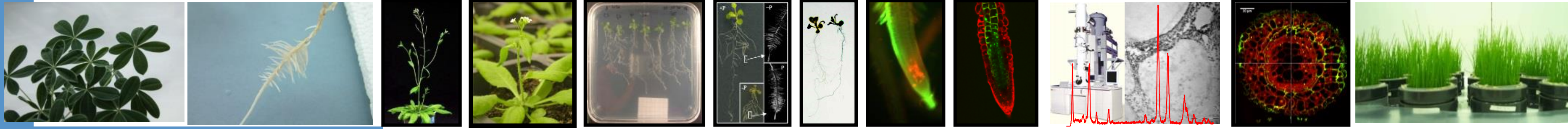

IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Faire avancer la sûreté nucléaire

Integrated approaches for a better understanding and modeling of radionuclides transfers along the soil-soil solution plant continuum

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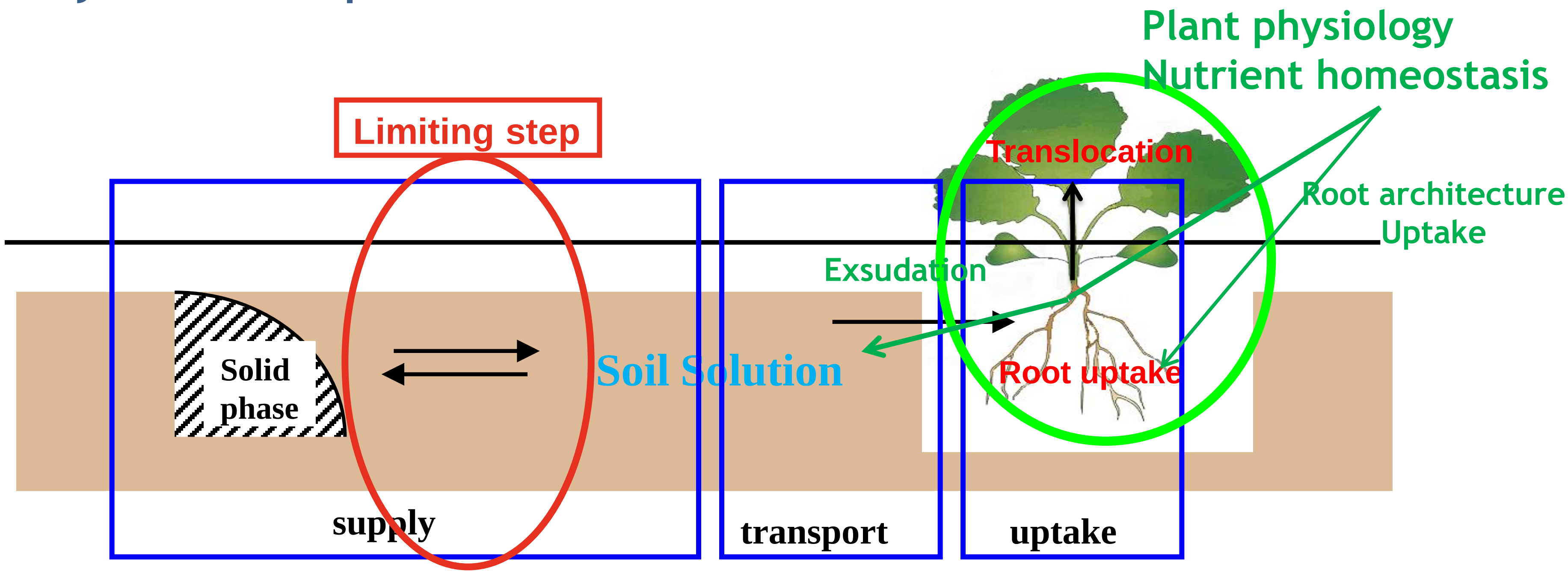
***Technical area** Agricultural land and Water*

➢ System description



Kinetics of re-supply

Kinetics of uptake

ISO17402

Physicochemical availability

Environmental bioavailability

Phytoavailaibility

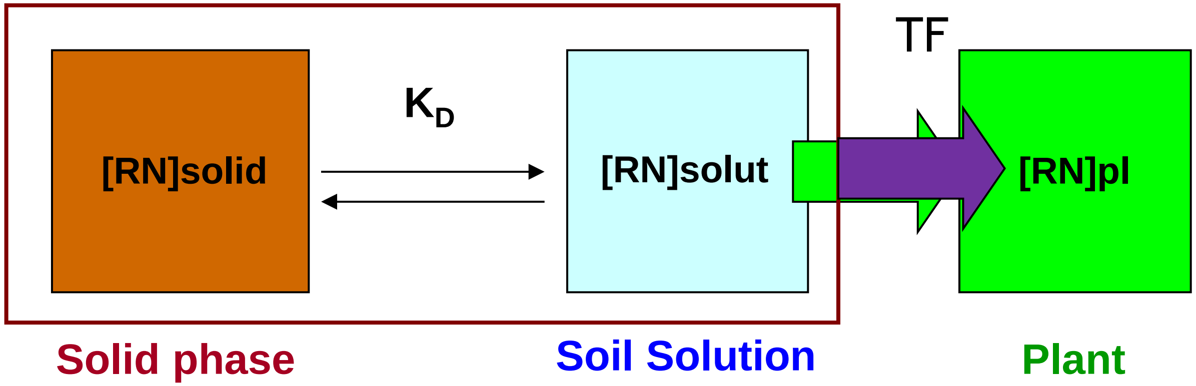
- ➢ Needs : any soil/plant conditions, various scenarii, spatial and temporal issues…

