



Brioschi Laure

CHRONO
ENVIRONNEMENT

UFC
UNIVERSITÉ DE FRANCHE-COMTÉ



Transfert des terres rares à l'interface géosphère-biosphère

Répartition, transferts roche-sol-végétation, et effets sur la physiologie des plantes

Le 13 novembre 2012 à Besançon devant le jury composé de :



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Peter Stille (DR CNRS Strasbourg)

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rapporteur

rapporteur

examinateur

examinateur

directeur

encadrant

encadrant



Transfert des terres rares à l'interface géosphère-biosphère



I : Introduction

II : Répartition et transferts des TR d'origine naturelle dans le système roche-sol-plante

III : Effets des TR sur la physiologie de la plante

IV : Conclusions et perspectives



I : Introduction

Présentation des terres rares

Terres rares (TR)

La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
57	58	59	60	61	62	63	64	65	66	67	68	69	70	71

Lanthanides

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	An	Lr														

Terres rares (TR) : série de 15 lanthanides + Y

Présentation des terres rares

Terres rares (TR)

La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
57	58	59	60	61	62	63	64	65	66	67	68	69	70	71

Lanthanides

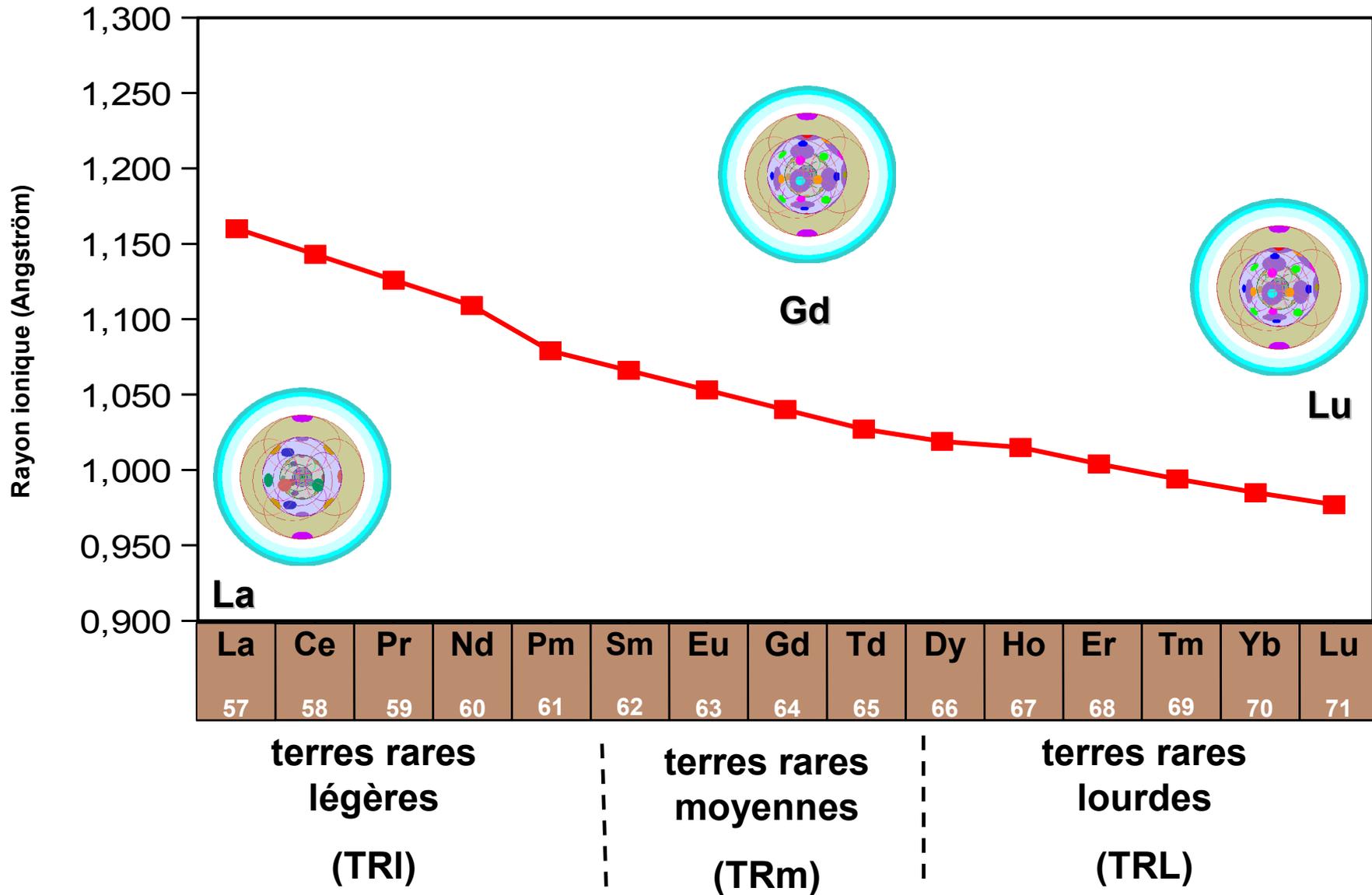
H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac	Lr														

Terres rares (TR) : série de 15 lanthanides + Y

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57	58	59	60	61	62	63	64	65	66	67	68	69	70	71

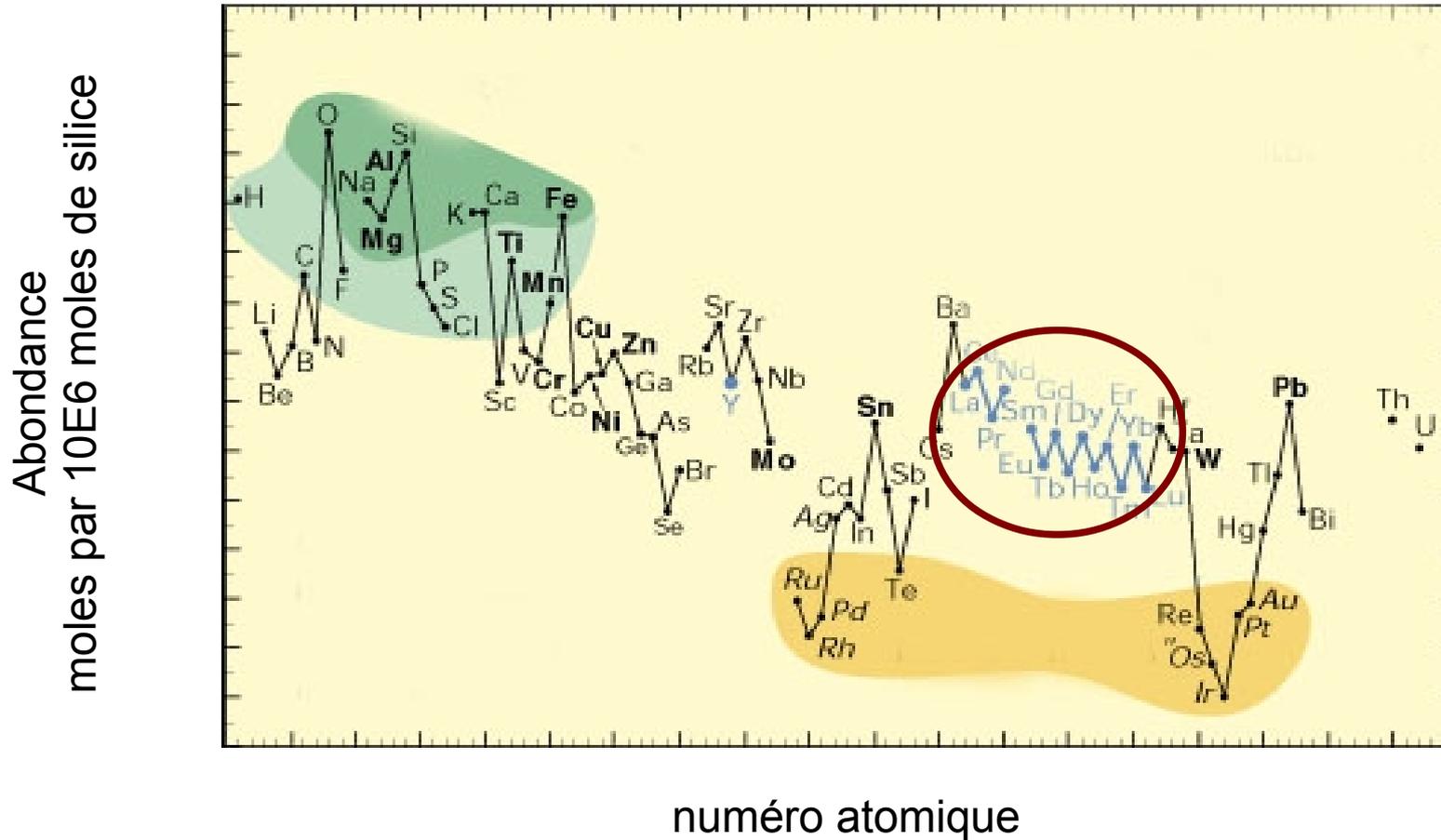
terres rares légères (TRI) terres rares moyennes (TRm) terres rares lourdes (TRL)

