Appendix 3.4-Colloid generation

1 Colloid generation on the surface

Colloid generation on the surface is a function of rainfall erosivity (related to kinetic energy or momentum of drops), rainfall erodibility and protecting elements such as a plant cover, litter/mulch or standing water.

Two different models are implemented to estimate kinetic energy, three different models are available to describe the reducing effect of a water layer (e.g., ponding) on splash detachment and three different models for generation of colloids at the surface are available:

- A method based on kinetic energy, but modified according to the MACRO model (Jarvis et al., 1999), (Jarvis and Larsson, 1998).
- A method based on momentum of the drops (Styczen and Høgh-Schmidt, 1988), and
- A method based on kinetic energy of rainfall (Morgan et al., 1998),

All three models consider that litter and mulch reduce the splash detachment, but they describe the effect of a canopy quite differently.

The two implemented models to estimate kinetic energy is based on the Universal Soil Loss Equation and the EUROSEM erosion model, respectively.

Kinetic Energy, Brown and Foster, 1987

Energy of rainfall can be calculated according to the revised Universal Soil Loss Equation (Brown and Foster, 1987):

$$E = 29\left(1 - 0.72\exp\left(-0.05 \cdot P_r\right)\right) \quad (1)$$

Where P_r is rainfall rate [mm h^{-1}] and E is kinetic energy [J m^{-2} mm^{-1}]

Total kinetic energy is then $KE_{DT} = E \cdot direct\ rain$ [J m^{-2} h^{-1}], where *direct rain* includes rain hitting ponded water or litter, but excludes rain hitting canopy or snow, as well as snow and all forms of irrigation. This method is by default used with the splash detachment model by Jarvis and Larsson (1998), implemented in the submodel “colgen_Jarvis99” and similar to the implementation in the MACRO-model. Thus, in this implementation, an area covered by canopy has no kinetic energy reaching the surface.

Kinetic Energy, Brandt (1989)

Kinetic energy can also be calculated as it is done in the EUROSEM erosion model. The total kinetic energy from the rainfall stems from rainfall hitting the soil directly and energy from rainfall dripping off leaves:

$$KE_{Tot} = KE_{DT} + KE_{LD} \quad (2)$$

KE_{DT} = Kinetic energy of drops falling directly on the ground [J cm^{-2} h^{-1}]

KE_{LD} = Kinetic energy from leaf drip [J cm^{-2} h^{-1}].

Energy of direct rainfall is estimated as a function of rainfall intensity developed by Brandt (1989):

$$KE_{DT} = (8.95 + 8.44 \cdot \log(I))J_{w,d} \tag{3}$$

I = rainfall intensity [mm hr^{-1}]

$J_{w,d}$ = direct rainfall = throughfall, eq. 3.17 in Chapter 3.

The energy of leaf drip is estimated by Brandt (1989) to be

$$KE_{LD} = \left(\left(15.8 \cdot H_{plant}^{0.5} - 5.87\right) J_{w,C}\right) \tag{4}$$

H_{plant} = effective plant height [m]

$J_{w,C}$ = drip-off from the plant canopy, [mm hr^{-1}], eq.3.22 in Chapter 3)

The kinetic energy is set to 0, when the vegetation is lower than 14 cm to avoid negative values of eq. (4). However, in this model, drip from the canopy contributes to splash detachment on the surface.

Water depth functions

The depth factor, K_h expresses the reduction in splash erosion with increasing water depth, h [m], of ponding on the surface due to absorption of energy by the water. Several exponential functions have been suggested to describe this reduction. In Daisy it is possible to choose between equations suggested by Park et al. (1982), Hairsine and Rose (1991), Morgan et al. (1998) and "none" ($K_h = 1$), see Figure 1.

The function by Morgan et al. (1998) (also used in the EUROSEM model) describes K_h as:

$$K_h = exp(-b \cdot h) \tag{5}$$

b = experimentally determined coefficient [mm^{-1}]. The range of "*b*" is from 0.9 to 3.1, and a default value of 2 is adopted.

The model by Park relates the depth factor to the median drop size:

$$K_h = 2.7183 \cdot exp(-h/dds) \tag{6}$$

dds = median drop diameter [m], calculated from the empirical relationship $dds = 1.238 \cdot I^{0.182}$.

