., 1998) and thus cannot be changed.

10.2 Overview of the crop model

A general overview of the crop model is shown in Figure 10.1. Photosynthesis is driven by “photosynthetically active radiation” (PAR) and is dependent on temperature. It is also influenced by different stresses and the development stage of the plant. Plant growth is driven by the assimilates (sugar molecules) generated through photosynthesis. Assimilates are allocated to different parts of the plant as a function of development stage. The growth of the different organs in turn feeds back on photosynthetic capacity and uptake of water and nitrogen. CO_2 is lost due to respiration and conversion of assimilates. Leaves and roots may die off during the growing season. Most of the processes are influenced by temperature. The parameterization, however, differs (sometimes considerably) for different crops, and the overall scheme may also be modified in different ways.

The crop component calls *CanopyStandard*, which shares the parameters *PARref, PARext, NIRref, NIRext, EPext, IntcpCap, EpFac, EPFacWet, EpFacDS, rs_max, rs_min* and *leaf_width* with *CanopySimple*, section 10.1.1. Some of these, and other parameters in CanopyStandard will be further described below.

The following section describe the crop phenology and the way it is governed in the model. This is followed by a description of photosynthesis, partitioning, senescence and harvesting. Roots and nitrogen in plants are treated separately in section 10.6 and 10.7, respectively.

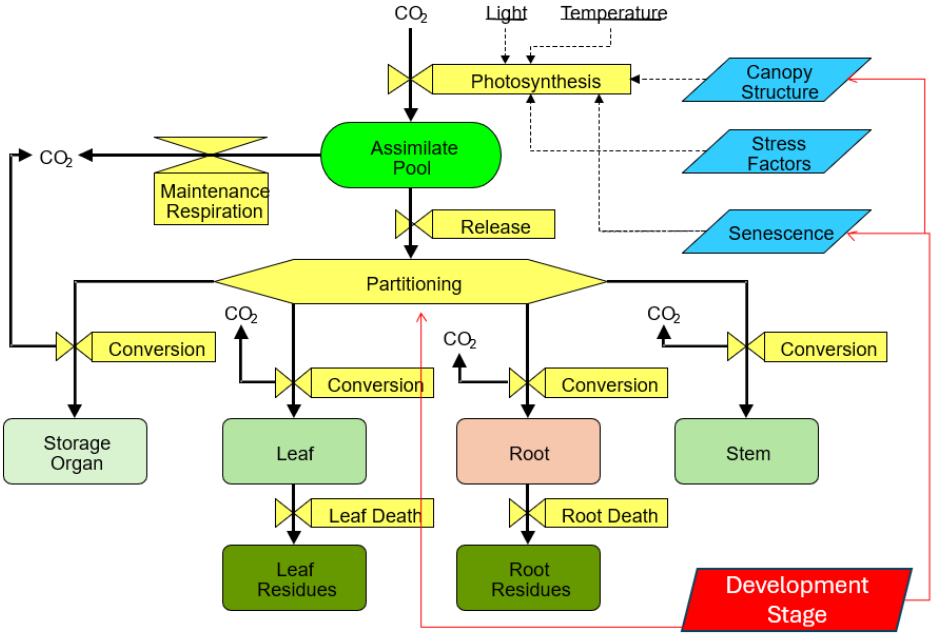


Figure 10.1. The overall principles of the Daisy crop model

10.3 Crop Phenology

Development stage, DS

In the Daisy model, the crop stage is described by the development stage, DS, which acts as a counter in the model. This counter only has the physical/biological meaning we assign to it. It is the only variable which can be calibrated independently of other crop parameters, as it is mainly governed by external factors such as temperature and photoperiod. The Daisy development stage is (-1) at sowing, 0.01 at emergence, 1 at flowering (or heading in grain crops) and 2 for a mature crop. The scale is continuous from emergence to harvest. The vegetative stage lies between emergence and flowering ($0.01<DS<1$), and the reproductive stage is defined from flowering to the crop is ripe ($1<DS<2$).

BBCH

To allow translation from DS to scientifically recognized growth stage definitions, like BBCH, a table can be included, linking DS to BBCH-values (see example below in box). So far, such tables have been developed for winter wheat and spring barley. The defined crop stage value is then logged as “phenology” in the crop-output-file.

It should be noted that while DS is a continuous scale, BBCH is not. Not all values exist and even if they exist, all values may not be obtained in a specific year (e.g. tiller number). So, the two scales are linked in steps, where the BBCH value is kept constant until the DS-value corresponding to the next BBCH-value is reached.

Example: Linking DS with BBCH

```
(defunit [DS] base)

(defcstage "BBCH; Spring Barley" BBCH
 (table (-1.00  0 "BBCH 00: Dry seed (caryopsis)")
        (0.00    9 "BBCH 09: Emergence")
        (0.01   10 "BBCH 10: First leaf through coleoptile")
        (0.03   11 "BBCH 11: First leaf unfolded")
        (0.08   12 "BBCH 12: 2 leaves unfolded")
        (0.15   13 "BBCH 13: 3 leaves unfolded")
        (0.19   14 "BBCH 14: 4 leaves unfolded")
        (0.20   21 "BBCH 21: Beginning of tillering")
        (0.29   22 "BBCH 22: 2 tillers detectable")
        (0.33   23 "BBCH 23: 3 tillers detectable")
        (0.35   24 "BBCH 24: 4 tillers detectable")
        (0.36   25 "BBCH 25: 5 tillers detectable")
        (0.39   26 "BBCH 26: 6 tillers detectable")
        (0.42   30 "BBCH 30: Beginning of stem elongation")
        (0.56   31 "BBCH 31: First node at least 1 cm above tillering
                    node")
        (0.73   32 "BBCH 32: Node 2 at least 2 cm above node 1")
        (0.75   33 "BBCH 33: Node 3 at least 2 cm above node 2")
        (0.80   37 "BBCH 37: Flag leaf just visible, still rolled")
        (0.90   43 "BBCH 43: Mid boot stage")
        (0.94   47 "BBCH 47: Flag leaf sheath opening")
        (0.95   49 "BBCH 49: First awns visible (in awned forms
                    only)")
        (0.97   53 "BBCH 53: 30% of inflorescence emerged")
        (1.03   55 "BBCH 55: Middle of heading")
        (1.10   59 "BBCH 59: End of heading")
        (1.15   61 "BBCH 61: Beginning of flowering: first anthers
                    visible")
        (1.23   65 "BBCH 65: Full flowering")
        (1.25   69 "BBCH 69: End of flowering")
        (1.35   71 "BBCH 71: Watery ripe")
        (1.49   75 "BBCH 75: Medium milk")
        (1.70   85 "BBCH 85: Soft dough")
        (1.90   87 "BBCH 87: Hard dough")
        (2.00   89 "BBCH 89: Fully ripe")))
```

10.3.1 Establishment and emergence

To introduce a crop in Daisy, it must be sown or planted, using an appropriate action, such as *sow* or *plant*. Actions are further described in Chapter 11. The mentioned operations require the name of the crop to be established. The seed weight is an optional parameter, by default the initial growth is governed by "typical" seed amounts, but the *seed* option for emergence requires a seed weight, see section 10.4.

Row width and position

Default settings (0) of the parameters *row_width* [cm] and *row_position* [cm] assume "no rows" and equal spread of seeds over an area. *row_width* is the distance between rows, while *row_position* is the position of plant row on the x-axis, mainly of interest for 2-D simulations. Rows are considered to be orthogonal to the x-axis. The parameters *plant_distance* and *plant_position* (both [cm]) are applied in 2-D-simulations, where rows are parallel to the x-axis.

Emergence

Emergence is governed by the soil temperature sum at emergence (*EMrTSum*), calculated from the date of sowing and the moisture conditions during the period. DS at emergence (*DS_Emr*) is given a value, which by default is 0.01. The process is described as:

$$T_{sum} = \sum_{sow.date}^{present} \left(T_{soil} \cdot \Delta t \cdot f(h_p) \right) \tag{10.1}$$

where

T_{sum} = The soil temperature sum from sowing date and forward [°C]. The sum must reach a specified value, *EMrTSum*, before emergence takes place.

T_{soil} = The average soil temperature at sowing depth [°C]. This is assumed to be the average temperature in from the soil surface to root depth at emergence, *DptEmr*.

Δt = the time step of the model (1 for daily values).

$f(h_p)$ = a plf, describing the influence of soil moisture levels, expressed as tension (*EmrSMF*). The default values are *(EmrSMF (-1000 [cm] 1[]) (-150 [cm] 1[]) (-50 [cm] 1[]) (-30 [cm] 1[]))*, equal to no effect.

The moisture relationship may be calibrated to consider reduced growth in particularly wet and/or dry conditions.

10.3.2 Vegetative stage

DSrate1

During the vegetative stage, the DS-value usually increases from 0.01 to 1, which represents flowering in most crops and heading in at least winter wheat and spring barley. The rate of increase for the vegetative stage (*DSRate1*) can be modified by temperature and photoperiod. Several other functions in the growth description are closely tied to the DS-value (e.g. the partitioning of assimilate, see section 10.5.4) because processes differ depending on the growth stage of the plant.

Daily increments of the development stage, ΔDS, are calculated from Eq. (10.2):

$$\Delta DS = d \cdot f_t(T_a) \cdot f_d(D_l) \tag{10.2}$$

where

d = the development rate at reference temperature and reference day length, $DSRate1$ [DS d^{-1}], for the vegetative stage,

T_a = the average daily temperature [°C],

$f_t(T_a)$ = modifying plf ($TempEff1$) accounting for air temperature in the vegetative stage,

$f_d(D_l)$ = modifying plf ($PhotEff1$) accounting for day length in the vegetative stage.

The day length is defined as the number of hours[1] where the top of the canopy receives more than 12.5 W m^{-2} in average. The calculation is shown in Appendix 10.1. The calculated daylength will usually be close to the astronomically defined day length, e.g. http://ptaff.ca/soleil/?lang=en_CA, but may differ especially for undersown crops.

Temperature- and daylength functions can be found in all the crop parameterisations in the lib-directory. Some examples from "Winter Wheat" in wwheat.dai are shown below:

(TempEff1 (-10.0 [deg C] 0.01 []) (0.0 [deg C] 0.01 []) (20.0 [deg C] 0.90 [])(25. [deg C] 1.00 []) (35. [deg C] 1.20 []))

(PhotEff1 (10. [h] 0.29 []) (11. [h] 0.55 []) (12. [h] 0.75 [])(13. [h] 0.89 []) (14. [h] 1.00 []) (15. [h] 1.08 []) (16. [h] 1.14 [])(17. [h] 1.18 []) (24. [h] 1.18 []))

10.3.3 Reproductive stage

DSrate2

During the reproductive stage, the DS-value usually increases from 1 to 2. The equation is similar to equation (10.2) for DS increase in the vegetative stage, but there is no dependency on daylength. The rate of increase for the reproductive stage ($DSRate2$) can be modified by temperature ($TempEff2$), similarly to the modification in the vegetative phase. DS_{Mature}, the development stage at maturation, is set to 2 by default, but can be user defined.