Présentation des terres rares

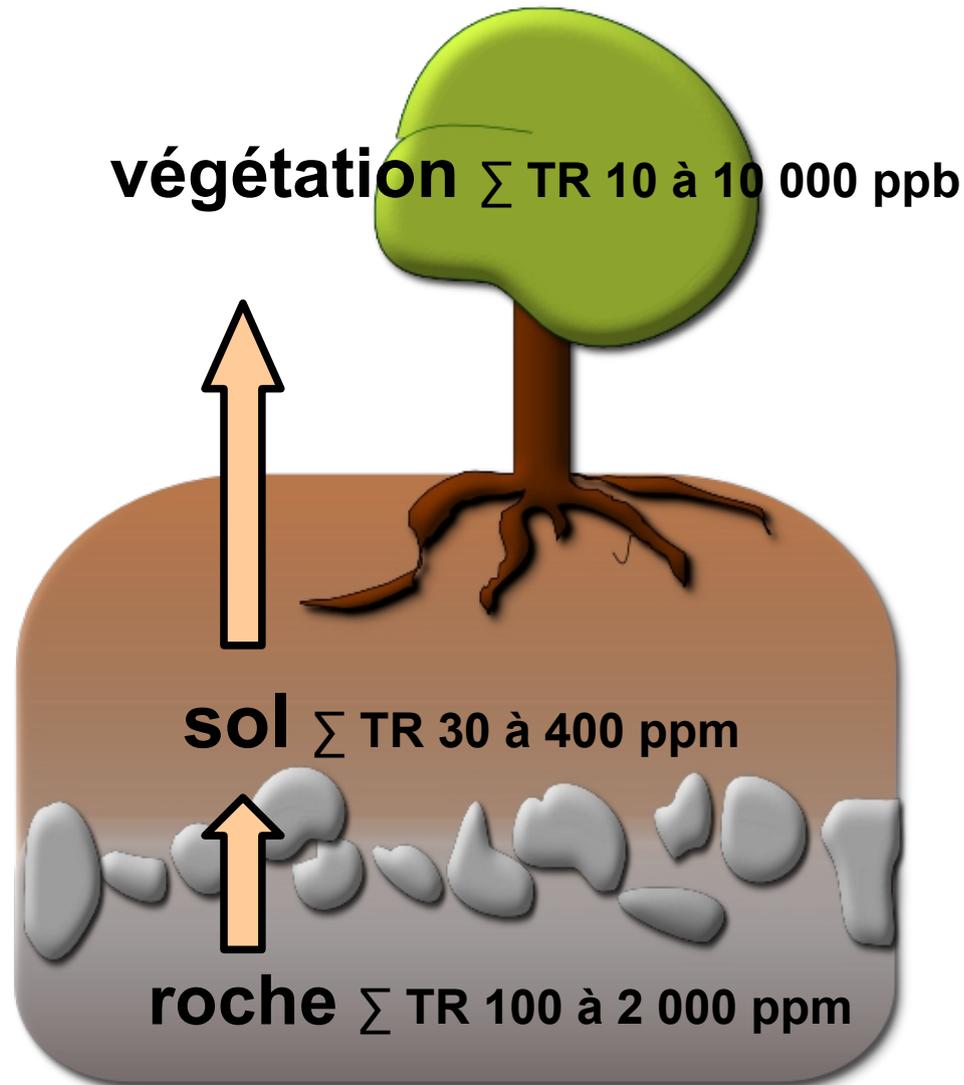


TR en milieu naturel

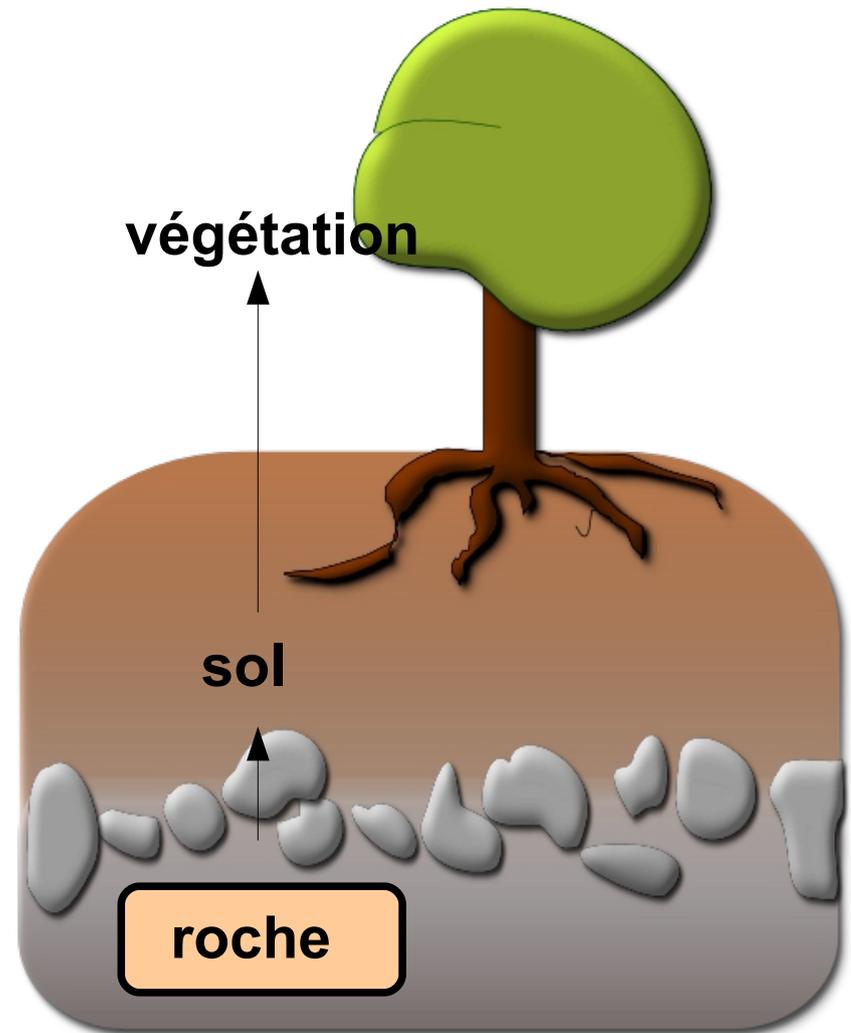
Abondance dans la croûte continentale



TR en milieu naturel



TR en milieu naturel

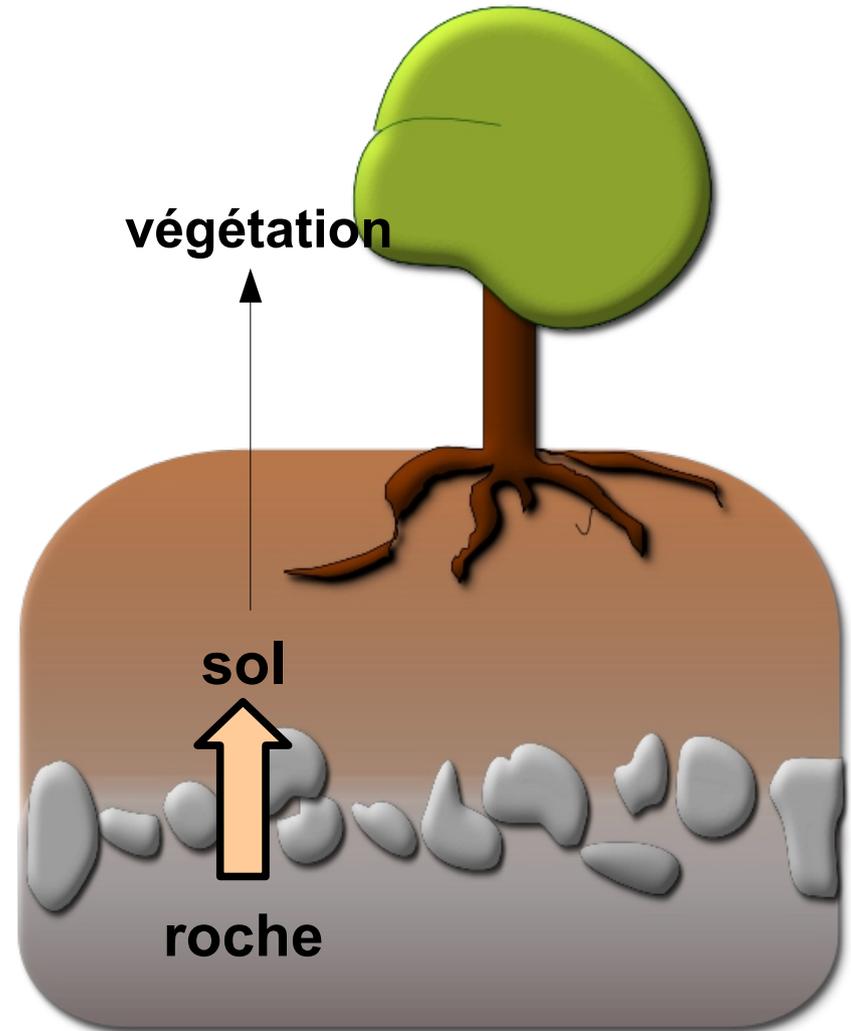


Roche = source principale de TR

TR en milieu naturel

Transfert différentiel des TR individuelles lors de la pédogenèse

Roche = source principale de TR

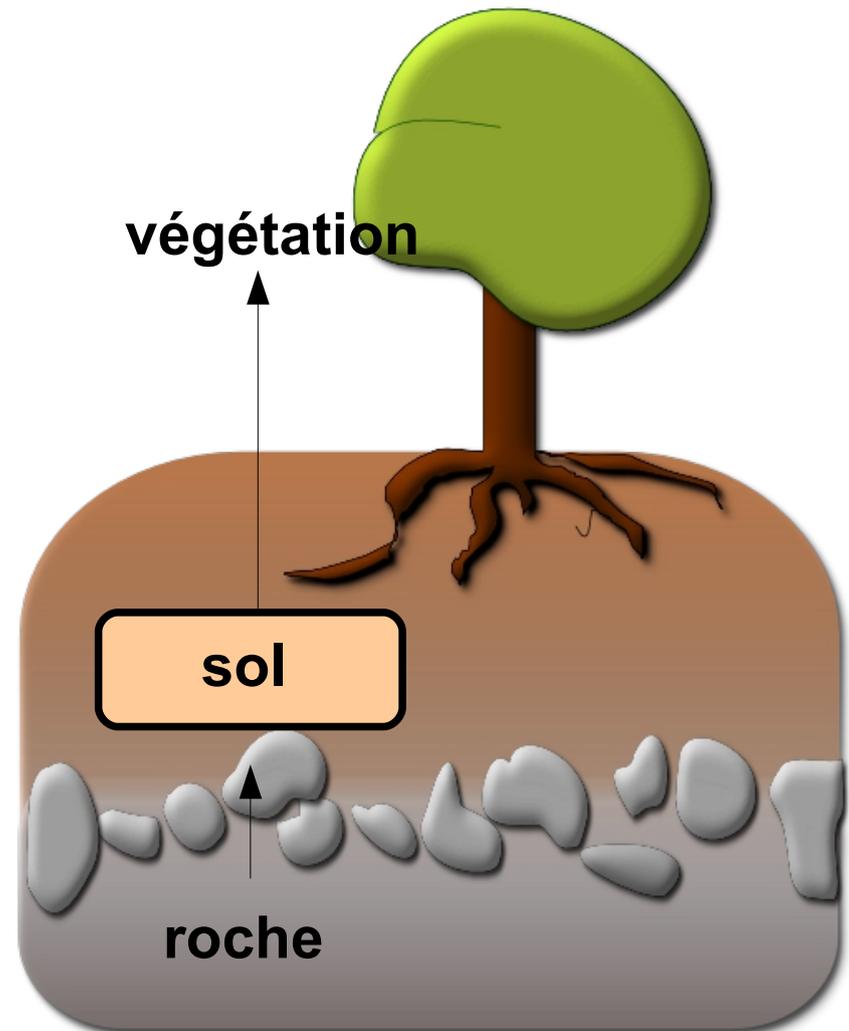


TR en milieu naturel

Lien entre mobilité des TR et paramètres pédologiques

Transfert différentiel des TR individuelles lors de la pédogenèse

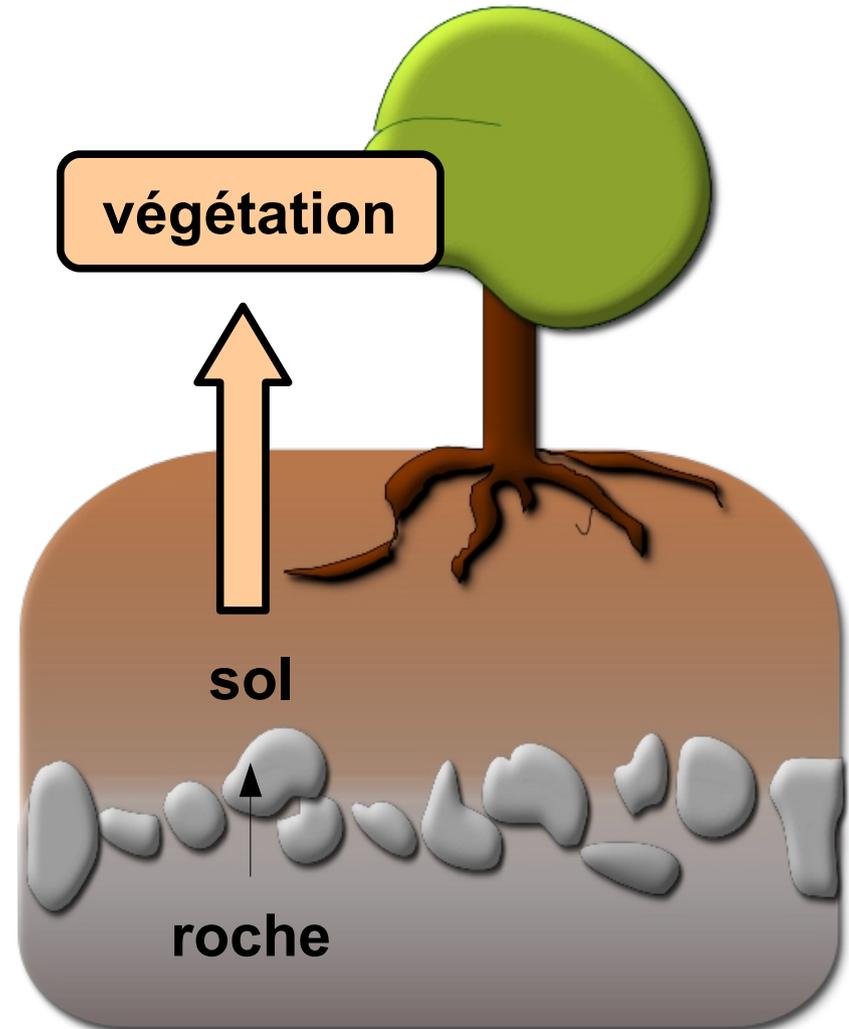
Roche = source principale de TR



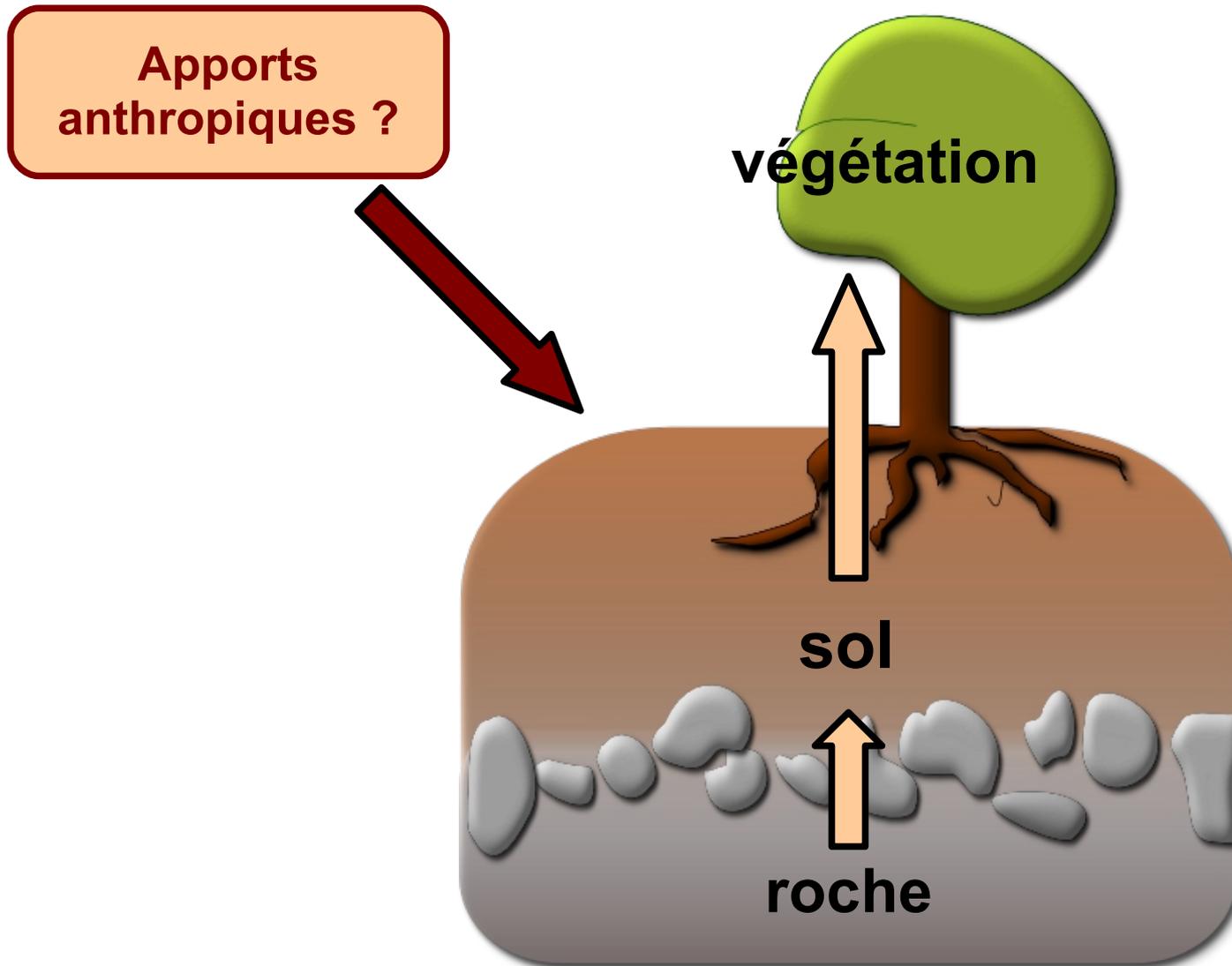
TR en milieu naturel

[TR] = racines > feuilles > tronc

**Absorption préférentielle de
certaines TR**



TR en milieu naturel



TR anthropiques

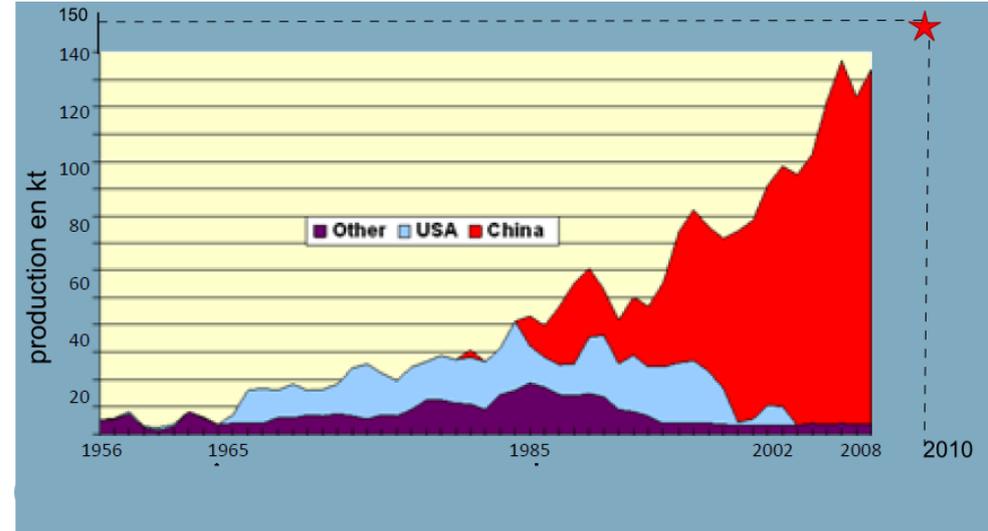


Exploitation des TR

TR anthropiques



Exploitation des TR

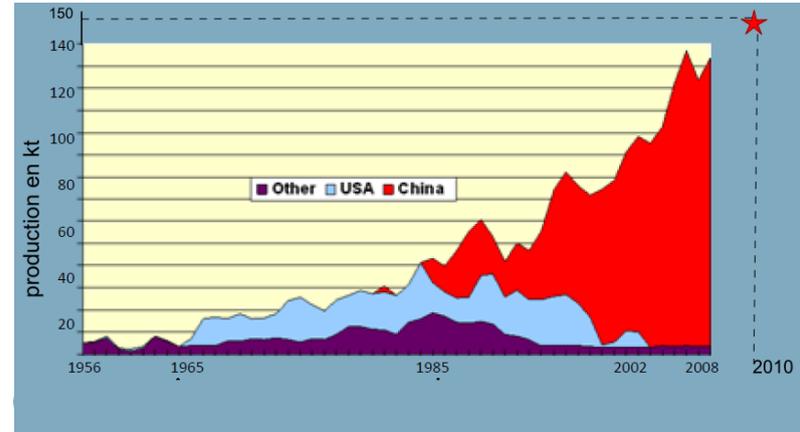


Production minière des TR en forte augmentation

TR anthropiques