A template that starts from the existing and try to improve it at different levels:

- ❑Kd/TF operationnal model
- ❑Idenfication and hierarchisation of processes and parameters/co-factors
  - solid/liquid processes (physicochemical availability)
  - extent of plant influence (sink / exudation)
  - in planta : from organism/organ scale down to molecular
- ❑develop an unified model of transfer in the soil-solution-plant continuum (Cs)
  - combine different solid/liquid and solution/plant models
  - define some alternatives for the solid/liquid interface

conclusion

➢ Kd and TF models used in radioecology



- Operationnal: respond to « any case » need
- Simple: wide database of parameter values generated (TRS472)

- Extrapolation from laboratory studies to reality (site, source term…)
- Problems: temporal, speciation…
- Associated hypothesis: linerity, instantaneous reversibility for K_D, linearity of soil/plant relationship…
- Wide variability of parameter values
- Great uncertainty of model output (e.g. dose to human) generated

➡ Improve what? Values? Parametrization? Description of processes? Models?

➢ Improve values/parametrization

K_D

Include knowledge on environmental co-factor

Cs : from texture discrimination to discrimination base on RIP

Element	Soil group	N	Mean	GSD[a]	Minimum	Maximum
Cs	All soils	469	1.2×10^3	7.0	4.3	3.8×10^5
	Sand	114	5.3×10^2	5.8	9.6	3.5×10^4
	Loam + clay	227	3.7×10^2	3.6	3.9×10^1	3.8×10^5
	Organic	108	2.7×10^2	6.8	4.3	9.5×10^4

TRS472

Cs	RIP[d]<150	47	7.4×10^1	2.4	1.0×10^1	7.3×10^2
	150<RIP<1000	78	3.2×10^2	5.6	1.0×10^1	3.4×10^4
	1000<RIP<2500	72	2.4×10^3	4.1	6.2×10^1	9.5×10^4
	RIP>2500	60	7.2×10^3	4.0	2.2×10^2	3.8×10^5

TF

From radioecological class to TF based on plant ionomics and phylogeny

	Tubers	Tubers	All	1	[illegible]			
Cs	Cereals	Grain	All	20	3.1×10^{-3}	3.7	2.4×10^{-4}	2.0×10^{-2}
			Sand	5	1.1×10^{-2}	2.6	2.0×10^{-3}	2.0×10^{-2}
			Loam	7	2.8×10^{-3}	3.3	2.4×10^{-4}	7.0×10^{-3}
			Clay	6	1.6×10^{-3}	4.1	2.8×10^{-4}	6.0×10^{-3}
			Organic	1	8.0×10^{-4}			
		Stems and shoots	All	13	3.9×10^{-2}	5.5	3.0×10^{-3}	6.8×10^{-1}
			Sand	4	2.8×10^{-1}	2.5	8.0×10^{-2}	6.8×10^{-1}
			Loam	6	7.0×10^{-3}	2.4	7.0×10^{-3}	6.0×10^{-2}
			Clay	3	3.0×10^{-3}	3.0	3.0×10^{-3}	2.7×10^{-2}
	Leafy vegetables	Leaves	All	1	6.0×10^{-3}			
	Leguminous vegetables	Seeds and pods	All	2	1.3×10^{-2}		6.0×10^{-3}	2.0×10^{-2}
			Sand	1	2.0×10^{-2}			
			Loam	1	6.0×10^{-3}			

TRS472

Ionomic groups in plants not linked to soil availability and plant use as food

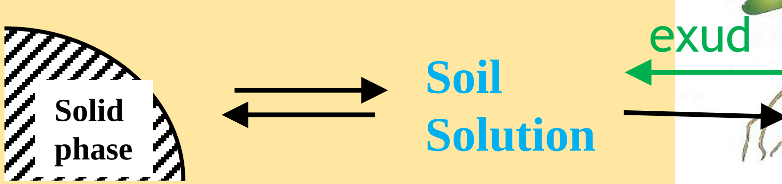
Phylogeny-based CR
REML models fro willife