10.3.4 Vernalization

Some crops require vernalization during the vegetative phase. This means that the crop requires a cold period to proceed in its development. In Daisy, this is governed by three parameters, namely the DS-value where the vernalization requirement sets in (DS_{Lim} [DS]), the required temperature threshold ($T_{a,Lim}$ [°C]), and the temperature sum required for the plant to develop further ($T_{a,Sum}$ [°C d]. $T_{a,Sum}$ is calculated as the difference between the actual temperature and $T_{a,Lim}$, so it needs to be negative. Thus, as long as the temperature sum has not been reached, DS does not change:

For $DS = DS_{Lim}$ and $T_{sum}^{vern} > T_{a,Lim}$: $\Delta DS = 0$

The temperature is updated as follows:

[1] More precisely, the sum of the length of the time steps during which the average radiation is above the specified threshold. This means the day length depends on the temporal discretization used.

$$T_{sum}^{vern} = T_{sum}^{vern} + (T_a - T_{a,\lim}), \qquad T_a < T_{a,\lim}$$
$$T_{sum}^{vern} = T_{sum}^{vern}, \qquad T_a \geq T_{a,\lim} \tag{10.3}$$

When T_{sum}^{vern}= $T_{a,Lim}$, DS increases as described in section 10.3.2.

10.3.5 Other modifiers of DS

DS modifiers that can be parameterised

The crop module includes other ways to modify DS for particular events, such as harvest actions/cuts (of e.g. grass). DS_{max} is the maximum DS-value for which the crop survives a harvest or cutting action. $DSnew$ is the value of DS after harvest if the plant is able to re-grow.

DS_{Repeat} and $DS_{SetBack}$ are a similar pair of parameters to modify DS. At the DS-value, specified by DS_{Repeat}, the DS-value is set back to the value defined by $DS_{Setback}$. A crop can thus continue to growth without being harvested.

A parameterization can be specified until a defined development stage using "*defined_until_ds*".

DS-modification due to lack of assimilate

In addition to the modifiers above, the progress of the DS-value stops if respiration becomes higher than the daily photosynthesis.

10.4 Conditions at emergence

To go from emergence to vegetative growth it is necessary to generate leaves that can carry out photosynthesis. Two functions exist that describe emergence. In the oldest one ("*LAI*"), the initial growth is governed by a forced leaf area index (LAI) function. This model is fragile and should not be used for new parameterisations. In the newer function (*"release"*), the initial crop growth is governed by carbon released from seeds. However, it has not yet been parameterised for all crops.

Old function ("LAI")

This function requires a parameter (*DSLAI0.5*) that sets the DS-value at which the Crop Area Index (CAI) is 0.5. By default, this DS-value is 0.15. CAI equals LAI if no photosynthetic capacity has been defined for other organs. Furthermore, a plf specifies the specific leaf weight from DS 0 to DS 0.6 (*SpLAIfac*). It is only used in the initial phase, where CAI is $\leq$ 0.5.

The "release" function

The "*release*" function requires information about the seeding rate [g w.w. m^{-2}], the dry matter content [-] in the seeds, the carbon and nitrogen fractions of the dry matter [-], and the release rate of seed carbon to the assimilate pool [h^{-1}]. The release process is a first order process, where the release is proportional to the size of the pool of C in the seed. The release rate can be modified by soil temperature ($f_{release}(T)$). By default, the temperature function for maintenance respiration is applied (eq. (10.4)):

$$f_{release}(T) = 0.4281 \cdot e^{(0.57-0.024\cdot T+0.0020\cdot T^2)} - e^{(0.57-0.042\cdot T-0.0051\cdot T^2)}$$

This will give a rate of 1 at 20°C, slightly above 2 at 30°C, and a bit below 0.5 at 10°C.

The carbon is then allocated between shoot and root according to the partition defined, see section 10.4.3.

Root penetration at emergence is given by the parameter *DptEmr* which, by default, is set to 10 [cm].

10.5 During the growing season

After emergence, photosynthesis is the major process, so the distribution of the canopy is very important. The canopy distribution is also relevant, if two crops are competing for light. The assimilate is used for respiration and for building the different plant organs. Towards harvest time, senescence steps in, and some of the plant organs decays. These different processes are described below.

10.5.1 Plant Height

Plant height is generally a simple, stepwise linear function of DS. It is defined with the plf *HvsDS* [DS -> cm], pre-defining the height at certain DS-values and interpolating linearly. Thus, the plant does not react to poor growing conditions.

However, it is possible to use the plf *HvsWStem* [g DM m^{-2} -> <fraction>], describing a relative crop height as function of stem weight. The default setting is: (*HvsWStem* (0 [g DM/m^2] 0.1 [ ]) (200 [g DM/m^2] 1 [ ])), thus requiring that the plant reaches stem weight of 200 g DM m^{-2} to reach full height.

10.5.2 Distribution of the canopy

Leaf Area Distribution (LAD)

The canopy structure is defined by the Leaf Area Distribution (LAD) as function of plant height. The leaf area index (L_{ai}) is the integral of LAD over height. If we have more than one crop, the distributions can be added to a composite canopy, and this is important with respect to competition for light.

The LAD is described by a row of three numbers (*Z1, Z2 and Z3*). *Z1* is the fraction of the height where the lowest leaves are present. *Z2* and *Z3* are the fractions of the height between which the highest leaf density is found. The highest point in the distribution always equals the plant height. The LAD is described at emergence (*LAIDist0*) and at *DS=1* (*LAIDist1*). Between the two growth stages, a linear development is assumed.

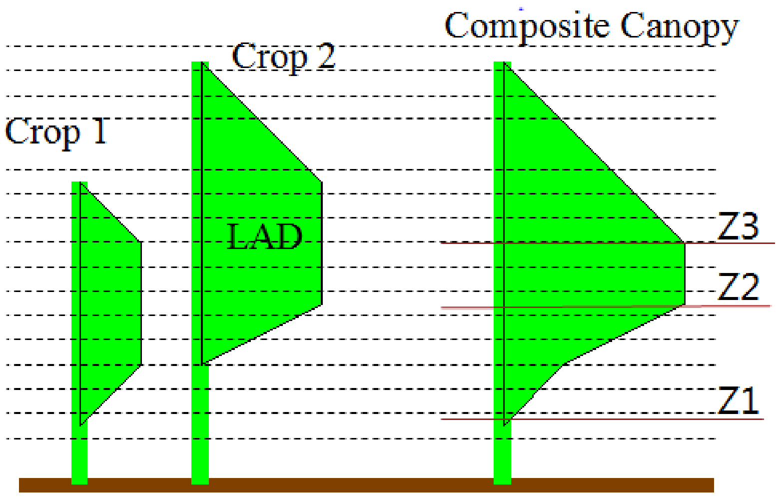


Figure 10.2. Two crops with different Leaf Area Distributions, combined to a composite canopy. The fractions of plant height, Z1, Z2 and Z3, used to describe the crop canopy, are indicated.

Example:

(0,0,1) describes a system where Z1 and Z2 are both located at ground level and Z3 at the top of the plant. In this case the leaves are evenly distributed along the whole height of the plant.

(0.1, 0.8, 1) describes a system where there are no leaves on the lower 10 % of the stem and between 0.1 and 0.8, there is a linear increase in leaf density. The maximum leaf density is present in the upper 20 % of the crop height.

(0.1, 0.6, 0.9) describes a system where there are no leaves on the lower 10 % of the stem and between 0.1 and 0.6 there is a linear increase in leaf density. The maximum leaf density is present between 60 and 90% of the crop height. Between 90 and 100 % of the height the leaf density decreases linearly from max to 0.

As mentioned earlier, the LAD and crop height is particularly important if crops are grown together, as they will govern the light distribution between the crops. Together with the specified stubble height, LAD and crop height also influence the amount of leaf dry matter harvested.

Calculation of Leaf Area Index (LAI)

The actual leaf area index (LAI) at a specific time is calculated as

$$L_{ai} = S_{la} \cdot f_{Sla}(DS) \cdot W_{leaf} \tag{10.5}$$

where

L_{ai} = LAI [m^2 m^{-2}],

S_{la} = specific leaf area (*SpLAI*) [(m^2 m^{-2})/(g DM m^{-2})].

$f_{Sla}(DS)$ = a modifying plf (*LeafAIMod*) [DS-><none>] that allows S_{la} to change as a function of DS.

W_{leaf} = leaf weight, updated hourly based on photosynthesis [g DM m^{-2}].

Stem and storage organs may also contribute to the efficient LAI. Their contributions are calculated analogous to the contribution from the real leaves using specific area, a modifier function and weight for stem and storage organs, respectively. In addition, weight factors accounting for the different photosynthetic efficiencies of stem and, storage organs are used in the calculation of the Crop Area Index (CAI). The weight factor is calculated as the ratio between the photosynthetic rates at saturated light intensity for the stem or storage organ and the corresponding value for the leaf. *SOrgPhotEff* and *StemPhotEff* [ ] are the relative photosynthetic efficiency of the storage organ and stem, respectively. If the necessary parameters are missing, then the contribution from stem or storage organs is neglected. The actual Leaf Area Distribution is calculated from CAI and the predefined relative LAD distribution, described above.

10.5.3 Photosynthesis

Intercepted radiation and conversion efficiency

Canopy gross photosynthesis of a crop is determined by the amount of photosynthetically active radiation (PAR) intercepted by the crop and by the efficiency by which the absorbed radiation energy is converted into chemical energy in terms of carbohydrates. In a natural environment, the flux density of photosynthetically active radiation varies considerably in time and space within the crop canopy. Consequently, the amount of energy in photosynthetically active radiation intercepted by the crop as well as the efficiency by which the intercepted radiation energy is converted to chemical energy also vary considerably in time and space within the crop canopy. In the default model, such spatial variations in the crop canopy and temporal variations over a day are integrated to yield an integrated value of daily absorbed photosynthetically active radiation energy and an average daily value of the radiation conversion efficiency.

Daisy is equipped with a default description of photosynthesis based on Goudriaan and Laar (1978) and a more advanced version based on Farquhar et al. (1980). The default description is found below, while the advanced version is described Appendix 10.3.

Photosynthetically active radiation

The driver of the photosynthesis is photosynthetically active radiation (PAR), which is radiation within the wavelength 400-700 nm. The energy in the radiation within this wave band constitutes a relatively constant fraction of the energy in global radiation (300-2500 nm) which can be expressed as:

$$S_v = f_{PAR} \cdot S_i \tag{10.6}$$

where

S_v = photosynthetically active radiation [W m^{-2}]

S_i = global radiation [W m^{-2}]

f_{PAR} = constant [ ].

In Hansen et al. (1990), the value of f_{PAR} is given to 0.48, but presently the value is hard-coded to 0.50 based on Ross (1975). The fraction of near infrared radiation

(NIR) is hardcoded to 0.47·S_i, referencing the same author. The calculation of S_i during the day is described in in Chapter 2, section 2.2.3 for daily values.

