Improvement of the model concept for volatilisation of pesticides from soils and plant surfaces in PEARL

Description and user’s guide for PEARL 2.1.1-C1

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Contents

1 Introduction

After spraying pesticide onto the soil surface, various processes influence the subsequent fate of the pesticide. Depending on the physico-chemical properties of the pesticide and the soil and weather conditions, the relative contribution of processes such as leaching, transformation and volatilisation to the overall fate will differ. For an accurate description of the fate of the pesticide in the soil model concepts are needed that adequately describe the different processes involved. So far, the description of the volatilisation process has been rather simple and especially for soil surface applied pesticides reliable estimates on the course with time of the rate of emission into the air could not be made.

The description of the volatilisation process from soil and plant surfaces was improved. Further, a concept was developed to describe the effect of the soil moisture content on the coefficient for the sorption of pesticide to soil particles. These improvements were implemented in PEARL 1.5.8-F2 (the model version included in FOCUS-PEARL 2.2.2). The resulting PEARL version is 2.1.1-C1. The character 'C' stands for 'Consensus', which means that this version of PEARL has been approved by both Alterra and RIVM.

In Chapters 2, 3 and 4 first the model concepts used in FOCUS-PEARL 1.1.1 and FOCUS-PEARL 2.2.2 is described and this is followed by a description of the improved concept as included in the new PEARL version. Chapter 2 gives a description of the model concepts for volatilisation from soil and plant surfaces, Chapter 3 gives a description of the moisture dependency of the sorption coefficient and in Chapter 4 the model concepts for the dissipation processes on the plant surface is presented. In Chapter 5 instructions are given how to execute runs with the new PEARL version and information is given on the modifications in the PEARL input and meteorological files.

2 Volatilisation

2.1 Description of current concept for volatilisation from bare soil

The volatilisation of the pesticide at the soil surface is described assuming a boundary air layer through which the pesticide has to diffuse before it can escape into the atmosphere. This concept has been adopted in FOCUS_PEARL versions 1.1.1 and 2.2.2 (Leistra et al., 2000; Tiktak et al., 2000). The transport resistance of this air boundary layer can be described as:

$$r_b = \frac{d}{D_a(T)} \qquad [2.1\text{-}1]$$

with:

r_b = resistance for transport through boundary air layer (d m^{-1})

d = thickness of boundary air layer (m)

D_a (T) = coefficient for diffusion in air (m^2 d^{-1}) at temperature T

The volatilisation flux density depends on the concentration gradient of the pesticide across the boundary air layer and this flux density is described as:

$$J_{v,a} = \frac{(c_{g,ss} - c_{air})}{r_b} \qquad [2.1\text{-}2]$$

with:

$J_{v,a}$ = volatilisation flux density through the boundary air layer (kg m^{-2} d^{-1})
$c_{g,ss}$ = concentration in the gas phase at the soil surface (kg m^{-3})
c_{air} = concentration in the air (kg m^{-3})

It is assumed that the concentration of the pesticide in the air is negligible compared to the concentration at the soil surface.

2.2 Description of improved concept for volatilisation from bare soil

The volatilisation flux density depends on physico-chemical properties of the substance but also on moisture and meteorological conditions at the site of application. The effect of the environmental factors can be taken into account with the concept of a resistance to transport of substance from the surface into the atmosphere (Wang et al., 1997; Asman, 1998). Using this concept, the flux density of volatilisation is given by:

$$J_{v,a} = \frac{(c_{g,ss} - c_{air})}{r_a + r_b} \qquad [2.2\text{-}1]$$

in which:

r_a = aerodynamic resistance (d m^{-1})
r_b = boundary layer resistance (d m^{-1})

The aerodynamic resistance is the resistance to transport between the roughness length for momentum z_{0m} and the height of the internal boundary layer, z_{bl}, into which the pesticide has mixed. This height depends on the length of the sprayed field, the roughness length and the stability conditions of the atmosphere (see Van der Molen et al., 1990). Hence, the aerodynamic resistance is given by:

$$r_a = \frac{\ln\left(\frac{z_{bl}}{z_{0m}}\right) - \psi_h\left(\frac{z_{bl}}{L}\right) + \psi_h\left(\frac{z_{0m}}{L}\right)}{\kappa u_*} \qquad [2.2\text{-}2]$$

in which:

z_{bl} = height of internal boundary layer (m)
z_{0m} = roughness length for momentum (m)
Ψ_h = stability correction for heat and substance (dimensionless)
L = Obukhov length (m)
κ = Karman constant (dimensionless)

u_* = friction velocity (m d^{-1})

Under neutral conditions, Eq [2.2-2] simplifies to:

$$r_a = \frac{\ln\left(\frac{z_{bl}}{z_{0m}}\right)}{\kappa u_*} \qquad [2.2\text{-}3]$$

The height of the internal boundary layer z_{bl}, at which the concentration in air is equal to the background concentration, can be calculated iteratively using the equation derived by Van der Molen et al. (1990). Under neutral conditions, z_{bl}, is given by:

$$z_{bl}\left[\ln(\frac{z_{bl}}{z_{0m}})\right] = \kappa^2 \cdot X_F \qquad [2.2\text{-}4]$$

in which:
X_F = length of the treated field (m)

In the new PEARL version, neutral conditions are assumed and the aerodynamic resistance is calculated using Eqs [2.2-3] and [2.2-4]

The resistance to the transport between the source height (i.e. the soil surface) and $z=z_{0m}$ can be described with the boundary resistance r_b. Different parameterisations have been given for this resistance. Wang et al. (1997) have described r_b by:

$$r_b = \frac{\mathrm{Re}_*^{1/4} \cdot Sc^{1/2}}{\alpha \cdot u_*} \qquad [2.2\text{-}5]$$

in which:
Re_* = roughness Reynolds number
Sc = Schmidt number
α = constant (-)
u_* = friction velocity (m d^{-1})

The constant α is taken to be 0.137.

The roughness Reynolds number Re_* (dimensionless) is given by:

$$\mathrm{Re}_* = \frac{u_* \cdot z_{0m}}{\upsilon} \qquad [2.2\text{-}6]$$

in which:
υ = kinematic viscosity of air (m^2 d^{-1})

The Schmidt number is given by:

$$Sc = \frac{\upsilon}{D_g} \qquad [2.2\text{-}7]$$

where:

D_g = diffusion coefficient of pesticide in air ($m^2\ d^{-1}$)

At sea level, the value of υ is 1.46 $\cdot 10^{-5}$ $m^2\ s^{-1}$; the temperature dependency of ν and D_g is about the same, so the quotient of the two variables is about constant, i.e. 0.71.

