An alternative model of Cs transfer to plants that accounts for Cs availability in soils and dynamics of transfer

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INRA SCIENCE & IMPACT

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INTRODUCTION

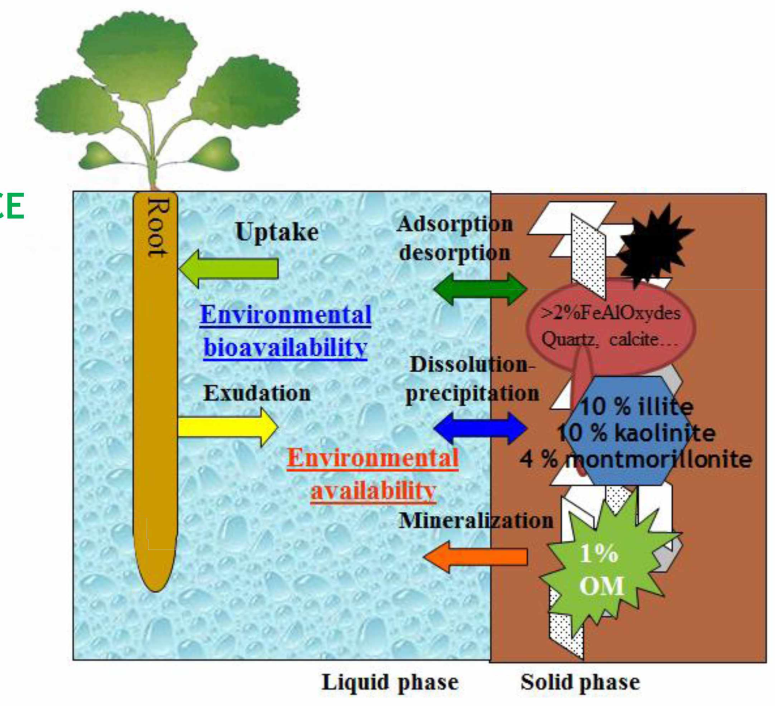
Understanding the behaviour of Cs in terrestrial ecosystems to predict its potential uptake by plants and further contamination of the human food chain still remains an issue. Bioavailability of Cs is controlled not only by the plant uptake and its associated kinetics, but also by the physico-chemical properties of the soil which determine the strength and the reversibility of Cs adsorption to the soil solid particles and their associated kinetics. Operational models (i.e. based on classical Kd and Ft aggregated factors) trying to link macroscopically the transfer factor of Cs to plant to soil physico-chemical properties (e.g. K^+ and NH_4^+ contents) have already been developed but often fail in predicting the plant Cs content in different soil/climate contexts.

Here, we report results of experiments designed to assess the kinetics of solution resupply and plant uptake, together with a proposal of a model coupling a mechanistic description of the interactions at the soil-solution interface and a physiological description of root absorption at the solution-plant interface. Genericity of the modelling approach is assessed by applying the model to several couples of soils and plants exhibiting different interactions with Cs.

MODELLING APPROACH

❑ PLANT-SOLUTION INTERFACE

- Root absorption model (Michealis-Menten like model) for Cs uptake.
- Parameters have been deduced from the experiments.



❑ SOLUTION - SOLID PHASES INTERFACE

- Use of model of complexation and surface exchange with generic database (1PK-DLM, Cherif 2017).
- Account for competition with major cations
- Soil = addition of soil components represented by mineralogical clays + W➔ generic exchange site taking into account CEC not explained by modelled mineralogical clays.

Plant flux ➔ F_p (mol/g/d)

$$F_p = \frac{F_{max1}*[Cs]\ C_W}{K_{m1}+[Cs]\ C_W} + \frac{F_{max2}*[Cs]\ C_W}{K_{m2}+[Cs]\ C_W}$$

$[Cs]\ C_W$ (mol/L)➔ Cs concentration in soil pore water solution.

The combination of F_{max} and K_m represent the plant capacity to absorb Cs.

F_{max} (mol/g/d) ➔ Maximum Cs flux to the plant for the experiment.

K_m (mol/L)➔ [Cs] C_W for which F_{max} reach half its maximum value.