Minimum PAR for photosynthesis

If the amount of PAR received at top of the canopy is less than a minimum value (*min_PAR*, default 0.1 [W m^{-2}]), photosynthesis will be disabled.

Minimum light fraction for crops

When multiple crops are competing for light, a parameter called *min_light_fraction* (default 0 [ ]) can be set, specifying a minimum fraction of the light that the crop (for which it is defined) will receive. The idea is that the field has patches where one crop is dominating, as specified by this parameter, and in these patches, the crop will not have to compete for light. The crop still needs LAI in order to catch the light, though. Competition for water and nutrients is unaffected.

The Gaudriaan and Larr-model

The photosynthesis model is based on the calculation of light distribution within the canopy (or composite canopy) and single light response curves. The light distribution within the canopy is calculated based on Beer's law. The extinction coefficient is assumed to be a characteristic value for a given crop, and so is the reflection coefficient. In the calculation of the light distribution, the canopy is divided into *n* distinct layers each containing 1/*n* of the total CAI. *n* is user defined (under *bioclimate*) and is by default set to 30. By applying Beer's law, the adsorption of light within layer *i*, counted from the top of the canopy, can be calculated as:

$$S_{a,i} = (1-\rho_c)\cdot S_{v,0}\cdot\left(e^{-k_c(i-1)\Delta L_{ai}} - e^{-k_c\cdot i\cdot\Delta L_{ai}}\right) \tag{10.7}$$

where

$S_{a,i}$ = the absorbed light in layer *i* [W m^{-2}],

ρ_c = the reflection coefficient of the canopy (*PARref* []),

$S_{v,0}$ = the incident light above the canopy [W m^{-2}],

k_c = the extinction coefficient (*PARext* []), and

$\Delta L_{ai} = L_{ai}/n$ is the effective crop area index [m^2 m^{-2}] within each canopy layer.

When a canopy consists of more than one crop, the absorbed light allocated to each of the crops in each canopy layer is proportional to the considered crop's contribution to the total CAI within the layer.

Gross photosynthesis is calculated for each individual crop, layer by layer, by applying a light response curve:

$$\Delta F_i = x\cdot\Delta L_{ai}F_m\left(1 - exp\left(-\frac{\varepsilon}{F_m}\cdot\frac{S_{a,i}}{\Delta L_{ai}}\right)\right) \tag{10.8}$$

where

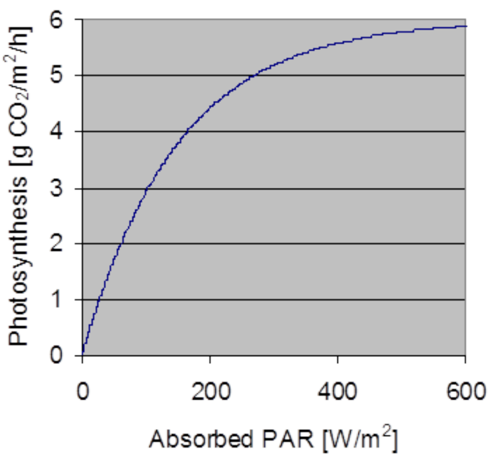
ΔF_i = the gross photosynthesis for layer *i* for the considered crop, [g CO_2 m^{-2} h^{-1}]

x = the CAI fraction of the considered crop [ ]. $x=1$ if only one crop is grown.

F_m = a crop specific leaf photosynthetic rate at saturated light intensity, (Fm) [g CO_2 m^{-2} h^{-1}], and

ε = a corresponding initial light use efficiency at low intensity ($Qeff$, [g CO_2 m^{-2} h^{-1} (W m^{-2})$^{-1}$].

Finally, gross photosynthesis is calculated by accumulating the contribution from the individual layers. The shape of the curve is shown in Figure 10.3. F_m is not a constant, but is assumed to be a function of temperature, as described below. The gross photosynthesis is calculated by accumulating the contribution from the individual layers. The time-step in this part of the model is one hour and the produced assimilates are transferred hourly to the carbohydrate reserves, Figure 10.1.



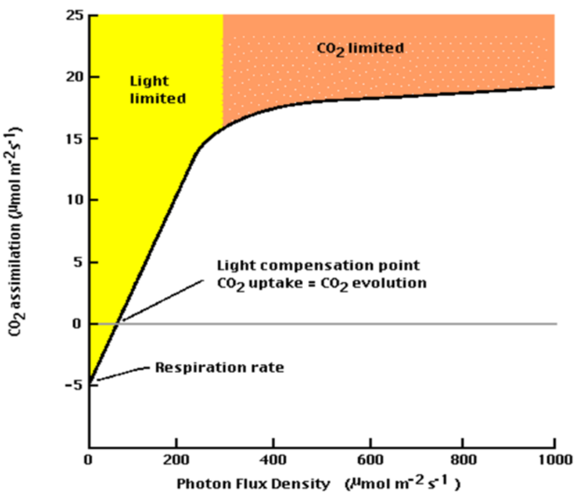


Figure 10.3. On top, the curve used by the standard photosynthesis function in Daisy, and bottom, a description based on plant physiology, as described in the Farquar-model (Appendix 10.3). Q_{eff} corresponds to the slope during the light-limited phase, while F_m equals the maximum rate, where CO_2 is limiting.

Minimum light required for leaves

Leaves require a certain amount of light to sustain them. The available light is reduced as it passes through the leaf layers. Leaves (at the bottom of the canopy) receiving less than $PARrel$, which by default is 5 % of the incoming light, die off (see also senescence, section 10.5.5).

Effects of temperature and senescence on photosynthesis

The efficiency of the photosynthetic system may be influenced by temperature or by plant age. Both relationships are described as plf´s, multiplied onto F_m. The temperature factor ($TempEff$) is crop specific and can be used to describe the relationship between gross assimilate production and temperature. Wang et al. (2017) provided excellent information of this function for winter wheat. The age-factor can be described by $DSEff$, where the gross assimilate production is regulated with plant stage or by $DAPEff$, where the age factor is given as day after planting. Reduced efficiency of photosynthesis with plant age is substantiated in studies of winter wheat (Loreto et al., 1994; Kong et al., 2010), particularly for the later part of the reproductive phase.

Effect of water stress on photosynthesis

Photosynthesis may also be influenced by water and N-stress. The assimilate production when the plant is water stressed may be described as:

$$F_w = F_p \cdot f\left(\frac{E_t + E_i}{E_{t,p} + E_{i,p}}\right) \tag{10.9}$$

where

F_w = water-limited photosynthesis, [g CO_2 m^{-2} h^{-1}]

F_p = potential photosynthesis, [g CO_2 m^{-2} h^{-1}]

E_t and $E_{t,p}$ = actual and potential transpiration, [mm h^{-1}]

E_i and $E_{i,p}$ = actual and potential evaporation of intercepted water [mm h^{-1}]

f = a function that describes the crop response to water stress. Its Daisy name is wse [ ]

The water stress function (wse) may be disabled all together ($none$), it may be described solely by the fraction in the brackets above ($full$), or it may be a modified function ($partial$), which is defined by the relative production level when the fraction in the brackets is 0.5. The water stress function(s) is shown in Figure 10.4 and is defined as:

$$f = \frac{y_{0.5} \cdot (1 - x)}{(1 - 2 \cdot y_{0.5}) \cdot x + y_{0.5}} \tag{10.10}$$

where $y_{0.5}$ is the relative production level [ ] when the water stress fraction is 0.5.

However, before entering into a calibration of water stress, soil and weather conditions must be well described. This also applies to the governing factors for water uptake by the plant such as root development.

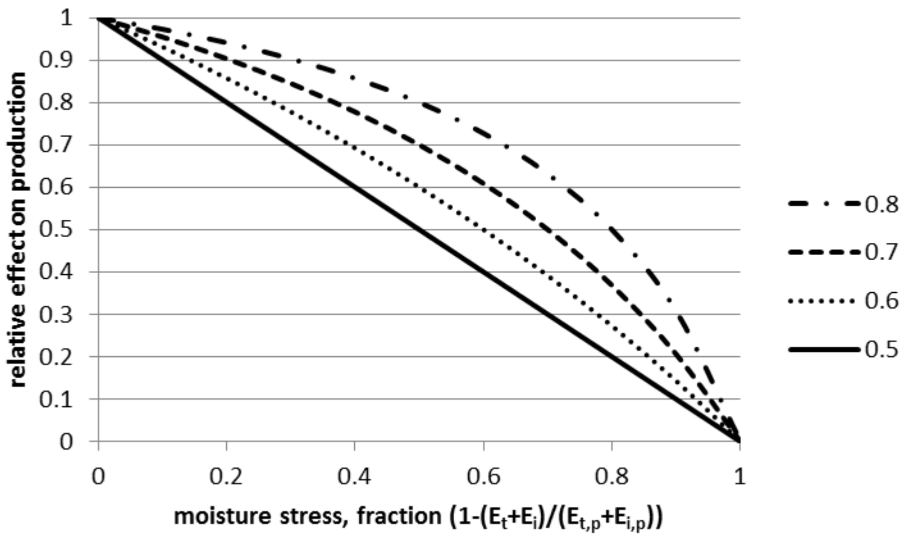


Figure 10.4. Examples of effects of moisture stress on crop growth defined based on the reduction in production at a moisture stress fraction of 0.5. The straight line is equal to the default effect (full).

Effect of nitrogen stress on photosynthesis

The influence of nitrogen status on photosynthesis (f_N) is described in section 10.5, equation (10.18). The factor is multiplied onto F_w in equation (10.9) to obtain $F_{w,N}$, which is the photosynthesis corrected for both water and N-stress.

10.5.4 Respiration and partitioning

10.5.4.1 Maintenance respiration

Respiration is assumed to comprise growth and maintenance respiration (McCree, 1974). Maintenance respiration is assumed to have priority over growth respiration; hence production only takes place if the available carbohydrate reserves exceed the required maintenance respiration. If a surplus of carbohydrate reserves exists, then this surplus is partitioned between the considered crop components, viz. root, stem, leaf and storage organs, and growth respiration is subtracted to calculate net production.

Maintenance respiration is assumed to be proportional to the dry weight of the plant components and each component is assumed to be characterized by a maintenance respiration coefficient, which is temperature dependent:

$$R_m^{component} = r_m^{component} \cdot f(T) \cdot W_{component} \qquad (10.11)$$

where

$R_m^{component}$ = the maintenance respiration of the component as fraction of the dry matter of the organ [g DM m^{-2}],

$r_m^{component}$ = the maintenance respiration coefficient of the component [d^{-1}],

$f(T)$ = the temperature function (eq. 10.12), and

$W_{component}$ = the dry weight of the considered crop component [g DM m^{-2}].

The crop maintenance respiration is the accumulated maintenance respiration originating from the maintenance respiration of the individual crop components.