An alternative description of the surface boundary layer resistance r_b is given by Hicks et al. (1987):

$$r_b = \frac{2}{\kappa \cdot u_*}\left(\frac{Sc}{\Pr}\right)^{2/3} \qquad [2.2\text{-}8]$$

This description has also been used by Asman (1998) to describe the ammonia fluxes to the atmosphere. The Prandtl number can be set at 0.72. In combination with a value of 0.4 for the Karman constant, Equation 2.2-8 can be simplified to:

$$r_b = \frac{6.22 \cdot Sc^{2/3}}{u_*} \qquad [2.2\text{-}9]$$

2.3 Description of improved concept for volatilisation from plants

The volatilisation of pesticides from plant surfaces can also be described using the concept of transport resistances. Firstly, the source has to be described because this determines the resistances for the transport between the source height (or source layer) and the atmosphere. During spraying of arable crops, spray droplets move downwards from the nozzles towards the plant surfaces. Part of the droplets will deposit on the top leaves, whereas others penetrate more deeply into the canopy. Model concepts for the volatilisation may be developed on the basis of a canopy layer with a distribution of pesticide deposits or on the basis of an apparent source height at some level between the soil surface and the crop height.

For a description of the transport resistances within and above a plant canopy, the displacement height has to be taken into account. The displacement height is defined as the height of the plane for absorption of momentum.

The displacement height d for the crop is given by (Van Dam et al., 1997):

$$d = \frac{2}{3} h_c \qquad [2.3\text{-}1]$$

in which:
d = displacement height (m)
h_c = height of the crop (m)

For a crop, the roughness length for momentum z_{0m} is given by:

$$z_{0m} = a \cdot (h_c - d) \qquad [2.3\text{-}2]$$

in which:
z_{0m} = roughness length for momentum (m)

a = coefficient (dimensionless)

Substitution of Equation 2.3-1 in 2.3-2 gives:

$$z_{0m} = a' \cdot h_c \qquad [2.3\text{-}3]$$

in which:
a' = coefficient (dimensionless)

Van Dam et al. (1997) have proposed a value for the coefficient a' of 0.123 (-).

For the description of the volatilisation flux, the aerodynamic transport resistance r_a for the substance is the resistance for transport from $d+z_{0m}$ and the height of the internal boundary layer z_{bl} (See chapter 3).

The aerodynamic resistance for the transport from $z= d+z_{0m}$ to $z=z_{bl}$ is given by:

$$r_a = \frac{\ln\left(\frac{z_{bl}-d}{z_{0m}}\right) - \psi_h\left(\frac{z_{bl}-d}{L}\right) + \psi_h\left(\frac{z_{0m}}{L}\right)}{\kappa u_*} \qquad [2.3\text{-}4]$$

in which:
r_a = aerodynamic resistance (s m^{-1})
z_{bl} = height of the internal boundary layer (m)
Ψ_h = stability correction for heat and substance (dimensionless)
L = Obukhov length (m)
κ = Karman constant (dimensionless)
u_* = friction velocity (m s^{-1})

Under neutral conditions, Eq. [2.3-4] simplifies to:

$$r_a = \frac{\ln\left(\frac{z_{bl}-d}{z_{0m}}\right)}{\kappa u_*} \qquad [2.3\text{-}5]$$

The boundary resistance, r_b, to transport between the source height and $z= d+z_{0m}$ can be described by Eq. 2.2-7 or 2.2-8.

The concentration of the pesticide in the gas phase at the plant surface depends on its vapour pressure at the prevailing temperature. Assuming perfect gas behaviour, the maximum concentration in the air at the plant surface is given by:

$$c_{g,ps} = \frac{M \cdot p_s}{R \cdot T} \qquad [2.3\text{-}6]$$

where:
$c_{g,ps}$ = concentration in the air at the plant surface (kg m^{-3})
M = molecular mass (kg mol^{-1})
p_s = saturated vapour pressure of the pesticide (Pa)

R = universal gas constant (J K^{-1} mol^{-1})
T = temperature (K)

The flux density of volatilisation from plant surfaces can be described by:

$$J_{v,a} = \frac{(c_{g,ps} - c_{air})}{r_a + r_b} \qquad [2.3\text{-}7]$$

in which:
r_a = aerodynamic resistance (d m^{-1})
r_b = boundary layer resistance (d m^{-1})

3 Sorption to soil

In FOCUS-PEARL 1.1.1 and FOCUS-PEARL 2.2.2, the sorption coefficient is assumed to be constant. However, an increase in this coefficient at low moisture contents in soil has been measured. This increase in sorption to soil particles is expected to result in lower volatilisation flux densities at the soil surface. A simple approach to take this effect into account is to specify a maximum sorption coefficient for air-dry soil and a moisture content below which the sorption coefficient increases. The increase in the sorption coefficient can be described using a linear or an exponential relation.

Assuming an exponential relationship the effect of the moisture content on the sorption coefficient can be described as follows:

$$K_{d,eff} = K_{d,\max} \cdot e^{-\alpha \cdot w} \qquad \text{for } w < w_{low} \qquad [3\text{-}1a]$$

and

$$K_{d,eff} = K_d \qquad \text{for } w \geq w_{low} \qquad [3\text{-}1b]$$

in which:

$K_{d,eff}$ = Effective sorption coefficient (L kg^{-1})
$K_{d,max}$ = Maximum sorption coefficient (L kg^{-1})
α = coefficient (-)
w = moisture content (kg kg^{-1})
w_{low} = moisture content below which sorption coefficient increases (kg kg^{-1})

The coefficient α can be calculated by substituting w_{low} for w and K_d for $K_{d,eff}$ in Eq 3-1a. This gives:

$$\alpha = \frac{1}{w_{low}} \cdot \ln\left(\frac{K_{d,\max}}{K_d}\right) \qquad [3\text{-}2]$$

Substituting Eq 3.2 in Eq 3.1a results in:

$$K_{d,eff} = K_{d,\max} \cdot e^{-\frac{w}{w_{low}} \cdot \ln \frac{Kd,\max}{Kd}} \qquad [3\text{-}3]$$

The value of w_{low} is set equal to the water content at pF4.2 (wilting point). At pF values greater than 4.2, the relative humidity of the air in the soil pores is no longer 100%. So, in the new PEARL version the only new parameter needed to describe this effect is $K_{d,max}$.

An example for both the linear and the exponential relation is given in Figures 1 and 2. Note that the data for Figures 1 and 2 are the same. The only difference is that in Fig 1 sorption data are presented on a linear scale and in Fig 2 on a logarithmic scale.