Physico-chemical characteristics	Illite	Montmorillonite	Kaolinite	W
Site capacity $\equiv X-$ (meq/Kg)	225	870	20	Tot CEC – Clay CEC
Site density $\equiv SOH$ (sites/nm²)	2.7 10^{-3}	3.6 10^{-5}	1.5 10^{-4}	
Surface specific area (m²/g)	97	800	10	
Surface complexation reaction on $\equiv SOH$ sites		Log K_{SC}		
$SO^{-0.5}+H^+ \leftrightarrow SOH^{0.5}$	3.46	3.4	5	
$SO^{-0.5}+Cs^+ \leftrightarrow SOCs^{0.5}+H^+$	5.2	4.3	3	
$SO^{-0.5}+Na^+ \leftrightarrow SONa^{0.5}+H^+$	-1.8	-1.3	-3.6	
$SO^{-0.5}+K^+ \leftrightarrow SOK^{0.5}+H^+$	0.6	0.1	-1.75	
$SO^{-0.5}+NH_4^+ \leftrightarrow SONH_4^{0.5}+H^+$	1.5		-1.75	
$SO^{-0.5}+Ca^{2+} \leftrightarrow SOCa^{1.5}+H^+$	-5	-1.4	-5.9	
$SO^{-0.5}+Mg^{2+} \leftrightarrow SOMg^{1.5}+H^+$	-5	-1.4	-5.9	
$SO^{-0.5}+Sr^+ \leftrightarrow SOSr^{1.5}+H^+$	-5	-1.4	-5.9	
Cation exchange reaction on $\equiv X-$ sites		Log K_{SC}		
$2X^-+Ca^{2+}=2XCa$				-3
$X^-+Cs^+=XCs$	2.6	0.85	2.245	2.8
$X^-+K^+=XK$	1.65	0.05	0.145	3
$X^-+Na^+=XNa$	0.15	-0.54	0.145	-4
$2X^-+Mg^{2+}=2XMg$		-0.75		-1

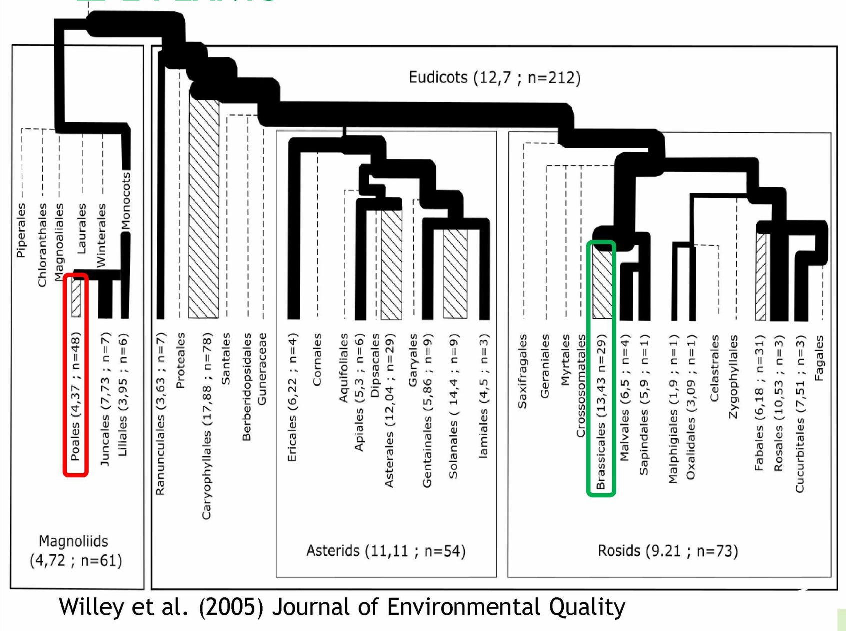
Cherif M.A. et al. (2017). Applied Geochemistry

SOIL-PLANT TRANSFER EXPERIMENTS

❑ 3 CONTRASTED SOILS

Soil	pH	Total CEC	Organic Carbon	Illite	Mont.	Kaolinite	CEC distribution (%)
		(meq/kg)	(g/kg)	(g/kg)	(g/kg)	(g/kg)	(I/M/K/W)
E	7.5	99	11.2	66.1	50	20.3	15/44/0,4/40
H	5.5	76	28.5	28.2	42	76.4	8/48/2/41
S	9.1	11	0.18	0.06	13.6	2.4	0,01/99/0,4/0

❑ 2 PLANTS



Willey et al. (2005) Journal of Environmental Quality

- Monocot ➔ millet ➔ Relative low Cs absorption capacity
- Dicot ➔ mustard ➔ Relative High Cs absorption capacity