Exploitation des TR



Production minière des TR en forte augmentation



Industrie



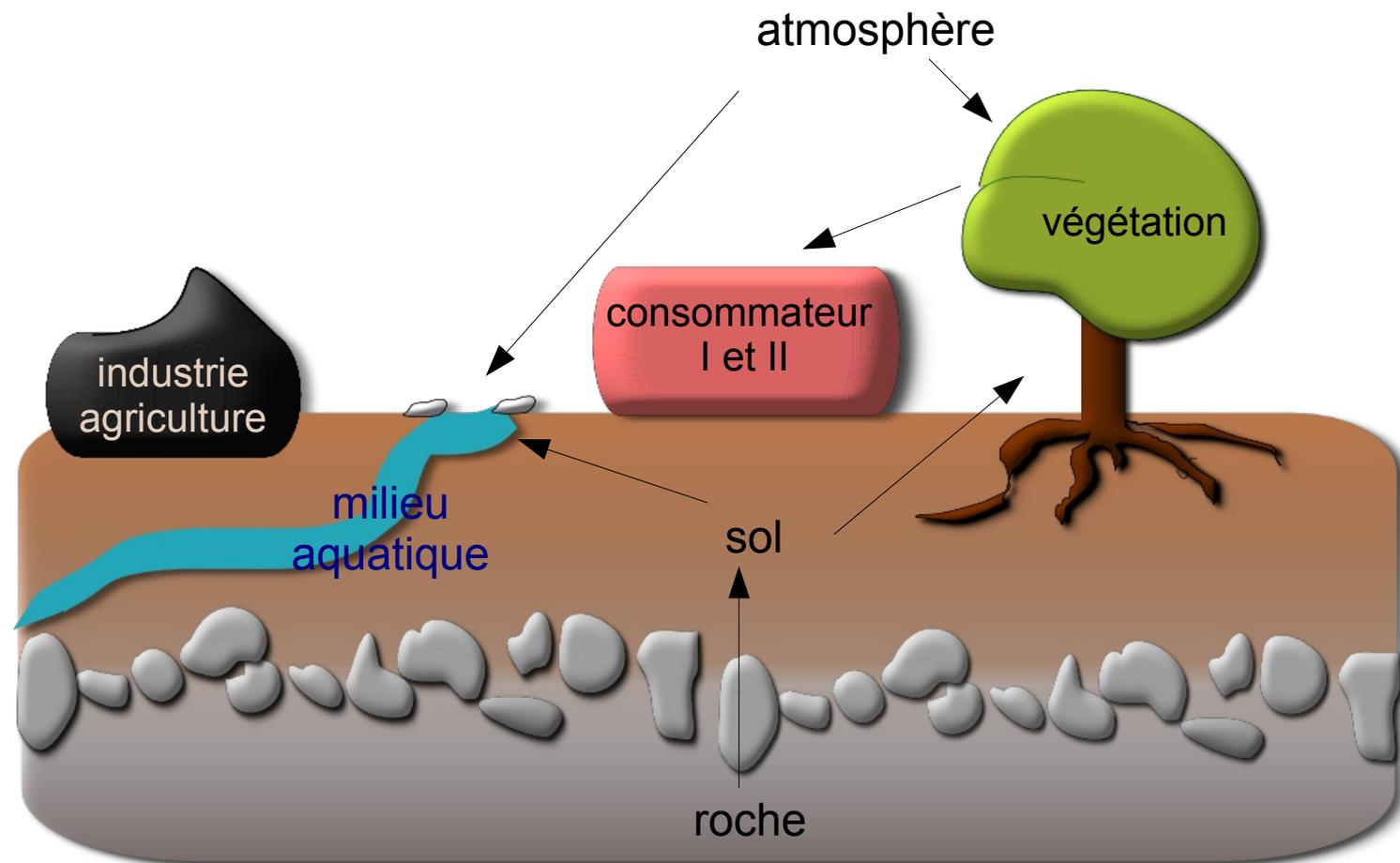
Agriculture



Médecine



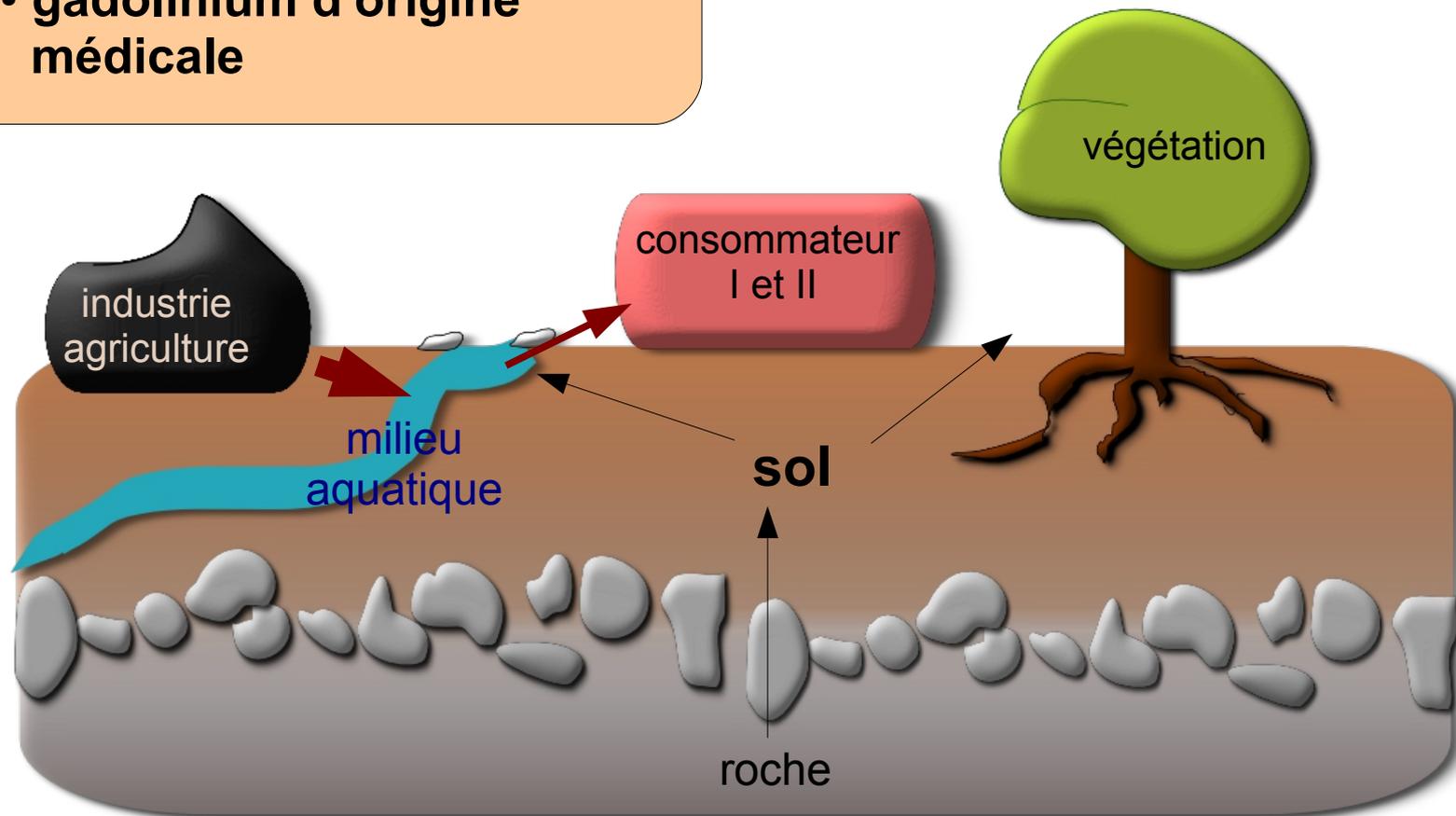
Transfert des TR anthropiques dans l'environnement



Transfert des TR anthropiques dans l'environnement

Milieu aquatique (Europe) :

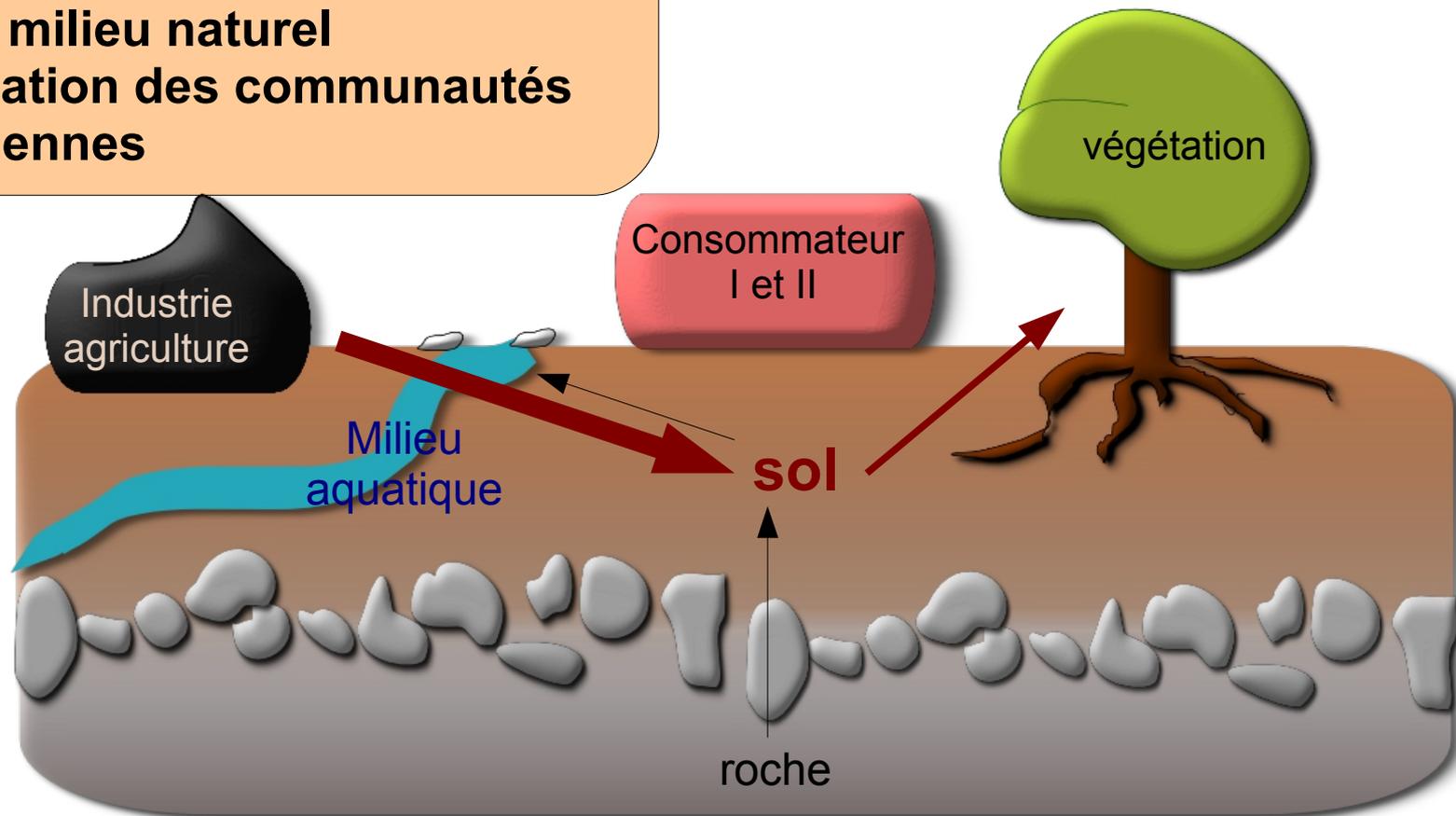
- gadolinium d'origine médicale



Transfert des TR anthropiques dans l'environnement

Sols (Chine) :

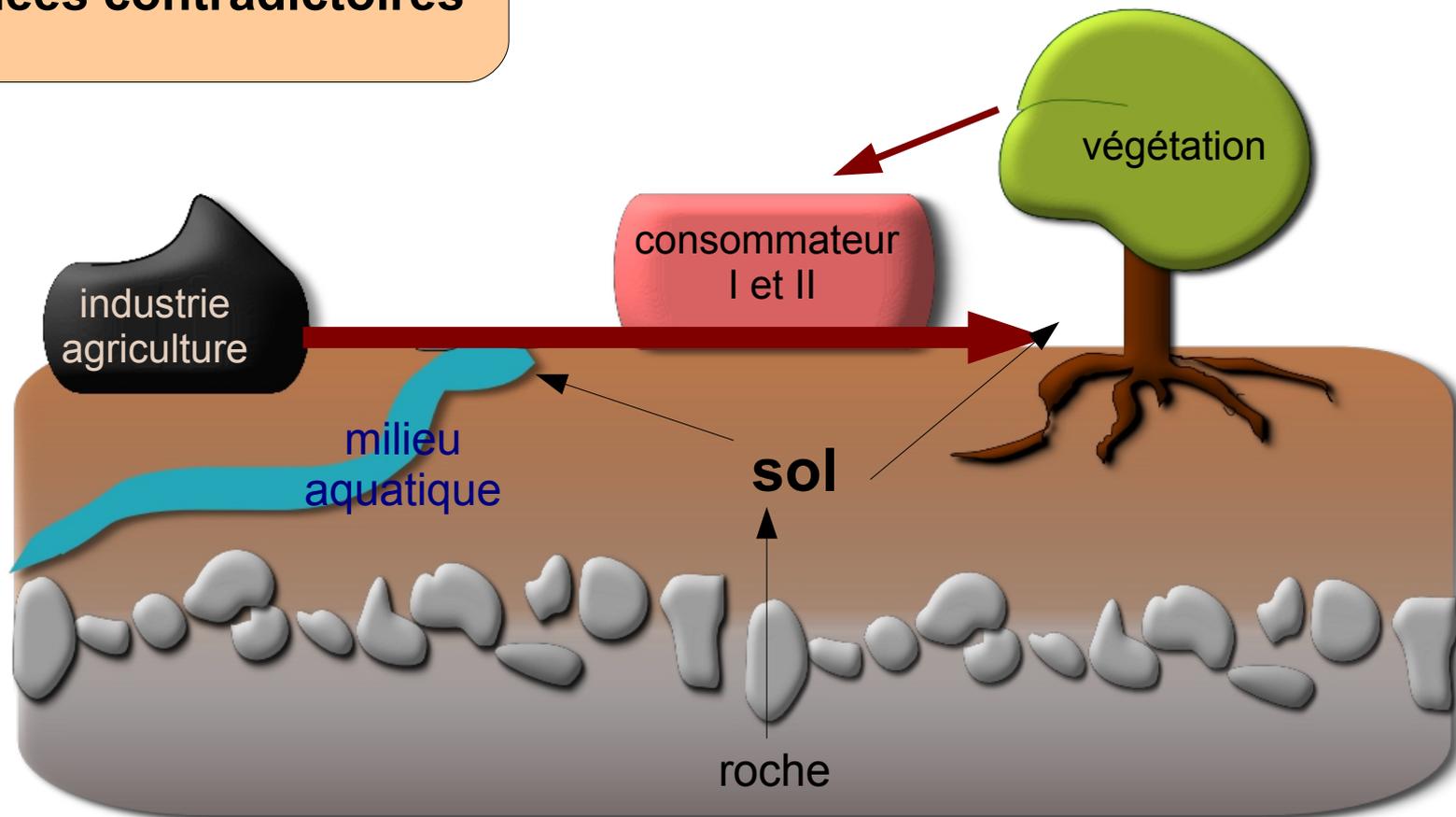
- augmentation des concentrations dans le milieu naturel
- modification des communautés microbiennes



Transfert des TR anthropiques dans l'environnement

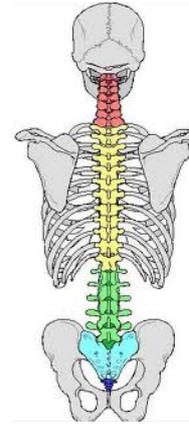
Végétation :

- données contradictoires



Effets des TR sur la santé

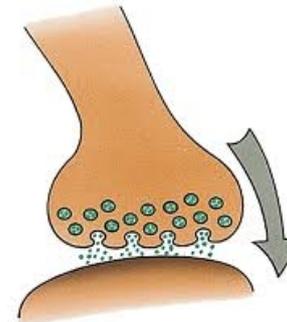
Fixation dans le squelette



Amélioration ou inhibition de la croissance cellulaire



Blocage des transmissions nerveuses



Problématiques

Risques liés à l'utilisation des TR par l'homme, mais manque de connaissances sur les cycles biogéochimiques.