Temperature relationship for maintenance respiration

The temperature relationship is based on de Vries et al. (1979). It is hard-coded and is described as shown in eq. (10.12) and Figure 10.5:

$$f(t) = max\Big(0.0, 0.4281 \cdot \big(exp(0.57 - 0.024 \cdot T + 0.0020 \cdot T^2) - exp(0.57 - 0.042 \cdot T - 0.0051 \cdot T^2)\big)\Big) \quad (10.12)$$

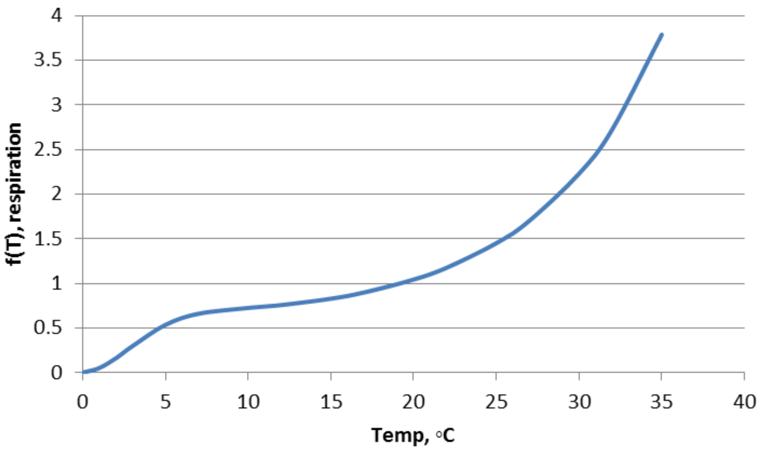


Figure 10.5. The dependency of maintenance respiration on temperature.

10.5.4.2 Partitioning of assimilate and growth respiration

Assimilate partitioning

The model only considers determinate crops. Furthermore, it is, in general, assumed that stress factors do not influence the assimilate partitioning (see later for modification); hence it can be assumed that partitioning is a function of the growth stage (DS) only. In the model the partitioning is described by piecewise linear functions, $\gamma_r(DS)$, $\gamma_s(DS)$, $\gamma_l(DS)$, and $\gamma_o(DS)$, representing the allocation to root, stem, leaf and storage organ, respectively. Note that first $\gamma_r(DS)$ is allocated to the root and then $(1\text{-}\gamma_r(DS))$ is allocated to the shoot, which is assumed to comprise stem, leaf and storage organs. Then the allocation to the shoot is distributed among stem, leaf and storage organ, hence $\gamma_s(DS)+\gamma_l(DS)+\gamma_o(DS)=1$. Thus, $\gamma_o(DS)$ is calculated as a difference. These relationships are illustrated in Figure 10.6.

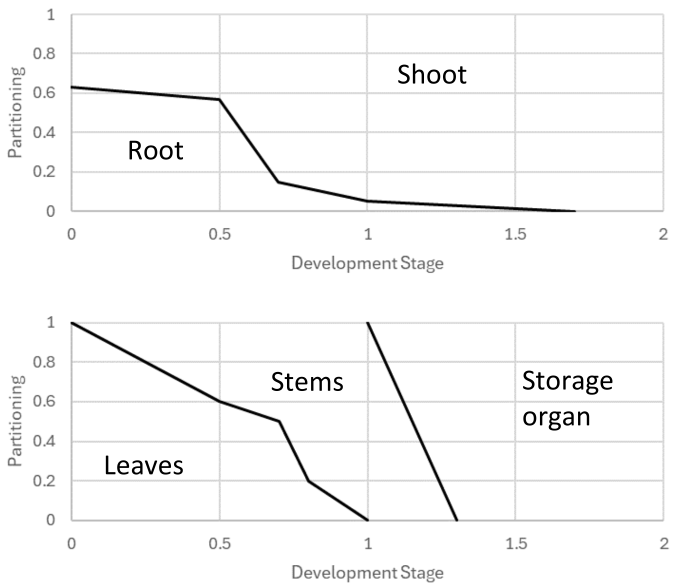


Figure 10.6. Example of partitioning between top: root and shoot, and bottom: individual parts of the shoot as function of the development stage.

Dependency of partitioning on root mass or root/shoot-ratio

The overall partitioning can be modified by various factors. The parameter max_WRoot describes a maximum root dry matter weight as function of development stage (pdf [DS ->g DM m^{-2}]). If the root DM is above this, no assimilate will be allocated to the roots despite the general partitioning rules described above. Also, a maximum root/shoot ratio (RSR) can be defined as a function of DS. If the root/shoot ratio is above this value, the roots will start dying. This is typically used in connection with crops such as grass that are cut, which leads to an abrupt change in root/shoot ratio, see section 10.5.6.

Dependency of partitioning on N

The nitrogen content can influence partitioning in a simple and a more complex manner in the model:

- A nitrogen stress limit can be set, ensuring that if the limit is crossed and DS is above 1, all assimilate is allocated to the storage organ. The default value is 1, at which point there is no production either, so the limit must be reduced to take effect. For calculation of the stress index, see section 10.7.
- In 2020, a function allowing the N-content of the plant to influence partitioning was introduced (Gyldengren et al., 2020). The function is also described in section 10.7.

Growth respiration

The growth respiration rate is assumed to depend only on the end-product formed when assimilate is converted to other substances; hence it can be characterized by a conversion efficiency. After subtraction of growth respiration, the net production for a specific crop component yields:

$$\frac{\Delta W_{component}}{\Delta t} = E^{component} \cdot \gamma^{component} \left(F - \sum_{j}^{components} R_m^j \right) \qquad (10.13)$$

where

$(\Delta W/\Delta t)$ = the net production rate [g DM d^{-1}],

$E^{component}$ = the conversion efficiency [ ],

$\gamma^{component}$ = fraction of assimilate allocated to the considered crop component (component = root, leaf, stem, and storage organ) [].

F = the assimilate flow from the carbohydrate reserves [g DM d^{-1}]. F is released from the carbohydrate reserve pool using 1st order kinetics. The release rate (*CH2OReleaseRate*) is by default set to 0.04 [h^{-1}].

Remobilisation

During the reproductive phase, plants may reallocate dry matter resources from the stem to the storage organ. The parameter *ShldResC* [] describes the fraction of stem dry matter that can be classified as “reserve to be mobilised”. *ReMobilDS* [DS] is the DS-value at which the remobilization can be initiated. Remobilization is a first-order process with the rate described via the parameter *ReMobilRt* [d^{-1}]. In Daisy, the reallocation takes place without an additional conversion cost.

10.5.5 Senescence

Root and leaf death

As indicated in Figure 10.1, it is assumed that root and leaf material is lost during growth due to senescence and shading. The rate at which dry matter is lost is assumed to be proportional to the root and leaf weight, respectively. The basic senescence functions are the plf-functions *RtDR* and *LfDR*, which specify the death rate of roots and leaves [d^{-1}], respectively, as a function of DS. The root death rate may also depend on temperature and the root/shoot ratio. This is further described in section 10.6. Root death also depends on waterlogging, but this is not yet fully implemented in Daisy.

The parameter *ExfoliationFac* [h^{-1}] regulates the loss of dead leaves from the plant to the surface. The default value is 1, causing all dead leaves to fall to the ground in a timestep.

Leaf death due to too little light

Leaves may also die when the irradiance received by the lower shaded leaves falls below a certain threshold (*PARrel*), i.e. when transmission of light falls below a predefined value, typically around 5 % (Monteith and Unsworth, 1990). The death rate is calculated internally in the model by first estimating the CAI required for reaching PARrel (*CAIm = -ln(PARrel)/PARext*), and then defining a parameter that measures if *CAIm* is larger than CAI, and if so, how much: *(CAImRat = max(0.0; (CAI-CAIm)/CAIm)*). If the default values for *PARrel* and *PARext* are applied

$CAImRat$ only becomes positive around a LAI-value of 5. The hourly death rate due to shading is now calculated as *(the dry weight of leaves)·0.333·CAImRat/24* [h^{-1}].

Finally, gross photosynthesis can be reduced due to senescence. This is introduced by multiplying the photosynthetic rate at saturated light intensity (F_m) by a reduction factor that is a function of DS, as already described in section 10.4.2.

10.6 Roots

The root system is characterized by root weight, root depth, and root length density distribution.

Root depth

At emergence, the root depth is defined by the parameter *DptEmr*, which by default is 10 [cm]. In order to penetrate further down, the following conditions should be fulfilled:

1. The daily net root production must be positive,
2. The soil temperature at the root tip is above a certain threshold temperature (by default 4°C), and
3. The actual rooting depth must be less that the maximum rooting depth.

The maximum rooting depth is determined either by the plant species itself (*MaxPen*) or by the chemical or mechanical properties of the particular soil considered (determining the parameter *MaxRootingDepth*). When the conditions above are fulfilled, the daily root growth can be described as (Jacobsen, 1976):

$$\frac{\Delta d_r}{\Delta t} = \begin{cases} 0 & T_s \leq T_p \\ \alpha_r \cdot (T_s - T_p) & T_s > T_p \end{cases} \tag{10.14}$$

where

$\Delta d_r/\Delta t)$ = the increment in root depth [cm] in the timestep [d^{-1}]

T_s = the soil temperature at the root tip [°C],

T_p = the threshold temperature (*PenPar2* [d°C]) and

α_r = the root penetration parameter (*PenPar1* [cm °C^{-1} d^{-1}]). The rate of penetration can be modified using plf-functions to describe the influence of clay, water and development stage.

The modifier functions that can be multiplied onto α_r are:

- *PenClayFac*, which allows modification of root penetration as a function of clay content (crop specific),
- *PenWaterFac*, which allows modification of root penetration as a function of relative water content (crop specific),
- *PenpFFac*, which allows modification of root penetration as a function of the pF of the soil (crop specific),
- *PenDSFac*, which allows modification of the root penetration depending on the development stage of the crop,
- *root_retardation*, a factor defined for a specific horizon and thus works on all crops with roots penetrating that particular horizon.

The water-related factors are useful to describe lower penetration in dry soil or in very wet soil. However, the retardation factor does not cause root death. The DS-dependent modifier has been used to slow down root growth in the early part of the vegetative phase to slow down uptake of water and N. McCully (1995) showed that water and nitrogen is only taken up some distance between the root tip, as it takes time to develop the necessary xylem, and it was attempted to use this factor to mimic the depth of the active root zone rather than the depth to the tips of the root. The *root_retardation* factor could be relevant for e.g. a plough layer, or it could be used to speed up root growth through macropores, where the resistance is small.

Root distribution

There are a number of root distribution functions included in Daisy. The distribution of roots with depth follows by default an exponential function described by Gerwitz and Page (1974). In this case, the total root length must obey two functions. First, the total root length is proportional to root weight (which is calculated based on allocation of assimilates and root respiration) and can be calculated using the specific root length:

$$l_r = S_r \cdot W_r \tag{10.15}$$

where

l_r = total root length [m m^{-2}]

W_r = root dry matter [kg m^{-2}]

S_r: = specific root length [m kg^{-1}], by default 100 [m g^{-1}])

Secondly, the root length at a given depth can be described using a logarithmic function:

$$L_z = L_0 \cdot e^{-a_z \cdot z} \tag{10.16}$$

where

L_z = root density at soil depth z [m m^{-3}]

L_0 = root density at soil surface [m m^{-3}]

z = soil depth [m]

α_z = root density distribution parameter [m^{-1}]

The total root length is then the integration of the root density in the root zone and equal to the total length calculated above:

$$l_r = S_r \cdot W_r = \int_0^{d_r} L_z \cdot dz = \frac{L_0}{a_z} \cdot \left(1 - e^{-a_z d_r}\right) \tag{10.17}$$

where

d_r = root depth [m].

