MODELING S-METOLACHLOR LEACHING IN AN AGRICULTURAL SOIL COVERED WITH PLANT-RESIDUE

How to take into account a mulch in a pesticide fate model?

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Context

- ✓ **Cover crops together with crop residues on the soil surface (mulching)** are agricultural practices, often associated with conservation tillage, carried out in many parts of the world as **sustainable alternatives to conventional tillage** to prevent soil degradation

- ✓ Cover crops and/or crop residues left at the soil surface allow:
  - Reduction of surface runoff and soil erosion (Prosdocimi et al., 2016)
  - Regulation of the soil surface temperature (Alletto et al., 2011)
  - Capture of rainfall water (Iqbal et al., 2013)
  - Reducing the evaporation from the soil surface and improving water infiltration (Thierfelder et al., 2013)
  - Control of weeds (Martins et al., 2016)
  - Increase in the total N and OC contents in the top soil (Castellanos-Navarrete et al., 2012)

- ✓ Cover crops and/or crop residues modify the fate of pesticides by:
  - Intercepting pesticides before they reach the soil
  - Increasing their adsorption (Cassigneul et al., 2015)
  - Increasing/decreasing their leaching (Kasteel et al., 2007; Alletto et al., 2012)
  - Increasing/decreasing their degradation (Gan et al., 2003; Cassigneul et al., 2016)
  - Increasing/decreasing their volatilization (Whang et al., 1993; Weber et al., 2006)

- ✓ Very few pesticide fate models were designed to simulate these crop management practices

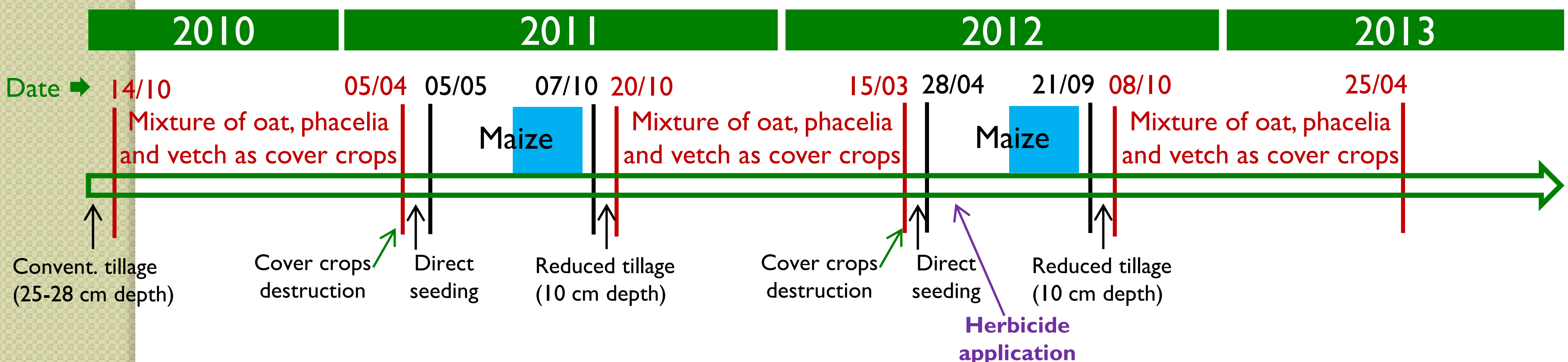
Objective of the work

- To develop an innovative approach to model the mulch layer linked to crop residues and its effects on the dynamics of water and S-metolachlor leaching in the MACRO pesticide fate model

Field experiment

- Experiments were set up on a field in Toulouse area (France)
- **Soil:** Stagnic Luvisol with clay-loam texture