Étude en milieu naturel :

- **État de référence**
- **Mécanismes de transfert**

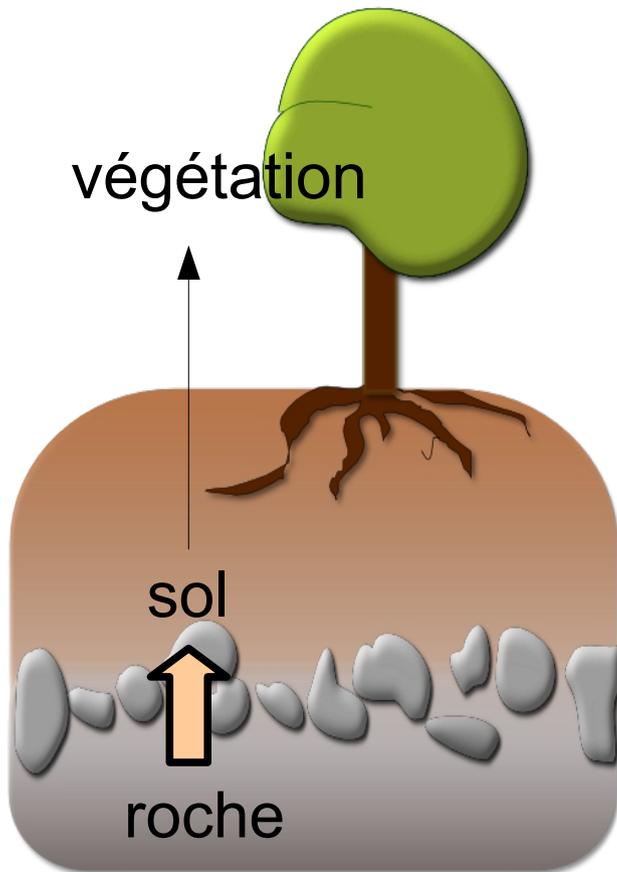
Étude en milieu contrôlé :

- **Effets écotoxicologiques**

Problématiques

milieu naturel

milieu contrôlé

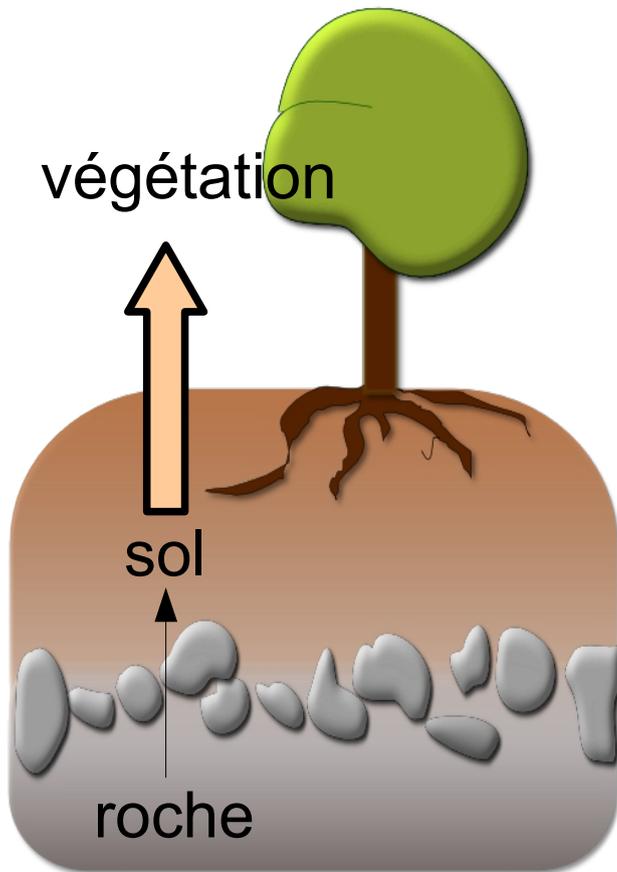


Transferts roche-sol

Problématiques

milieu naturel

milieu contrôlé



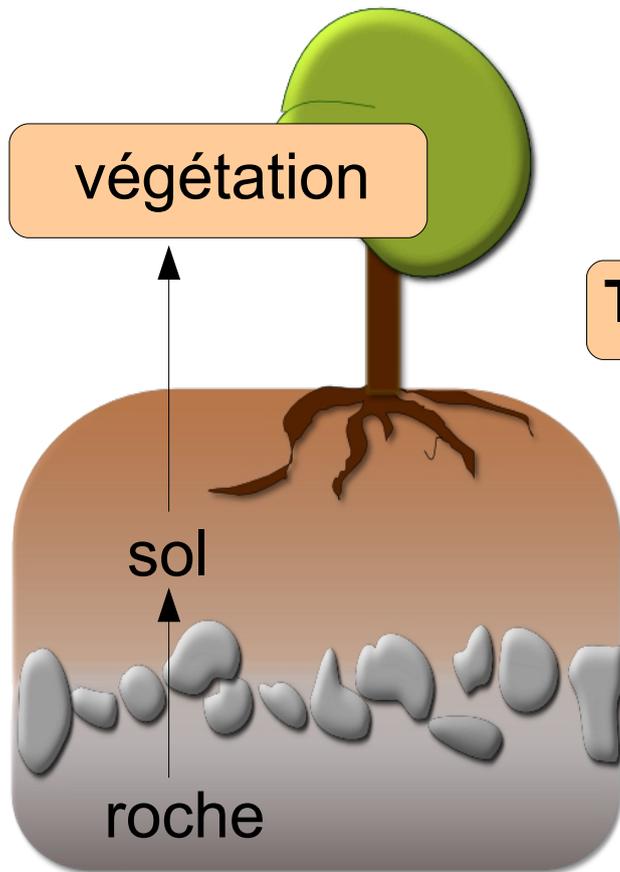
Transferts sol-plante

Transferts roche-sol

Problématiques

milieu naturel

milieu contrôlé



Translocation et accumulation dans la végétation

Transferts sol-plante

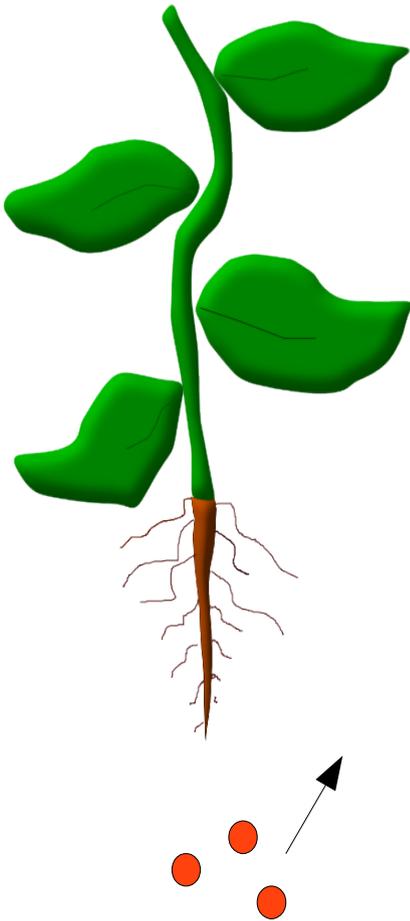
Transferts roche-sol

Problématiques

milieu naturel

milieu contrôlé

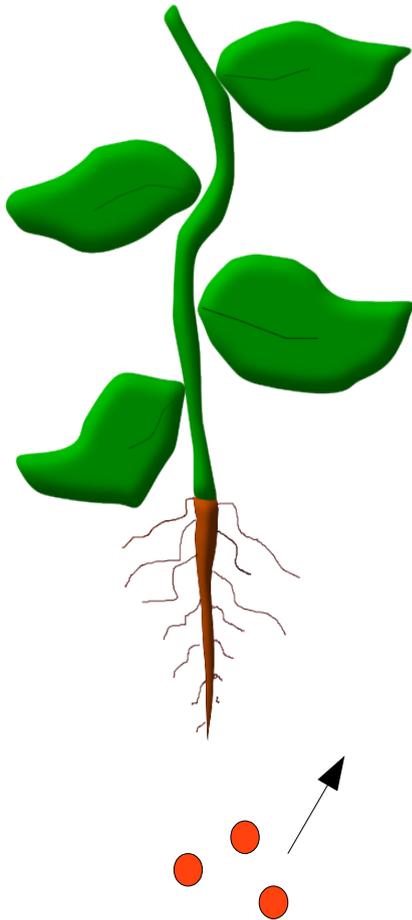
Répartition et absorption



Problématiques

milieu naturel

milieu contrôlé



Répartition et absorption

Effets du lanthane, de l'euprécium et de l'ytterbium sur la physiologie de la plante



II : Répartition et transferts des TR d'origine naturelle dans le système roche-sol-plante

Matériels et méthodes

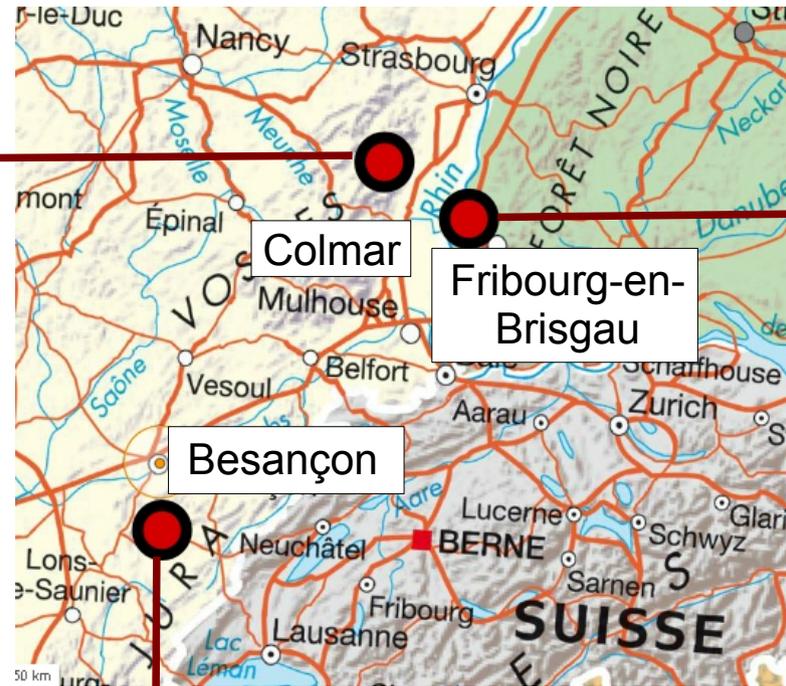
Résultats : roche-sol
végétation

Discussion

3 sites d'étude



granite (Vosges)



carbonatite
(Kaiserstuhl)



calcaire (Jura)

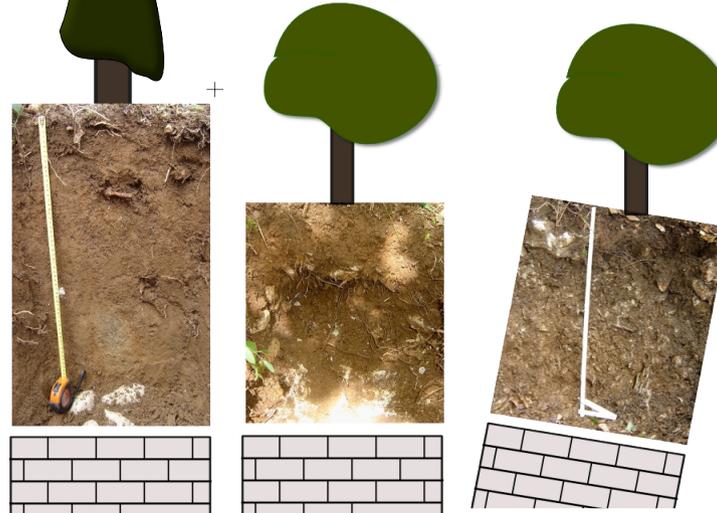
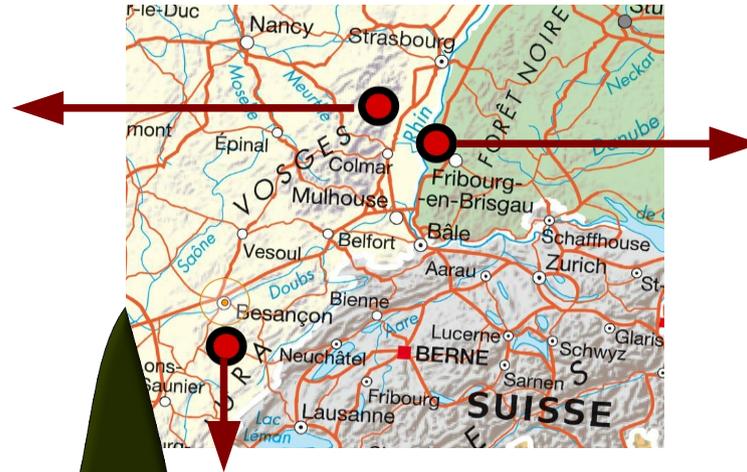
3 sites d'étude