Assuming that the root density at the potential rooting depth (L_d) is 0.1 [cm cm^{-3}], the equation can be solved for α_z and L_0 for each time step (Gerwitz and Page, 1974).

If the root depth is limited by soil properties, then the actual root density distribution is calculated again by assuming the Gerwitz and Page distribution and setting the root density at the actual rooting depth equal to the density obtained from the potential distribution at this depth, see Figure 10.7.

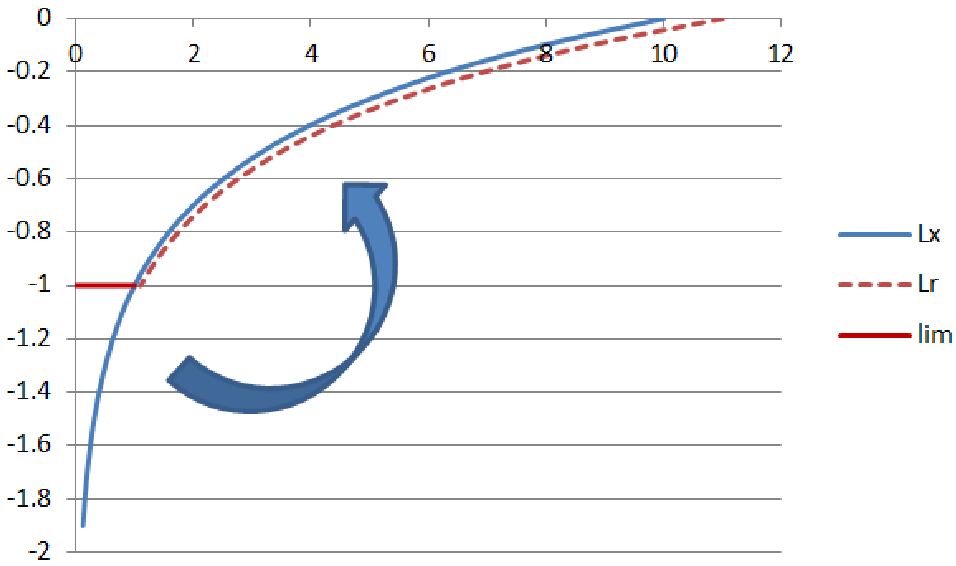


Figure 10.7. Redistribution of root mass if the penetration is limited by soil properties. The blue line shows the distribution without limitation, while the red curves show the same root mass redistributed due to a limiting layer at 1 m's depth.

The main parameters determining the root growth and distribution are therefore T_p, α_r and the S_r, the specific root length, as well as the allocation of assimilates to the roots, determining the total biomass.

The Gerwitz and Page-option also contain a parameter for minimum root density (*MinDens*, default 0 [cm cm^{-3}]). Root density will never be below this value, as long as there is enough root mass. Any extra root mass will be distributed according to Gerwitz and Page. If the root mass is too low, the root will have the same density from top to bottom.

Uneven root distribution

Observations of roots show that roots in some cases prefer preferential flow paths and therefore are not uniformly distributed. The factor *root_homogeneity* may be multiplied onto the root density of all crops in a given horizon, reducing the efficiency of water and nutrient uptake. *DensityDSFac* is a similar parameter (factor) but based on DS for effective root density and thus works on the whole root system. It is particularly relevant in the first growth phase, where roots do not cover the total area, as implicitly assumed in the model.

Other root descriptions

Several root density models are available, but generally not well tested. They are briefly described below.

Anders Pedersen

The *Anders Pedersen* option is based on the Gerwitz and Page-description, but the "a"-parameter in eq. (10.16) is user-specified as a function of DS. In this case, the root density at L_d is calculated by the model. A parameter "q" specifies an extra rooting depth below the L_d, and between L_d and $L_d + q$, the root density decreases linearly to 0.

DS_Depth

DS_Depth requires specification of the root density as a function of development stage. The option requires a list of pairs, where the first element of each pair is a development stage, and the second element is a PLF specifying the relative root density as a function of soil depth in cm (a positive number). To find the absolute root density, Daisy will interpolate the relative root density distribution specified for the entries before and after the current development stage, and scale them to match the current total root mass.

DS_Rel

DS_Rel is similar to *DS_Depth*, except that the depth is specified relative to the total soil depth. It requires a list of pairs, where the first element of each pair is a development stage, and the second element is a plf, specifying the relative root density as a function of soil depth relative to the total depth. To find the absolute root density, Daisy will interpolate the relative root density distribution specified for the entries before and after the current development stage, and scale them to match the current total root mass.

Depth_Depth

The *Depth_Depth*-option describes root density as a function of the changing root depth over the season. It requires a list of pairs, where the first element of each pair is the root depth, (a positive number), and the second element is a plf specifying the relative root density as a function of soil depth in cm (a positive number). To find the absolute root density, Daisy will interpolate the relative root density distribution specified for the entries before and after the current development stage, and scale them to match the current total root mass.

GP1D

The GP1D-option is similar to the Gerwitz and Page-option, but the solution method is different (see Appendix 10.2). The function takes two parameters: *DensRtTip* with the same default as used in the Gerwitz and Page option (0.1 [cm cm^{-3}]) and an optional parameter (*DensIgnore* [cm cm^{-3}]), which sets a minimum value for root density in cells that should be considered for root calculations. By default, the value is the same as *DensRtTip*.

GP2D

The GP2D-option is an exponential function for root density in row crops. It is a two-dimensional model (z,x), where the z-axis is vertical, and the x-axis is horizontal and orthogonal to the row. The row is assumed to be uniform (dense), allowing us to ignore that dimension. It is assumed that the root density decreases with horizontal distance to the row, as well as with depth below the row. In addition to the two parameters specified for GP1D, it requires the location of the plant row in the 2-D-model (default 0 [cm]), and the distance between rows of crops [cm]. For details, see Appendix 10.2.

Root death

Roots may die off over time, particularly in the later stages of the growing period, as described in section 10.5.5. The death rate of roots [d^{-1}] as function of DS is specified as a plf, e.g.

(RtDR (0.00 0.00) (0.60 0.00) (1.20 0.01) (2.00 0.01))

In this case, 1 % of the root biomass dies off every day between DS-stage 1.2 and 2. The root death rate can be made temperature dependent by applying a temperature factor (*RtDR_T_factor*, default = 1), specifying the modifying factor as a function of temperature [°C]. Root death may also take place if the root biomass becomes too large compared to shoot biomass, for example when the above-ground vegetation is cut. The limiting root-shoot-ratio (*RSR*) is a plf specifying the maximal root/shoot ratio as a function of development state. If the root/shoot ratio is above this, the roots will start dying with the rate *Large_RtDR*, which by default is 0.05 [d^{-1}].

Roots as storage organ for growth

Some crops build up reserves in the root during their first growth year and use those to boost growth in the second year. This can be simulated by specifying an initial and an end DS value for release of root reserves (*IntDSRelRtRes* and *EndDSRelRtRes*, respectively, both by default = 0.8), as well as a release rate for root reserves (*RelRateRtRes*, default = 0.05 [d^{-1}]). A maximum leaf/root ratio can be set for this transfer process (*LfRtRelRtRes*, default = 0.8] to avoid imbalance between shoot and root.

Linking roots to water and N-uptake

The root depth, density and distribution determine the possible uptake of water and nitrate/ammonium in a given soil. These processes are described elsewhere (Chapter 4 and Chapter 7). Particularly three root-related input parameters are important for water uptake. These are *Rad*, the effective root radius, which by default is 0.005 [cm], *h_wp*, representing the matrix potential at wilting point (-15000 [cm] by default) and *Rxylem*, which is the transport resistance in the xylem [ ]. The two first are hardly ever changed. The last parameter influences the uptake of water from the soil and detailed measurements of weather and soil conditions, including continuous recording of moisture conditions or soil suction is required for calibration. The maximum rates for uptake of NH_4^+ and NO_3^- ($2.5 \cdot 10^{-7}$ [$g\ cm^{-1}\ h^{-1}$] are also given as root parameters (and are explained in Chapter 7.7).

10.7 Nitrogen in the plant

The uptake of nitrate and ammonia in the plant is determined by demand and supply. This is described in Chapter 7.7. The growth of the plant, however, depends on to which extent certain concentrations of N are reached in the different organs. The plant model in Daisy considers four governing concentrations for each organ: the potential (C_{pot}), the critical (C_{crit}), the non-functional (C_{nonf}) and the actual concentration (C_{act}) [g N (g DM)$^{-1}$].

- The potential concentration (C_{pot}) is the highest concentration that will drive the N-uptake, as described in Chapter 7.7.
- The critical concentration (C_{crit}) is the concentration below which growth is subject to N-stress. N-uptake between C_{crit} and C_{pot} is luxury uptake.
- The concentration below which the plant will die (C_{nonf}). At this concentration, the plant will be extremely stressed. Between C_{nonf} and C_{crit} the plant is subject to N-stress.

The actual crop content can be calculated as: $N_{act} = \sum W_i * C_{act,i}$, where N_{act} is the actual N-content [g N m^{-1}], W_i is the weight of plant organ i [g DM m^{-2}], and $C_{act,i}$ [g N (g DM)$^{-1}$] is the actual concentration of N in plant organ i. The potential crop content, the critical crop content and the non-functional crop content are calculated in a similar fashion, using the respective concentrations, which are described as plf-functions of the development stage (DS).

There is, in practice, only one nitrogen pool in the simulated plant, and the nitrogen is allocated to each plant organ proportionally to the concentration requirements specified for each organ in each timestep.

N-stress

In the default description, plant growth is not affected by the N-concentration as long as $N_{act} \geq N_{crit}$. If N_{act} is lower than N_{crit}, the plant will be subject to N-stress, which influences the photosynthesis. In that case, the carbon assimilation will be reduced by the fraction:

$$f_N = \frac{N_{act} - N_{nonf}}{N_{crit} - N_{nonf}} \qquad (10.18)$$

It is possible to disable N-stress by setting *enable_N_stress* to *false* under the *crop* component.

