# Module
# **mulch_heat_bi**

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2024-02-28

## Contents



## 1 Introduction

We propose a model for the evolution of the temperature within a soil surface mulch made of organic matter (plant residues, straw, etc) We assume that the mulch is made of two superposed layers, one in contact with the soil that could be decomposed by biological mechanisms, and the other, not in contact with the soil, that cannot be decomposed, and intercepting a part of the rain and of the climatic demand. This two layers modeling appears to be more realistic to simulate the decomposition of the mulch by microbial processes that are strongly dependent on the temperature, the water content and the availability of the nitrogen of the soil.

## 2 Equations

We note $V_c$ the volume of the part *in contact* with the soil and $V_{nc}$ the volume of the mulch *not in contact* with the soil. We assume that the mulch is characterized by a relationship between the volumetric water content and the water potential that is the same for the two layers. For the two layers, the volumetric water content is bounded by a maximum volumetric water content $\theta_s$ and a minimum $\theta_{\min}$. The volumes $V_c$ et $V_{nc}$ varies in time and are given by a module simulating the decomposition of the mulch.

The two mulch layers cover soil surface fractions noted: $\tau_c$ et $\tau_{nc}$ that are also function of time since the mulch volumes change in time. These fractions of the soil surface covered are also provided by the module simulating the decomposition of the mulch.

For the mulch layer *not in contact* with the soil we assume that its temperature results from one part of its evaporation deficit and also of the thermal exchanges existing with the atmosphere and with the mulch layer *in contact* with the soil. Let $E_{nc}$ be the evaporation deficit, $V_{nc}$ its volume ($m^3$), and $\theta_{nc}$ its volumetric water content ($m^3.m^{-3}$). Considering evaporation deficit, the temperature of the mulch layer $T_{nc}$ is given by the equation:

$$V_{nc}\left(C_p\rho + C_w\theta_nc\right)\frac{dT_{nc}}{dt} = L_v E_{nc} \tag{1}$$

with $C_p$ and $C_w$ the mass heat capacity ($J.kg^{-1}.K^{-1}$) of the mulch elements and water respectively, $\rho$ the bulk density of the mulch ($kg.m^{-3}$), and $L_v$ the latent heat of water vaporisation ($J.kg^{-1}$).

We assume that the exchanges with the atmosphere and with the mulch layer in contact with the soil can be modeled by first-order processes. Adding these processes, the equation becomes:

$$V_{nc}\left(C_p\rho + C_w\theta_{nc}\right)\frac{dT_{nc}}{dt} = L_v E_{nc} - k_{ext}\left(T_{nc} - T_{ext}\right) - k_c\left(T_{nc} - T_c\right) \tag{2}$$

with $k_c$ and $k_{ext}$ the exchange coefficients ($W.m^{-2}.K^{-1}$) and $T_{ext}$ the temperature calculated as a mean between the air temperature and the temperature of the vegetation when it is present.

For the mulch layer in contact with the soil, the thermal balance accounts for the evaporation deficit, the exchange with the mulch layer above and the conductive exchange with the soil. This leads to the following differential equation:

$$V_c\left(C_p\rho + C_w\theta_c\right)\frac{dT_c}{dt} = L_v E_c + k_c\left(T_{nc} - T_c\right) + 2\lambda(\theta_c)\left(T_s - T_c\right)/\delta_c \tag{3}$$

where $T_s$ is the soil surface temperature, $\lambda(\theta_c)$ the thermal conductivity of the mulch ($W.m^{-1}.K^{-1}$) and $\delta_c$ the thickness of the mulch layer in contact with the soil ($m$).

Hence, we have two coupled ordinary differential equations:

$$\begin{pmatrix} \frac{dT_c}{dt} \\ \frac{dT_{nc}}{dt} \end{pmatrix} = \begin{bmatrix} -\frac{k_c+2\lambda/\delta_c}{C_c} & \frac{k_c}{C_c} \\ \frac{k_c}{C_{nc}} & -\frac{k_c+k_{ext}}{C_{nc}} \end{bmatrix} \begin{pmatrix} T_c \\ T_{nc} \end{pmatrix} + \begin{pmatrix} \frac{L.E_c+2\lambda T_s/\delta}{C_c} \\ \frac{L.E_{nc}+k_{ext}T_{ext}}{C_{nc}} \end{pmatrix}$$

where $C_c = V_c\left(C_p\rho + C_w\theta_c\right)$ and $C_{nc} = V_{nc}\left(C_p\rho + C_w\theta_{nc}\right)$ the volumic heat capacity of the two mulch layers.