épicéa

hêtre

granite

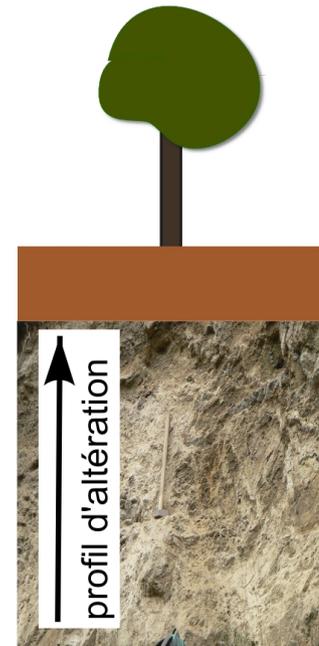


épicéa

hêtre
plateau

hêtre
pente

calcaire



chêne

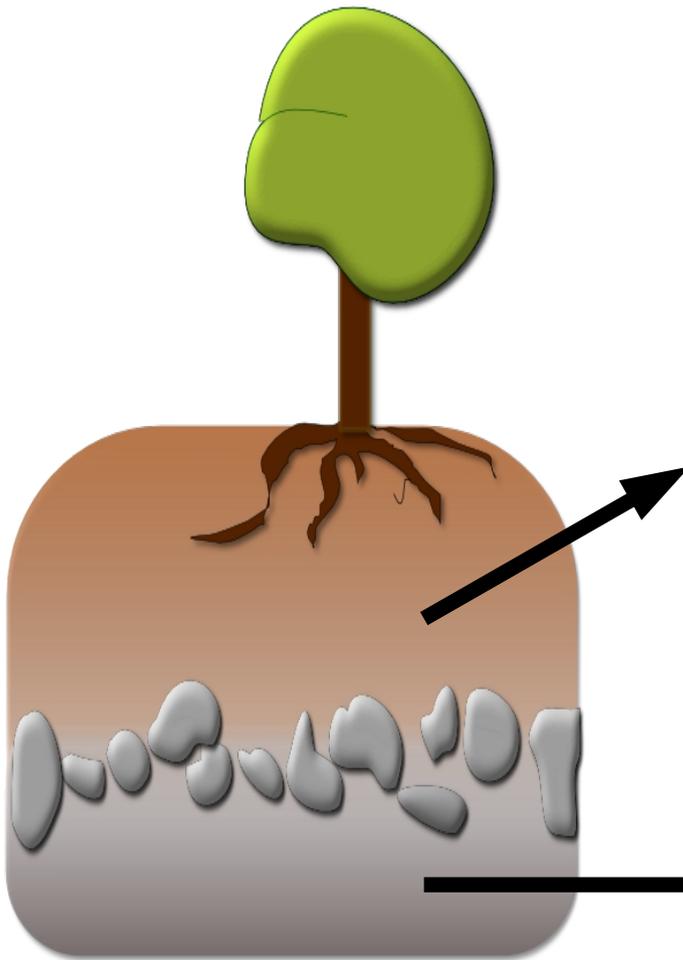
carbonatite

Prélèvements

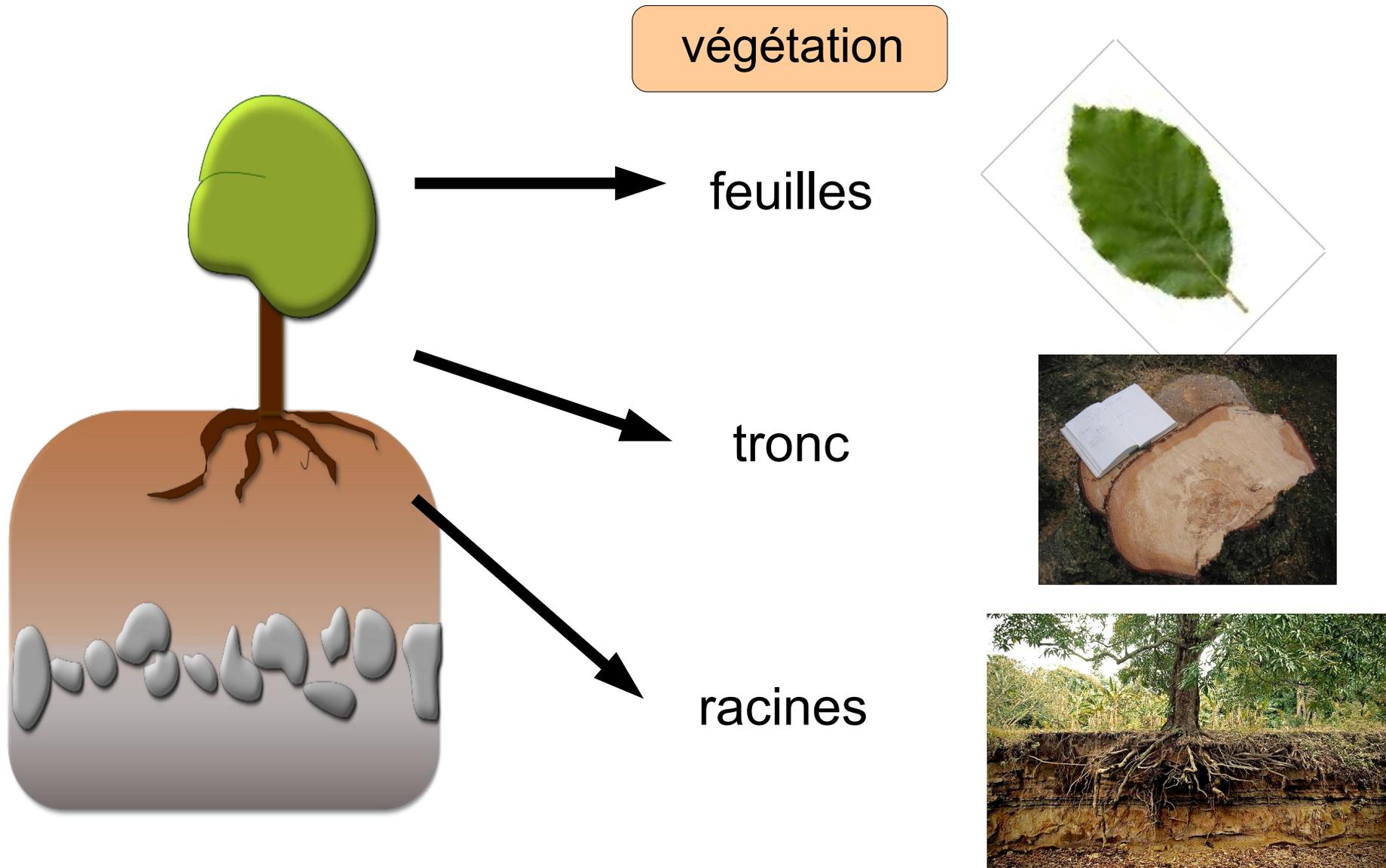
Sol et eau du sol



Roche



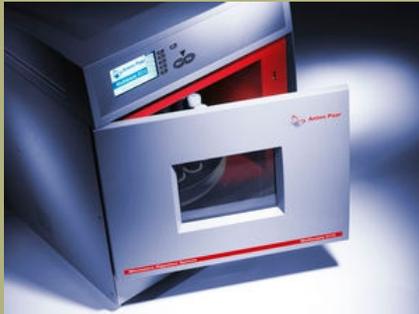
Prélèvements



Analyses

Mise en solution des échantillons

Micro ondes



Attaque acide

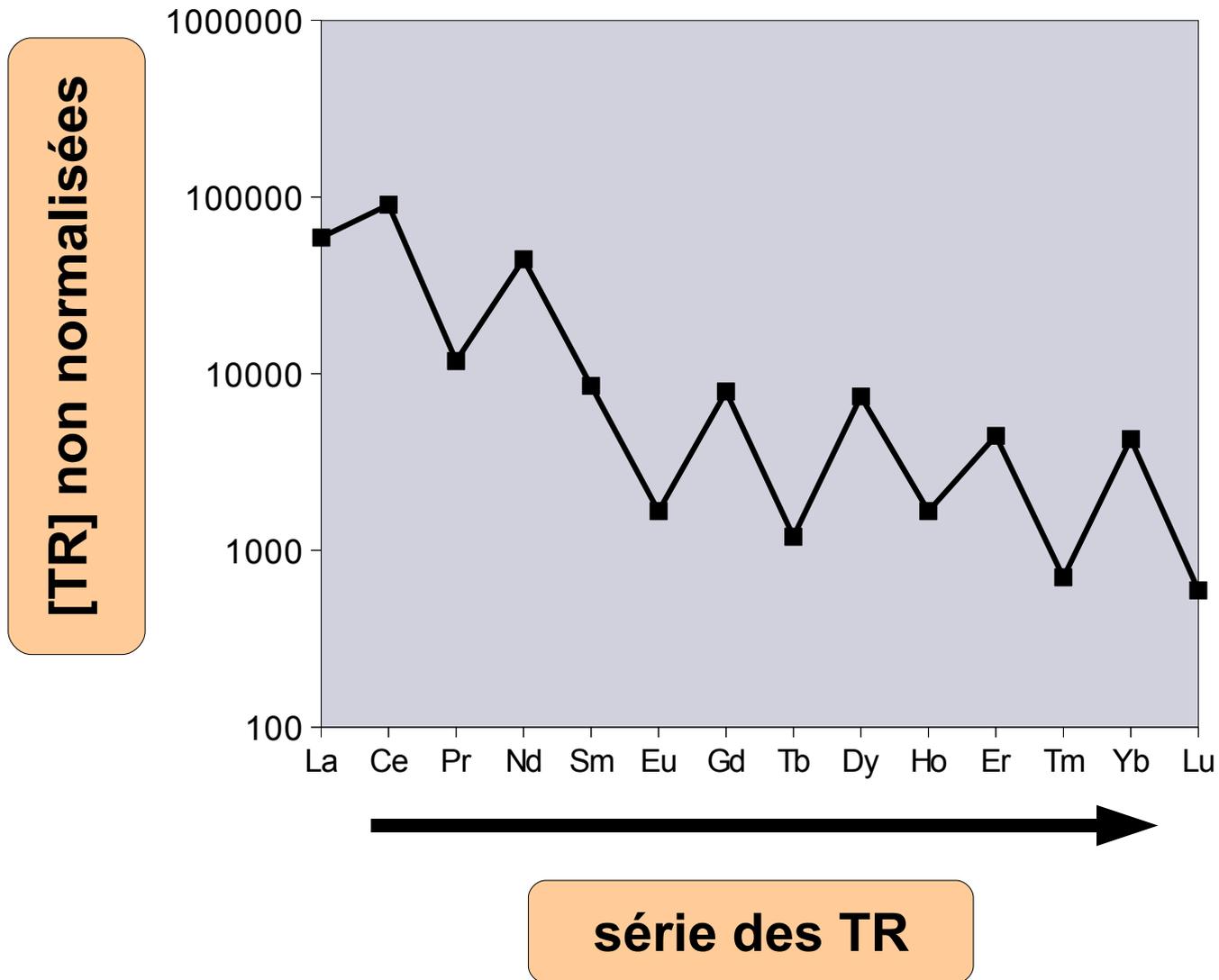


ICP-MS et ICP-E



[TR] et [éléments majeurs]