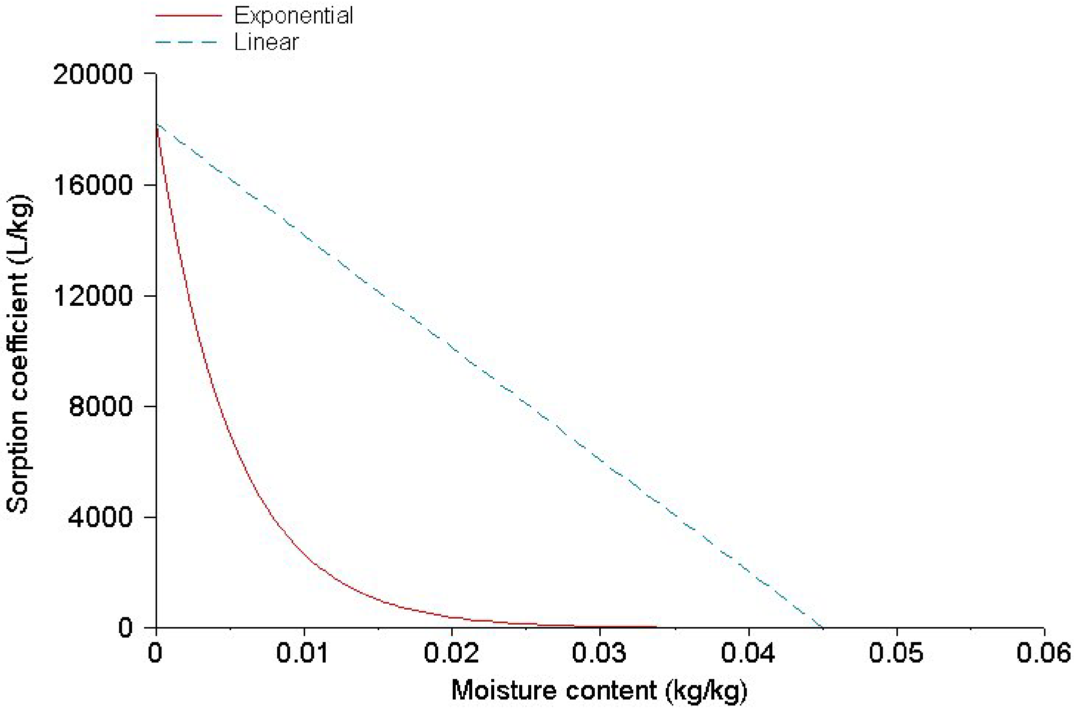

Figure 1: The sorption coefficient as a function of the moisture content. Increase in sorption coefficient taken to be linear or exponential.

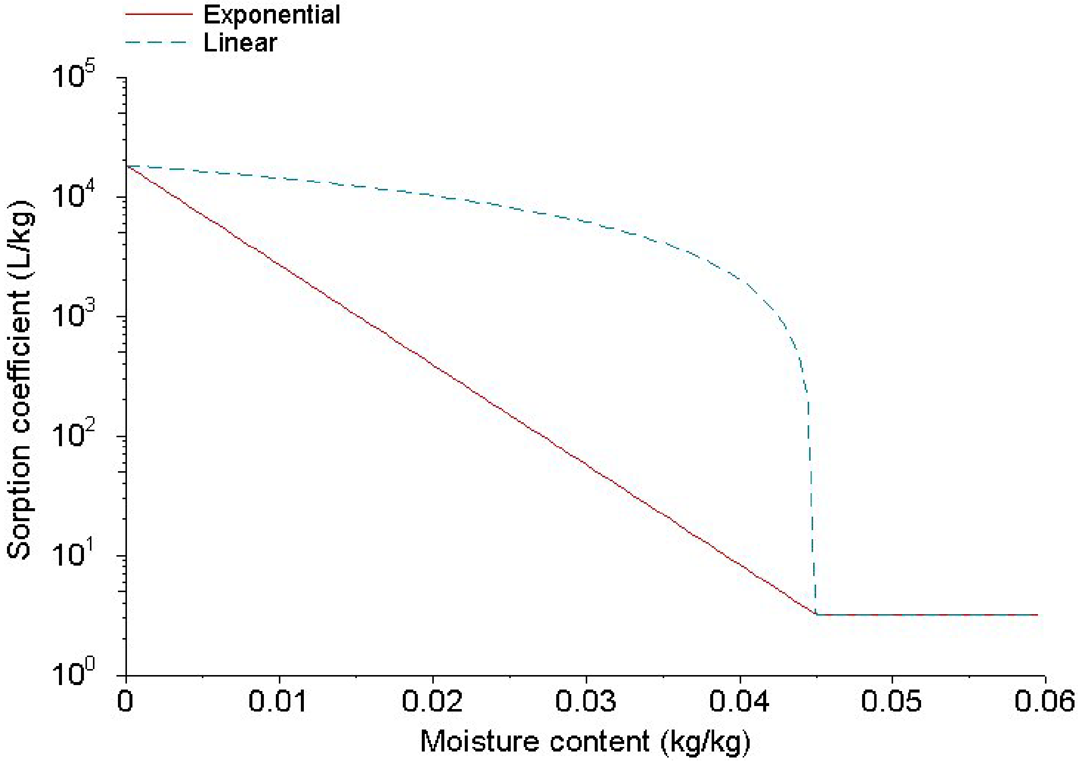

Figure 2: The sorption coefficient as a function of the moisture content. Increase in sorption coefficient taken to be linear or exponential. Logarithmic Y-axis.

4 Dissipation processes on the plant

After application to the plant, the fate of the compound is influenced by different processes, such as volatilisation, penetration into the plant tissue, transformation and wash-off. In FOCUS-PEARL versions 1.1.1 and 2.2.2, an overall half-life could be specified or values had to be specified for the half-life for each of these processes. Using this concept the effect of environmental factors, such as solar radiation or air temperature could not be taken into account. Therefore, model concepts for each of these processes were developed.

4.1 Volatilisation

The saturated vapour concentration of the pesticide in the air at the deposit surface on the leaves is calculated from the vapour pressure by using the Gas Law as described in Eq. 2.3-6.

The potential rate of volatilisation of pesticide from the deposit/leaf surface is calculated by (similar to Eq 2.1-2):

$$J_{v,pot} = \frac{\left(c_{g,ps} - c_{air}\right)}{r} \qquad [4.1\text{-}1]$$

with:

$J_{v,pot}$ = potential flux of volatilisation from the surface, kg m^{-2} d^{-1}

c_{air} = concentration in the turbulent air just outside the laminar air layer = (kg m^{-3} ;set at zero)

r = resistance to transport from plant surface to atmosphere (d m^{-1})

All the areic quantities, such as fluxes, are expressed per m^2 field surface (not plant surface).

The actual rate of pesticide volatilisation is described by taking into account the mass of pesticide on the plants:

$$J_{v,act} = f_{mas}\, J_{v,pot} \qquad [4.1\text{-}2]$$

with:

$J_{v,act}$ = actual rate of pesticide volatilization (kg m^{-2} d^{-1})

f_{mas} = factor for the effect of pesticide mass on the plants (-)

The pesticide is assumed to be deposited on the leaves in spots of variable thickness. The thinner the deposit at a certain place, the sooner that place will be depleted by volatilisation. The concept is that the volatilising surface decreases in proportion to the decrease in mass of pesticide in the deposit. So:

$$f_{mas} = \frac{A_p}{A_{p,ref}} \qquad [4.1\text{-}3]$$

with:

A_p = areic mass of pesticide on the plants (kg m^{-2})
$A_{p,ref}$ = reference areic mass of pesticide on the plants, 1.0 10^{-4} kg m^{-2} (= 1 kg ha^{-1}).

4.2 Penetration of substance into plant tissue

Pesticide penetration into the leaves is influenced by many factors, but no quantitative relationships are known. Therefore, the description of the process in the plant module can be kept simple. The rate of pesticide penetration into the leaves is calculated by:

$$R_{pen} = k_{pen} A_p \quad [4.2\text{-}1]$$

with:
R_{pen} = rate of pesticide penetration into the leaves (kg m^{-2} d^{-1})
k_{pen} = rate coefficient of penetration (d^{-1})

The coefficient k_{pen} is one of the quantities to be calibrated in the computation on the basis of the measurements or it is derived from other studies on pesticide and formulation.