- **Cropping system:** Conservation tillage maize monoculture system

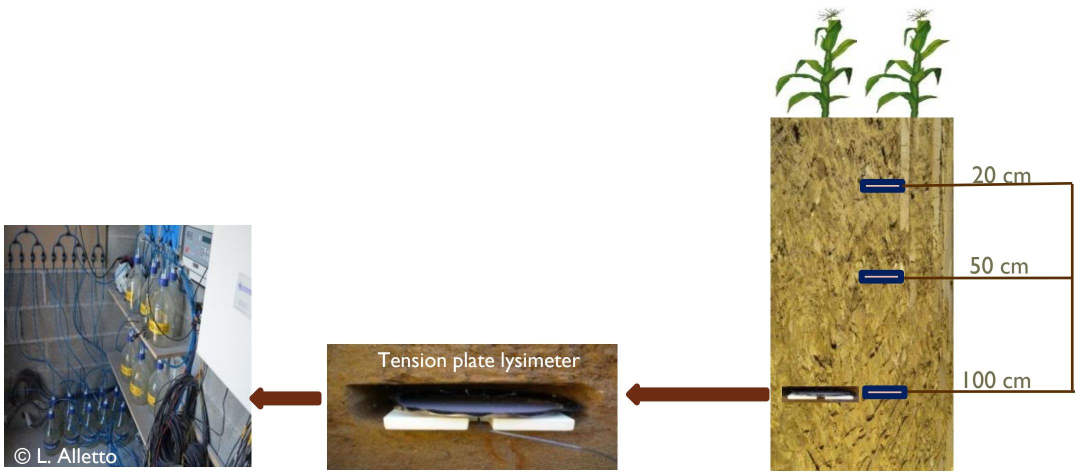


➡ Residues were left at the soil surface after maize harvest and after cover crops destruction by the herbicide glyphosate

- **Irrigation:** applied in summer during the maize growing season (220 mm in 2011 and 255 mm in 2012).
- **Herbicide:** S-metolachlor as Calibra (Syngenta) formulation
  ➡ 1.52 kg a.i./ha on 3 May 2012 (49 days after the cover crop destruction)

Field instrumentation and measurements

- Soil water content (SWC) and temperature were monitored at 20, 50 and 100 cm depth
- Water flow measurements and quantification of herbicide leaching were carried out with a tension plate lysimeter at 100 cm depth



- Temperature sensors
- TDR probes

- Climatic data were collected with a meteorological station located at the field site

Pesticide fate model

- A being developed version of MACRO* (v. 5.3) was used:
  - **Hydrology:** Richards´ equation (micropores) + gravity flow (macropores), capillary rise, preferential flows
  - **Crop:** monoculture, crop rotation, **NO MULCHING**
  - **Pesticides processes (fate):** adsorption, degradation, leaching, plant uptake

- The model was parameterized with:

  1) All available site-specific measured parameters (K_{sat} for soil, K_d and DT_{50} for soil and mulch, ...)

  2) For non-measured parameters:

     - Pedotransfer functions (θ_s, α, n for soil, ...)
     - Literature (K_{sat}, θ_s, α and n for the mulch, ...)
     - Default values according to the model user manual (θ_r, CTEN, ...)

* *Macropore flow model (Larsbo & Jarvis, 2003)*

Proposed approch to represent the mulch

- **Assimilate the mulch to a 5-cm-thickness high organic soil layer** with specific physical, hydrodynamical and pesticide-reactivity characteristics

Mulch layer

Depth (m) / Characteristic	0-0.05	0.05-0.15	0.15-0.35	0.35-0.65	0.65-2.05
Clay (%)	0.00	39.8	40.1	45.8	51.5
Silt (%)	0.00	47.2	45.3	42.2	38.2
Sand (%)	100	13.0	14.6	12.0	10.3
OC (%)	42.8	1.40	1.16	0.88	0.60
θ_r (m^3 m^{-3})	0.01 [a]	0.01	0.01	0.01	0.01
θ_s (m^3 m^{-3})	0.766 [a]	0.420	0.445	0.385	0.382
α (cm^{-1})	0.013 [a]	0.022	0.026	0.018	0.014
n (-)	1.204 [a]	1.111	1.121	1.072	1.058
K_{sat} (mm h^{-1})	3.3 [a]	98.7	126.0	44.2	14.5
K_b (mm h^{-1})	0.289	0.289	0.303	0.229	0.179
θ_b (m^3 m^{-3})	0.756	0.413	0.435	0.381	0.379
HERBICIDE					
K_d (cm^3 g^{-1})	25.45 [b]	1.9	1.58	1.2	0.482
DT_{50} (d)	61.5 [b]	57	57	105	169

[a] *Wösten et al., 1999*

[b] *Considering 50% covered soil surface by mulch*

Effect of the mulch on the soil water balance

- Introduction of a correction factor (K_m) in the estimation of the potential evapotranspiration (ETP_m) through a **two-step approach**

$$ETP_m = (ET_0 \times K_c) \times K_m$$

ETP_m = ETP in the presence of mulch
ET_0 = reference evapotranspiration
K_c = crop factor
K_m = correction factor due to the mulch presence

Step1. Non-optimized K_m values defined according to the nature of mulch (Khaledian et al., 2012)