Spectre non normalisé



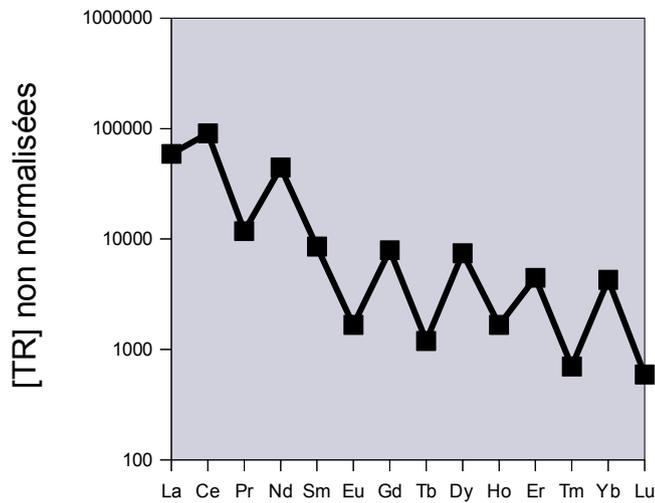
Spectre

Spectre non normalisé

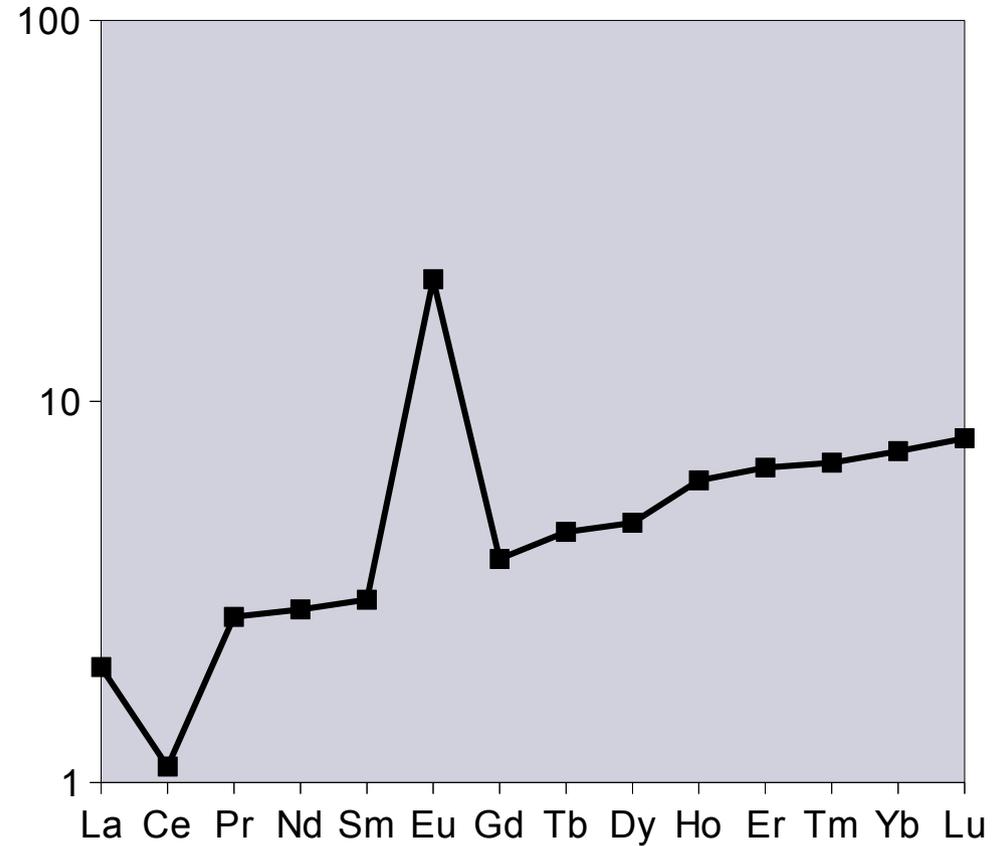
normalisation



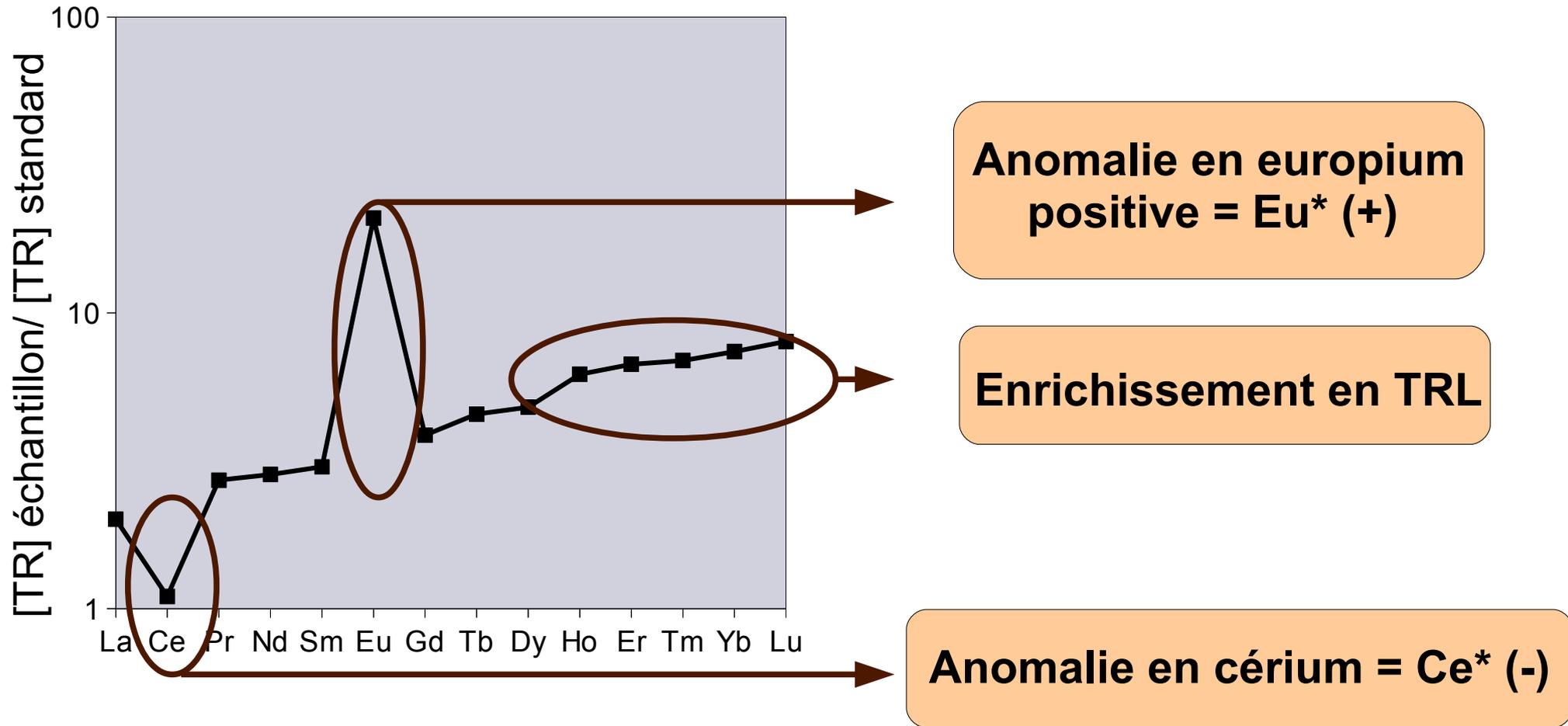
Spectre normalisé



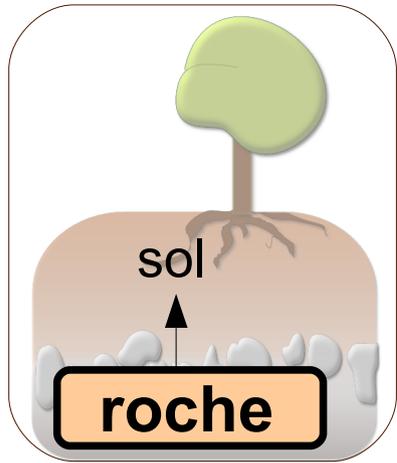
[TR] échantillon / [TR] standard



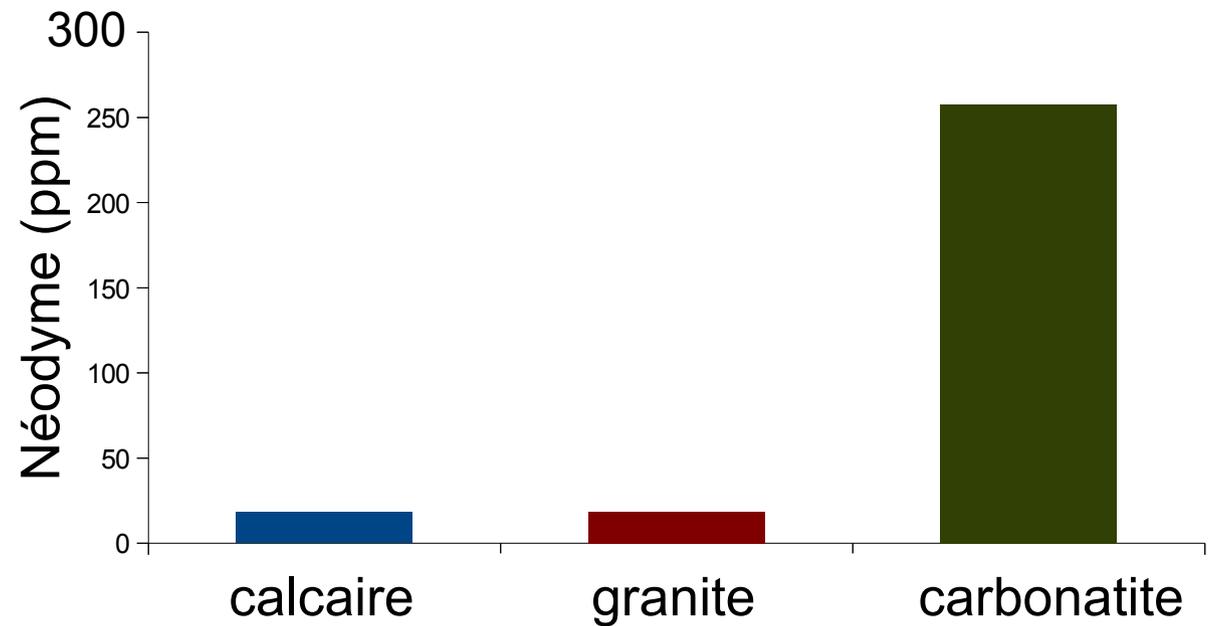
Spectre normalisé

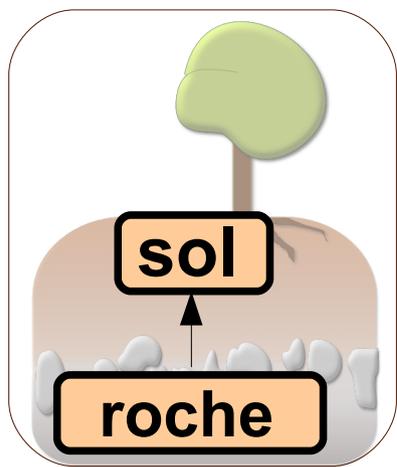


Transfert roche-sol



roche

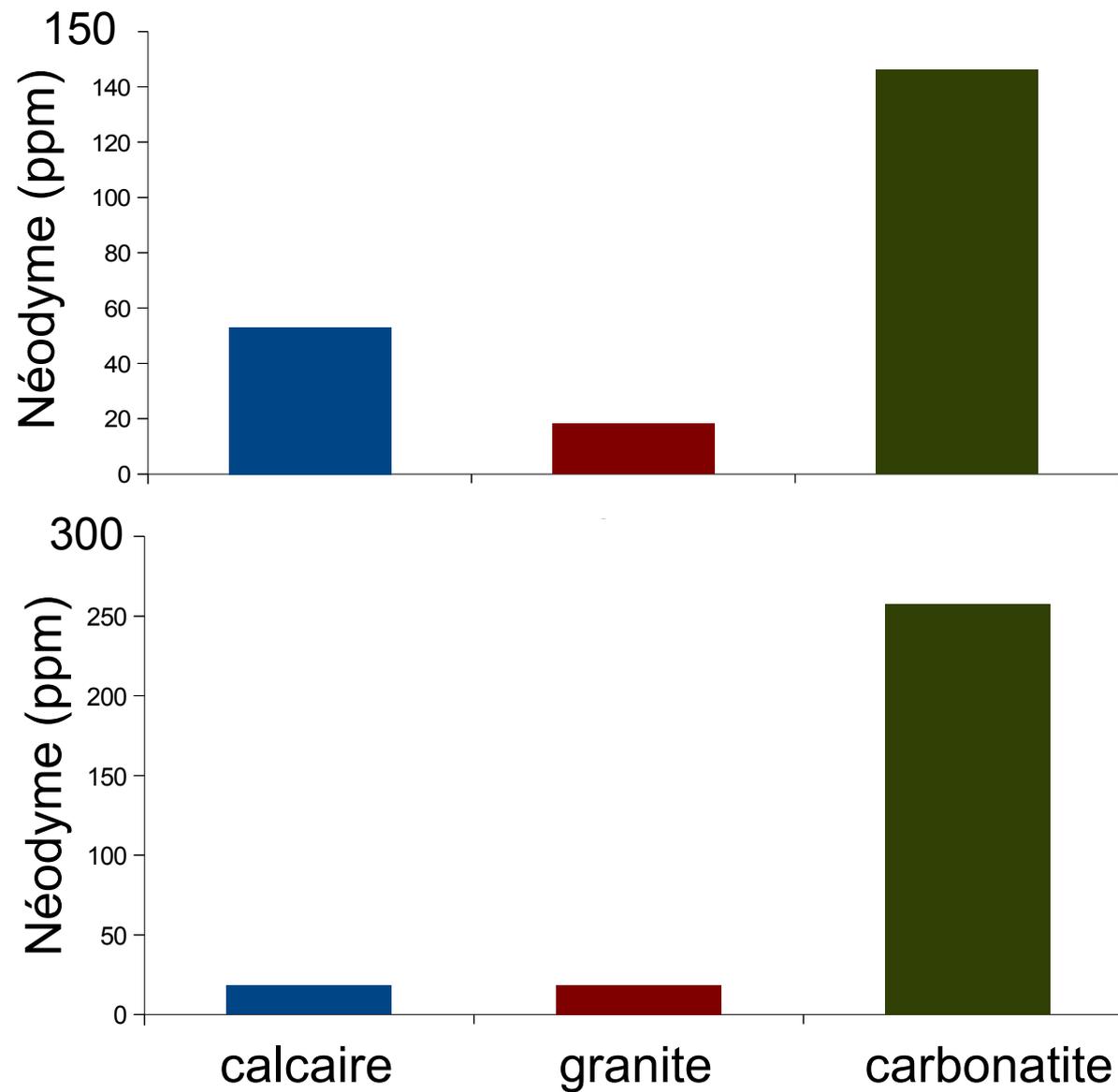




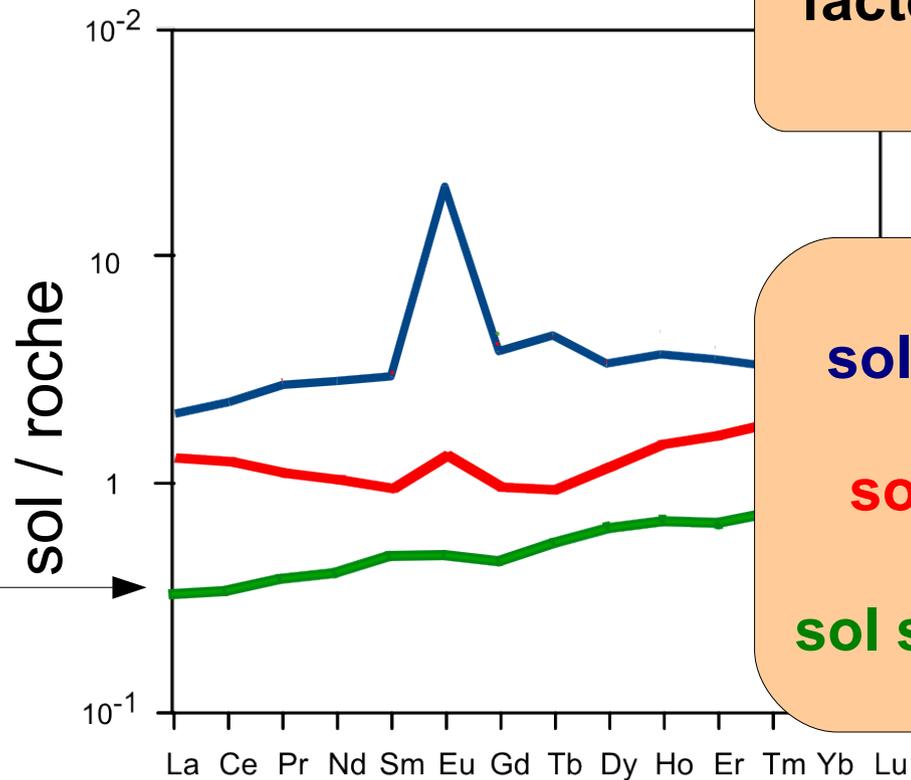
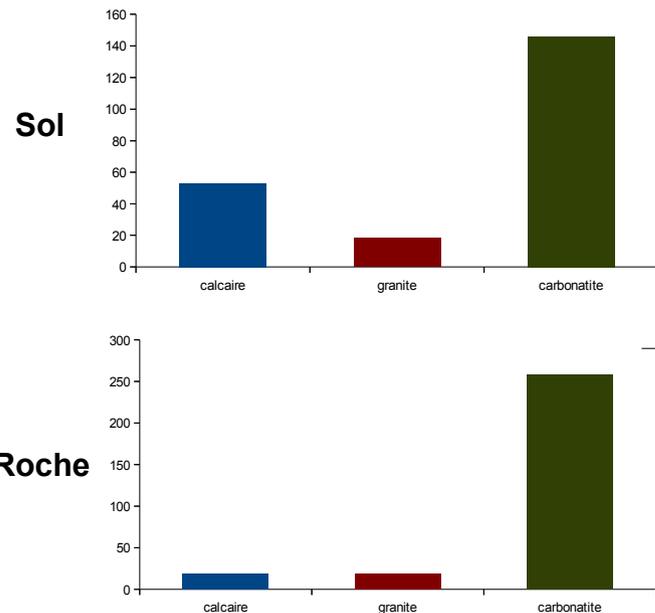
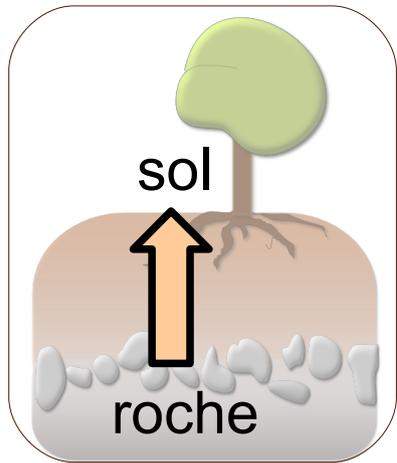
sol

roche

Transfert roche-sol

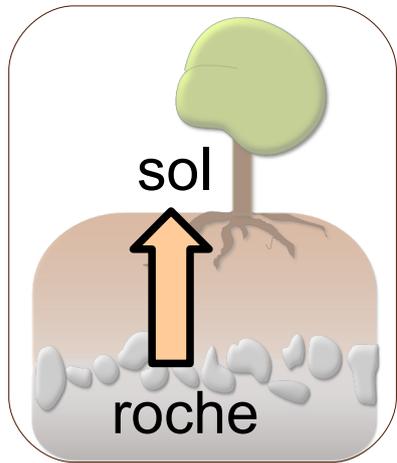


Transfert roche-sol

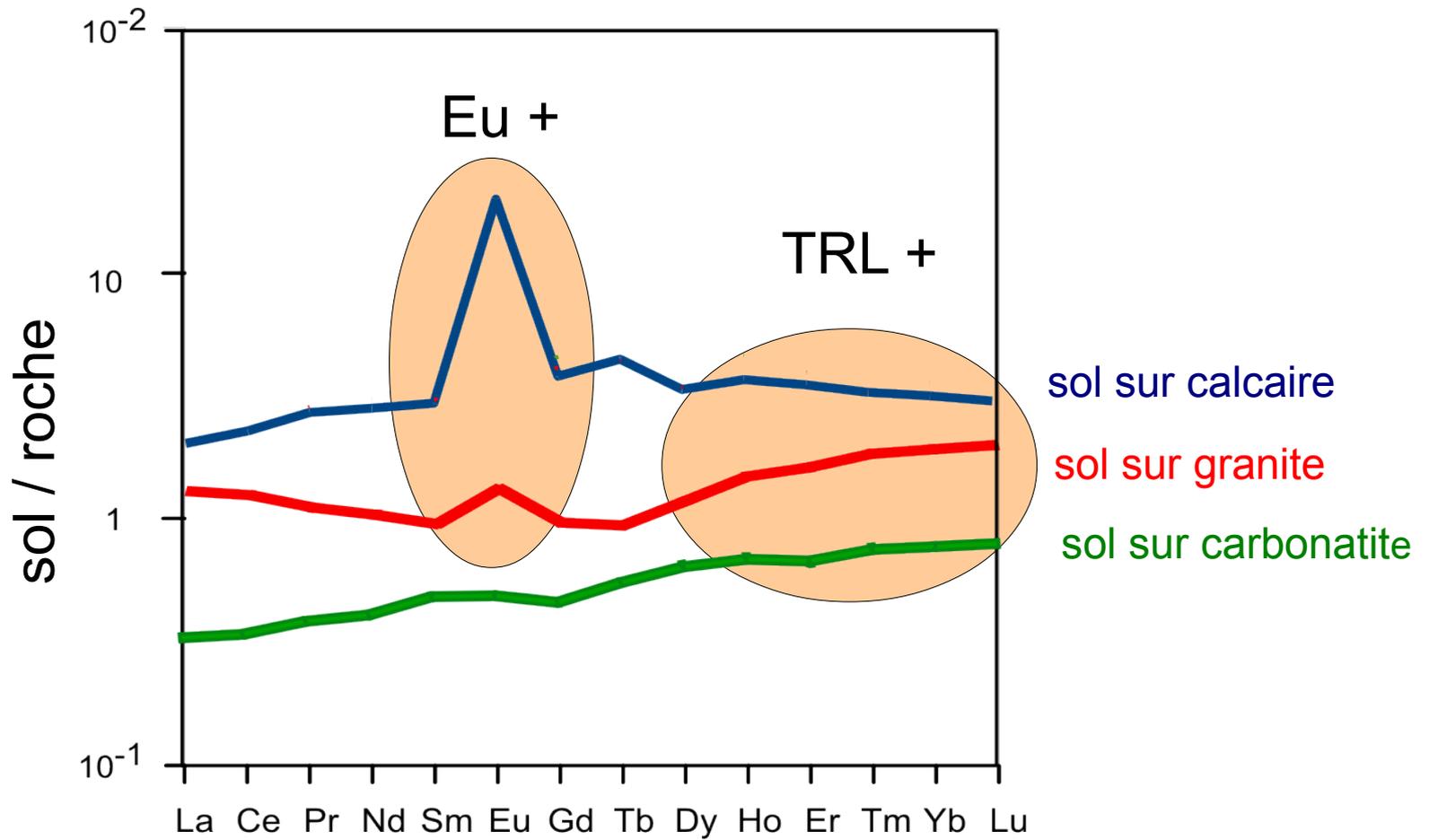


facteur de transfert
sol/roche

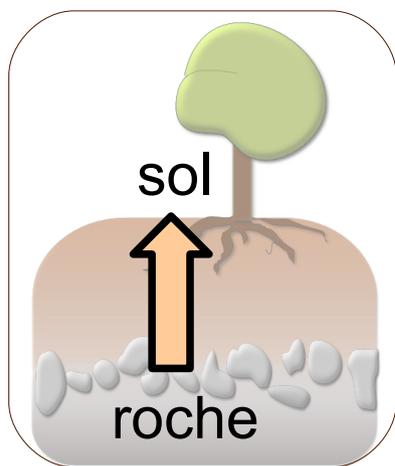
sol sur calcaire
>
sol sur granite
>
sol sur carbonatite



