Appendix 3.1 - Water and solute flow in the mulch model

1 Water flow in the mulch

1.1 Introduction

The mulch model in Daisy resembles the PASTIS mulch module described in Aslam et al. (2018), Findeling et al. (2007), and Vuaille (2022). It differs from the standard litter model (see section 3.2.3) in Daisy in the sense that the mulch layer has a specified retention curve. Thus, the mulch storage fills gradually rather than instantaneously and the potential flow to the soil underneath is calculated based on the water pressure difference between the mulch and the soil. The processes in the mulch and the exchange between the mulch and soil are governed by the conditions in the upper part of the soil, $\Delta z_{M,}$ (eq. 3), which is a user defined depth. It is assumed that moisture conditions, microbiology and nutrient content, in this soil layer, influence the water flow in and breakdown of the mulch. The water flow to, interception in, percolation through and percolation out of the mulch layer is described below. Bypass, $J_{M,bypass}$, as well as potential and actual evaporation from the mulch, $E_{p,M}$ and E_M, is calculated as for the standard litter model (described in part 3.2.3, eq. 3.26, 3.28 and 3.27).

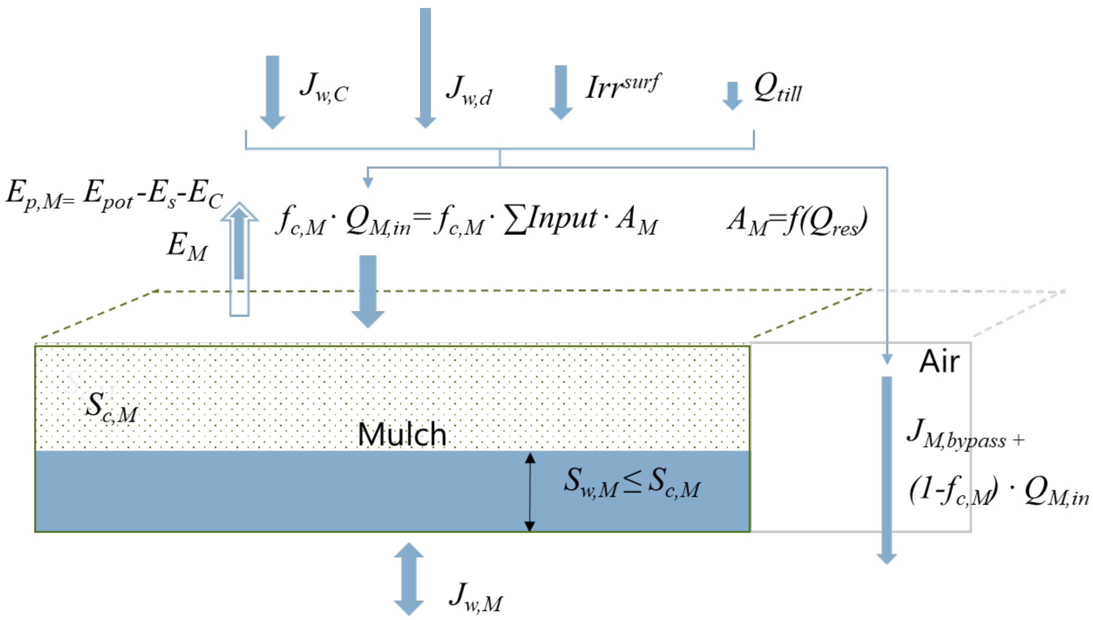

Figure 1: The major components of the water balance for the mulch model. Abbreviations used are described in the text below. The dotted lines illustrate that mulch is treated as areas, calculated as a function of the mass of residue.