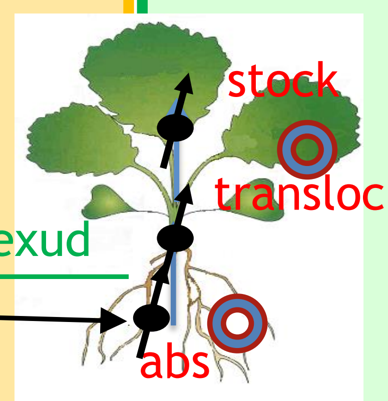
➢ Identification, hierarchization and description of key processes and co-factors

- Focuses at different scale – associated experimental tools and modelling

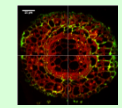
- Rhizospheric processes (interface)
  - ✓ **Effect of soil/solution speciation, effect of root exudation…**
  - ✓ **Sink effect don soil/solution equilibrium using passive (DGT) or active (root) « samplers »**

rhizotest





- processes in planta
  - ✓ **Internal speciation**



  - ✓ **Modulation of fluxes and retroactions by induced toxicity or nutrient homeostasis**

Ex: Cs/K regulation or co-effetcs U / P /Fe nutrition

  - ✓ **Molecular approach:**

Ex: transporters (transporters of K responsible of Cs tranfer)

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Experimental tools:

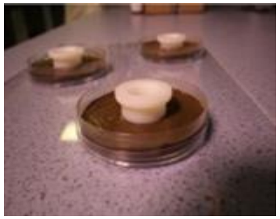
- open, growing complexity, conducted further away very short term (continuous or repeted extraction) :

- decrease of ions at the soil/solution interface with time =f(t)

(soil column or stirred flow through reactors),

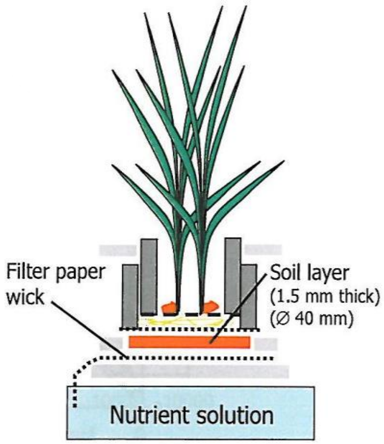
- use of an artificial sink to remove ions from soil solution (DGT as a surrogate of root uptake ;

- simplified soil/solution/plant interface (inclusion of exudation, homeostasis, RhizoTest)



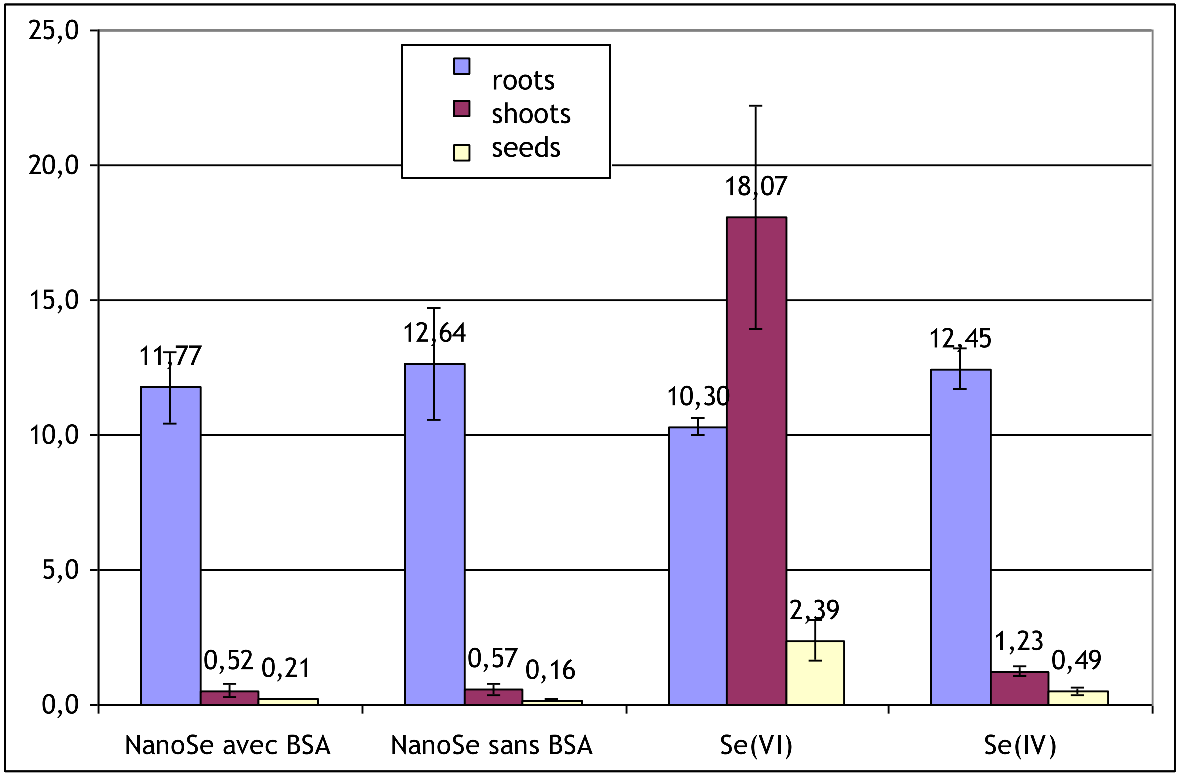
- Identification and hierarchization of processes and co-factors at different scales (root interface, plant, transporter), benefit of experimental tools