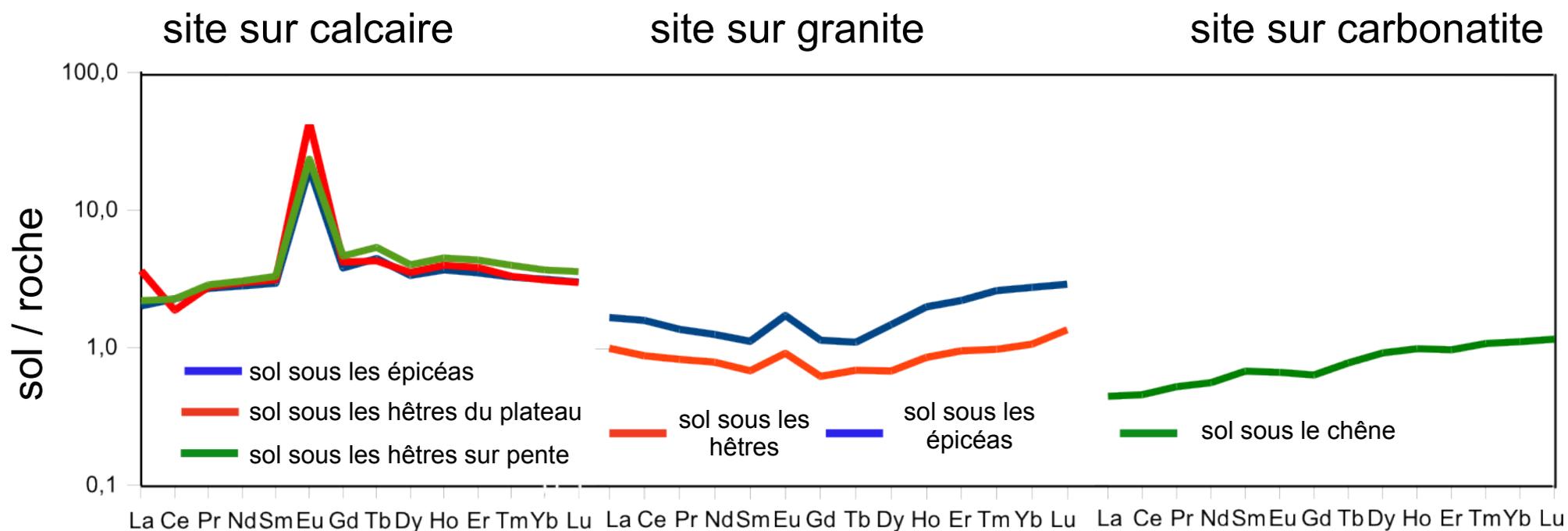
Transfert roche-sol



Transfert roche-sol

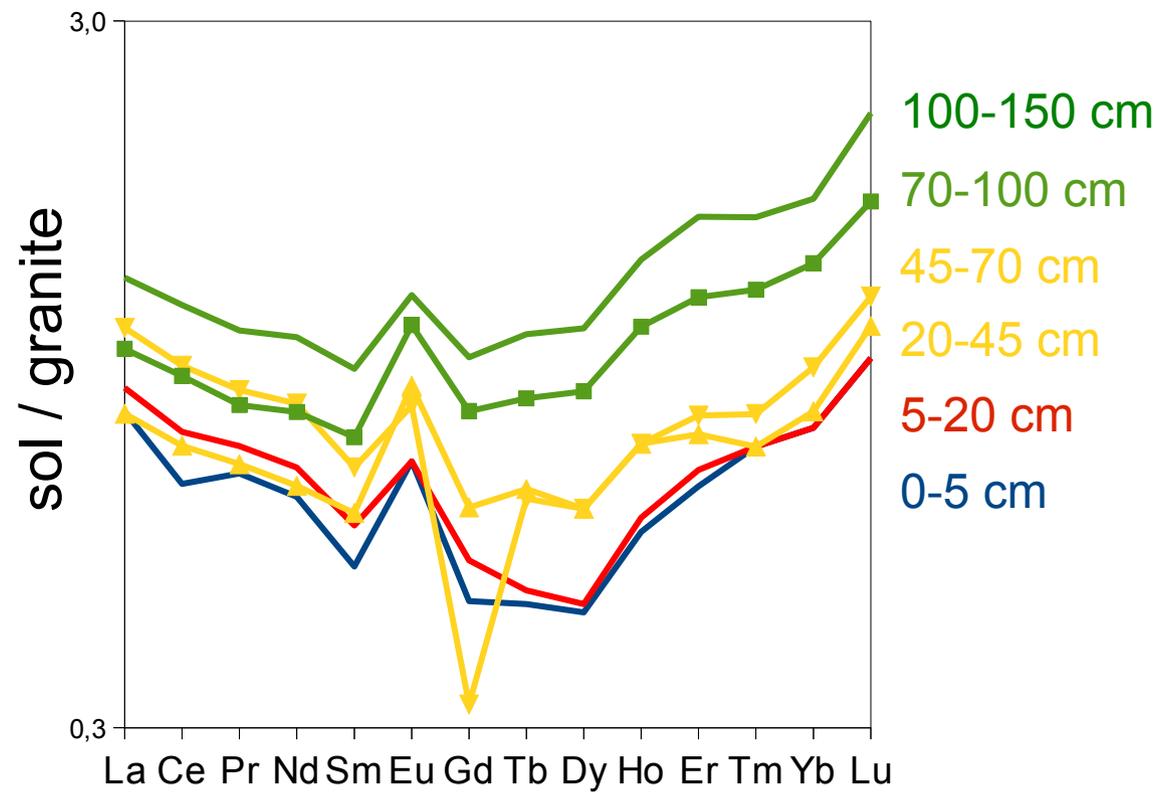
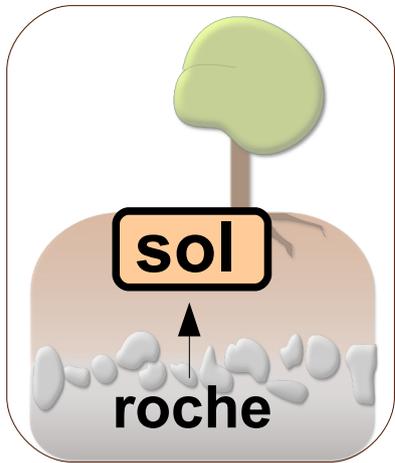


Fractionnement identique au sein de chaque site



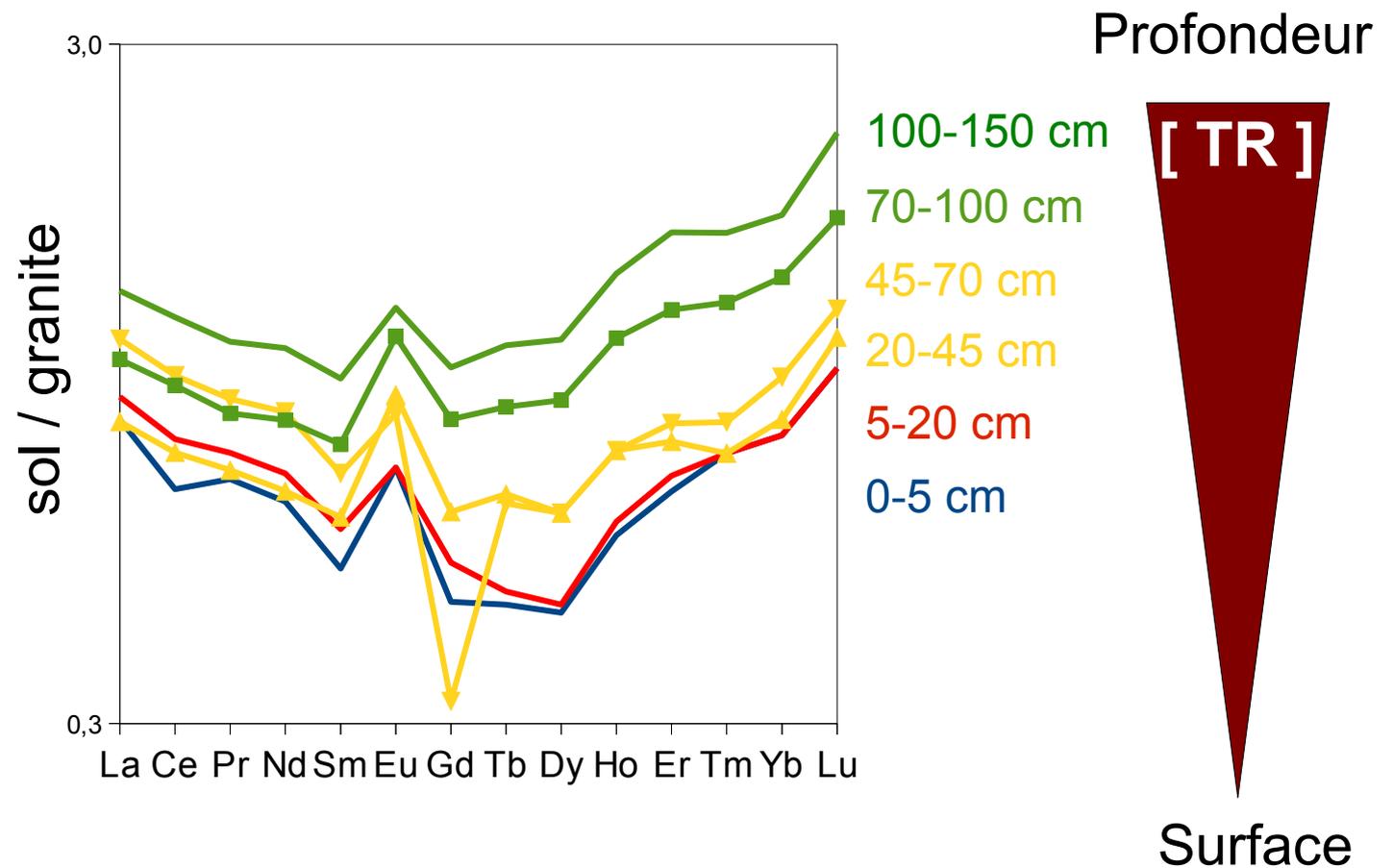
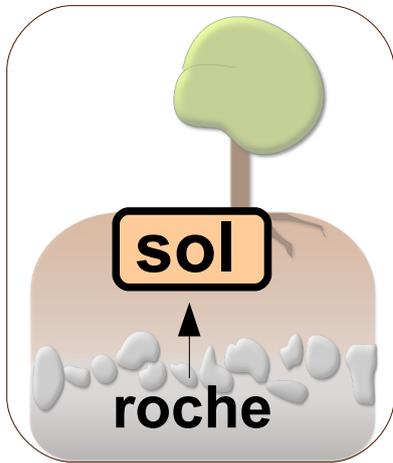
Répartition dans les sols

Ex : sol brun acide pessière Vosges

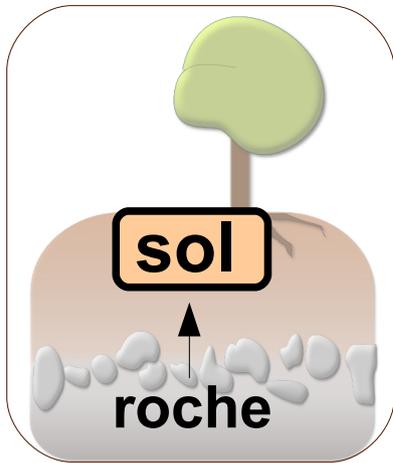


Répartition dans les sols

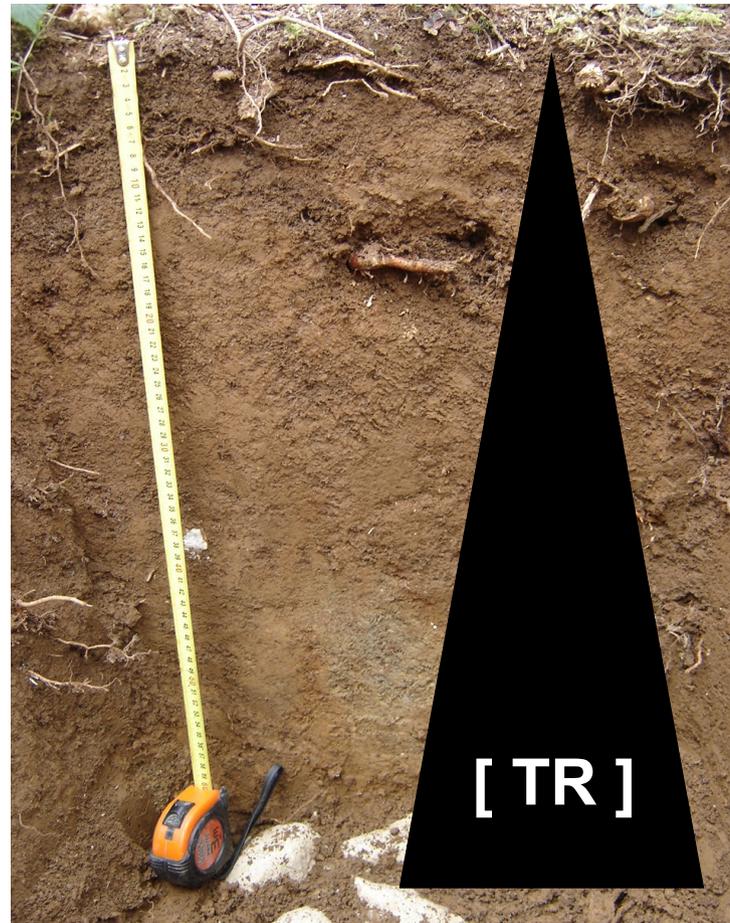
Ex : sol brun acide pessière Vosges



Répartition dans les sols

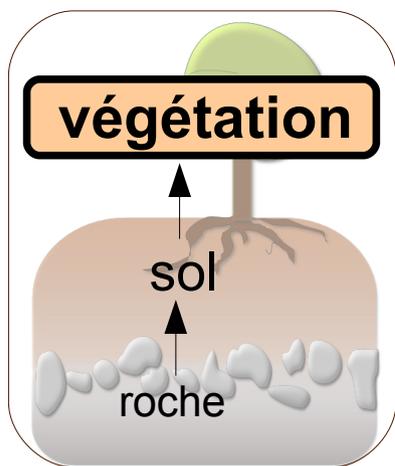


- [TR] en surface

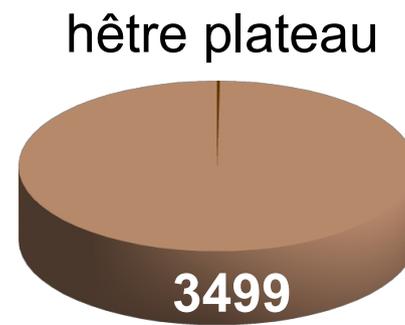
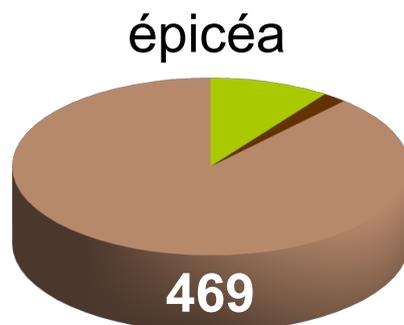


+ [TR] en profondeur

Répartition dans la végétation



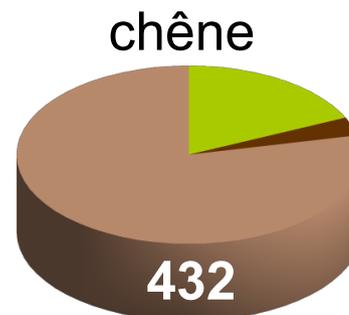
calcaire



granite



carbonatite

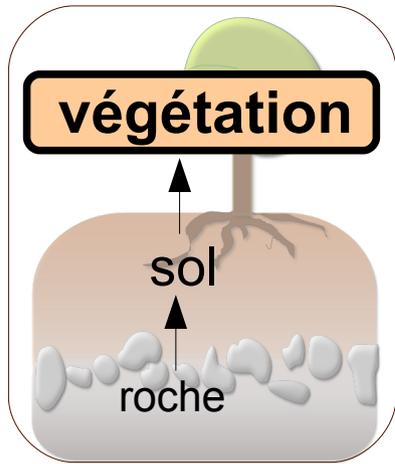


- racines
- tronc / branche
- feuilles

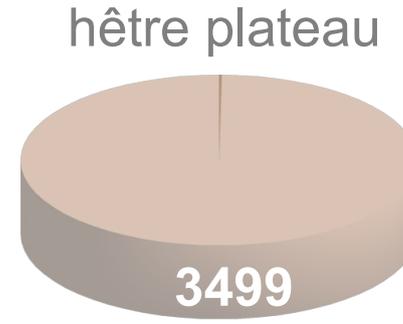
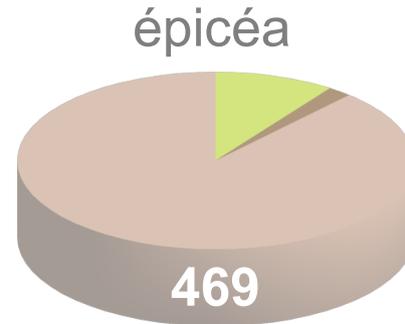


Nd dans les racines (ppb)

Répartition dans la végétation



calcaire

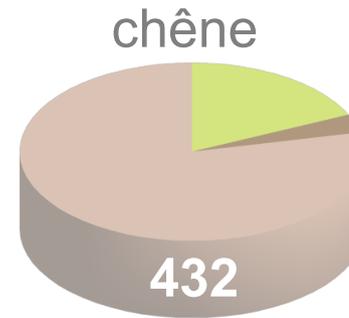


TR = [racines] > [feuilles] > [tronc]

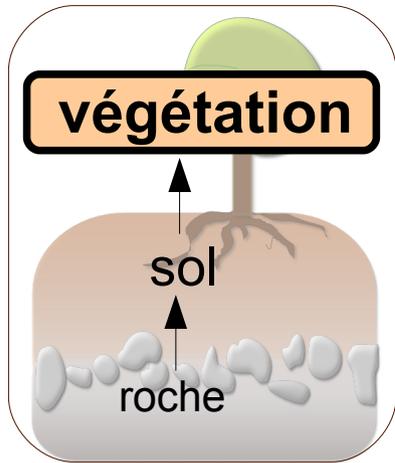
gran



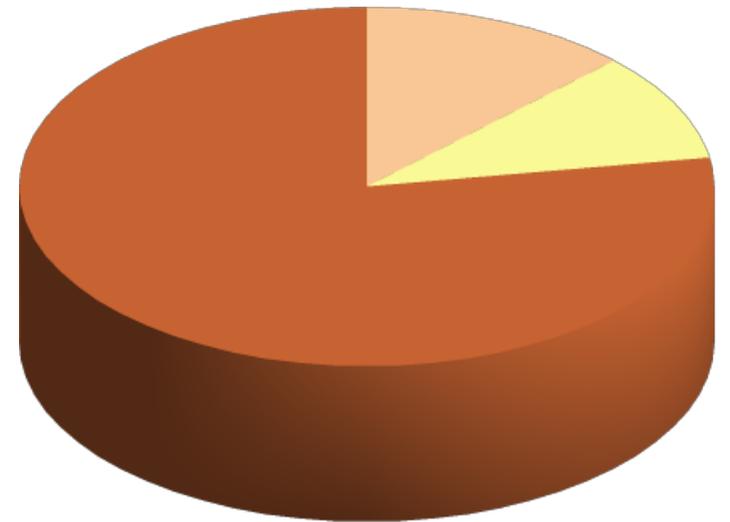
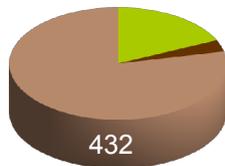
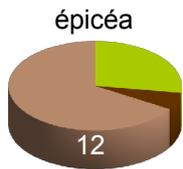
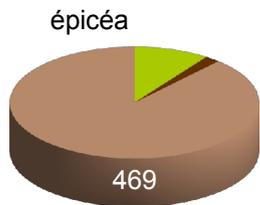
carbonatite