1.2 Interception of water in the mulch

As for the standard litter model, the amount of water that hits the mulch is the sum of canopy throughfall, $J_{w,C}$, canopy spill of, $J_{w,d}$, surface irrigation, Irr^{surf} ,and potentially excess soil water after tillage, Q_{till} times the fraction of the area with mulch coverage, A_M (calculated as for the litter model, Eq. 3.24 in part 3.2.3). But, contrary to the litter model, only a fraction, $f_{c,M}$ [-], of the water that hits the mulch is intercepted by the mulch. The rest percolates through the mulch.

$$f_{c,M} \cdot Q_{M,in} = f_{c,M} \cdot \left(J_{w,d} + J_{w,C} + Irr^{surf} + Q_{till} \right) A_M \tag{1}$$

$f_{c,M}$[-] is calculated as:

$$f_{c,M} = \exp\left(-\alpha \frac{\left(\theta_{sat} - \theta_{res}\right)}{\left(\theta_{sat} - \theta\right)} \right) \tag{2}$$

where

$-\alpha$ = Propensity to water recharge [-], by default 0.

θ_{sat}= Saturated water content of the mulch, see below.

θ_{res}= Residual water content of the mulch. The mulch module requires specification of a θ_{res} and a h_{min} [cm], referring to the water content and pressure where biological activity stops. The default value for h_{min} is -3.16228E06, equal to a pF-value of 6.5.

θ = Water content of the mulch.

The remaining water, $(1 - f_{c,M}) \cdot Q_{M,in}$, percolates through the mulch. Thus the effective bypass is the sum of $J_{M,bypass}$ (given by eq. 3.26 in part 3.2.3) and $(1 - f_{c,M}) \cdot Q_{M,in}$. The default value of α is 0, resulting in interception of all water hitting the mulch layer.

1.3 Retention of water in the mulch layer

Two different retention curves can be applied to the mulch layer. The first equation is similar to the one used in the PASTIS model and the default-choice.

$$h_\theta = -(-h_{\min})^\beta \wedge \beta = 1 - \frac{(\theta - \theta_{res})}{(2/3\, \theta_{sat} - \theta_{res})} \tag{3}$$

This module calculates θ_{sat} based on a user specified water capacity [L kg^{-1}] and bulk density (ρ_M) [kg DM m^{-3}] of the mulch. The two multiplied and adjusted with a factor of 1000 will provide a value in [m^3 m^{-3}].

The second equation that can be selected in the mulch submodule is shown below:

$$\theta_h = \exp\left(k \cdot h \cdot \left(\theta_{sat} - \theta_{res}\right)\right) + \theta_{res}$$

$$or$$

$$h_\theta = \frac{1}{k} \ln\left(\frac{\theta - \theta_{res}}{\theta_{sat} - \theta_{res}} \right) \tag{4}$$

For this retention curve option, θ_{sat}, θ_{res}, and h_{min} are optional parameters (otherwise θ_{sat} is calculated as above, and the two other parameters are taken the values specified for the mulch module), while k requires specification.

The total amount of water in the mulch layer depends on the Height (H) of the mulch, which is calculated based on the dry matter amount (which varies over time) and the bulk density of the mulch (which is constant).

1.4 Evaporation from the mulch layer

The mulch layer does not have an interception capacity storing water on the surface, as the litter. Instead, part of the water present in the mulch is available for evaporation while the rest is protected. This is specified by a parameter, D (default 1000 [cm]), to which depth, the water in the mulch can be affected by evaporation. The mulch layer is assumed to be filled up from the bottom.

The total amount of water in the mulch at a given time that potentially could be evaporated is specified as $(\theta - \theta_{res}) \cdot H$. The total amount of storage capacity for water in the mulch below the evaporation depth is $(\theta_{sat} - \theta_{res}) \cdot (H-D)$, assuming that $D < H$. Thus, evaporation from the mulch can take place only if the amount of available water is larger than the sheltered storage. Otherwise, it is zero.