# 3 Resolution

The system of equations is solved with a Cranck-Nicholson method. We note $[A]$ the matrix in the system of equations and $S$ the vector in the second member.

The Cranck-Nicholson schema leads to:

$$\begin{aligned} \begin{pmatrix} T_c \\ T_{nc} \end{pmatrix}_{t+dt} = \begin{pmatrix} T_c \\ T_{nc} \end{pmatrix}_t &+ \frac{dt}{2}\begin{bmatrix} a_{1,1} & a_{1,2} \\ a_{2,1} & a_{2,2} \end{bmatrix}\begin{pmatrix} T_c \\ T_{nc} \end{pmatrix}_{t+dt} \\ &+\frac{dt}{2}\begin{bmatrix} a_{1,1} & a_{1,2} \\ a_{2,1} & a_{2,2} \end{bmatrix}\begin{pmatrix} T_c \\ T_{nc} \end{pmatrix}_t \\ &+\frac{dt}{2}\left(\begin{pmatrix} S_1 \\ S_2 \end{pmatrix}_{t+dt} + \begin{pmatrix} S_1 \\ S_2 \end{pmatrix}_t\right) \end{aligned}$$

Grouping the terms at time $t + dt$ and those at time $t$, we get the linear system:

$$\begin{bmatrix} 1-\frac{dt}{2}a_{1,1} & \frac{dt}{2}a_{1,2} \\ \frac{dt}{2}a_{2,1} & 1-\frac{dt}{2}a_{2,2} \end{bmatrix} \begin{pmatrix} T_c \\ T_{nc} \end{pmatrix}_{t+dt} = \begin{bmatrix} 1+\frac{dt}{2}a_{1,1} & \frac{dt}{2}a_{1,2} \\ \frac{dt}{2}a_{2,1} & 1+\frac{dt}{2}a_{2,2} \end{bmatrix} \begin{pmatrix} T_c \\ T_{nc} \end{pmatrix}_{t} + \frac{dt}{2}\left( \begin{pmatrix} S_1 \\ S_2 \end{pmatrix}_{t+dt} + \begin{pmatrix} S_1 \\ S_2 \end{pmatrix}_{t} \right)$$

The linear system is written:

$$\begin{bmatrix} \alpha_{1,1} & \alpha_{1,2} \\ \alpha_{2,1} & \alpha_{2,2} \end{bmatrix} \begin{pmatrix} T_c \\ T_{nc} \end{pmatrix}_{t+dt} = \begin{pmatrix} \sigma_1 \\ \sigma_2 \end{pmatrix}$$

Let "det" be the determinant of the linear system, the solutions are given by:

$$T_c = \frac{\sigma_1\alpha_{2,2} - \sigma_2\alpha_{1,2}}{\det}$$

$$T_{nc} = \frac{\sigma_2\alpha_{1,1} - \sigma_1\alpha_{2,1}}{\det}$$

The terms of the matrix are given by:

$$\begin{aligned} \alpha_{1,1} &= 1 + \frac{dt}{2}\frac{k_c + 2\lambda/\delta}{C_c} \\ \alpha_{1,2} &= -\frac{dt}{2}\frac{k_c}{C_c} \\ \alpha_{2,1} &= -\frac{dt}{2}\frac{k_c}{C_{nc}} \\ \alpha_{2,2} &= 1 + \frac{dt}{2}\frac{k_c + k_{ext}}{C_{nc}} \end{aligned}$$

and for the second member we have:

$$\begin{aligned} \sigma_1 = &\left(1 - \frac{dt}{2}\frac{k_c + 2\lambda/\delta}{C_c}\right) T_c(t) + \frac{dt}{2}\frac{k_c}{C_c} T_{nc}(t) \\ &+ \frac{dt}{2} L \frac{E_c(t+dt) + E_c(t)}{C_c} + \frac{dt}{2}\frac{2\lambda}{\delta}\frac{T_s(t+dt) + T_s(t)}{C_c} \\ \sigma_2 = &\frac{dt}{2}\frac{k_c}{C_{nc}} T_c(t) + \left(1 - \frac{dt}{2}\frac{k_c + k_{ext}}{C_{nc}}\right) T_{nc}(t) \\ &+ \frac{dt}{2} L \frac{E_{nc}(t+dt) + E_{nc}(t)}{C_{nc}} + \frac{dt}{2} k_{ext} \frac{T_{ext}(t+dt) + T_{ext}(t)}{C_{nc}} \end{aligned}$$

# 4 Inputs

Some of the inputs below are *tagged* in the sense of the VSOIL platform. The *taggs* are used to identify which transported species are concerned by the input terms. Tagged variables are indicated below by the following keyword: [*tagged*].