Example 1: Fluxes at the scale of soil-root interface



Rhizotest

Transfer of Se from Se-contaminated soil to ryegrass : Effect of Se speciation



Associated modelling: water flux and availability of Se as a function of speciation (empirical)

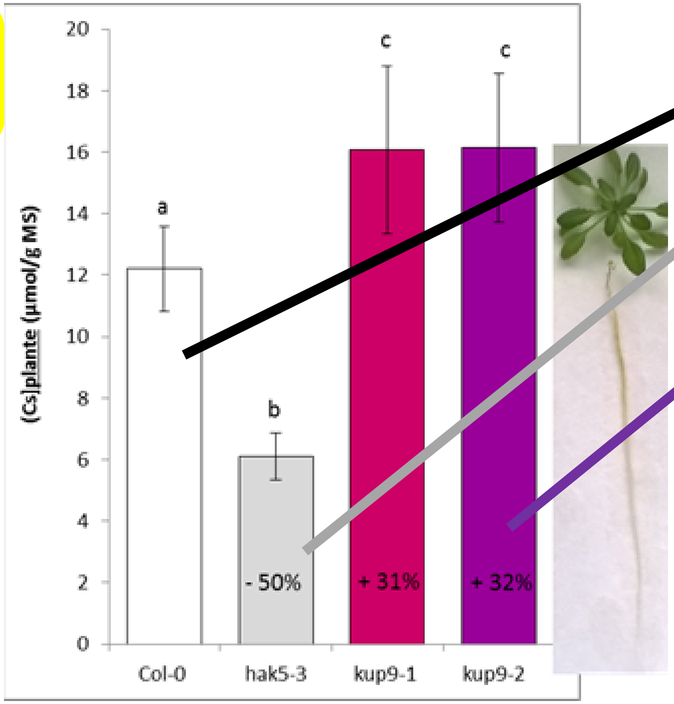
Example 2: at the molecular scale

insight in K transporters involved in Cs transfer
=> topics of nutrient homeostasis/RN transfers