Direct measurements on the rate of penetration of pesticides into plants are usually not available. Quantitative predictions on such penetration on the basis of process theory do not seem to be available. A major problem is that, besides the physico-chemical properties of the pesticide, the substances in the formulation may have a great effect on penetration. An attempt could be made to classify (formulated) pesticides into e.g. five classes with respect to their propensity to penetrate into the plants. A representative rate coefficient could be assigned to each of the classes, as a first approximation of the rate of penetration.

The following five main classes of penetration rate are distinguished:
1) very fast penetration: half-life = 0.04 d (1 h; k_{pen} = 17 d^{-1});
2) fast penetration: half-life = 0.21 d (5 h; k_{pen} = 3.3 d^{-1});
3) moderate penetration rate: half-life = 1.0 d (k_{pen} = 0.69 d^{-1});
4) slow penetration: half-life = 5.0 d (k_{pen} = 0.14 d^{-1});
5) very slow penetration: half-life = 25 days (k_{pen} = 0.03 d^{-1}).

If the above classification is too rough, one of the boundaries between the classes could be selected: half-life = 0.13 d (3 h; k_{pen} = 5.5 d^{-1}), half-life = 0.63 d (15 h; k_{pen} = 1.1 d^{-1}), half-life = 3.0 d (k_{pen} = 0.23 d^{-1}), half-life = 15 d (k_{pen} = 0.05 d^{-1}).

In this way the available empirical knowledge on penetration is translated into a rate coefficient. The classification allows for penetration into the plants to be included in the computations, as a process competing with volatilisation.

4.3 Wash-off

The rate of pesticide wash-off from the leaves by (simulated) rainfall is set dependent on rainfall intensity and a wash-off coefficient:

$$R_w = k_w W_r A_p \quad [4.3\text{-}1]$$

with:
R_w = rate of pesticide wash-off from the leaves (kg m^{-2} d^{-1})
k_w = coefficient for pesticide wash-off (mm^{-1})
W_r = rainfall intensity (mm d^{-1})

Various factors are known to affect pesticide wash-off with rainfall from plants. However, no relationships are available for a mechanistic and quantitative description of this process. Only a rough classification of wash-off based on the experimental results seems to be possible at present. It is proposed to classify wash-off in a certain situation in one of the following five classes:
k_w = 0.09 mm^{-1} (e.g. 90% wash-off with 10 mm rainfall);
k_w = 0.07 mm^{-1} (70% with 10 mm);
k_w = 0.05 mm^{-1} (50% with 10 mm);
k_w = 0.03 mm^{-1} (30% with 10 mm);
k_w = 0.01 mm^{-1} (10% with 10 mm).

If this classification is too rough, a value at the boundary of two classes can be selected. In this classification it is assumed that the crop is only sprayed if no rain is expected in the first period of e.g. 6 hours. It should be noted that in some experiments rainfall was simulated to occur very soon after spraying, which may result in very high wash-off.

4.4 Transformation

The rate of pesticide transformation on the plant surface by solar irradiation is described by first-order kinetics:

$$R_{ph} = k_{ph} \, A_p \qquad [4.4\text{-}1]$$

with:
R_{ph} = rate of phototransformation on the leaves (kg m^{-2} d^{-1})
k_{ph} = rate coefficient of phototransformation (d^{-1})

The rate coefficient k_{ph} is set dependent on the intensity of solar irradiation:

$$k_{ph} = \left(\frac{I_{act}}{I_{ref}} \right) k_{ph,ref} \qquad [4.4\text{-}2]$$

with:
I_{act} = actual solar irradiation intensity (W m^{-2})
I_{ref} = reference solar irradiation intensity (500 W m^{-2})
$k_{ph,ref}$ = rate coefficient of phototransformation at reference irradiation intensity (d^{-1})

The coefficient $k_{ph,ref}$ is one of the quantities to be calibrated in the computation on the basis of the measurements or it has to be derived from other studies on the pesticide. Usually, direct measurements on the phototransformation of a pesticide on plant surfaces are not available. Types of information that may be available are:

- photolysis in water, purified or natural;
- phototransformation on artificial surfaces;
- phototransformation on soil or other natural surfaces;
- phototransformation in air.

These types of measurements give an indication whether phototransformation on plant surfaces may occur. However, translation of rates between such media does not seem to be possible yet.

The rate of phototransformation on plant surfaces may show a wide variation. Possible factors are: a) the substances in the formulated product; b) the substances at the plant surface, c) the substances in the local air, etc.

An attempt could be made to classify a pesticide in one of five classes of vulnerability to phototransformation on plant surfaces, on the basis of available research data. The following representative values of the rate coefficient $k_{ph,ref}$ are assigned to each of these classes:

1) very fast phototransformation: half-life = 0.04 d (1 h; $k_{ph,ref}$ = 17 d^{-1});
2) fast phototransformation: half-life = 0.21 d (5 h; $k_{ph,ref}$ = 3.3 d^{-1});
3) moderate rate of phototransformation: half-life = 1.0 d ($k_{ph,ref}$ = 0.69 d^{-1});
4) slow phototransformation: half-life = 5.0 d ($k_{ph,ref}$ = 0.14 d^{-1});
5) very slow phototransformation: half-life = 25 days ($k_{ph,ref}$ = 0.03 d^{-1}).

If the above classification is too rough, one of the boundaries between the classes could be selected: half-life = 0.13 d (3 h; $k_{ph,ref}$ = 5.5 d^{-1}), half-life = 0.63 d (15 h; $k_{ph,ref}$ = 1.1 d^{-1}), half-life = 3.0 d ($k_{ph,ref}$ = 0.23 d^{-1}), half-life = 15 d ($k_{ph,ref}$ = 0.05 d^{-1}).

If the rate of phototransformation at plant surfaces is critical in the environmental evaluation, special measurements should be made.

4.5 Mass conservation equation on the plant surface

The equation for the conservation of mass of pesticide on the plant surface reads:

$$\frac{dA_p}{dt} = -J_{vol,act} - R_{pen} - R_w - R_{ph} \qquad [4.4\text{-}2]$$

with:
t = time (d)

All areic quantities in this equation are expressed on the basis of m^2 field surface. The definition of the two deposit classes of a) well-exposed deposit and b) poorly exposed deposit requires the use of two mass conservation equations, one for each of these classes.

5 Getting started running the new PEARL model

As the new PEARL version requires new input records, the GUI of FOCUS-PEARL 2.2.2 cannot be used to prepare input files. However, an input file made by the GUI of PEARL 2.2.2 can be taken as a starting point for the preparation of an input file that contains the correct records required by the new PEARL version. In the following section the changes in the input file are described.

The PEARL input file contains the following sections:
1. Control
2. Soil
3. Weather and irrigation
4. Lower boundary flux and drainage/infiltration
5. Compound
6. Management
7. Crop section Crop calendar and crop properties
8. Output

In the *Control* section, the following records are added or modified:
CallingProgram
Because the new version is not a FOCUS version, the record 'CallingProgram' should be set at 'Consensus'.