The water depth factor by Harisine and Rose resembles the expression by Park, but applies a power function:

$$K_h = (-h/dds)^{-0.8} \tag{7}$$

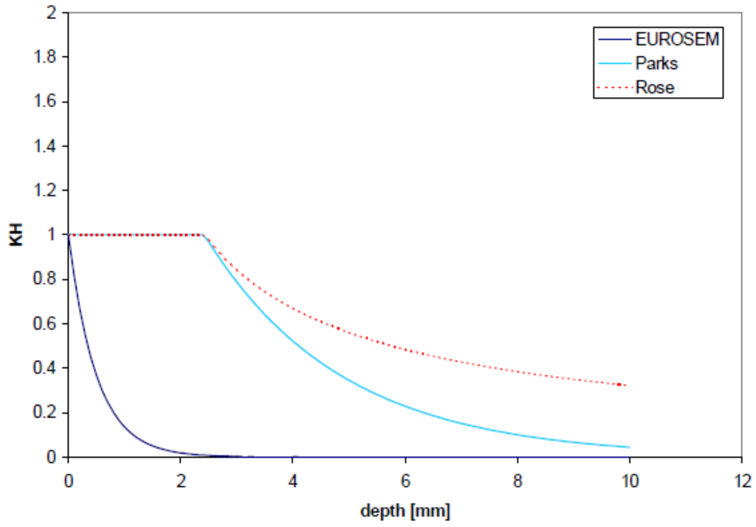

Figure 1. The water depth functions calculated for a rainfall intensity of 40 mm hr⁻¹.

Detachment, MACRO-model

Splash detachment of particles in the colgen_Jarvis99-submodel (similarly to splash detachment in the MACRO-model) is described as

$$D_s = K_h \cdot k_d \cdot KE_{Tot} \cdot \left(1 - A_M\right) \cdot M_s \tag{8}$$

D_s = Splash detachment [g cm^{-2} hr^{-1}]

K_h = a water depth function (default = 1 []),

k_d = an erodibility index, [g J^{-1}]

KE_{Tot} = total kinetic energy, by default calculated by the Brown and Foster-method, eq. (1).

A_M = the litter/mulch cover fraction protecting the soil from drops [].

M_s = mass fraction of dispersible/movable particles [g (g soil)$^{-1}$]

The amount of particles (colloid size) that can be detached from M_s is time dependent, as described in eq .(9):

$$\rho_s \cdot z_i \frac{\partial M_s}{\partial t} = -\alpha \cdot D_s + R_{rep} \tag{9}$$

ρ_s = bulk density of the soil [g m^{-3}],

z_i = depth of topsoil influenced by detachment and dispersion [m],

α = the faction of particles which are transported away from the surface ($0 \leq \alpha < 1$) [],

R_{rep} = the rate with which the amount of particles which can be detached are reproduced [g m^{-2} s^{-1}].

The process of reproduction of particles for detachment is described as

$$R_{rep} = k_r \left(1 - \frac{M_s}{M_{max}}\right) \quad (10)$$

k_r = rate of particle reproduction [g m^{-2} s^{-1}],

M_{max}= the maximum amount of colloids available [g g soil^{-1}].

M_{max} is, by default calculated as M_{max} = 0.362 * clay [%] – 0.00518 (Brubaker et al., 1992). Experience has shown that M_{max} may vary over time. It is possible to modify the value as a function of days after tillage. The fraction to multiply with may be specified as a piecewise linear function (plf).

Detachment, Morgan (1998)

The detachment of soil particles by splash erosion is described as in the EUROSEM model (Morgan et al., 1998):

$$D_S = K_h \cdot k_d \cdot KE_{Tot} \cdot (1 - A_M) \quad (11)$$

KE_{Tot} = Total kinetic energy of the rainfall [J cm^{-2} hr^{-1}] by (Brandt, 1989), eq. 2-4.

K_d = A soil erodibility index [g J^{-1}]

K_h = a water depth factor. The default choice is eq. (5).

Effects of plant canopy are considered in the calculation of kinetic energy.

Detachment, Rainfall Momentum Model

Styczen and Høegh-Schmidt (1988) describe splash erosion as a function of the squared momentum of drops hitting directly and drops generated on leaves.

$$D_s = A(e)(1 - A_M) K_h C_M M_R \quad (12)$$

$A(e)$ a soil resistance factor [hr^2 g^{-1} cm^{-2}] originally [s^2 kg^{-1} m^{-2}], describing the average amount of energy required to detach a particle as well as the probability that it will be moved into the water layer.

K_h one of the equations 5-7, above, chosen by the user.

C_M the total squared momentum of drops hitting the soils divided by the squared momentum of drops falling directly [],

M_R The squared momentum of drops falling directly on bare soil [g^2 hr^{-3}]. The original unit was (N s)^2 m^{-2} s^{-1}.

The squared momentum depends on the drop size distribution of the rainfall. For rainfall following the Marshall Palmer distribution, it is approximately proportional to rainfall intensity to a power [(N s)^2 m^{-2} s^{-1}]:

$$M_R = \begin{cases} (2.04 \cdot 10^{-8}) \cdot I^{1.63} & \text{for } I \le 75 \text{ mm hr}^{-1} \\ (4.83 \cdot 10^{-8}) \cdot I^{1.43} & \text{for } I > 75 \text{ mm hr}^{-1} \end{cases} \quad (13)$$

The Canopy cover-momentum factor, CM, describes the relative effect of vegetation on soil detachment and can be described as the actual squared momentum of drops hitting the soil directly and from canopy drip-off, divided by the squared momentum calculated without vegetation cover:

$$C_M = \frac{(1 - A_C)M_R + J_{w,C} \cdot M_C}{M_R} \quad (14)$$

A_C = fraction covered by a canopy

M_C = squared momentum of drops from the vegetation [$kg^2\ m^{-1}\ s^{-2}$]

$J_{w,C}$ = Canopy drip-off. [$m\ s^{-1} = m^3\ m^{-2}\ s^{-1}$]

MC depends on drop velocity which again depends on drop size and fall height. Drop velocities were measured by Epema and Riezebos (1983) for different combinations of drop sizies and fall height. The relationship is described as:

$$M_C = a + bH_C + cH_C^2 + dH_C^3 \quad (15)$$

Where the values of the constants are given in Table 1. below and HC is the height of the canopy from which the drops fall.