RHIZOTEST

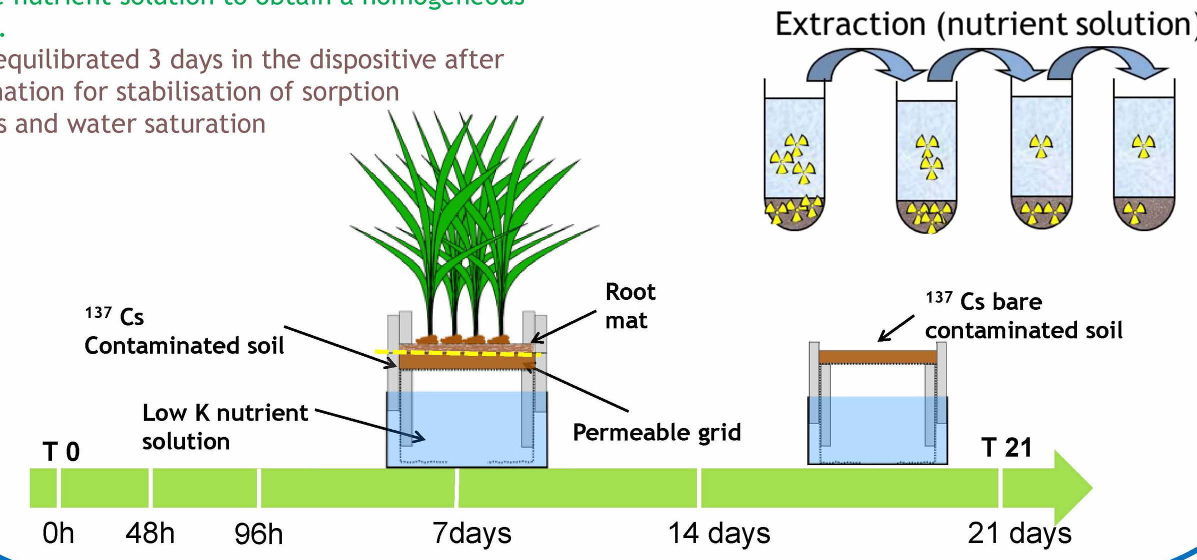
Plants pre-cultured in hydroponics for 21d in complete nutrient solution to obtain a homogeneous root mat.

Soil pre-equilibrated 3 days in the dispositive after contamination for stabilisation of sorption processes and water saturation

Soil available fraction

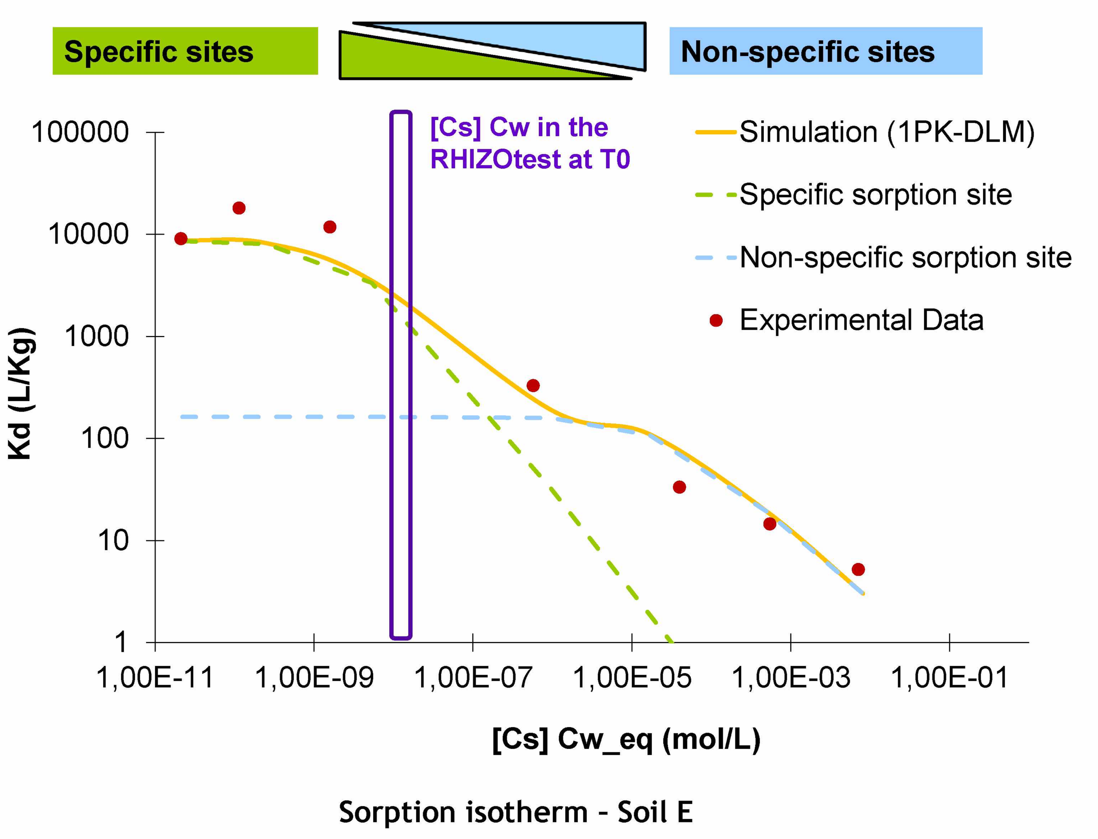
Available ^{137}Cs estimated with successive extractions at the end of RHIZOtest