ModelVersion
The version number of the new PEARL consensus version is 1.

OptSys
If this option is set at 'PlantOnly' then no input records are needed to describe the soil and the lower boundary and drainage conditions. In this case, only the processes on the plant are simulated. If this option is set at 'All' then the soil as well as the plant system is simulated and no records can be left out.

OptOutSWAP
This option gives the possibility to run SWAP on an hourly or daily basis. The options are: 'Daily' and 'Hourly'.

OptDelTimPrn
A new possible option has been added: 'Hour', If set at 'Hour', then hourly output is generated. If this option is used then OptOutSWAP should be set at 'Hourly'

In the *Weather and Irrigation* section, the following records are added or modified:
OptMetInp
This option gives the possibility to read hourly or daily meteorological data. If OptOut SWAP is set at 'Hourly', then OptMetInp should also be set at 'Hourly'

OptResBou
This option is used to select either the parameterisation by Hicks et al. (1987) to calculate the boundary resistance or that by Wang et al. (1997).

ZmeaWnd
The height of the measurements of the wind speed

ZmeaTem
The height of the measurements of the air temperature

LenRghMmtLcl
The roughness length of the soil or plant surface

LenFld
The length of the field (upwind fetch)

In the *Compound* section, the following records are added or modified:
KomEqlMax
The maximum value for the sorption coefficient, i.e. under very dry soil conditions

OptTraRes
This option gives the possibility to select either the concept of a laminar air boundary layer to calculate the volatilisation flux density (Eq. 2.1-1) or the concept of a combination of a boundary and aerodynamic resistances to calculate this flux (Eq 2.2-3, 2.2-5 (Wang et al.) or 2.2-3, 2.2-8(Hicks et al.)). Options are: 'Laminar' and 'Aerodynamic'. If set to 'Laminar' in combination with the option of hourly meteorological data, then the thickness of the laminar air boundary layer depends on the sign of the temperature gradient. If the temperature decreases with height than the value for the thickness of the laminar layer is equal to that specified in the input file; if the temperature increases with height then atmospheric conditions are assumed to be stable and the value of the thickness of the laminar layer is set at 100 times the value specified in the input file.

RadGloRef
Reference global radiation for the factor for the effect of radiation on the pesticide on the plant

FraDepRex
Fraction of applied mass to be put in deposit with reduced exposure. If set at 0 then all mass applied is fully exposed.

FacTraDepRex
Factor for the effect of restricted exposure of deposit on transformation

FacVolDepRex
Factor for the effect of restricted exposure of deposit on volatilisation

FacPenDepRex
Factor for the effect of restricted exposure of deposit on penetration

FacWasDepRex
Factor for the effect of restricted exposure of deposit on wash-off

In the *Output* section, the following record is modified:
OptReport
A new possible option has been added: 'Air', If set at 'Air', then report on the volatilisation is generated with a hourly volatilisation losses during the first 24 h after application. The volatilisation fluxes that are required by the EVA model are also generated.

A full list of records for the new PEARL version is given in Appendix 1. An example PEARL input file is given in Appendix 2.

The format of the file with daily meteorological data is unchanged. If the hourly option is used then the format of the meteorological file is the following

```
*    MSTAT      HH     DD     MM    YY YY    RAD   TAIR   TAIRLow   HUM    WIN    RAI   ETREF
*                                           kJ/m2   C          C    kPa    m/s    mm     mm
**************************************************************************************************************
     JUL-M      1      11     5      1995    0       8.25    8.25   1.082  2.945   3.0    0
```

A new column specifying the hour during the day is added. Further, air temperatures at two heights can be specified. If only measurements for one height are available, then these measured values can be copied to the column with the header ‘TAIRLow’. Measurements of the temperature at two heights are needed to assess the temperature gradient (stable or unstable/neutral).

To run the PEARL version create a .bat file with the following command:

```
[dir Pearl exe]pearlmodel example
```

After double clicking on the .bat file, pearlmodel exe will look for the input file ‘example.prl’ and if present in the same directory as the .bat file the run will start.

It should be noted that the pearlmodel exe can be put in any directory. The command line in the .bat file should then specify the directory where the pearlmodel is located. Further, the swap209 exe must be in the same directory as the pearlmodel exe.

References

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Appendix 1: PARAMETERISATION OF PEARL

Author: Erik van den Berg
Date: 1 September 2004
Characteristics of the parameterisation: Example run

At run time the PEARL user interface produces two input files:
1. X.PRL containing all soil and substance input parameters with X as the run identification
2. Y.MET containing meteorological input in which Y is the name of the meteorological station.
If the irrigation option is used, there is a third input file:
3. Z.IRR containing irrigation input in which Z is the name of the irrigation scheme.

X.PRL

PARAMETER	DESCRIPTION	VALUE, SOURCE & COMMENTS
Section 1: Control		
CallingProgram	Release type	Set to Alterra
ModelVersion	Version number of the model	Set to 1
OptSys	Option for system to be simulated	Set to 'All'. Options are 'All' and 'PlantOnly'. If 'PlantOnly' is selected then soil profile input data are not required.
		1
ScreenOutput	Output to screen	Yes
TimStart	Starting time of simulation	1-Jan -2001 Start of simulation period
TimEnd	End time of simulation	31-Dec-2002 End of simulation period.
AmaSysEnd	Stopcondition (kg.ha^{-1})	0
ThetaTol	Maximum difference in water content between iterations	0.001
OptDelTimPrn	Option to set output interval	Set to 'Hour'. Options are Hour, Day, Month, Decade, Year, Other. For volatilisation studies select 'Hour'
DelTimPrn	Print interval (d)	Only required if OptDelTimPrn is set to 'Other'
OptScreen	Option to write output to screen	Set to Yes
RepeatHydrology	Repeat the same hydrology each year	No
OptHyd	Hydrology simulation option	Automatic
DelTimSwaMin	Minimum time step	1.E-8
DelTimSwaMax	Maximum time step	0.2
OptDelOutput	Option to delete detailed output	No
PrintCumulatives	Option to output cumulative data	Set to 'Yes'. Options are: 'Yes' and 'No'
GWLTol	Tolerance for groundwater level	Set to 1 m
MaxItSwa	Maximum number of iterations in SWAP	Set to 10000.
OptHysteresis	Option to include hysteresis	Set to No.
PreHeaWetDryMin	Minimum pressure head to switch drying/wetting	Set to 0.2. Treated as a dummy.
Section 2: Soil		