1.5 Exchange of water between mulch and soil

The exchange of water between the mulch and soil, by percolation of intercepted water in the mulch and/or capillary rise from the soil, is calculated based on the Darcy-equation, the water pressure in the soil and the water pressure in the mulch, derived from the water content and the retention curve:

$$J_{w,M}^{Darcy} = A_M * f_{M,w-ext} \cdot \left(K_{soil} \frac{(h_M - h_{soil})}{\Delta z_M} \right) \tag{5}$$

$J_{w,M}^{Darcy}$ = Potential Darcy flow, [cm h^{-1}]

$f_{M,w\text{-}ext}$ = Factor between 0 and 1 describing the degree of poor contact between the two media.

h_M = Pressure in the mulch [cm]

h_{soil} = Pressure [cm] in the middle of the soil layer defined by Δz_M

Δz_M = Depth of soil layer [cm], affecting processes in the mulch layer. It can be user defined, but suggested height = 5 cm (Aslam et al. 2018).

K_{soil} = Saturated hydraulic conductivity of the soil [cm h^{-1}]

Furthermore, a test value, $J_{w,M}^{evac}$ [mm h^{-1}], is calculated as

$$J_{w,M}^{evac} = \frac{S_{w,M}}{dt} \tag{6}$$

The actual outflow is calculated by first choosing the maximum of the overflow, $J_{w,M}^{overflow}$ (given by Eq. 3.29 in part 3.2.3) and the $J_{w,M}^{Darcy}$, and then choosing the minimum of this value and the mulch evacuation, $J_{w,M}^{evac}$. The maximum outflow [mm h^{-1}] is thus limited by the amount of available water.

$$J_{w,M}^{t+1} = \min\left\{ J_{w,M}^{evac}, \max\left(J_{w,M}^{overflow}, J_{w,M}^{Darcy} \right) \right\} \tag{7}$$

Where $J_{w,M}^{evac}$ [mm h^{-1}] express the amount of available water, securing that $J_{w,M}^{t+1}$ does not excessed the amount of available water on and in the mulch.

1.6 Water storage in the mulch

Finally, the amount of water in the mulch is updated, similarly to Eq. 2.33 for the litter model, taking into account the outflow:

$$\frac{dS_{w,M}}{dt} = \left(f_{c,M} \cdot Q_{M,in} - E_M - J_{w,M}^{t+1} \right) \tag{8}$$

$S_{w,M}$ has values in the interval *[0; $S_{c,M}$]* due to the criteria specified in eq. 3.28, 3.29 and by the test-value in eq.4 above.

2 Solute in the mulch

2.1 Input to mulch

The total amount of solute available above a mulch layer ($Q^C_{M,in}$ [g m^{-2} h^{-1}]) is the amount lost from the canopy itself (eq. (3.53) in part 3.6.6), the canopy throughfall and any solute sprayed or distributed with irrigation water on the mulch (plus any contribution from degradation of products already in or on the mulch, as described in eq. (3.54) in part 3.6.6). The only difference from the calculations for the litter layer is that solute may be stored both on and in the mulch, meaning that transformations of solute, $R^C_{M,transform}$, may take place both places. Bypass is calculated using eq. (3.55) in part 3.6.6 for litter.

2.2 Losses from mulch

Solute in the mulch may be lost though wash-off, diffusion from stored water in the mulch, or through degradation. The wash-off rate from mulch, $k^C_{w,M}$ [h^{-1}] is calculated similarly to the wash-off from canopy, based on a wash-off coefficient, $\kappa^C_{w,M}$ [], and the rate of water leaching from the mulch given by eq. (5).

$$k^C_{w,M} = \kappa^C_{w,M} \cdot \frac{J^t_{w,M}}{S^t_{w,M}} \tag{9}$$

Eq. (7) is similar to eq. (3.56) in part 3.6.6 for litter. However, for the submodel “mulch”, the solute can diffuse from the stored water in the mulch to water passing on the surface. The diffusion rate, k^C_{w,M_diff} [h^{-1}], is provided by the user as input. It is calculated as a simple first-order process and not based on differences in concentration. It is, however, dependent on water content. A water content, S_i, is specified (as a fraction of θ_{sat}) above which diffusion takes place.