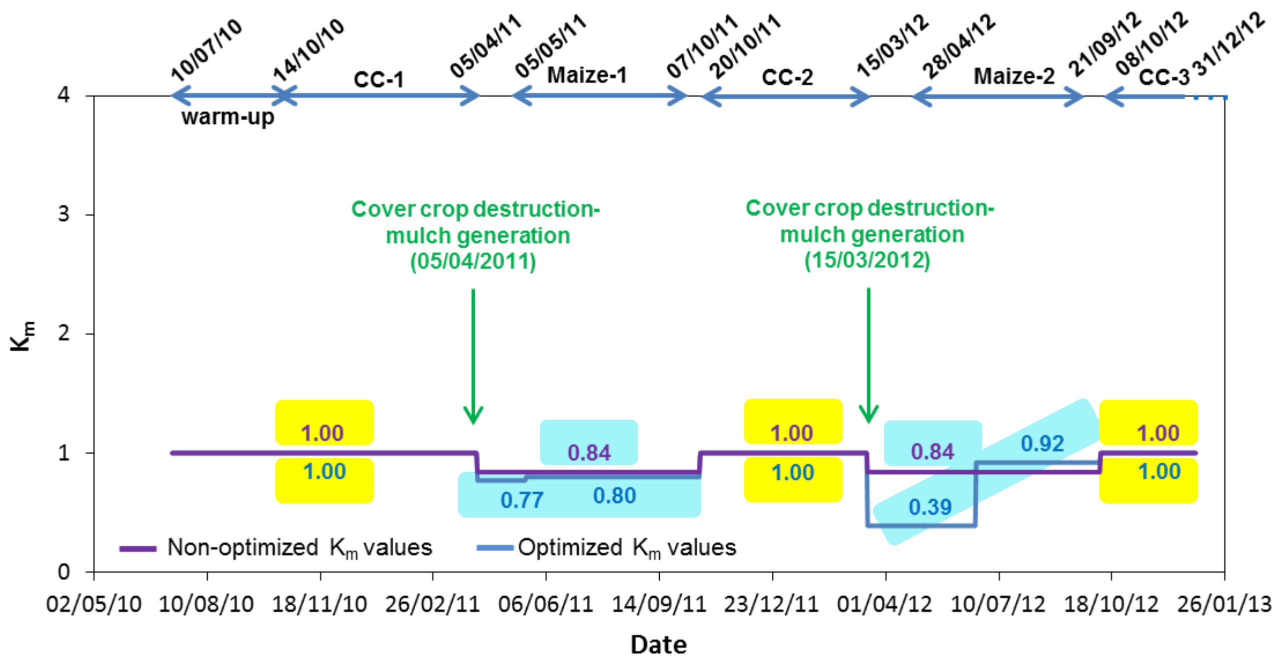
Step 2. Optimized K_m values calibrated for each maize and cover crop cycle to take into account the effects of:

- Crop development stage
- Amounts of irrigation applied and thus of water stored in the crop residues
- Year period
- Amount of crop residues and/or degree of mulch decomposition

(Findeling et al., 2007)

Control of the mulch effects on the soil water balance by the K_m factor

- **Step 1:** Definition of K_m values
  - ✓ Growth of cover crops: No reduction of evaporation => **K_m = 1**
  - ✓ After destruction of cover crops and during maize seasons: Constant reduction of evaporation due to the presence of the mulch => **K_m = 0.84** (Khaledian et al., 2012)
- **Step 2:** Calibration of K_m values for each maize and cover crop cycle
  - ✓ **K_m = 1** during all growth cycles of the cover crop
  - ✓ **Two different pairs of K_m values** for each maize cropping period