SoilTypeID	Name of soil type	HAMB_SOIL
Location	Name of location	HAMBURG
table SoilProfile	Table defining the soil profile: specify for each horizon the thickness (m) and the number of numerical soil compartments	0.3 12 0.3 12 0.3 6 0.1 2 1.5 15 Comment: the thickness of numerical layers is 2.5 cm in the top 0.6 m, then 5 cm up to 1.0 m depth and 10 cm to 2.5 m depth
table SoilProperties	Table specifying the soil composition for each horizon: horizon number fraction sand (kg/kg) fraction silt (kg/kg) fraction clay (kg/kg) content organic matter (kg/kg) pH	1 0.389 0.41 0.201 0.0172 8.4 2 0.4 0.398 0.202 0.0113 7.9 3 0.39 0.449 0.161 0.0063 7.8 4 0.434 0.427 0.139 0.0045 8 5 0.434 0.427 0.139 0.0045 8 Source: file ITB.SCP
table VanGenuchtenpar	Table specifying the VanGenuchten parameters for each horizon using the format: horizon number ThetaSat (-) ThetaRes (-) AlphaDry (cm^{-1}) AlphaWet (cm^{-1}) n (-) Ksat (m/d) L (-)	1 0.599 0.06 0.06 0.06 1.5 0.3 -1 2 0.355 0.01 0.06 0.06 1.2 0.03 -1 3 0.355 0.01 0.05 0.05 1.3 0.03 -1 4 0.355 0.01 0.05 0.05 1.3 0.03 -1 5 0.355 0.01 0.05 0.05 1.3 0.03 -1 Source: Values obtained by fitting data as presented in ITB.HCU and ITB.WRC files.
OptRho	Option for input of bulk density data	Input
table horizon Rho	Table specifying the bulk density for each horizon: number bulk density (kg/m3)	Nr Rho (kg/m3) 1 1050 2 1700 3 1700 4 1700 5 1700 Source: Data taken from ITB.HCU
ZpndMax	Maximum thickness of ponding water layer (m)	0.0
OptSolEvp	Option to select evaporation reduction mPESTd	Set to 'Boesten'.
FacEvpSol	Coefficient for potential evaporation from bare soil (-)	1 Source: FOCUS (2000)
CofRedEvp	Coefficient for reduction of evaporation from bare soil resulting from drying of top layer ($cm^{1/2}$)	0.63 Default value in PEARL
PrcMinEvp	Minimum rainfall to reset reduction	Set to 1 cm d^{-1}.
table horizon LenDisLiq	Dispersion length of solute in liquid phase (m)	0.05 Default value in PEARL.
OptCofDifRel	Option for tortuosity	MillingtonQuirk Default in PEARL
ExpDifLiqMilNom	Exponent in nominator of relation of Millington & Quirk for diffusion in liquid phase	2 Default value in PEARL

ExpDifLiqMilDen	Exponent in denominator of relation of Millington & Quirk for diffusion in liquid phase	0.6667 Default value in PEARL
ExpDifGasMilNom	Exponent in nominator of relation of Millington & Quirk for diffusion in gas phase	2 Default value in PEARL
ExpDifGasMilDen	Exponent in denominator of relation of Millington & Quirk for diffusion in gas phase	0.6667 Default value in PEARL
Section 3: Weather and Irrigation		
MeteoStation	Name of MeteoStation	HAMB-M
OptEvp	Option to select the type of data used by model	Input
OptMetInp	Option to select the time resolution of meteo data	Set to ‘Hourly’. Options are ‘Hourly’ and ‘Daily’
Lat	Latitude of the meteo station	2.12
Alt	Altitude of the meteo station (m)	55.12
LenRghMmtLcl	(m)	
LenFld	(m)	
ZMeaWnd	(m)	
ZMeaTem	(m)	
OptResBou		Set to ‘Hicks’. Options are ‘Hicks’ and ‘Wang’
TemLboSta	Initial lower boundary soil temperature [-20|40] (^{o}C)	7
FacPrc	Correction factor for precipitation	Set to 1.0.
DifTem	Correction for temperature	Set to 0.0.
FacEvp	Correction factor for evapotranspiration	Set to 1.0.
OptIrr	Option to choose between a scenario with and a scenario without irrigation	No
IrrigationScheme	Identification of irrigation scheme	No
IrrigationData	Name of file with irrigation data	The filename consists of the name of the irrigation scheme with the extension .irr.
Section 4a: Lower Boundary Flux		
ZgrwLevSta	Initial depth of groundwater level (m)	
OptLbo	Option for bottom boundary condition	GrwLev
table GrwLev	Table containing daily values of groundwater level for the full experimental period using the format: date (e.g. 01-Jan) groundwater level (m)	
Section 4b: Drainage/ infiltration section		

OptDra		Default set to 'No'
OptSurDra	Option to consider surface drainage	Default set to 'No'
NumDraLev	Number of drainage levels	0
Section 5: Substance		
PEST		
SubstanceName	Name of substance	PEST
table Compounds	List of names of parent compound and metabolites	PEST
table FraPrtDau	Table containing fractions formed (on amount of substance basis) for all parent and metabolite combinations	empty
MolMas_PEST	Molar mass (g/mol) of PEST	200.0
OptCntLiqTraRef_PEST	Option to use the moisture content during the incubation study of PEST	OptimumConditions comment: this implies that DT50Ref has to be specified at matric suction of 100 hPa
DT50Ref_PEST	Half-life for transformation of PEST in topsoil at reference temperature and a matric suction of 100 hPa	8.2
TemRefTra_PEST	Temperature at which half-life of transformation of PEST was measured (^{o}C)	25
ExpLiqTra_PEST	Coefficient describing the relation between the transformation rate of PEST and the volume fraction of liquid (-)	0.7 Default value recommended by FOCUS.
CntLiqTraRef_PEST	Reference content of liquid in transformation study from which DT50Ref of PEST was derived (kg/kg)	Set to 1. Not relevant in this run
MolEntTra_PEST	Molar activation enthalpy of transformation of PEST (kJ/mol)	54. Default value recommended by FOCUS.
table horizon FacZTra Hor PEST	Factor for influence of depth on transformation rate in soil as a function of soil horizon [0|1] using the format: number of horizon Factor (-)	1 1 2 0.5 3 0.11 4 0 5 0
OptCofFre	Option to choose between pH-dependent, pH-independent or user-defined sorption	Set to pH-independent, so the Freundlich sorption equation is used. The sorption coefficient is calculated by multiplying the coefficient of sorption on organic matter and the organic matter content
ConLiqRef_PEST	Reference liquid concentration for sorption coefficient of PEST (mg/L)	1
ExpFre_PEST	Freundlich exponent of PEST	0.9. Default value in PEARL
KomEql_ PEST	Coefficient of equilibrium sorption of substance on organic matter (Kom).	Set at 45 L/kg. Measured at temperature TemRefSor
KomEqlMax_ PEST	Coefficient of equilibrium sorption of substance on organic matter (Kom) under	Set at 4500 L/kg. Measured at temperature TemRefSor