Extraction (nutrient solution)



RESULTS & DISCUSSION

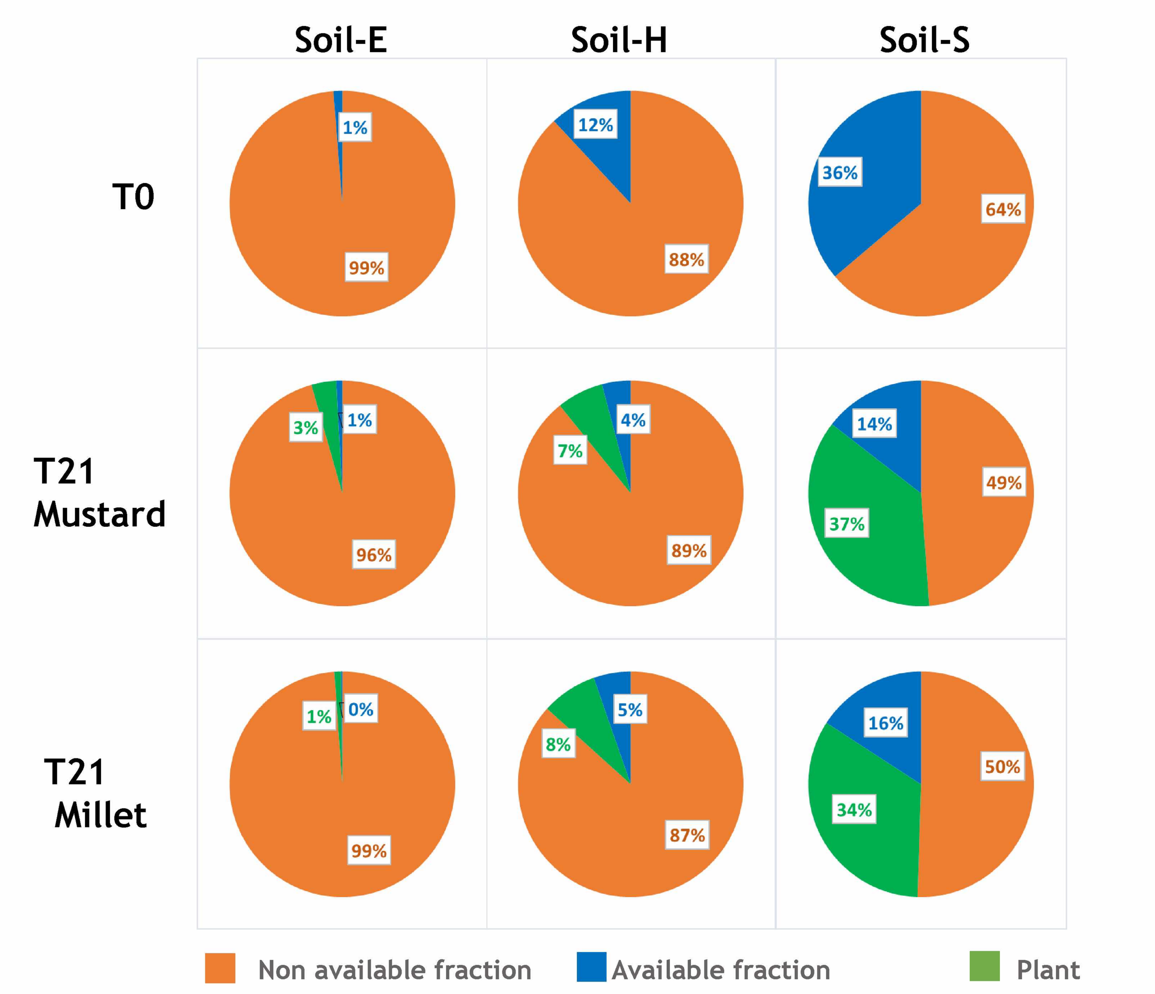
Modelling of Cs distribution in the soil-solution system