Evaluation of model performance

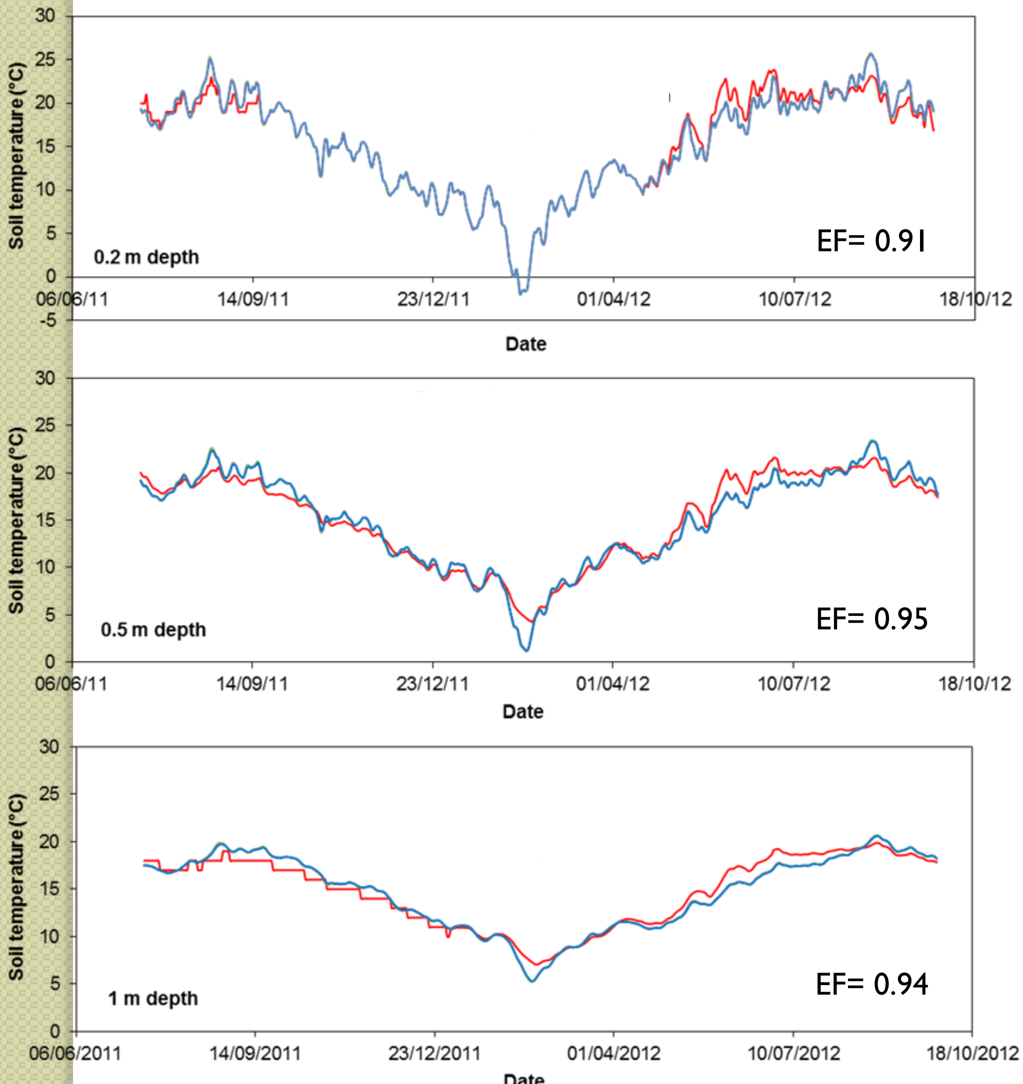
- Efficiency (EF) (Nash & Sutcliffe, 1970):

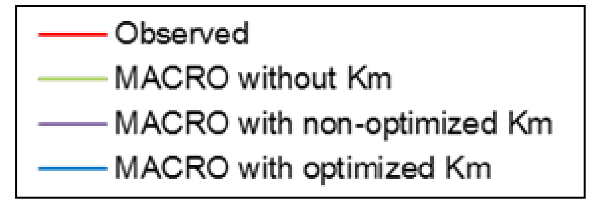
$$EF = 1 - \frac{\sum_{i=1}^{n}(S_i - O_i)^2}{\sum_{i=1}^{n}(O_i - O_m)^2}$$

S_i : Simulation
O_i : Observation
O_m : Mean of O_i
n : Number of measurements

The optimum value of *EF* is 1 (perfect fit)