	dry conditions.	
MolEntSor_ PEST	Molar enthalpy of sorption	Describing the relation between the sorption coefficient of the substance and temperature. Default value defined by FOCUS workgroup 0 kJ/mol.
TemRefSor_ PEST	Temperature of reference at which the sorption coefficient was measured	In degrees Celsius.
KSorEql_PEST	Equilibrium sorption coefficient for soil of PEST (L/kg)	Only needed if OptCofFre set to 'user-defined'
table horizon FacZSor Hor PEST	Factor for influence of depth on sorption in soil as a function of soil horizon [0|1] using the format: number of horizon Factor (-)	1 1 2 0.66 3 0.37 4 0.26 5 0.26
PreVapRef_PEST	Saturated vapour pressure of PEST (Pa)	4.0E-3
TemRefVap_PEST	Temperature of reference at which the saturated vapour pressure of PEST was measured (Celsius)	25
SlbWatRef_PEST	Water solubility of PEST (mg/L)	90
TemRefSlb_PEST	Temperature of reference at which the water solubility of PEST was measured (^{o}C)	25
MolEntSlb_PEST	Molar enthalpy of the dissolution of PEST (kJ/mol)	27 Default value in PEARL
MolEntVap_PEST	Molar enthalpy of the vaporization process of PEST (kJ/mol)	95 Default value in PEARL
CofDesRat_PEST	Desorption rate coefficient of PEST (d^{-1})	0
FacSorNeqEql_PEST	Factor relating coefficients for equilibrium and non-equilibrium sorption of PEST (-)	0.0 Not relevant because CofDesRat was set to zero.
FacUpt_PEST	Coefficient for uptake by plant roots of PEST (-)	0.5 Default value in PEARL
OptTraRes	Option for the description of the volatilisation	Options are: 'Laminar' and 'Aerodynamic'.
ThiAirBouLay	Thickness of stagnant air layer at soil surface (m)	0.01 Default value in PEARL
OptDspCrp	Option for the description of the loss routes of parent compound from the crop surface	Options are: 'Lumped', 'Specified', 'Calculated' If 'Calculated' is selected then wash-off, volatilisation, penetration and transformation are simulated.
DT50DspCrp	Half-life for dissipation of the parent compound at the crop surface (d)	1000000
FacWasCrp	Factor for the wash-off of parent compound from the crop by rainfall or irrigation (m^{-1})	0.0001 Default value in PEARL. Not relevant because substance is applied to soil.
RadGloRef	Reference global radiation for the factor for the effect of	Default value 500 W/m2.

	radiation on the pesticide on the plant (W.m-2)	
FacTraDepRex	Factor for the effect of restricted exposure of deposit on transformation (-)	Range: 0.0 to 1.0. If set to 1.0 then no effect of reduced exposure
FacVolDepRex	Factor for the effect of restricted exposure of deposit on volatilisation (-)	Range: 0.0 to 1.0. If set to 1.0 then no effect of reduced exposure
FacPenDepRex	Factor for the effect of restricted exposure of deposit on penetration (-)	Range: 0.0 to 1.0. If set to 1.0 then no effect of reduced exposure
FacWasDepRex	Factor for the effect of restricted exposure of deposit on wash-off (-)	Range: 0.0 to 1.0. If set to 1.0 then no effect of reduced exposure
FraDepRex	Fraction of applied mass to be put in deposit with rediced exposure (-)	
TemRefDif_PEST	Temperature of reference at which diffusion coefficients were measured (C)	20
CofDifWatRef_PEST	Coefficient of diffusion of PEST in water (m^2/d)	0.43E-4 Default value in PEARL.
CofDifAirRef_PEST	Coefficient of diffusion of PEST in air (m^2/d)	0.43 Default value in PEARL
Section 6: Management		
ApplicationScheme	Name of application scheme	App_PEST
Zfoc	FOCUS target depth (m)	1
DelTimEvt	Time difference in years between subsequent applications	NoRepeat Implies that the application is not repeated each year
table Applications	Table defining the applications using the format: date type application rate (kg/ha)	01-May-2001-1100 AppCrpLAI 0.691 The hour of application can be specified (then format is dd-mmm-yyyy-hhmm)
table TillageDates	data and depth of tillage event using the format: data (e.g. 01-Jan-1999) depth (m)	Empty
table interpolate CntSysEql	Table defining the initial content of parent compound in the equilibrium domain of the soil using the format: depth (m) content (mg/kg)	Empty
table interpolate CntSysNeq	Table defining the initial content of parent compound in the equilibrium domain of the soil using the format: depth (m) content (mg/kg)	empty
DepositionScheme	Option for including deposition	No
table FlmDep	Table defining the flux of deposition using the format: date daily deposition rate (kg ha^{-1} d^{-1})	empty

Section 7: Crop		
RepeatCrops	Option to repeat growth of same crop each year	No
OptLenCrp	Option to make the length of the crop cycle dependent on temperature sum	Fixed
table Crops	Table that specifies the crops and their emergence and harvest dates using the format: emergence date harvest date crop code	Example: 12-Jun-2001 10-Oct-2001 SUNFLOWER1 22-May-2002 30-Sep-2002 SUNFLOWER2
table CrpPar_crop1	Table that specifies crop parameters of crop1 as a function of development stage using the format: - development stage (-) which is 0 at emergence and 1 at harvest - Leaf Area Index (-) - crop factor (-) for description of potential evapotranspiration - rooting depth (m) - crop height (m)	For all three crops: 0 0 1 0 0 0.4 4 0.7 0.3 3 1 4 0.7 0.3 3
table RootDensity_ crop1	Table that specifies the root density distribution over the rooting depth using the format: - relative rooting depth (i.e. depth divided by rooting depth) - relative root density	For all crops: 0 1 1 1 Default values from SWAP
HLim1_ crop1	pressure head above which there is no water extraction (cm)	-15; same value for other crop
HLim2_ crop1	pressure head below which optimal water extraction starts (cm)	-30; same value for other crop
HLim3U_crop1	pressure head below which reduction starts when potential transpiration is high (cm)	-325; same value for other crop
HLim3L_crop1	pressure head below which reduction starts when potential transpiration is low (cm)	-600; same value for other crop
HLim4_crop1	pressure head below which there is no water extraction (cm)	-8000; same value for other crop
RstEvpCrp_crop1	Canopy resistance (s/m)	70; same value for other crop Source: Allen et al. (1989)
CofExtRad_crop1	Extinction coefficient for global radiation (-)	0.39; same value for other 2 crops Source: Feddes et al. (19878); Ritchie (1972)
CofIntCrp_crop1	Interception coefficient (cm)	0.0001; same value for other crop This value implies zero interception in practice.
FraCovCrpInp	Fraction of surface covered by crop (-)	Only required if OptSys is set to ‘PlantOnly’. Otherwise read from SWAP output

HgtCrpInp	(m)	Only required if OptSys is set to 'PlantOnly'. Otherwise read from SWAP output.