N-affected partitioning

To take into account the observations that the N-status of the plant may influence the partitioning of assimilate between stem and leaves, a new sub-model was added to Daisy in 2020 (Gyldengren et al., 2020). It builds on an empirical model proposed by Ratjen and Kage (2016), which relies on earlier work (Poorter et al., (2012) and Ratjen et al. (2016)). The function required a new state variable, NNI:

$$NNI = \frac{N_{act}}{N_{crit}} \qquad (10.19)$$

The modifying function by Ratjen and Kage (2016) is described as:

$$cf(t) = max(1; 1 + (NNI_{crit} - NNI) \cdot NNI_{inc}) \qquad (10.20)$$

where NNI_{crit} and NNI_{inc} are parameters set by the user. By default, both are 0. *cf(t)* is multiplied onto the partitioning fraction for the stem. When used in the growth model, this function implies that at an NNI below a certain threshold, NNI_{crit}, the default partitioning of assimilated dry matter to the stem fraction increases, and this increase can be described as a fixed fraction, NNI_{inc}, of the current N deficit below NNI_{crit}. When the assimilate allocation to the stem is increased, the allocation to leaves is reduced accordingly. This means that the default partitioning reflects the partitioning in an N-unlimited situation. Ratjen and Kage (2016) determined the values of NNI_{crit} = 1.38 and NNI_{inc} = 0.6 for winter wheat , while Gyldengren et al. (2020) obtained the best fit to observations with the values NNI_{crit} = 1.50 and NNI_{inc} = 0.55 for winter wheat.

As stems commonly have lower N-concentrations than leaves, the function tends to reduce the N-stress experienced by the simulated plant. On the other hand, less leaves tend to reduce photosynthesis and thus total dry matter production.

Translocation efficiency

When leaves and roots die, they still contain a certain amount of N. Some of this is moved back into the plant using parameters for translocation efficiency (for N), but only the amount $(N\text{-}N_{nonf})$ can be moved. The N-translocation efficiency for leaves (*TLLeafEff*) is a plf linking the fraction of movable N, that is retained in the plant, to DS. By default, this parameter has a constant value of 0.9. Thus 90 % of the N-content above N_{nonf} will be retained in the plant when the leaves die.

The N-translocation efficiency for roots, *TLRootEff*, is described similarly, but has a default constant value of 0.1. Thus, only 10 % is retained in the plant when the roots die.

Fixation of nitrogen

Leguminous plants may, in combination with rhizobium bacteria, fixate nitrogen from the air. It is possible to define a DS-value, where the fixation of atmospheric N will start (*DS_fixate* [-], (default = 42000, so the parameter is only active if specified differently) and a fraction describing to which degree, the potential N-uptake will be covered by fixation (*fixate_factor*, default = 0.8 [h^{-1}]).

After a cut of the fixating crop, the fixation of nitrogen may be restored using the parameter *DS_cut_fixate*, specifying the DS after which the fixation should be restored. Its default value is 0 [-]. The parameter *DS_start_fixate* is a state variable keeping track of whether *DS_fixate* or *DS_cut_fixate* is active.

Parameters described elsewhere

The parameters *NO3_root_min*; *NH4_root_min*, *NO3_root_min_luxury* and *NH4_root_min_luxury* (all [g N cm^{-3}]) relate to uptake of N by roots and are described in chapter 7.7.

10.8 At harvest

The harvest action

The harvest operation itself is a management operation (action; see Chapter 11). The harvest operation requires specification of which crop to harvest. The default is “all”, meaning all crops on the field. It is also necessary to specify stub height (default 0 [cm]), and the fractions of stem, leaf and storage organ above stub to be harvested. The default for all of these is 1 [-]. A boolean parameter, *combine* (default false), can be set that, if true, combines all crop parts into “stem” in the harvest log files. This is mostly useful for silage. A *cut* (of e.g. grass) is also a type of harvest operation.

AOM-allocation

The fixed component *Harvesting* allows specification of a range of parameters related to the plant and plant material at harvest. First, it allows specification of the AOM-pools to which the left-over materials of root, stem, leaves, dead material and storage organ should be allocated. This is further described in

Economic yield

Chapter 9.6. Secondly, it allows specification of *EconomicYield_W* and *EconomicYield_N*, which are the fractions of dry matter and N in the storage organ that is harvested as yield. For example, for grain crops, the thrashing process removes chaffs and husks from the grain itself, thus reducing the weight of the yield compared to the simulated storage organ. As most of the N is usually in the storage organ itself, the N-fraction in the yield may be higher than the dry-weight fraction. The default value for *EconomicYield_W* is 1 [-] and if nothing else is specified, the value for *EconomicYield_W* is also used for *EconomicYield_N*.

Re-growth possibilities

For crops that are harvested in their vegetive stage, the latest development stage, where the plant can survive harvest or cutting can be set (*DSmax*, default = 0.8 []). After the harvest operation DS will by default be set back to the DS where an uncut crop would first reach the height it now has after the cut. Thus, it uses the inverse function of the HvsDS Canopy parameter to find the new DS. Optionally, the DS-value after the harvest operation can be specified as *DSnew*.

Crop cuts may result in depressed production. A delay in production after cuts may be specified (*cut_delay).* This is a plf [kg DM ha^{-1} ->d] linking the shoot dry matter removed by harvest with a production delay in days. By default, there is no delay.

In most cases (and as default), the storage organ is assumed to be located far above the ground. If this is not the case, the parameter *sorg_height* [cm] can be set. If it is a negative number (root crops), this will cause harvesting to imply a suitable tillage operation, and guarantee that harvest will kill the plant.

The harvesting component also includes a state variable for total water use, keeping track of the total evapotranspiration since emergence. This is useful for calculation of water use efficiency (kg yield produced per m^3 of water evaporated), which is an output in the harvest log-file. Similarly, the harvest index (HI= dry matter yield per total above-ground biomass produced) is calculated based on the biomass components at harvest and reported in the harvest log-file.

10.9 Parameter overview

Table 1.1. Related Parameter names in Daisy.

Name and explanation		**Model (in Daisy)**	**Parameter name (Daisy reference manual)**	**Default**	**Default unit**
Permanent vegetation	Simple vegetation model for permanent vegetation	Vegetation	*permanent*		
afforestation	Simple vegetation model for growing permanent vegetation	Vegetation	*afforestation*		
Crops	Model for crops in the field	Vegetation	*crops*	Default vegetation model	
β	Parameter used to redistribute unused soil evapotranspiration to transpiration, see eq. (3.39) in Ch. 3.3.	Vegetation	*EpInterchange*	0.6	[ ]
Height	Pre-defined height for permanent vegetation	permanent	*Height*	80	[cm]
Root dry matter	Pre-defined amount of root dry matter	permanent, afforestation	*Root_DM*	2	[Mg DM ha^{-1}]
LAI description	Distribution of LAI over the year as function of Julian day.	permanent	*LAIvsDay*	User-defined plf	[yday->m^2 m^{-2}]
LAI description	Sequence describing LAI development over several years combining year with *LAIvsDay*	permanent	*YearlyLAI*	User-defined sequence < *year LAIvsDay* >	
LAI factor	Multiplication factor for LAI function for easy scaling	permanent	*LAIfactor*	1	[ ]

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
DM/LAI-ratio	Dry matter content per LAI-unit	permanent	*DM_per_LAI*	0.5	[Mg DM ha^{-1} LAI^{-1}]
N/LAI-ratio	Nitrogen content per LAI-unit	Permanent, afforestation	*N_per_LAI*	10	[kg N ha^{-1} LAI^{-1}]
litter turn over	Litter turn-over parameters for dead material on the surface (Ch. 9)	Permanent, afforestation	*litter_am*	AOM-SLOW, AOM-FAST, see Ch. 8.	
Albedo	Light reflection factor	Permanent, afforestation	*Albedo*	0.2	[ ]
Root turn-over	Root turn-over parameters for rhizodeposition (Ch.9).	afforestation	*root_am*	AOM-SLOW, AOM-FAST, see Ch. 8.	
Planting time	Reference time for yearly growth parameters	afforestation	*planting_time*	User specified	
Canopy height	Description of forest height as function of years after planting	afforestation	*canopy_height*	User specified plf	[y->cm]
Root depth	Depth of the effective root zone as a function of years after planting. **NB: Not active in the model.**	afforestation	*root_depth*	User specified plf.	[y->cm]
LAI shape function	LAI factor as a function of Julian day.	afforestation	*LAI_shape*	User specified plf. The value “1” represents LAImin and the value “5” represents LAImax for the specific year	[d->none]

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
Yearly LAI min	Yearly minimum LAI as a function of years after planting	afforestation	*LAI_min*	User specified plf	[y->m^2 m^{-2}]
Yearly LAI max	Yearly maximum LAI as a function of years after planting	afforestation	*LAI_max*	User specified plf	[y->m^2 m^{-2}]
N not in leaves	Nitrogen not accounted for by seasonal LAI-variation as function of years after planting.	afforestation	*N_nonleaves*	User specified plf	[y->kg N ha^{-1}
Litterfall shape function	Relative speed of litterfall over a year	afforestation	*litterfall_shape*	User specified plf	[d-><none>]
Total litterfall	Yearly litterfall as function of years after planting	afforestation	*litterfall_total*	User specified plf.	[y-> Mg DM ha^{-1}]
C-content in DM of litter	Carbon content of litter dry matter	afforestation	*litterfall_C_per_DM*	Default = 0.42	[ ]
C/N ratio, litter	C/N ratio of litter	afforestation	*litterfall_C_per_N*	User specified	[ ]
Rhizodeposition shape function	Relative speed of rhizodeposition over a year	afforestation	*rhizodeposition_shape*	User specified plf	[d-><none>]
Total rhizodeposition	Yearly rhizodeposition as function of years after planting	afforestation	*rhizodeposition_total*	User specified plf.	[y-> Mg DM ha^{-1}]
C-content in DM of rhizodeposition	Carbon content of rhizodeposition dry matter	afforestation	*rhizodeposition_C_per_DM*	Default = 0.42	[ ]

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
C/N ratio, rhizodeposition	C/N ratio of rhizodeposition	afforestation	*rhizodeposition_C_per_N*	User specified	[ ]
$\boldsymbol{\rho_c}$	Reflection of PAR, eq. 10.7.	CanopySimple CanopyStandard	*PARref*	0.06	[ ]
$\boldsymbol{k_c}$	PAR extinction coefficient, eq.10.7	CanopySimple, CanopyStandard	*PARext*	0.6	[ ]
	Reflectance of near infrared light	CanopySimple, CanopyStandard	*NIRref*	0.51	[ ]
	NIR extinction coefficient	CanopySimple, CanopyStandard	*NIRext*	0.18	[ ]
$\boldsymbol{K_l}$	Extinction coefficient used for transpiration, eq. (3.35)	CanopySimple, CanopyStandard	*EPext*	0.5	[ ]
$\boldsymbol{C_i}$	Interception capacity for canopy, eq. (3.19).	CanopySimple, CanopyStandard	*IntcpCap*	0.5	[mm]
$\boldsymbol{k_{c,canopy}}$	Scaling factor for transpiration, eq. (3.36)	CanopySimple, CanopyStandard	*EpFac*	1.2	[ ]
	Potential evapotranspiration factor for wet surface	CanopySimple, CanopyStandard	*EpFacWet*	Default=*EpFac*	[ ]
	DS-dependent potential evapotranspiration factor	CanopySimple, CanopyStandard	*EpFacDS*	User defined plf, by default constantly equal to 1.	[ ]
	Maximum transpiration resistance	CanopySimple, CanopyStandard	*rs_max*	Default = 100000	[s m^{-1}]
	Minimum transpiration resistance, used by the	CanopySimple, CanopyStandard	*rs_min*	Default = 100	[s m^{-1}]