Sorption isotherm - Soil E

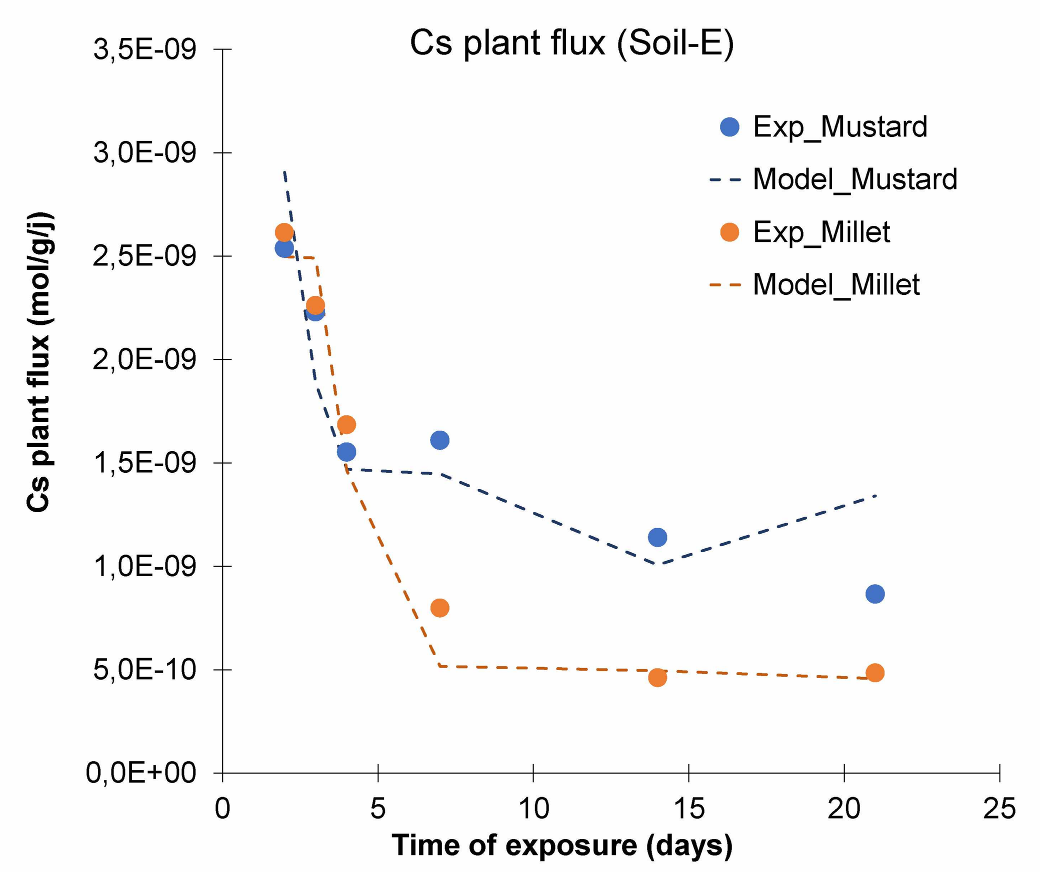
- ❑ Cs is adsorbed on specific and non-specific sites
- ❑ At high concentrations, relative contribution of specific sites is negligible.

Distribution of Cs in the soil-solution plant continuum



- ❑ Sandy soil (Soil-S) exhibits higher Cs availability
- ❑ Difference between Millet and Mustard has been observed only for soil-E in which Cs availability is limited,
- ❑ Is this observation due to the limited duration experiment?

Modelling of Cs transfer to plants, as a function of time



- ❑ F_{max1} & K_{m1} are the same for Mustard and Millet till 4 days of exposure.
- ❑ F_{max2} & K_{m2} are necessary only for Millet to fit the 7,14,21 exposure data points. This change can be induced by the different potassium management of the two plants.

CONCLUSIONS & PERSPECTIVES

- ❑ Cs availability in soils is controlled by the reaction of sorption on the soil surfaces. Different sorption sites exhibiting different strength of retention are involved depending on Cs concentration.
- ❑ The speciation of Cs on the soil phases controls its availability but physiology of plants play also a role in the uptake for long time scale.
- ❑ However the duration of our experiments did not allow to deplete completely the stock of Cs available in the soils for most experiments.
- ❑ Results were appropriately simulated with the proposed integrated model, using plant uptake values fitted on experimental data. It allows to got insights on the dynamics of soil solution resupply by solid phase as a function of Cs solid speciation and the level of corresponding environmental availability and bioavailability.
- ❑ A first perspective is to validate the proposed model on a longer time scale. This will require comparisons with experimental data acquired on a different experimental design
- ❑ A second perspective is to validate the proposed model as a generic tool. To achieve this the frame will be deployed on a wide range of substrates to vary soil properties and different plant species and using Michaelis-Menten literature parameters.