File Y.MET

PARAMETER	DESCRIPTION	VALUE, SOURCE & COMMENTS
Station	Name of weather station	HAMBURG
DD	Number of day	
MM	Number of month	
YYYY	Number of year	
RAD	Daily global radiation (kJ/m^2)	
Tmin	Minimum air temperature (^{o}C)	
Tmax	Maximum air temperature (^{o}C)	
HUM	Air humidity (kPa)	
WIND	Daily average wind speed (m/s)	
RAIN	Daily rainfall (mm)	
ETref	Daily reference evapotranspiration (mm)	

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Appendix 2: Example PEARL input file using option OptSys is 'PlantOnly'

```
*-------------------------------------------------------------------
* INPUT FILE for Pearl version 1.5.8.1.1-A1
*-------------------------------------------------------------------
*-------------------------------------------------------------------
* Section 1: Control section
*-------------------------------------------------------------------
Consensus         CallingProgram
3                 ModelVersion
01-May-2001       TimStart
03-May-2001       TimEnd
0                 AmaSysEnd (kg.ha-1)
No                RepeatHydrology
Automatic         OptHyd
PlantOnly         OptSys
Hour              OptDelTimPrn
Yes               OptScreen
No                OptDelOutput
Yes               PrintCumulatives


*-------------------------------------------------------------------
* Section 2: Soil section
*-------------------------------------------------------------------

HAMB-S_Soil SoilTypeID
Hamburg Location


*-------------------------------------------------------------------
* Section 3: Weather and irrigation section
*------------------------------------------------------------------

HAMB-M            MeteoStation
Hourly            OptMetInp
Laminar           OptTraRes
PenmanMonteith    OptEvp
52                Lat
50                Alt             (m)
100               LenFld        (m)
0.01              LenRghMmtLcl  (m)
10                TemLboSta       (C)
10.0              ZMeaWnd (m)
2.0               ZMeaTem (m)
Hicks             OptResBou
No                OptIrr
No                IrrigationScheme
1.0               FacPrc (-)
1.0               FacTem (-)
1.0               FacEvp (-)

*-------------------------------------------------------------------
* Section 4a: Lower boundary flux
*-------------------------------------------------------------------

*-------------------------------------------------------------------
* Section 4b: Drainage/infiltration section
*-------------------------------------------------------------------
No OptDra
*-------------------------------------------------------------------
* Section 5: Compound section
*-------------------------------------------------------------------

SUB1 SubstanceName
```

```
table compounds
SUB1
end_table
303.5              MolMas_SUB1 (g.mol-1)
table FraPrtDau (mol.mol-1)
end_table
OptimumConditions OptCntLiqTraRef_SUB1
table horizon FacZTra (-)
hor SUB1
1      1
2      1
3      0.5
4      0.5
5      0.5
6      0.3
7      0.3
8      0
end_table
table horizon FacZSor (-)
hor SUB1
1      0.5
2      0.5
3      0.5
4      0.5
5      0.5
6      0.5
7      0.5
8      0.5
end_table
67               DT50Ref_SUB1 (d)
20               TemRefTra_SUB1 (C)
0.7              ExpLiqTra_SUB1 (-)
1                CntLiqTraRef_SUB1 (kg.kg-1)
54               MolEntTra_SUB1 (kJ.mol-1)
pH-independent   OptCofFre_SUB1
2075             KomEql_SUB1 (L.kg-1)
207500           KomEqlMax_SUB1 (L.kg-1)
1                ConLiqRef_SUB1 (mg.L-1)
0.9              ExpFre_SUB1 (-)
0.0042           PreVapRef_SUB1 (Pa)
20               TemRefVap_SUB1 (C)
4.3              SlbWatRef_SUB1 (mg.L-1)
20               TemRefSlb_SUB1 (C)
27               MolEntSlb_SUB1 (kJ.mol-1)
95               MolEntVap_SUB1 (kJ.mol-1)
0                CofDesRat_SUB1 (d-1)
0                FacSorNeqEql_SUB1 (-)
0.0              MolEntSor_SUB1 (kJ.mol-1)
20.0             TemRefSor_SUB1 (C)
0.5              FacUpt_SUB1 (-)
0.0006           ThiAirBouLay (m)
Calculated       OptDspCrp
1000000          DT50DspCrp (d)
0.330            DT50PenCrp (d)
1000000          DT50VolCrp (d)
0.433            DT50TraCrp (d)
500.0            RadGloRef (W.m-2)
0.0              FacWasCrp (m-1)
0.2              FacTraDepRex (-)
0.2              FacVolDepRex (-)
0.2              FacPenDepRex (-)
0.2              FacWasDepRex (-)
0.1              FraDepRex (-)
20               TemRefDif_SUB1 (C)
4.3E-5           CofDifWatRef_SUB1 (m2.d-1)
0.36             CofDifAirRef_SUB1 (m2.d-1)


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

```
* Section 6: Management section
*--------------------------------------------------------------------

Ap-SUB1 ApplicationScheme
1                 ZFoc (m)
table Applications
01-May-2001-0000   AppCrpLAI 0.691
end_table
NoRepeat          DelTimEvt (a)
table VerticalProfiles
end_table
table TillageDates
end_table
No DepositionScheme
table    FlmDep   (kg.ha-1.d-1)
end_table
*--------------------------------------------------------------------
* Section 7: Crop section
*--------------------------------------------------------------------

HAMB-SUGARBEET CropCalendar
Yes               RepeatCrops
Fixed             OptLenCrp
table  Crops
15-Apr-2001      08-Oct-2001   SUGARBEET1
end_table
table  CrpPar_SUGARBEET1
0      0      1      0      0
0.78   4.2    0.87   1.2    0
1      4.2    0.87   1.2    0
end_table
0.765            FraCovCrpInp (-)
0.3              HgtCrpInp (m)
*--------------------------------------------------------------------
* Section 8: Output control
*--------------------------------------------------------------------
None   OutputDepths
No     OptDelOutFiles
Air               OptReport
DaysFromSta       DateFormat
G12.4             RealFormat
table OutputDepths (m)
end_table
Yes               print_AmaAppCrp
Yes               print_AmaAppSol
Yes               print_AmaCrp
Yes               print_AmaCrpFex
Yes               print_AmaCrpRex
No                print_AmaHarCrp
Yes               print_AmaWasCrpFex
Yes               print_AmaWasCrpRex
Yes               print_AmaWasCrp
Yes               print_AmaPenCrpFex
Yes               print_AmaPenCrpRex
Yes               print_AmaTraCrpFex
Yes               print_AmaTraCrp
Yes               print_AmaPenCrp
Yes               print_AmaTraCrpRex
Yes               print_AmaVolCrpFex
Yes               print_AmaVolCrpRex
Yes               print_AmaVolCrp
Yes               print_AmrDspCrp
Yes               print_AmrWasCrp
Yes               print_AmrVolCrp
No                print_AmaHarCrp
No                print_DelTimPrl
Yes               print_FacCrpEvp
Yes               print_FlmDepCrp
Yes               print_FraCovCrp
```

```
Yes                 print_TemAir
Yes                 print_RstAer
Yes                 print_RstBou
Yes                 print_VelWnd
Yes                 print_RstAirLam
Yes                 print_VelFriLcl
No                  print_LAI
No                  print_ZRoot
No                  print_GrwLev
Yes                 print_Tem
No                  print_PreHea
Yes                 print_FlmGas
Yes                 print_FlmGasVol
Yes                 print_FlmLiq
Yes                 print_FlmLiqInf
Yes                 print_FlmLiqLbo
Yes                 print_FlvLiqEvpIntIrr
Yes                 print_FlvLiqEvpIntPrc
Yes                 print_FlvLiqEvpSol
Yes                 print_FlvLiqEvpSolPot
Yes                 print_FlvLiqPrc
Yes                 print_FlvLiqTrp
Yes                 print_FlvLiqTrpPot
No                  print_FlvLiqGrw
No                  print_StoCap
No                  print_AvoLiqErr
No                  print_DelTimPrl
*--------------------------------------------------------------------
```