Table 1. Constants required to calculate the relationship between drop size, fall height and squared momentum of drops.

Plant		Drop sizes, mm			
height		4.5	5.0	5.5	6.0
<2 m	a	-			
	b	0.7954	1.1058	1.4916	1.9601
	c	-	-	-	-
	d	-	-	-	-
2-13 m	a	-0.5	-0.5	-0.5	-0.5
	b	1.2031	1.5930	2.0692	2.5496
	c	-0.12416	-0.15954	-0.20184	-0.23976
	d	4.33E-3	5.44E-3	6.70E-3	7.68E-3
>13 m	a	3.8647	5.4080	7.2934	9.5310
	b	-	-	-	-
	c	-	-	-	-
	d	-	-	-	-

1.1.1 Interaction between colloids and solute at the surface

The detached colloids are then mixed into the ponding water and water in the mixing layer, just as a solute. However, colloids can also, if so parameterized, sorb solutes to the surface, and thus create an additional transport pathway for (strongly) sorbing solutes. Colloids entering the soil with water can be filtrated from the water in the soil, see Chapter 6.

A solute sorbed to the surface soil will be distributed between colloids and the soil in the mixing layer according to the weight fraction the colloids constitute of the mixing layer. Colloids may have a larger K_d-value for sorption than the original soil, as colloids typically are made of finer material with a larger surface area. A soil enrichment factor [] can be set, specifying what the K_d of the soil should be multiplied with to represent K_d of the colloids.

Using the “sorption” function in Daisy (under “reaction”) it is possible to define a system where a solute is present in the water phase, sorbed to soil or sorbed to colloids, with sorption and desorption rates defined, thus describing kinetic sorption. The solute will move with the water and with transported colloids. In the soil, colloids may be filtered from the water phase. These different processes are further described in Chapter 6

Table 2. Related Parameter names in Daisy.

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
$\boldsymbol{b}$	Exponent in the expression for dampening splash erosion by water on the surface, eq. (5) (Morgan et al., 1998)	EUROSEM	*b*	2	[mm^{-1}]
$\boldsymbol{K_h}$	A water depth function	colgen_Jarvis99 colgen_Morgan98 colgen_Styczen88	*ponddamp*	1 (the option "none") EUROSEM optional	[]
$\boldsymbol{k_d}$	Detachment rate coefficient	colgen_Jarvis99 colgen_Morgan98	*kd*	User specified	[$g\ J^{-1}$]
$\boldsymbol{M_s}$	Current concentration of detachable particles in the topsoil	colgen_Jarvis99	*Ms*	10 % of *Mmax* (for initialization)	
$\boldsymbol{M_{max}}$	Maximum amount of detachable particles	colgen_Jarvis99	*Mmax*	M_{max} = 0.362 * clay [%] – 0.00518 (Brubaker et al., 1992)	[$g\ g^{-1}$]
	Sets *Ms=Mmax* after tillage	colgen_Jarvis99	*Tillage_replenish all*	false	
	Modifier to *Mmax* over time	colgen_Jarvis99	*Mmax_tillage_factor*	(Mmax_tillage_factor (0 1) (1 1))	plf [d → <none>]
$\boldsymbol{k_r}$	Replenishment rate coefficient	colgen_Jarvis99	*kr*	User specified	[$g\ cm^{-2}\ h^{-1}$]
$\boldsymbol{z_i}$	Thickness of surface soil layer	colgen_Jarvis99	*zi*	z_mixing from "Surface"	[cm]
$\boldsymbol{A(e)}$	a soil resistance factor describing the average amount of energy required to detach a particle as well as	colgen_Styczen88	*Ae*	User specified	[$hr^2\ g^{-1}\ cm^{-2}$]

Name and explanation		Model (in Daisy)	Parameter name (Daisy reference manual)	Default	Default unit
	the probability that it will be moved into the water layer.				
$\boldsymbol{A_M}$	Protective cover	colgen_Styczen88	*MA*	Cover predicted by the litter model	[]
dropsize	Size of droplets from vegetation	colgen_Styczen88	*Droplet_diameter*	User specified	[mm]
	Factor describing how many times higher the K_d of sorption to colloids is compared to the K_d of the soil.	sorption	*soil enrichment factor*	1	[]

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