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
	Penman Monteith equation when calculations are made for the actual field crop (not reference) and in SSOC.				
Leaf width	Used by the SSOC-model for calculation of boundary layer conductance of sunlit and shaded leaves, as well as for calculation of soil aerodynamic conductance.	CanopySimple, CanopyStandard	*leaf_width*	User defined plf, default = constant value of 3	[DS-> cm]
ForcedLAI	Submodel that combines *year* with *LAIvsDAY* allowing substitution of simulated with measured LAI.	crops	*ForcedLAI*	Default: an empty sequence of year (to use forced LAI) *LAIvsDAY* (plf)	 [yday->m^2 m^{-2}]
Crop stages	Growth stages in Daisy. Only sowing (-1), 0, 1 and 2 have meaning	cstage	*Daisy*	This model is default in *crop*	
- ***BBCH***	Linking DS with BBCH	cstage	*BBCH*	User defined table, default is the DS-scale	
Crop to establish	Name of the crop to establish	action: sow	*crop*	User defined	
Seed weight	Amount of seed applied	action: sow	*seed*	Optional parameter. By default, initial growth is	[g w.w. m^{-2}]

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
				governed by a "typical" seed amount	
Row width	Distance between rows	action: sow	*row_width*	Default = 0 specifies uniform seed distribution = no rows.	[cm]
Plant distance	If set, overrules row_width. Only used in 2D-simulations, where the x-axis is parallel with the row.	action: sow	*plant_distance*	Optional parameter	[cm]
Row position	Position of plant row on x-axis.	action: sow	*row_position*	Default = 0 (indicating uniform seed distribution = no rows.	[cm]
Plant position	If set, overrules "row position". Only used in 2D-simulations, where the x-axis is parallel with the row.	action: sow	*plant_position*	Optional parameter	[cm]
T_{sum}	Soil temperature at emergence, eq. (10.1)	phenology, default	*EmrTSum*	User defined	[°C d]
$f(h_p)$	Soil moisture effect on emergence	phenology, default	*EmrSMF*	User defined, default: constant of 1	[cm-> none]
DSEmr	Development stage at emergence	phenology, default	*DS_Emr*	Default:0.01	[DS]
d	Development rate in the vegetative stage, eq. (10.2)	phenology, default	*DSRate1*	User defined	[DS d^{-1}]
(d)	Development rate in the reproductive stage.	phenology, default	*DSRate2*	User defined	[DS d^{-1}]

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
$f_t(T_a)$	Temperature effect on development rate, vegetative stage, eq. (10.2)	phenology, default	*TempEff1*	User defined plf	[°C ->none]
$(f_t(T_a))$	Temperature effect on development rate, reproductive stage.	phenology, default	*TempEff2*	User defined plf	[°C ->none]
$f_d(D_l)$	Effect of photoperiod on development rate, vegetative stage, eq. (10.2)	phenology, default	*PhotEff1*	User defined plf	[h->none]
DS_{mature}	Development stage at maturation	phenology, default	*DSMature*	Default = 2	[DS]
DS_{repeat}	At this DS-value, DS is changed to the DS-value specified by *DSSetBack*.	phenology, default	*DSRepeat*	User defined	[DS]
$DS_{SetBack}$	New value of DS when *DSRepeat* has been reached.	phenology, default	*DSSetBack*	User defined	[DS]
	This parameterization is only valid until the specified development stage.	phenology, default	*defined_until_ds*	Default = 2	[DS]
DS_{Lim}	Development stage, where the vernalization requirement sets in	vernalisation	*DSLim*	Default: *none* -option	[DS]
$T_{a,Lim}$	Vernalization temperature threshold	vernalisation	*TaLim*	Default: *none* -option	[°C]

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
$\boldsymbol{T_{a,Sum}}$	Vernalization temperature-sum requirement, eq. (10.3)	vernalisation	*TaSum*	Default: *none* -option	[°C d]
	DS at which the crop area index (CAI) is 0.5. The initial phase is DS≥ this parameter.	seed: LAI	*DSLAI05*	Default = 0.15	[DS]
$\boldsymbol{S_{la}}$ ***,initial phase***	Factor defining maximum specific leaf weight. It is only used in the initial phase. Plf.	seed: LAI	*SpLAIfac*	Default: (SpLAIfac (0 [DS] 3 []) (0.2 [DS] 1.5 []) (0.4 [DS] 1.25 []) (0.6 [DS] 1 []))	[DS->none]
Release rate	Release rate of seed carbon to assimilate pool.	seed: release	*rate*	User specified	[h^{-1}]
$\boldsymbol{f_{release}(T)}$	Soil temperature effect on release rate, eq. (10.4).	seed: release	*T_factor*	By default, the same as for maintenance respiration.	[°C-> <fraction>]
Initial weight	Initial seed weight to use when not specified by the sow operation.	seed: release	*initial_weight*	Optional parameter	[g w.w. m^{-2}]
	Dry matter content in seeds	seed: release	*DM_fraction*	User specified	[ ]
	Carbon fraction of dry matter	seed: release	*C_fraction*	User specified	[ ]
	Nitrogen fraction of dry matter.	seed: release	*N_fraction*	User specified	[ ]
Plant height	Crop height as function of DS	CanopyStandard	*HvsDS*	User specified	[DS->cm]

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
Height modifier	Relative crop height as function of stem weight.	CanopyStandard	*HvsWStem*	By default: (HvsWStem (0 0.1) (200 1)); Thus, 200 g DM m^{-2} is required to reach full height.	[g DM m^{-2}-> fraction>]
Z1, Z2, Z3 at emergence	Relative CAI distribution at emergence (DS=0), see section10.5.2	CanopyStandard	*LAIDist0*	User defined array of 3 numbers	[ ]
Z1, Z2, Z3 at DS=1	Relative CAI distribution at emergence (DS=1), see section10.5.2	CanopyStandard	*LAIDist1*	User defined array of 3 numbers	[ ]
S_{la}	Specific leaf area, eq. (10.5)	CanopyStandard	*SpLAI*	User defined	[(m^2 m^{-2}) (g DM m^{-2})$^{-1}$
$f_{Sla}(DS)$	DS-dependent modifyer function of specific leaf area, active after the initial phase.	CanopyStandard	*LeafAIMod*	User defined plf	[DS-><none>]
	Specific storage organ weight (CAI-contribution)	CanopyStandard	*SpSOrgAI*	Default = 0	[(m^2 m^{-2}) (g DM m^{-2})$^{-1}$
	DS-dependent modifier function of specific storage organ weight.	CanopyStandard	*SOrgAIMod*	User specified plf with default constant value of 1.	[ ]
	Relative photosynthetic efficiency of storage organ.	CanopyStandard	*SOrgPhotEff*	Default = 1	[ ]
	Specific stem weight (CAI-contribution). Only used after the initial phase.	CanopyStandard	*SpStemAI*	Default = 0	[(m^2 m^{-2}) (g DM m^{-2})$^{-1}$

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
	DS-dependent modifier function of specific stem weight.	CanopyStandard	*SpStemAIMod*	User specified plf with default constant value of 1.	[ ]
	Relative photosynthetic efficiency of stem. Only used after the initial phase.	CanopyStandard	*StemPhotEff*	Default = 1	[ ]
PARrel	Relative PAR below canopy at which the bottom leaves will start dying.	CanopyStandard	*PARrel*	Default = 0.05	[ ]
n	Number of vertical intervals in which the canopy is partitioned for light interception calculations	bioclimate	*NoOfIntervals*	Default = 30	[ ]
Minimum PAR	Minimum PAR at top of the canopy for photosynthesis.	photosynthesis	*Min_PAR*	Default = 0.1	[W m^{-2}]
ε	Quantum efficiency at low light, eq. (10.8).	Photosynthesis: GL	*Qeff*	User defined	[(g CO_2 m^{-2} h^{-1}) (W m^{-2})$^{-1}$]
F_m	Maximum assimilation rate, eq. (10.8)	Photosynthesis: GL	*Fm*	User defined	[g CO_2 m^{-2} h^{-1})]
TempEff	Temperature factor for assimilate production	Photosynthesis: GL	*TempEff*	User defined plf	[°C-> <none>]
DSEff	Development stage factor for assimilate production	Photosynthesis: GL	*DSEff*	User defined plf, by default constant value of 1	[DS-> <none>]

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
DAPEff	Age factor for assimilate production, where age is given as day after planting.	Photosynthesis: GL	*DAPEff*	User defined plf, by default constant value of 1	[d-> <none>]
$y_{0.5}$	Effect of water stress on assimilate production when the amount of available soil water covers exactly half E_{pot}.See eq. (10.10)	wse	*y_half*	User defined	[ ]
r_m^{root}	Maintenance respiration coefficient, root. Eq. (10.11).	Production	*r_Root*	Default =0.15	[d^{-1}]
r_m^{leaf}	Maintenance respiration coefficient, leaf. Eq. (10.11).	Production	*r_Leaf*	User defined	[d^{-1}]
r_m^{stem}	Maintenance respiration coefficient, stem. Eq. (10.11).	Production	*r_Stem*	User defined	[d^{-1}]
r_m^{SOrg}	Maintenance respiration coefficient, storage organ. Eq. (10.11)	Production	*r_SOrg*	User defined	[d^{-1}]
$\gamma_r(DS)$	Fraction of assimilate going to the roots, as function of DS, eq. (10.13).	Partition	*Root*	User defined plf	[DS-><fraction>]
$\gamma_s(DS)$	Fraction of shoot assimilate going to the stem, as function of DS, eq. (10.13).	Partition	*Stem*	User defined plf	[DS-><fraction>]

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
$\gamma_l(DS)$	Fraction of shoot assimilate going to the leaf, as function of DS, eq. (10.13).	Partition	*Leaf*	User defined plf	[DS-><fraction>]
Maximum root/shoot ratio	Maximal root/shoot ratio as function of DS. If the ratio is higher, the roots will start dying	Partition	*RSR*	User defined plf	[DS-><none>]
Max_WRoot	Maximal root DM as function of DS. No assimilate will be allocated to roots if root DM is above this value.	Partition	*max_WRoot*	User defined plf, default is a constant value of $1 \cdot 10^6$.	[DS-> g DM m^{-2}]
Nitrogen stress limit	If DS>1 and nitrogen stress is above this number, all assimilate is allocated to the storage organ.	Partition	*Nitrogen_stress_limit*	Default = 1	[ ]
E^{Root}	Conversion efficiency, root, eq. (10.13)	Production	*E_Root*	Default = 0.69	[g DM-C (g Ass-C)$^{-1}$]
E^{Leaf}	Conversion efficiency, leaf, eq. (10.13)	Production	*E_Leaf*	Default = 0.68	[g DM-C (g Ass-C)$^{-1}$]
E^{Stem}	Conversion efficiency, stem, eq. (10.13)	Production	*E_Stem*	Default = 0.68	[g DM-C (g Ass-C)$^{-1}$]
E^{SOrg}	Conversion efficiency, storage organ, eq. (10.13).	Production	*E_SOrg*	Default = 0.66	[g DM-C (g Ass-C)$^{-1}$]

