Modules mulch_water_bi

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1 Introduction

We propose a model for the evolution of the water content 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 θ_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: τ_c et τ_{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.

To model the water content θ_c and θ_{nc} evolutions in the mulch layers, we distinguish two situations: the rain periods and the phases of evaporation.

2.1 Rain conditions

During water applications, we assume that the mulch layer *without soil contact* intercepts a fraction of the water flux that is proportional to its soil surface coverage τ_{nc}. A fraction of this water is sorbed by the mulch elements, and the remaining part is then partially intercepted by the mulch layer *with soil contact*, according to its soil surface covering percentage τ_c. The fraction not retained by the two mulch layers arrives at the soil surface.

We assume that the fraction retained by a mulch layer is proportipnnal to the water flux arriving on this layer. This assumption results from the idea that the higher the rain rate the higher is the mulch surface wetted by the rain, thus increasing the water exchange with the mulch elements.

Since mulch elements can be viewed as porous media, we assume that the exchange of water between the water at the surface of mulch elements and their inner part decreases when their water content increases during wetting.

Last, we assume that during rain events, there is no exchange of water between the soil and the mulch layer in contact with it, neither between the two mulch layers. These exchanges are considered negligeable compared to the flux of water through the mulch and the flux retained by wetting.

If we note P the rain intensity and $f(\theta)$ the function modeling the reduction of sorption when water content increases in mulch elements, the instantneous flux of water retained by the mulch layer *without contact* is given by the product: $P.\tau_{nc}.f(\theta_{nc})$.

In the module, the function $f(\theta)$ writes:

$$f(\theta) = \exp\left(-\alpha \frac{\theta_s - \theta_{\min}}{\theta_s - \theta}\right) \quad (1)$$

with α a parameter allowing to define the maximum water sorption rate of the mulch. When $\theta = \theta_{\min}$, i.e. when water sorption is maximum, the fonction equals $e^{-\alpha}$. When $\theta = \theta_s$, the function is set to 0.

The differential equation modeling the water content of the mulch layer changes in time is then:

$$V_{nc}\frac{d\theta_{nc}}{dt} = P(t)\tau_{nc} f(\theta_{nc}) \quad (2)$$

It is a non-linear equation. An iterative method will be used. From the solution, we have the water flux retained by the mulch: $R_{nc}(t) = V_{nc}\frac{d\theta_{nc}}{dt}$.

For the mulch layer *with contact*, the only difference is that rain P is replaced by the rain minus the flux retained by the mulch layer *without contact*. In this case, we have the following différential equation:

$$V_c\frac{d\theta_c}{dt} = (P(t) - R_{nc}(t))\tau_c f(\theta_c) \quad (3)$$

2.2 Evaporation

We assume that Beer law can be used to calculate the fraction of the evaporative demand that each mulch layer intercepts. We calulates first for the layer *without contact*. The evaporative demand intercepted is given by:

$$Ep_{nc}(t) = Ep(t).(1 - e^{-B_{nc}\tau_{nc}}) \quad (4)$$

with $Ep(m.s^{-1})$ the evaporative demand and B_{nc} the coefficient of Beer law. The term Ep is provided by a module calculating the sharing of the climate evaporative demand between the crop canopy and below the canopy.

The evaporative demand intercepted by the mulch layer *with contact* is given by:

$$Ep_c(t) = Ep(t).e^{-B_{nc}\tau_{nc}}(1 - e^{-B_c\tau_c}) \tag{5}$$

The evaporative demand applied to the soil is given by:

$$Ep_{sol} = Ep - Ep_{nc} - Ep_c \tag{6}$$

By analogy with a porous medium, we suppose that the evaporation rate from the mulch elements decreases when the water content diminishes. So, per time unit, the amount of water lost by evaporation depends on the demand calculated above and on the water content of the mulch elements. The evaporation rates for the mulch layers write:

$$Ep_c = Ep_c.g(\theta_c) \tag{7}$$

$$Ep_{nc} = Ep_{nc}.g(\theta_{nc}) \tag{8}$$

We suppose that the function $g(\theta)$ is defined by:

$$g(\theta) = \left[\frac{\theta - \theta_{\min}}{\theta_s - \theta_{\min}}\right]^{\epsilon} \tag{9}$$

The water content in the *without contact* mulch layer is then modeled by the differential equation:

$$V_{nc}\frac{d\theta_{nc}}{dt} = -Ep_{nc}.g(\theta_{nc}) \tag{10}$$

For the mulch layer *with contact* exchanges with the soil are considered. We assume they are proportionnal to a water potential gradient between the mulch elements and the soil and also controled by the contact area between the mulch and the soil. We note ψ_{pail} the water potential in the mulch elements and ψ_{soil} the water potential in the soil in contact with the mulch, the flux exchanged is given by: $-K(\psi_{pail} - \psi_{sol}).\tau_c.\gamma/\delta$ with δ a distance soil-mulch and γ a reduction factor ($\gamma < 1$) to account for the contact area. The distance soil-mulch is difficult to define.