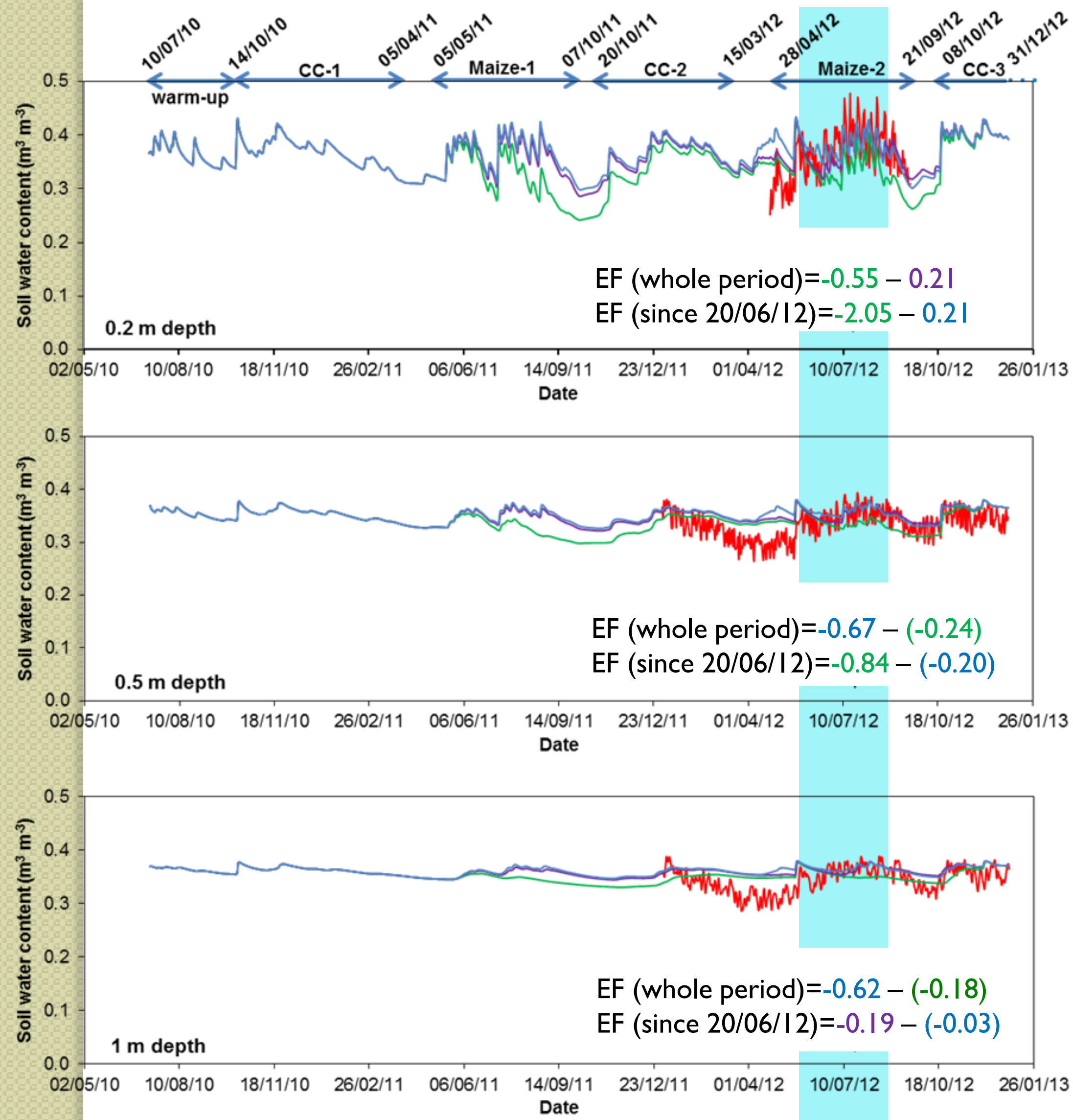
Soil temperature observed and simulated at 0.2, 0.5 and 1 m depth





- No correction of the soil temperature regarding the possible effects of crop residues was done
- Use of different K_m values had no effect on soil temperature simulation
- MACRO simulated very well the soil temperature (EF>0.90)

Soil water content observed and simulated at 0.2, 0.5 and 1 m depth

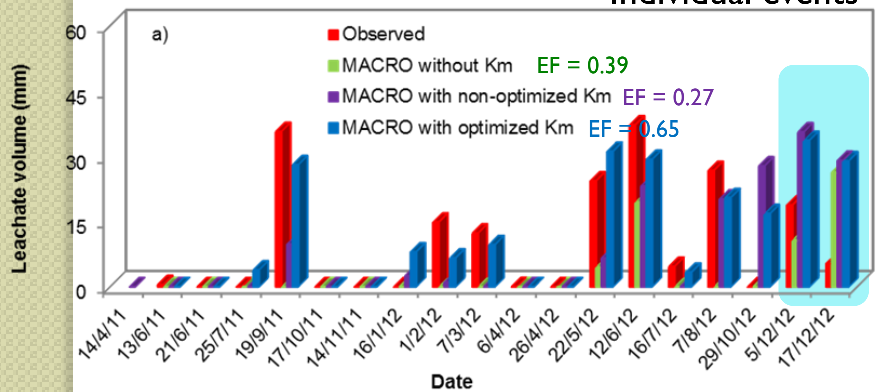


- Simulation without K_m prevent the right simulation of water content during irrigation