Low K

DEMETERRES

RSNR-11-0005



wild-type ecotype

mutant line without HAK5 induced by low K

mutant line without KUP9 not induced by low K

K homeostasis (K_{plant} & K_{medium}) ➔ **transporters**

Cs or ~~Cs~~

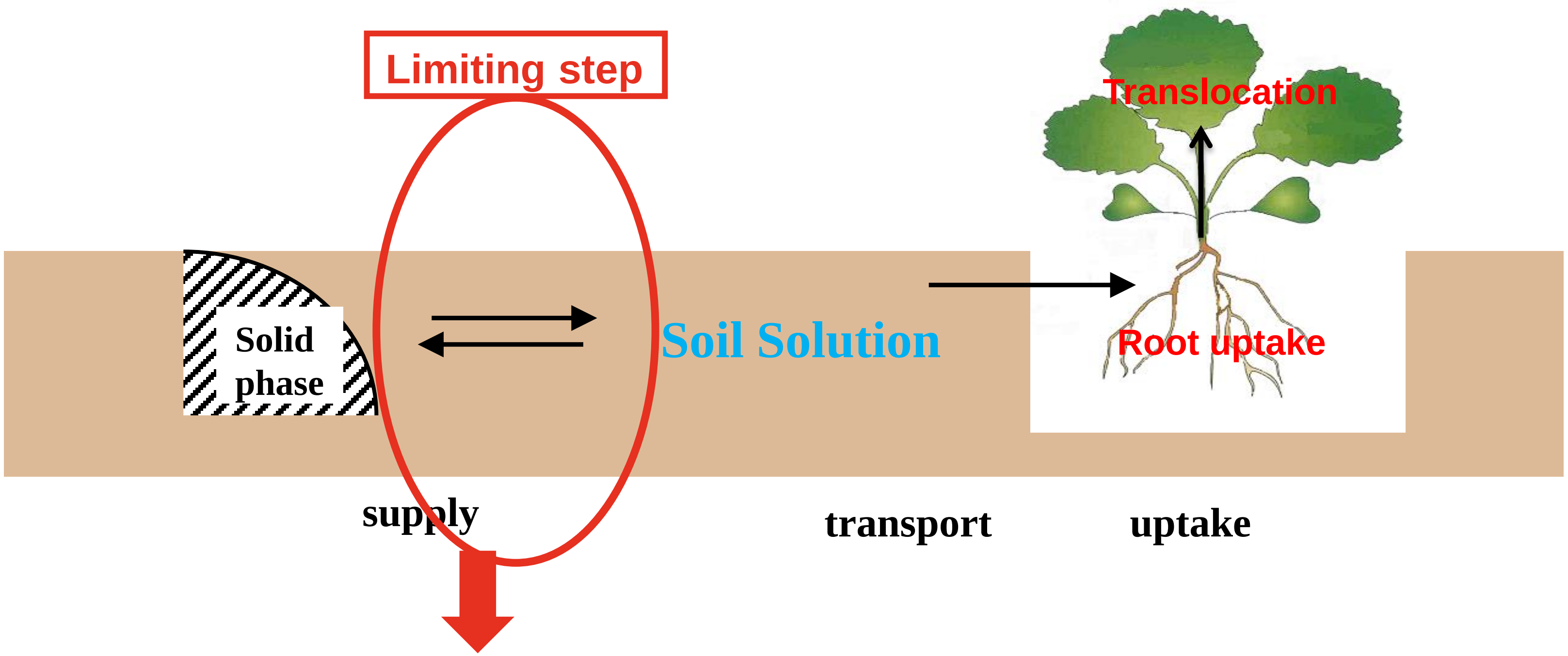
TF ≠

≠ values of model parameters
e.g. Michaelis-Menten K_m / V_m

(PhD L. Genies, Fujimura et al. 2014)

➢ Towards the modélisation of the soil-plant continuum

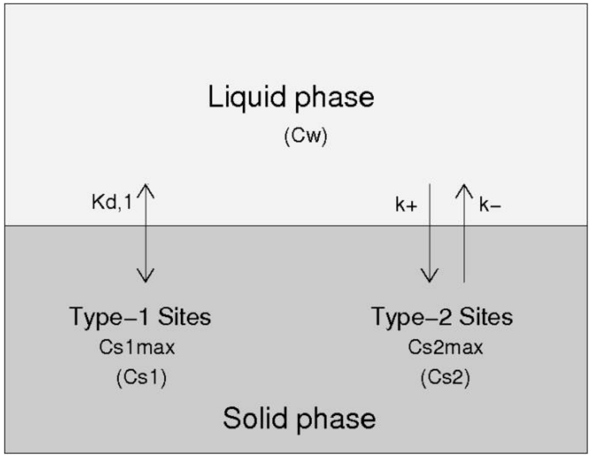
- Coupling solid/liquid and solution/plant models
- Models: operationnal, phenomenological, kinetical, mecanistic
- Validation or testing by comparison model/measure (experimental tool).



Evaluation of the stock used to calculate the transfer before refining transfer treatment itself, conditonnal Kd

The E-K (Equilibrium and Kinetics) model to calculate K_D and temporal validity range or as alternative to K_D and mecanistic models

(in accordance with TECDOC 1616)



- $Kd = K'd + \frac{k^{+}}{k^{-}}$
- $t_{1/2} \gg k^{-} + \frac{mk+}{V+mK'd}$

Stirred Flow Through Reactors for parameters acquisition

RN sorbed on solid phase:

1- Labile/exchangeable fraction

2 - Less exchangeable or introduction of kinetics limitation)