Decomposition is specified either by a litter decomposition rate, $k^C_{M,\deg}$ [h^{-1}], or as half-life [h], as for the litter model. The total relative loss rate is thus the sum of the calculated wash-off-, diffusion- and degradation rates.

2.3 Storage in and on the mulch layer

The new storage in the mulch layer ($S^{C,t}_{w,M}$, [g m^{-2}]) is calculated with eq. (3.45) in part 3.6.1 and the combined loss from spill-off ($J^C_{w,M}$ [g m^{-2} hr^{-1}]), diffusion (J^C_{w,M_diff}) and degradation ($R^C_{M,\deg}$ [g m^{-2} hr^{-1}]) is calculated similarly to eq. 3.49 in part 3.6.4 for loss of solute from the snow compartment. The individual losses are calculated similarly to eq. (3.53) in part 3.6.5.

2.4 Temperature in mulch

The temperature calculations for the mulch layer are equal to the ones carried out for litter, described in Chapter 3.

2.5 Organic matter processes in mulch

Daisy mulch biomass consists of the above-ground part of all the AOM pools (see Chapter 9) and can be incorporated through tillage operations, bio-incorporated by earthworm activity or decomposed on the soil surface. Contrary to residues incorporated in the soil, mulch residues first degrade to form dissolved organic matter (DOM) as described in Garnier et al. (2003). The breakdown process requires specification of a decomposition height for the mulch considered in contact with the soil, which is the part of the mulch layer that will decompose, and a soil depth contributing to decay, Δz_M.

The soil microbial pool in the layer defined by the soil depth can contribute to breaking down the mulch biomass within the decomposition height. The default is that the SMB2-pool is active, but it is possible to choose the SMB1 pool or both pools. The mulch breakdown will then follow the 1st order breakdown process defined for the AOM pools by the SMB2-microbes.

However, with the mulch module implementation, a new microbial modifier function f_b [-] affecting the residue degradation was introduced inspired by Michaëlis-Menten reaction kinetics (based on (Garnier et al. 2003)) such as:

$$f_b = \frac{SMB_{ref} + K_M}{SMB_{ref}} \cdot \frac{SMB2}{SMB2 + K_M} \tag{10}$$

With $SMB2$ [g C cm^{-3}] the active soil organic biomass, assumed to decompose AOM, and K_M [g C cm^{-3}] a Michaëlis-Menten constant for the decomposition of AOM. If $SMB2$ equals SMB_{ref}, f_b becomes 1. SMB_{ref} is a specific carbon content of the SMB-pool. . The f_b factor is multiplied onto the standard breakdown rate for AOM by SMB2.

With f_b, mulch decomposition in Daisy is affected by water potential, temperature, and microbial biomass, SMB2, of the uppermost soil layer (0-5 cm, where residues are in direct contact with the soil surface), which reflects observations from laboratory studies (Aslam et al. (2018), Findeling et al. (2007). However, it is also possible to specify separate heat and water modifiers for the process in the mulch, if required.

Pesticide degradation is assumed to occur through co-metabolism (Aslam et al. 2018). In a co-metabolic transformation, the soil microbial biomass growing during mulch decomposition can fortuitously transform pesticides (Bollag and Liu 1990). Pesticide degradation in Daisy follows first-order reaction kinetics and is affected by soil water pressure potential, temperature and depth (Abrahamsen and Hansen 2000) (Chapter 8). In combination with the mulch module pesticide breakdown can also be subjected to the microbial factor f_b (Eq. (10)) to account for co-metabolism. In Daisy mulch module, pesticide and mulch degradations are thus controlled by the same microbial biomass (SMB2 pool) and occur simultaneously. The K_M factor in Eq. (10) might differ between pesticides and organic residues, as the increase in SMB2 might not necessarily affect equivalently the degradation of mulch and pesticide. It is therefore possible to specify separate K_M values and other relevant parameters above for each pesticide under the definition of a chemical (default).