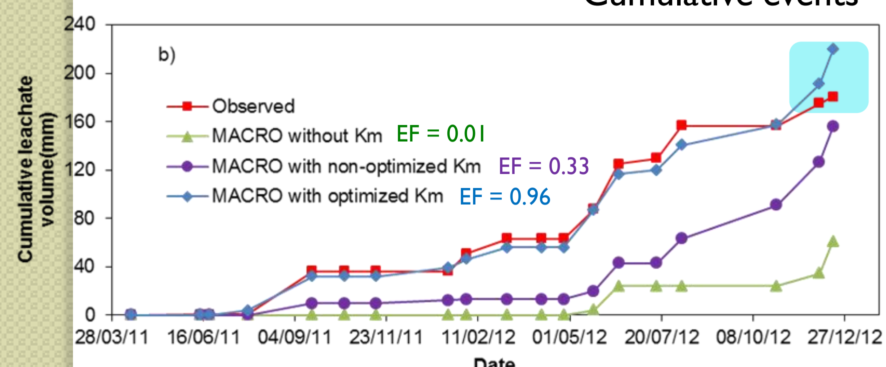
- Use of K_m improved simulation of soil water content

Water percolation observed and simulated at 100 cm depth

Individual events



Cumulative events



Simulation without K_m :

- MACRO underestimated the volume of water measured in the lysimeter (except 17 December 2012)
- The total volume of water leachates (181 mm) was underestimated by 66%

Simulation with non-optimized K_m :

- Improved slightly the simulation of the cumulative percolation
- Underestimation of 14% of the total volume

Simulation with optimized K_m :

- Improved the individual leaching events and the cumulative percolation
- MACRO overestimated the cumulative percolation by 39 mm (22%)

➡ Use of K_m allowed a good simulation of water percolation

Herbicide leaching (concentrations and flows) observed and simulated at 1 m depth

Herbicide application: 3 May 2012

Period	Mean concentrations of S-metolachlor				Cumulative flows of S-metolachlor			
	Observed	MACRO			Observed	MACRO		
		Without K_m	With non-optimized K_m	With optimized K_m		Without K_m	With non-optimized K_m	With optimized K_m
26/04 - 22/05/2012	7.10	0.04	0.46	5.14	172.8	0.166	3.083	160.1
23/05 - 12/06/2012	5.20	0.74	2.68	6.48	193.5	14.48	61.94	189.5
13/06 - 16/07/2012	2.30	0.00	4.83	4.80	61.49	0.000	97.25	98.18
30/10 - 05/12/2012	0.64	0.25	1.42	1.17	12.04	2.720	50.38	39.22
06/12 - 17/12/2012	0.08	1.13	4.96	4.24	0.430	29.87	143.9	122.6
		EF=-0.62	EF=-1.24	EF=0.47		EF=-0.62	EF=-1.14	EF=0.19

Concentrations: Underestimation (without / with non-optimized K_m); Acceptable (with optimized K_m)

Flows: Underestimation (without / with non-optimized K_m); Acceptable (with optimized K_m)

- ✓ The herbicide was detected and also predicted by MACRO in the water leachate 19 days after the application (3 May 2012) independently of the simulation done (with or without K_m)
- ✓ The **high cumulated rainfall** from 4 to 22 May 2012 (79 mm) together with the **high solubility in water** of this herbicide (480 mg L^{-1}) could be responsible for the quick leaching of a high amount of S-metolachlor
- ✓ For optimized K_m, the marked overestimation of the S-metolachlor concentrations and flows measured in the period 6-17 December 2012 by the model lowered the EF values

➡ Use of optimized K_m values allowed acceptable simulation of S-metolachlor leaching

Conclusions

- ✓ The strategy used allowed to reproduce satisfactorily the field observations of water percolation, soil temperature, and herbicide leaching although the performance of MACRO to simulate the soil water content was more limited

- ✓ This strategy could be one option to assess the environmental risks of pesticides used in conservation tillage cropping systems and it could be considered **in future improvements of the code of pesticide fate models** (e.g. implementing a module that allows to input different K_m values) **to take into account the mulch effects**

- ✓ The **method** developed in this work **needs to be tested against various crops and pesticides** to propose a guidance making a list of different values of ETP correction factors depending on the crop development stage, the amount of crop residues, the surface covered by the mulch, its decomposition degree, etc

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