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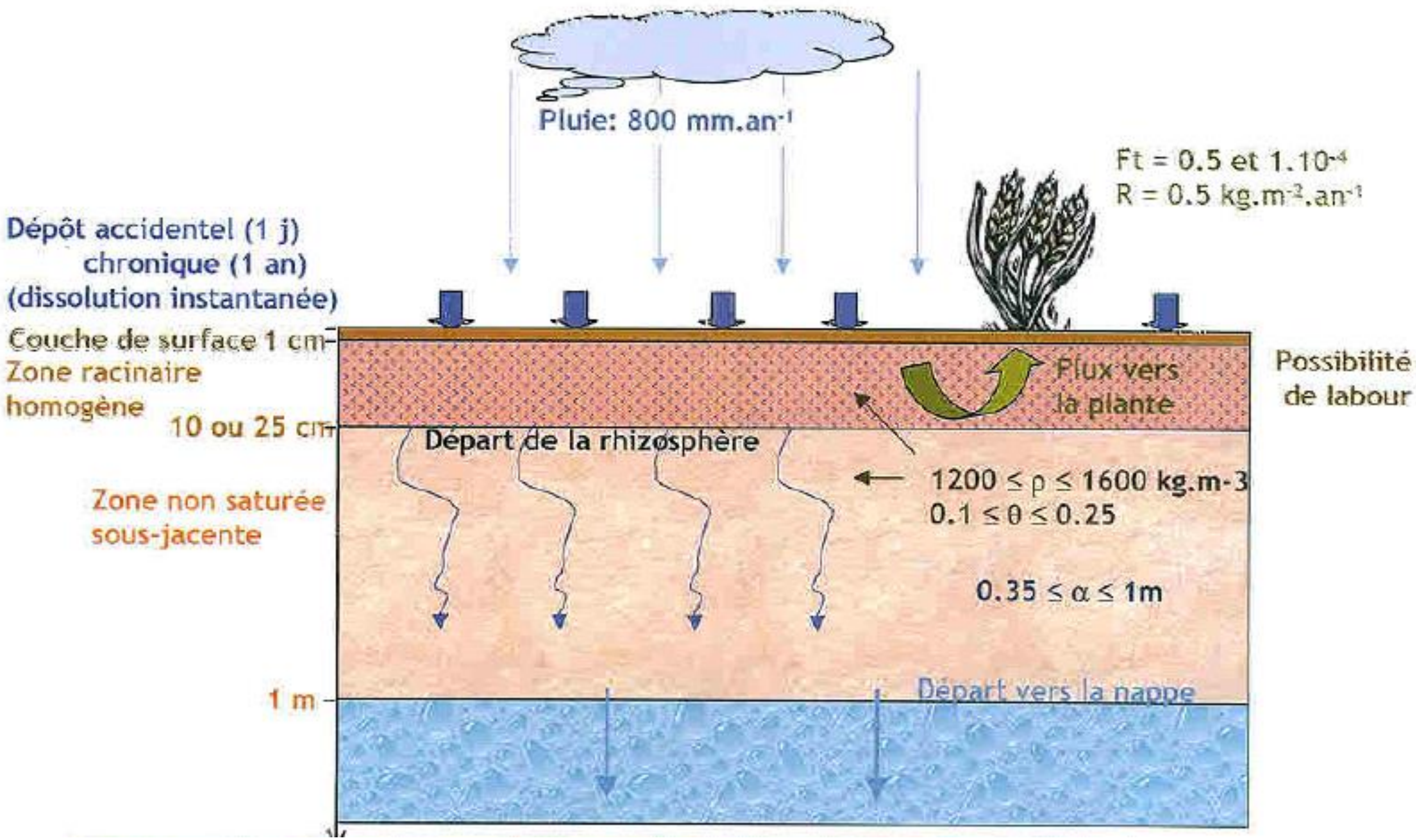
- With only 2 to 5 parameters

Kd_1 ($m^3.kg^{-1}$) , k^+ ($m^3.kg^{-1}.s^{-1}$) , k^- (s^{-1}), C_{s1max}, C_{s2max} ($mol.kg^{-1}$)

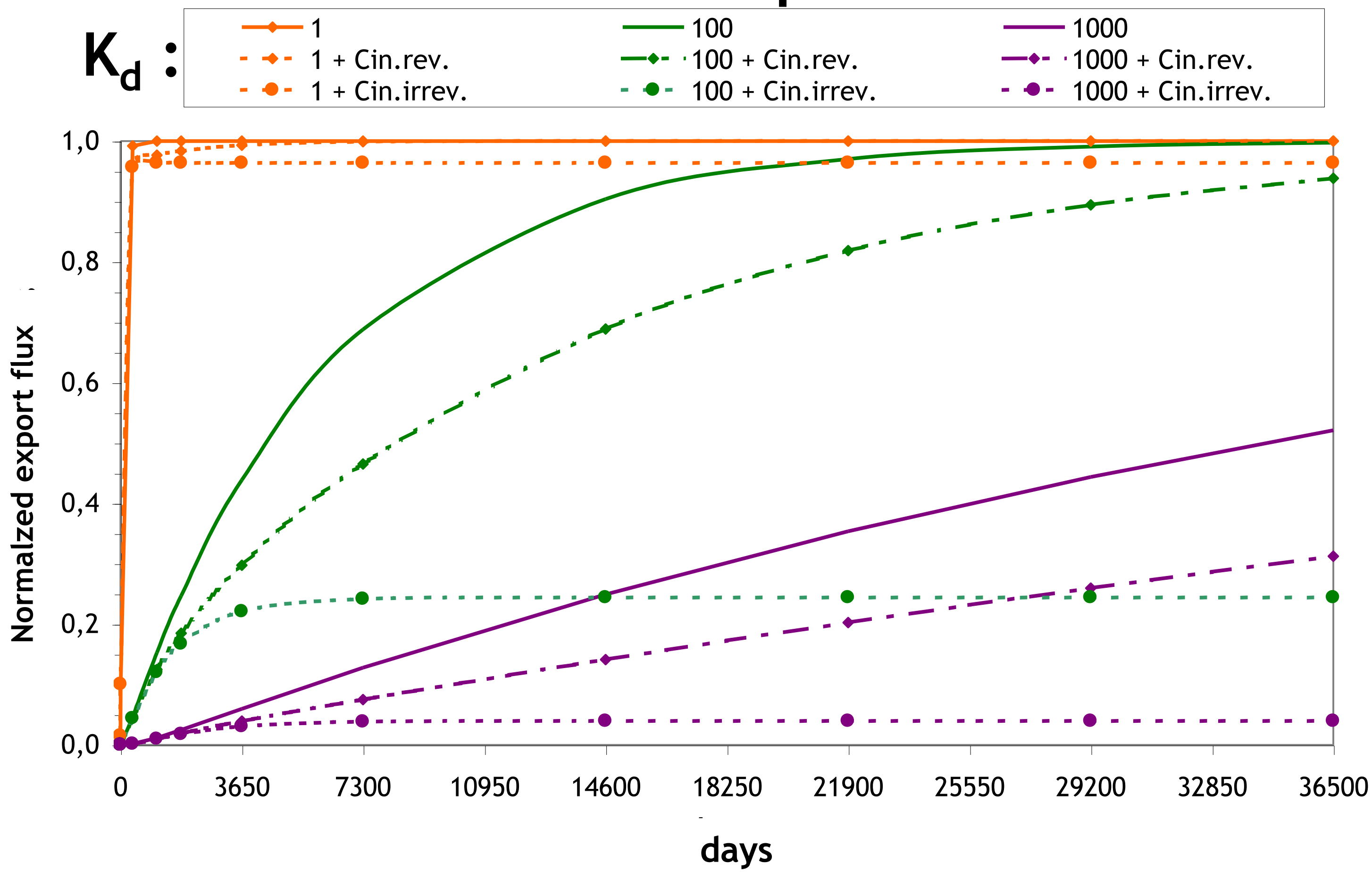
- Include K_D (sorption on Sites 2 = 0),
- Describe well hysteresis between sorption and desorption,
- Large range of behaviors including non linear sorption sorption (C_{s1max} and/or C_{s2max}), partial reversibility or irreversibility (k^-=0),
- Allow calculation of equilibrium K_D and associated time to reach equilibrium
- Phytoavailability: estimation of a phytoavailable fraction varying in time based on hypothesis of $C_w + C_{s1}$ being the sole available fractions