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
F	Assimilate flow rate from the carbohydrate reserves, eq. (10.13).	Production	*CH2OReleaseRate*	Default = 0.04	[h^{-1}]
ShldResC	Capacity of shielded reserves as fraction of stem DM.	Production	*ShldResC*	Default = 0	[<fraction>]
ReMobilDS	The DS-value at which the remobilization of shielded reserves is initiated	Production	*ReMobilDS*	Default = 1.2	[DS]
ReMobilRt	The rate of remobilization of shielded reserves.	Production	*ReMobilRt*	Default = 0.1	[d^{-1}]
Leaf death rate	Death rate of leaves as function of DS.	Production	*LfDR*	User defined plf	[DS->d^{-1}]
Root death rate	Death rate of roots as function of DS.	Production	*RtDR*	User defined plf	[DS->d^{-1}]
ExfoliationFac	The fraction of dead leaves lost to the soil surface [0-1].	Production	*Exfoliationfac*	Default = 1	[h^{-1}]
Root depth at emergence	Root penetration at emergence	RootSystem	*DptEmr*	Default = 10	[cm]
Maximum rooting depth (crop specific)	Maximum penetration depth (crop specific)	RootSystem	*MaxPen*	Default = 100	[cm]
Soil specific rooting depth	Depth at the end of the root zone	Soil	*MaxRootingDepth*	User defined	[cm]

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
α_r	Root penetration rate (coefficient), eq. 10.14.	RootSystem	*PenPar1*	Default = 0.25	[cm (°C)$^{-1}$ d^{-1}]
T_p	Threshold temperature for root growth.	RootSystem	*PenPar2*	4	[°C]
PenClayFac	Modifier of root penetration as function of clay content.	RootSystem	*PenClayFac*	User defined plf. Default = constant of 1.	[<fraction>-> <none>]
PenWaterFac	Modifier of root penetration as function of relative water content.	RootSystem	*PenWaterFac*	User defined plf. Default = constant of 1.	[<fraction>-> <none>]
PenFFac	Modifier of root penetration as function of pF.	RootSystem	*PenFFac*	User defined plf. Default = constant of 1.	[pF-> <none>]
PenDSFac	Modifier of root penetration as function of DS.	RootSystem	*PenDSFac*	User defined plf. Default = constant of 1.	[DS-> <none>]
Root retardation	Factor multiplied to root penetration speed	horizon	*root_retardation*	User defined, default = 1.	[ ]
S_r	Specific root length, eq. (10.15)	rootdens	*SpRtLength*	Default = 100	[m g^{-1}]
Root density at penetration depth	Root density at potential rooting depth (L_d), eq. (10.17).	Rootdens: Gerwitz+Page74	*DensRtTip*	Default = 0.1	[cm cm^{-3}]
Minimum root density	See text in section 10.5.6.	Rootdens: Gerwitz+Page74	*MinDens*	Default = 0	[cm cm^{-3}]

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
Root homogeneity	Factor multiplied to the root density of all crops in this horizon, emulating uneven distribution of roots in soil.	horizon	*root_homogeneity*	User defined, default = 1.	[ ]
DensityDSFac	DS-based factor for effective root density.	RootSystem	*DensityDSFac*	User specified, default is constant value of 1.	[DS-><none>]
q	Extra root length below maximum rooting depth.	rootdens: Anders Pedersen	*q*	User specified	[cm]
"a"	Form parameter as function of DS	rootdens: Anders Pedersen	*a_DS*	User specified plf	[DS->cm^{-1}]
	Pairs of DS and and a plf specifying relative root density as function of soil depth [cm]	rootdens: DS_Depth	*entries*	User specified sequence	
	Pairs of DS and and a plf specifying relative root density as function of relative soil depth	rootdens: DS_Rel	*entries*	User specified sequence	
	Pairs, where the first element is root depth and the second element is relative root density as function of soil depth [cm].	rootdens: Depth_Depth	*entries*	User specified sequence	
L_m	Root density at (potential) penetration depth	GPD1 GPD2	*DensRtTip*	Default = 0.1	[cm cm^{-3}]

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
	Ignore cells with less than this root density.	GPD1 GPD2	*DensIgnore*	Optional parameter, by default the same as *DensRtTip*	[cm cm^{-3}]
MaxWidth	Maximum horizontal distance of roots from plant used in GDP2.	RootSystem	*MaxWidth*	Optional parameter, default = *MaxPen*	[cm]
Death rate based on RSR	Extra death rate for large root/shoot ratio.	Production	*Large_RtDR*	Default = 0.05	[d-1]
Root death temperature factor	Modifier function for root death rate based on temperature.	Production	*RtDR_T_factor*	User defined plf, default is a constant value of 1.	[°C-><none>]
	Initial DS for release of root reserves	Production	*IntDSRelRtRes*	Default = 0.8	[ ]
	End DS for release of root reserves	Production	*EndDSRelRtRes*	Default = 0.8	[ ]
	Release rate for root reserves	Production	*RelRateRtRes*	Default = 0.05	[d^{-1}]
	Maximum leaf/root ratio for release of root reserves	Production	*LfRtRelRtRes*	Default = 0.8	[ ]
	Effective root radius, eq. (4.39).	RootSystem	*Rad*	Default = 0.005	[cm]
	Matrix potential at wilting point, Chapter 4.	RootSystem	*h_wp*	Default = -15000	[cm]
	Transport resistance in the xylem, eq. (4.41)	RootSystem	*Rxylem*	Default = 10	[ ]

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
	Maximum NH_4^+ uptake per unit root length, Ch. 7.7.	RootSystem	*MxNH4Up*	Default = $2.5 \cdot 10^{-7}$	[g cm^{-1} h^{-1}]
	Maximum NO_3^- uptake per unit root length, Ch. 7.7.	RootSystem	*MxNO3Up*	Default = $2.5 \cdot 10^{-7}$	[g cm^{-1} h^{-1}]
C_{pot}^{leaf}	Upper limit for N-concentration in leaves.	CrpN	*PtLeafCnc*	User defined	[DS->g N (g DM)$^{-1}$]
C_{crit}^{leaf}	Critical limit for N-concentration in leaves.	CrpN	*CrLeafCnc*	User defined	[DS->g N (g DM)$^{-1}$]
C_{nonf}^{leaf}	Non-functional limit for N-concentration in leaves.	CrpN	*NfLeafCnc*	User defined	[DS->g N (g DM)$^{-1}$]
C_{pot}^{stem}	Upper limit for N-concentration in stems.	CrpN	*PtStemCnc*	User defined	[DS->g N (g DM)$^{-1}$]
C_{crit}^{stem}	Critical limit for N-concentration in stems.	CrpN	*CrStemCnc*	User defined	[DS->g N (g DM)$^{-1}$]
C_{nonf}^{stem}	Non-functional limit for N-concentration in stems.	CrpN	*NfStemCnc*	User defined	[DS->g N (g DM)$^{-1}$]
C_{pot}^{SOrg}	Upper limit for N-concentration in storage organ.	CrpN	*PtSOrgCnc*	User defined	[DS->g N (g DM)$^{-1}$]
C_{crit}^{SOrg}	Critical limit for N-concentration in storage organ.	CrpN	*CrSOrgCnc*	User defined	[DS->g N (g DM)$^{-1}$]
C_{nonf}^{SOrg}	Non-functional limit for N-concentration in storage organ.	CrpN	*NfSOrgCnc*	User defined	[DS->g N (g DM)$^{-1}$]

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
C_{pot}^{root}	Upper limit for N-concentration in roots.	CrpN	*PtRootCnc*	User defined	[DS->g N (g DM)$^{-1}$]
C_{crit}^{root}	Critical limit for N-concentration in roots.	CrpN	*CrRootCnc*	User defined	[DS->g N (g DM)$^{-1}$]
C_{nonf}^{root}	Non-functional limit for N-concentration in roots.	CrpN	*NfRootCnc*	User defined	[DS->g N (g DM)$^{-1}$]
	If true, nitrogen stress will limit production.	crop	*enable_N_stress*	By default: true if the photosynthesis model handles nitrogen stress implicitly	
NNI_{crit}	When $NNI = N_{act}/N_{crit}$ is below this value, the stem/leaf-partitioning should be modified, eq. (10.20)	Partition	*NNI_crit*	Default = 0	[ ]
NNI_{inc}	Stem/leaf partitioning modifier for low *NNI*, eq. (10.20)	Partition	*NNI_inc*	Default = 0	[ ]
N-fixation, start	DS where fixation of atmospheric N will start	CrpN	*DS_fixate*	Default 42000	[ ]
N-fixation, rate	Fraction rate relative to the potential N-uptake	CrpN	*fixate_factor*	0.8	[h^{-1}]
N-fixation after cut	Restore fixation at this DS-value after cut.	CrpN	*DS_cut_fixate*	Default = 0	[ ]
Crop to harvest	Name of crop to be harvested	action: harvest	*crop*	Default = “all”	string

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
	If true, all crop parts are combined into stem in harvest log files.	action: harvest	*combine*	Default = false	
Stub	Stem and leaves below this height are left on the field. Above, they are harvested.	action: harvest	*stub*	Default = 0	[cm]
Stem fraction harvested	Fraction of stem above stub to harvest.	action: harvest	*stem*	Default = 1	[fraction]
Leaf fraction harvested	Fraction of leaves above stub to harvest.	action: harvest	*leaf*	Default = 1	[fraction]
Storage organ fraction harvested	Fraction of storage organ above stub to harvest.	action: harvest	*sorg*	Default = 1	[fraction]
Economic Yield of DM	Valuable fraction of storage organ, e.g. grain or tuber.	Harvesting	*EconomicYield_W*	Default = 1	[ ]
Economic Yield of N	N-content in the valuable fraction of storage organ	Harvesting	*EconomicYield_N*	By default, the value for *EconomicYield_W* will be used.	[ ]
DSmax	The “oldest” development stage for which the crop survives harvest	Harvesting	*DSmax*	Default = 0.8	[ ]
	New development stage after harvest.	Harvesting	*DSNew*	Optional parameter. If not specified, see text for calculation	[ ]
	Date of last cut. Used for calculating cut delay	Harvesting	*last_cut*	Optional submodel	

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
	Production and development delay in days as function of the shoot DM removed by harvest	Harvesting	*cut_delay*	User defined plf, default is constant value of 0.	[kg DM ha^{-1}-> d]]
	Vertical location of storage organ, negative for root crops. If negative, harvesting will imply a suitable tillage operation and ensure killing the plant.	Harvesting	*sorg_height*	Optional parameter. By default, it is assumed that the storage organ is located far above the ground.	[cm]

Original text from	A10, Daisy Description, lecture notes	
Updated by	date	For Daisy version
Styczen, M	2025 04 10	7.0.7

10.10 References

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