- **atmosphere air temperature** Temperature of the air. [$K$].
- **crop temperature** Temperature of the crop canopy. [$K$].

- **mulch bulk density** Bulk density of mulch elements. $[kg.m^{-3}]$.
- **mulch with soil contact evaporation volumetric flux density** Actual evaporation rate of the mulch with soil contact. $[m.s^{-1}]$
- **mulch with soil contact maximum evaporation volumetric flux density** Potential evaporation of the mulch in contact with the soil. $[m.s^{-1}]$
- **mulch with soil contact thickness** Thickness of the mulch in contact with the soil. $[m]$.
- **mulch with soil contact volume** Volume of mulch in contact with the soil surface. $[m^3.m^{-2}]$.
- **mulch with soil contact water volumetric content** Water content of the mulch fraction assumed to be with contact with the soil. $[m^3.m^{-3}]$
- **mulch without soil contact evaporation volumetric flux density** Actual evaporation rate of the mulch without soil contact. $[m.s^{-1}]$
- **mulch without soil contact maximum evaporation volumetric flux density** Potential evaporation of the mulch without contact with the soil. $[m.s^{-1}]$
- **mulch without soil contact volume** Volume of mulch without contact with the soil surface. $[m^3.m^{-2}]$.
- **mulch without soil contact water volumetric content** Water content of the mulch fraction assumed to be without contact with the soil. $[m^3.m^{-3}]$
- **soil temperature** Temperature of the soil. $[K]$.

# 5 Outputs

The module provides the following variables. All the informations (localisation, type, description, unit) concerning a variable are available inside the VSOIL-MODULES application. Tagged variables are indicated by the following keyword: [*tagged*].

- **atmosphere mulch without soil contact radiative heat flux density** Radiative heat exchange between the mulch not in contact with the soil and the atmosphere or the vegetation cover. A positive flux corresponds to a mulch temperature higher than the atmosphere or vegetation cover temperature. $[W.m^{-2}]$
- **mulch with soil contact evaporation volumetric flux density deficit** This is the energy received by the mulch in contact with the soil that is used to heat the mulch. It corresponds to the energy that was not used to evaporate water and consequently to a evaporation deficit. $[W.m^{-2}]$
- **mulch with soil contact mulch without soil contact radiative heat flux density** Radiative heat exchange term between the mulch not in contact with the soil and the mulch in contact with the soil. A positive flux results from a temperature of the mulch without soil contact higher than the temperature of the mulch in contact with the soil. $[W.m^{-2}]$

- **mulch with soil contact temperature** This is the temperature of the mulch fraction assumed to be in contact with the soil. In contact, means that it can be decomposed and it can exchange water and heat with the underlying soil. $[K]$ **Initial value required**
- **mulch without soil contact evaporation volumetric flux density deficit** This is the energy received by the mulch in not in contact with the soil that is used to heat the mulch. It corresponds to the energy that was not used to evaporate water. $[W.m^{-2}]$
- **mulch without soil contact temperature** This is the temperature of the mulch fraction assumed to be without contact with the soil. In contact, means that it cannot be decomposed and it cannot exchange water and heat with the underlying soil. $[K]$ **Initial value required**
- **soil surface mulch with soil contact conductive heat exchange** Heat exchange term between the soil and the mulch in contact with the soil. A positive value means a mulch contact temperature higher than the soil surface temperature. $[W.m^{-2}]$

# 6 Parameters

The description of the parameters and their characteristics are available inside the VSOIL-MODULES application when editing the module and in the Graphic User Interface. The parameters are however decribed hereafter. Default values are available within the platform when this is possible. **These values are given to ease the use of the module but they are not waranted and probably not correct for all the situations. The user must verify the default values.**

- **echcouv** $[W.K^{-1}.m^{-2}]$ Coefficient for calculating heat exchange between mulch and crop canopy.
- **ech_layer** $[W.K^{-1}.m^{-2}]$ Coefficient for calculating heat exchange between the two mulch layers.
- **capa_therm_mulch** $[J.Kg^{-1}.K^{-1}]$ Heat capacity of mulch elements.
- **ctherm1**, $[W.m^{-1}.K^{-1}]$ Zero order coefficient for calculating mulch thermal conductivity as a function of its water content.
- **ctherm2**, $[W.m^{-1}.K^{-1}]$ First order coefficient for calculating mulch thermal conductivity as a function of its water content.
- **fixtemp**, $[-]$ Logical to keep mulch temperature at its initial value