Test of different hypothesis with SYMBIOSE (IRSN/EDF) modelling platform



Output: consequence of hypothesis regarding available fraction on fluxes outward rhizosphere and to plant

Outward flux from rhizosphere



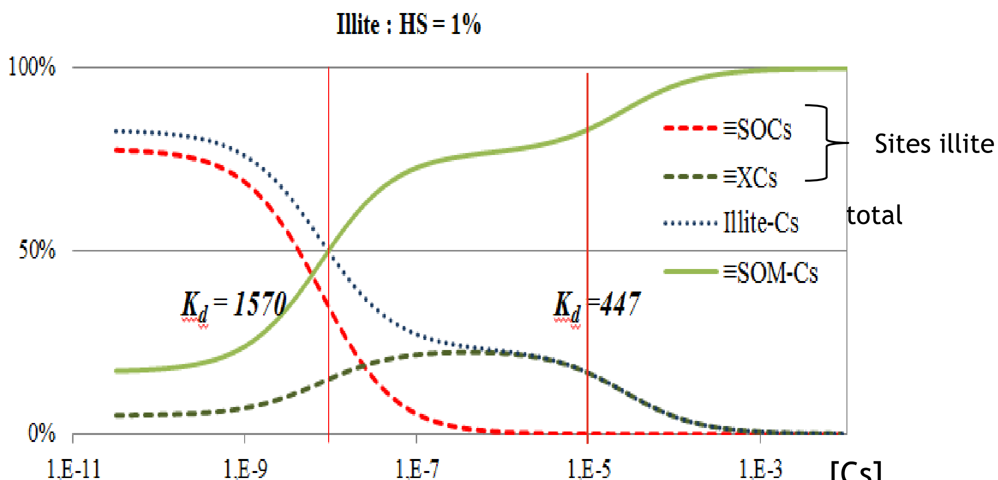
Proximity of results for short timescales but great divergence for longer timescales depending the hypothesis

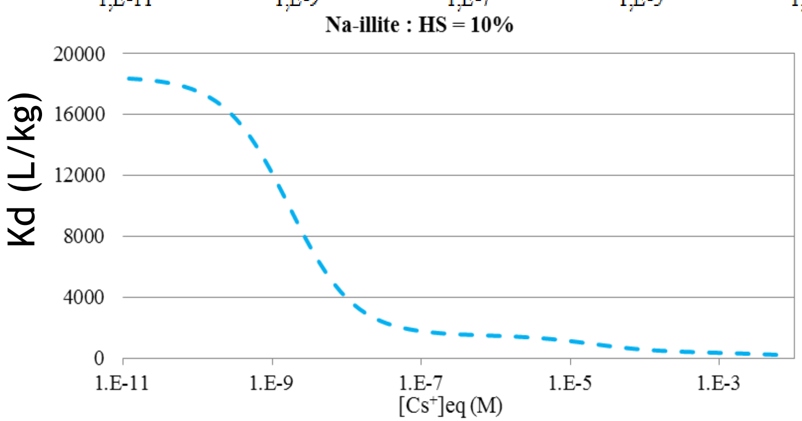
Same improvement for flux to plant

❑ Improve soil/solution modelling through work on interaction sites and differential affinity that would result in differential bioavailavility