The differential equation for the water content in the mulch layer *with contact* is:

$$V_c\frac{d\theta_c}{dt} = -Ep_c(t)g(\theta_c) - K_{sol}(\psi_{pail} - \psi_{sol})\tau_c\gamma/\delta \tag{11}$$

Here also the equation is non linear and must be solved with with an iterative method.

3 Resolution

Equations for the rain and evaporation periods are similar and of the form:

$$V\frac{d\theta}{dt} = I(t)f(\theta) \tag{12}$$

with an initial situation $\theta_{t=0} = \theta_0$

A Crank-Nicholson schema leads to:

$$V\left[\theta(t+dt)-\theta(t)\right]=dt\left[I(t+dt)f(\theta(t+dt))+I(t)f(\theta(t))\right]/2 \quad (13)$$

and we have

$$\theta(t+dt)=\theta(t)+\frac{dt}{2V}\left[I(t+dt)f(\theta(t+dt))+I(t)f(\theta(t))\right] \quad (14)$$

We construct the series of values θ^k_{t+dt} as follows:

$$\theta^k_{t+dt}=\theta(t)+\frac{dt}{2V}\left[I(t+dt)f(\theta^{k-1}_{t+dt})+I(t)f(\theta(t))\right] \quad (15)$$

This series is convergent if $\|f'\|_\infty < 1$ in the vicinity of the solution. Howevere, in some cases, convergence can be long to obtain and in particular when the values of θ^k_{t+dt} oscillate around the limit of the series. This situation is detected by testing the sign of the product: $(\theta^k_{t+dt}-\theta^{k-1}_{t+dt})(\theta^{k-1}_{t+dt}-\theta^{k-2}_{t+dt})$. If it is negative, the new estimation θ^{k+1}_{t+dt} is calculated by

$$\theta^{k+1}_{t+dt}=(\theta^{k+1}_{t+dt}+\theta^k_{t+dt})/2. \quad (16)$$

This eliminates the cases of slow convergence. If convergence is not obtained before a prescribed number of iterations, the module returns a message to reduce the time step.

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*].

- **below canopy water volumetric flux density** Incoming flux of water (rain, irrigation, etc) that passed through the canopy and is applied to the soil-mulch system. $[m.s^{-1}]$.
- **below vegetation maximum evaporation volumetric flux density** This is the evaporative demand applying below the canopy, that is to the combination mulch/soil. It results from the sharing of the PET by the crop model. $[m.s^{-1}]$.
- **mulch with soil contact area index** Index for soil surface coverage with the mulch in contact with the soil. It is used for rain interception by mulch and also for calculating the fraction of the evaporation demand intercepted by the mulch. $[m^2.m^{-2}]$.
- **mulch with soil contact volume** Volume of mulch in contact with the soil surface. $[m^3.m^{-2}]$.
- **mulch without soil contact area index** Index for soil surface coverage with the mulch without contact with the soil. It is used for rain interception by mulch and also for calculating the fraction of the evaporation demand intercepted by the mulch. $[m^2.m^{-2}]$.
- **mulch without soil contact volume** Volume of mulch without contact with the soil surface. $[m^3.m^{-2}]$.
- **soil hydraulic** To access the hydraulic properties functions. $[-]$.
- **soil water matrix potential** Matrix soil water potential. $[m]$.

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*].