When the mulch breaks down, it becomes dissolved organic carbon and nitrogen. Both chemicals thus must be defined for the simulation and be traced to appear in the log-files. Above the soil, these two compounds behave as tracers. When arriving in the soil, they will be broken down according to the parameters specified in the reaction “DOM_turnover” (see Chapter 9).

3 Parameter overview

Table 1: Related parameter names in Daisy. For parameters shared with the litter model see table 3.1 in Chapter 3.

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
water capacity	Parameter in calculation of water entering mulch. Eq. 2.	residue	*water capacity*	User specified	[L/kg]
$\boldsymbol{\alpha}$	Parameter in calculation of water entering mulch. Eq. 2.	mulch	*alpha*	0	[]
$\boldsymbol{f_{M,w\text{-}ext}}$	Limiting factor when calculating Darcy exchange between mulch and soil, describing poor contact. Eq. 2.	mulch	*factor_exch*	user defined	[]
	Choice of retention curve	mulch	*Retention*	PASTIS (alternative exp)	[]
$\boldsymbol{\theta_{res}}$	In mulch: water content where biological act. stops. In exp: residual water	Mulch exp	*Theta_res*	User specified	[ ]
$\boldsymbol{h_{min}}$	Water pressure where biological activity stops	Mulch exp	*h_min*	-3.16228e+06 (pF 6.5)	[cm]
$\boldsymbol{\theta_{sat}}$	Saturated water content	exp	*Theta_sat*	(calculated or user specified)	[ ]
$\boldsymbol{k}$	Parameter in retention curve exp (eq. 4).	exp	*k*	User specified	[cm^{-1}]
$\boldsymbol{\rho_M}$	Bulk density of mulch layer	mulch	*density*	User specified	[kg DM m^{-3}]
	Particle density of mulch layer.	mulch	*particle_density*	Optional parameter	[kg DM m^{-3}]
$\boldsymbol{D}$	Depth from the surface into the mulch contributing to evaporation	mulch	*evaporate_depth*	1000	[cm]

Δz_M	Height of soil layer contributing to decay. Eq. 3.	mulch	*soil_height*	negative number, user defined	[cm]
	Height of mulch layer in contact with the soil and decomposing	mulch	*Decompose_height*		[cm]
$\kappa_{w,M}^{C}$	Litter/mulch wash-off coefficient, eq. 7	chemical	*litter_washoff_coefficient*	user specified	[]
$k_{M,\deg}^{C}$	Decomposition or degradation rate for solute on litter	chemical	*litter_decompose_rate* *litter_decompose_halftime*	user specified	[h^{-1}] [h]
k_{w,M_diff}^{C}	Rate of diffusion from solute store in mulch to passing water	chemical (mulch)	*litter_diffusion_rate*	0	[h^{-1}]
	Water content where diffusion to wash-off begins, relative to θ_{sat}.	mulch	*Si*	user specified	[]
	Specifies SMB-pools to decompose mulch.	mulch	*decompose_SMB_pool*	1	
K_M	Michaelis-Menten parameter in Eq. (10) for AOM-turnover.	mulch	*decompose_SMB_KM*	0	[g C m^{-3}]
K_M	As above but this time for breakdown of pesticides as co-metabolites	Chemical (default)	*decompose_SMB_KM*	0	[g C m^{-3}]
	Reference SMB-carbon for decomposition of mulch. The SMB-factor (Eq. 10) will be scaled so it is 1 at this amount of SMB carbon.		*SMB_ref*	Optional parameter. By default, no scaling	[g C m^{-3}]
	Heat factor on decomposition		*decompose_heat_factor*	Default: not applied	plf [°C -><none>]

	Reference temperature for decomposition (scales the heat factor so it is 1 at this temperature).	*T_ref*		
	Water potential factor on decomposition.	*decompose_water_factor*	Default: not applied	plf [cm-><none>]
	Use temperature and moisture of topsoil (Δz_M) for turnover and decomposition.	*use soil decompose*	true	

Original text from	New text	
Updated by	date	For Daisy version
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4 References

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