Thermodynamic approach using addition of reactive soil components. Example for Cs, clay minerals and organic matter

Solid speciation of Cs as a function of [Cs] and [sites]





Affinitys : ≡SOM-Cs << ≡XCs < ≡SOCs

$$K_d = \Sigma (\equiv Cs) / [Cs]_{tot}$$

Sorption of Cs on sites = f([Cs] and clay content)

Desorption: sites OM then NS clay then S clay => increase in Kd with the exhaustion of solid

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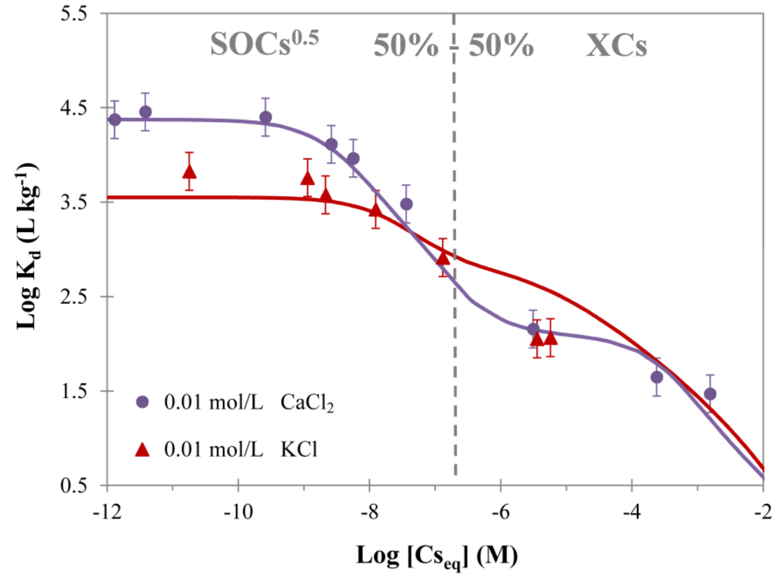
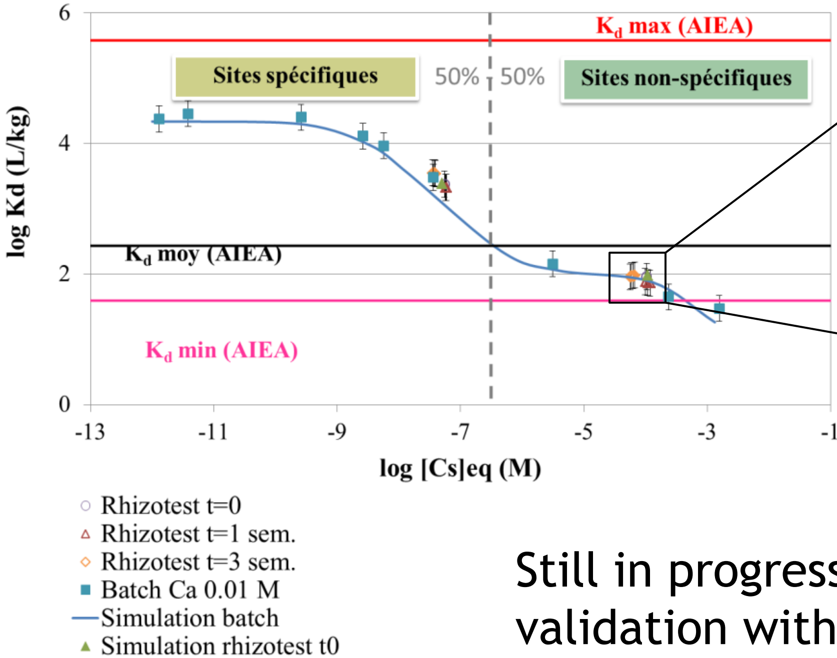
Advantages: predict « available » stock and the kinetics of resupply for plant uptake connection, include effect of competitors on sorption/desorption



Rhizotest study on Cs-contaminated soil



- Flux to ryegrass (2-20%) = f(Cs associated to non specific) sites
- Ryegrass did not exhaust the pool of Cs associated to non specific sites
- SFTR allow to go further with exhaustion function

Still in progress: link of soil and plant modules, validation with rhizotest results

Conclusion : combined approach(es) / tools for the soil/plant continuum

- Start with existing widely used models (Kd/FT)
- Work on associated data/data treatment to improve variability
- Perform experiment on processes at various depths within the system to identify co-factors or key processes and use them for at least help in operationnal model parametrization
- Refine soil/solution module with different topics and use results to go back to operationnal models with either substitution or change of calculation methods/addition of validity ranges
- Connect soil/solution and solution/plant models and test on real data

Better performance of soil-plant transfer assessment