- **mulch evaporation volumetric flux density** Actual evaporation rate of the mulch. Sum of the evaporation rates of the contact and non contact layers. $[m.s^{-1}]$
- **mulch evaporation volumetric flux density daily** Actual evaporation rate of the mulch on a daily basis. $[m]$
- **mulch evaporation volumetric flux density time cumulated** Actual evaporation rate of the mulch cumulated in time. $[m]$
- **mulch maximum evaporation volumetric flux density** Evaporative demand applying to the mulch. It is a fraction of the below canopy evaporative demand. $[m.s^{-1}]$
- **mulch maximum evaporation volumetric flux density time cumulated** Evaporative demand applying to the mulch cumulated in time. $[m]$
- **mulch rain flux density evaporation** Flux density of rain that is substracted from evaporation demand for the mulch fractions. This is done when the evaporation demand applying to the mulch is higher than the rain flux density. $[m.s^{-1}]$
- **mulch rain flux density evaporation time cumulated** Time cumulated amount of rain substracted from the evaporation demand applying to the mulch during the rain events. $[m]$
- **mulch with soil contact evaporation volumetric flux density** Actual evaporation rate of the mulch with soil contact. $[m.s^{-1}]$
- **mulch with soil contact evaporation volumetric flux density time cumulated** Actual evaporation rate of the mulch with soil contact cumulated in time. $[m]$
- **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 maximum evaporation volumetric flux density time cumulated** Potential evaporation of the mulch in contact with the soil cumulated in time. $[m.s^{-1}]$
- **mulch with soil contact rain interception volumetric flux density** Rate of interception of the rain by the mulch fraction in contact with the soil. $[m.s^{-1}]$
- **mulch with soil contact rain interception volumetric flux density time cumulated** Rate of interception of the rain by the mulch fraction in contact with the soil cumulated in time. $[m]$
- **mulch with soil contact water amount** Water amount stored in the mulch in contact with the soil. $[m]$
- **mulch with soil contact water pressure** Water pressure in the mulch in contact with the soil. $[m]$

- **mulch with soil contact water saturation index** Water saturation index of the mulch in contact with the soil. $[-]$
- **mulch with soil contact water volumetric content** Water content of the mulch fraction assumed to be with contact with the soil. $[m^3.m^{-3}]$ **Initial value required**
- **mulch without soil contact evaporation volumetric flux density** Actual evaporation rate of the mulch without soil contact. $[m.s^{-1}]$
- **mulch without soil contact evaporation volumetric flux density time cumulated** Actual evaporation rate of the mulch without soil contact cumulated in time. $[m]$
- **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 maximum evaporation volumetric flux density time cumulated** Potential evaporation of the mulch without contact with the soil cumulated in time. $[m.s^{-1}]$
- **mulch without soil contact rain interception volumetric flux density** Rate of interception of the rain by the mulch fraction without contact with the soil. $[m.s^{-1}]$
- **mulch without soil contact rain interception volumetric flux density time cumulated** Rate of interception of the rain by the mulch fraction without contact with the soil cumulated in time. $[m]$
- **mulch without soil contact water amount** Water amount stored in the mulch without contact with the soil. $[m]$
- **mulch without soil contact water pressure** Water pressure in the mulch without contact with the soil. $[m]$
- **mulch without soil contact water saturation index** Water saturation index of the mulch without contact with the soil. $[-]$
- **mulch without soil contact water volumetric content** Water content of the mulch fraction assumed to be without contact with the soil. $[m^3.m^{-3}]$ **Initial value required**
- **soil mulch water volumetric flux density** Water flux from the soil to the mulch during evaporation periods. $[m.s^{-1}]$
- **soil mulch water volumetric flux density time cumulated** Water flux from the soil to the mulch during evaporation periods cumulated in time. $[m]$
- **soil surface maximum evaporation volumetric flux density** This is the evaporative demand that is applied at the soil surface. $[m.s^{-1}]$
- **soil surface maximum evaporation volumetric flux density time cumulated** This is the evaporative demand that is applied at the soil surface cumulated in time. $[m]$
- **soil surface water volumetric flux density** This is the water flux applied to the soil after influences of crop canopy and mulch have been accounted for. $[m.s^{-1}]$

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.**

- **thetas_pail** $[m^3.m^{-3}]$ Maximum water content of mulch elements.
- **thetar_pail** $[m^3.m^{-3}]$ Minimum water content of mulch elements.
- **alpha_rain_pail** $[-]$ Parameter to control water sorption by mulch elements during rain periods.
- **beer_pail**, $[-]$ Parameter of Beer law to calculate evaporative demand as function of mulch soil surface covering index.
- **fech_pail**, $[-]$ Multiplying factor of mulch area index to calculates water flux from soil to mulch during evaporation periods.
- **expo_pail**, $[-]$ Parameter for controling rates of water loss by mulch elements during evaporation.
- **thick_soil**, $[m]$ Soil thickness used to evaluate water exchange between soil and mulch elements during evaporation periods.
- **epsi**, $[-]$ Convergence criteria for equation modeling water sorption by mulch elements during rain events.
- **nitermax** $[-]$ Maximum number of iterations in the solution of the mulch wetting equation