Répartition dans la végétation

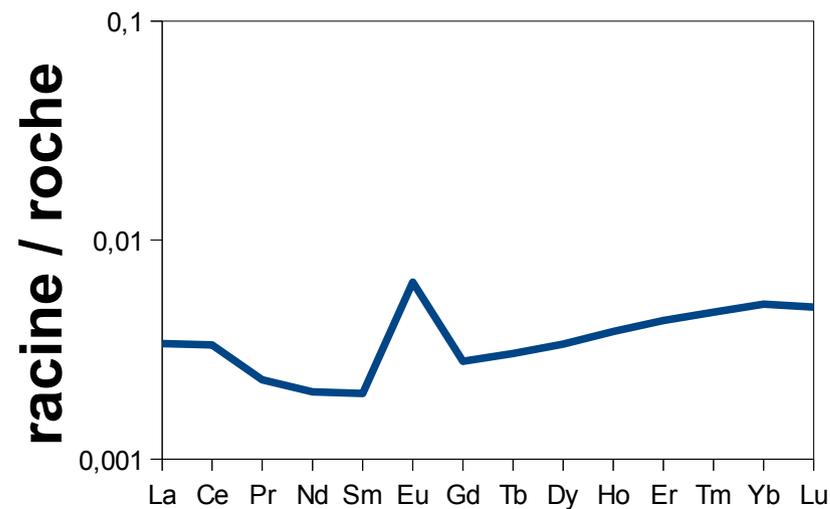
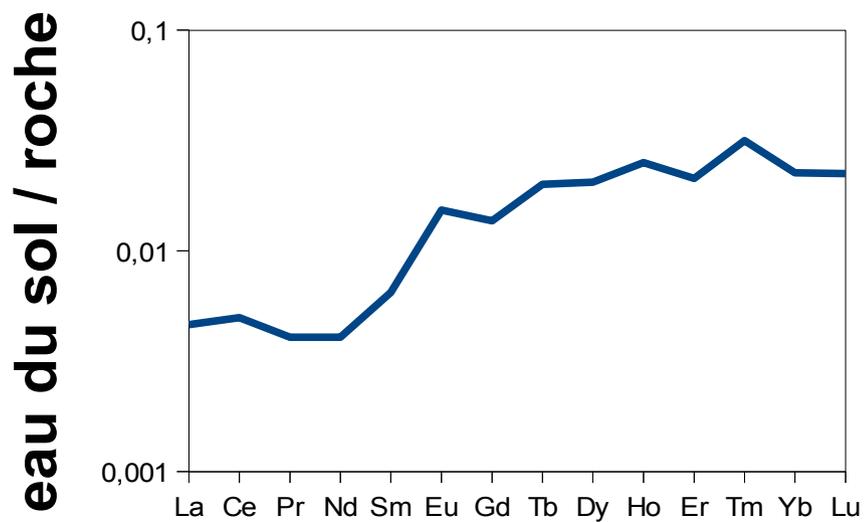
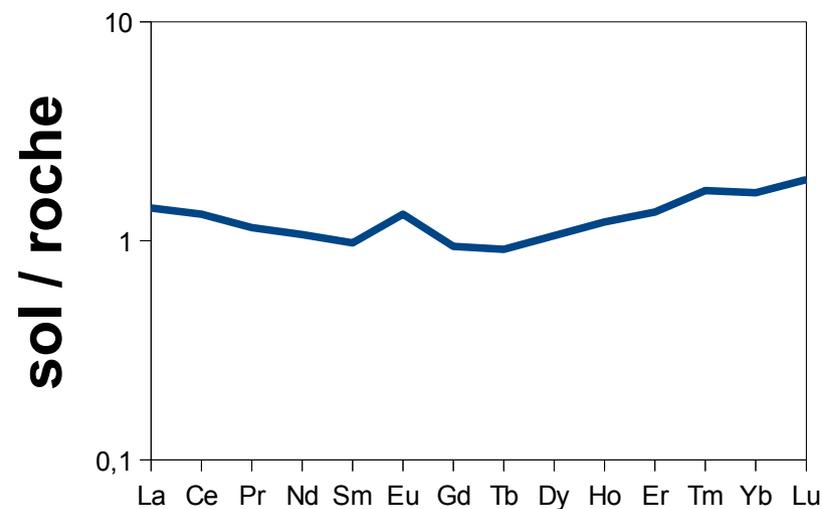
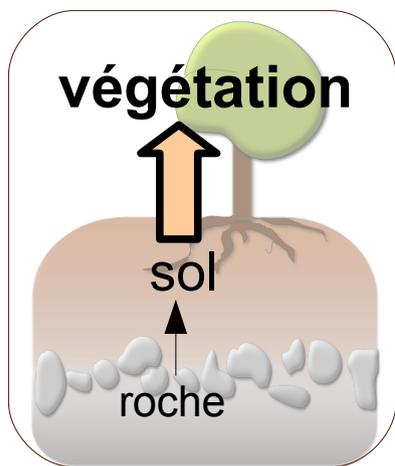


Dans les racines
[TR] = petites > moyennes > larges

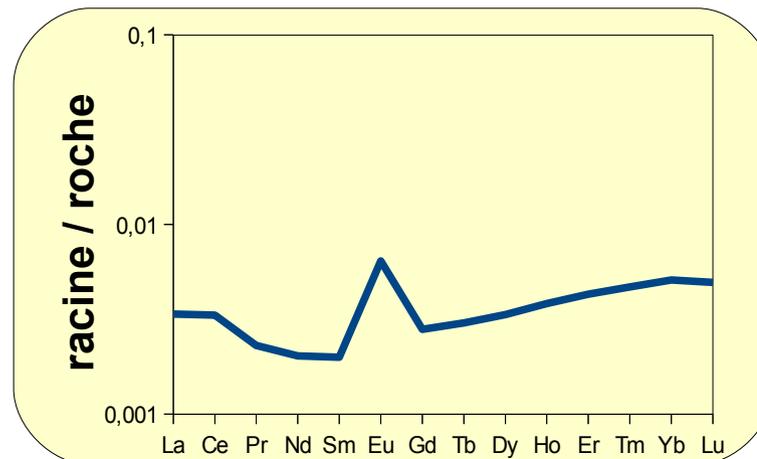
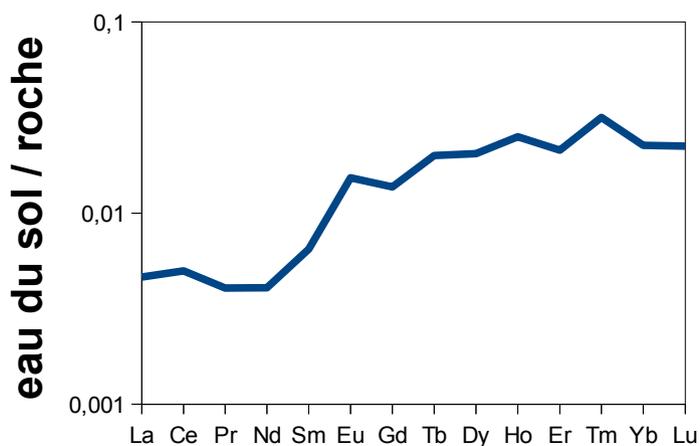
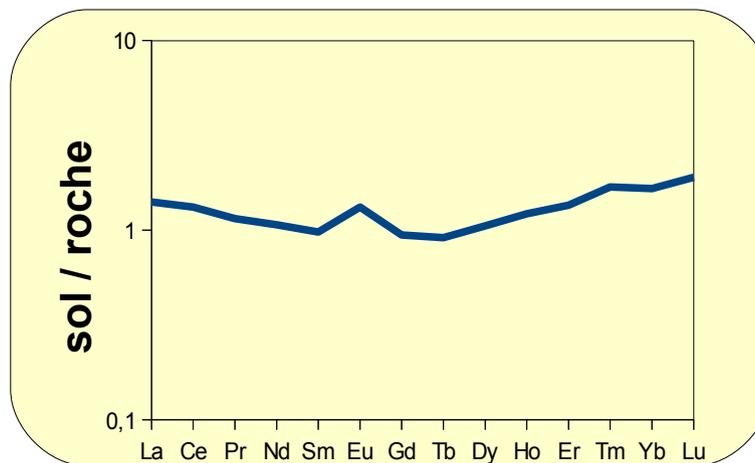
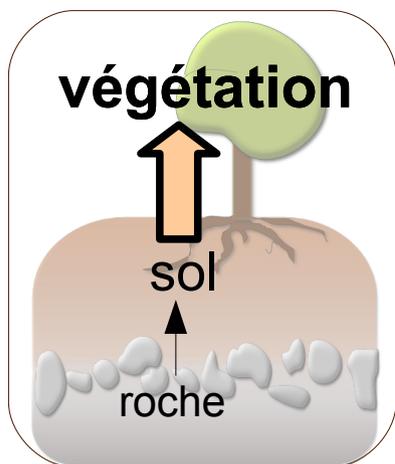


- petites
- moyennes
- larges

Normalisation : similitudes des spectres

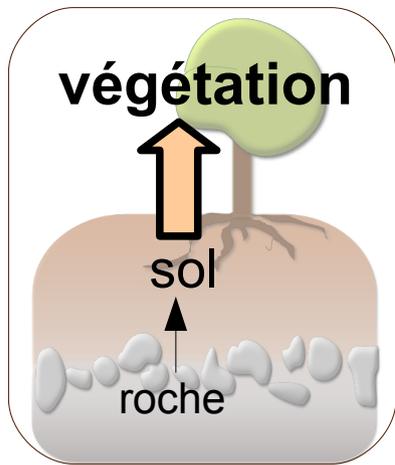


Normalisation : similitudes des spectres

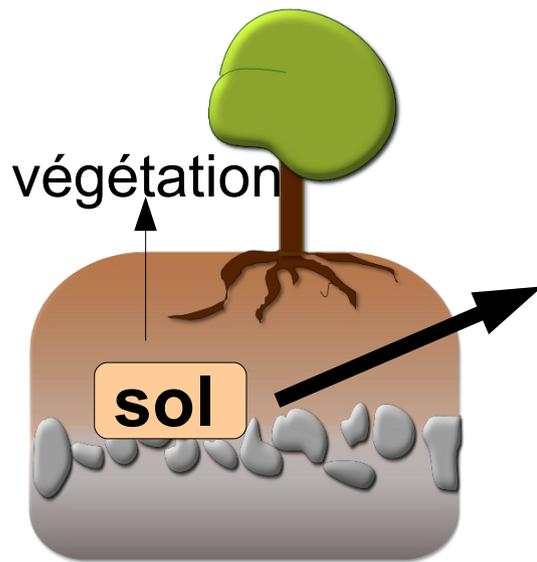
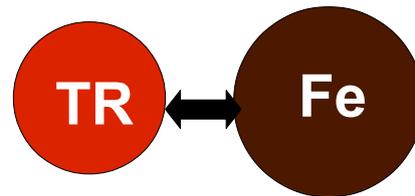


Spectres racine/roche et sol/roche : similaires

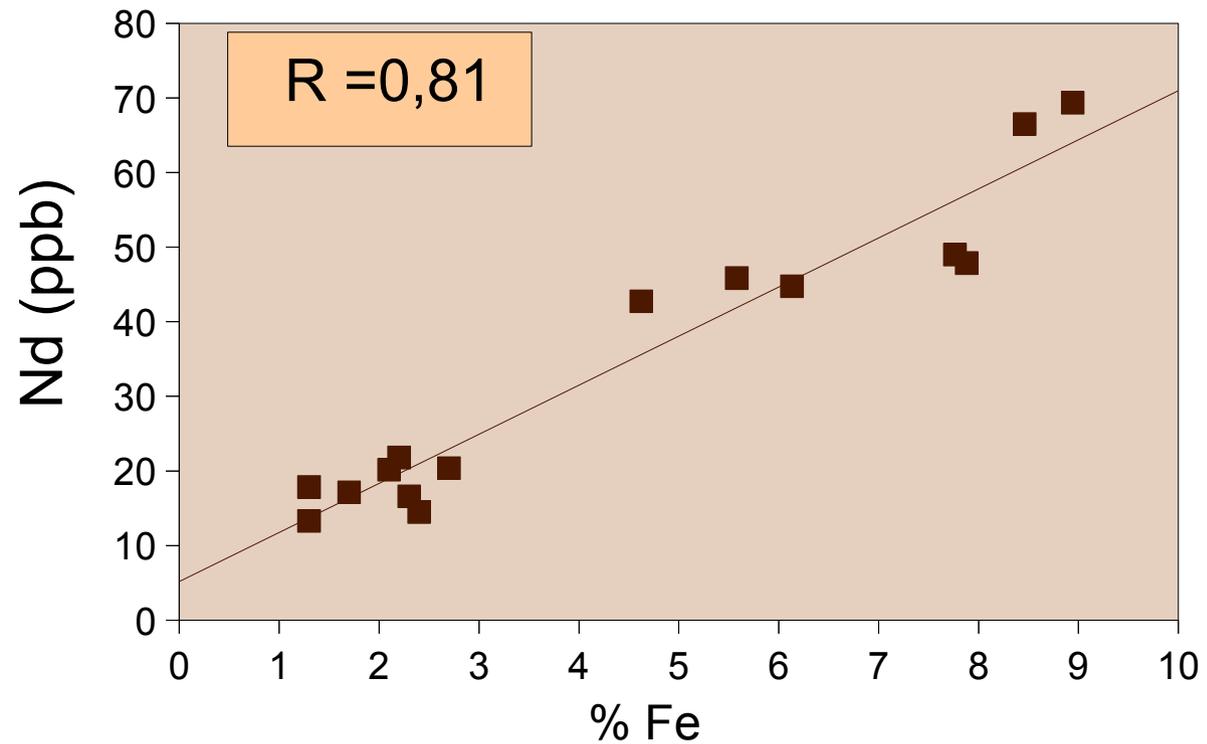
Normalisation : corrélation avec le fer



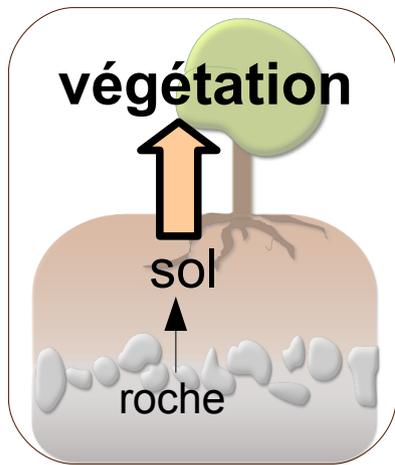
Sol



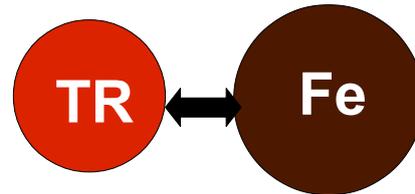
Sol



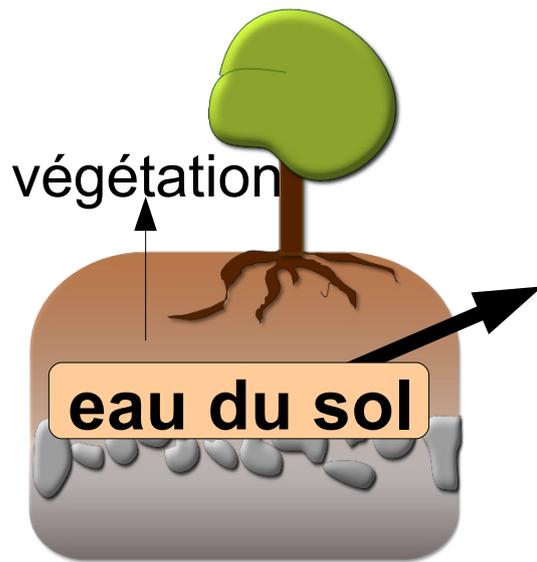
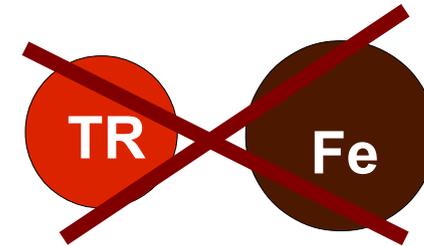
Normalisation : corrélation avec le fer



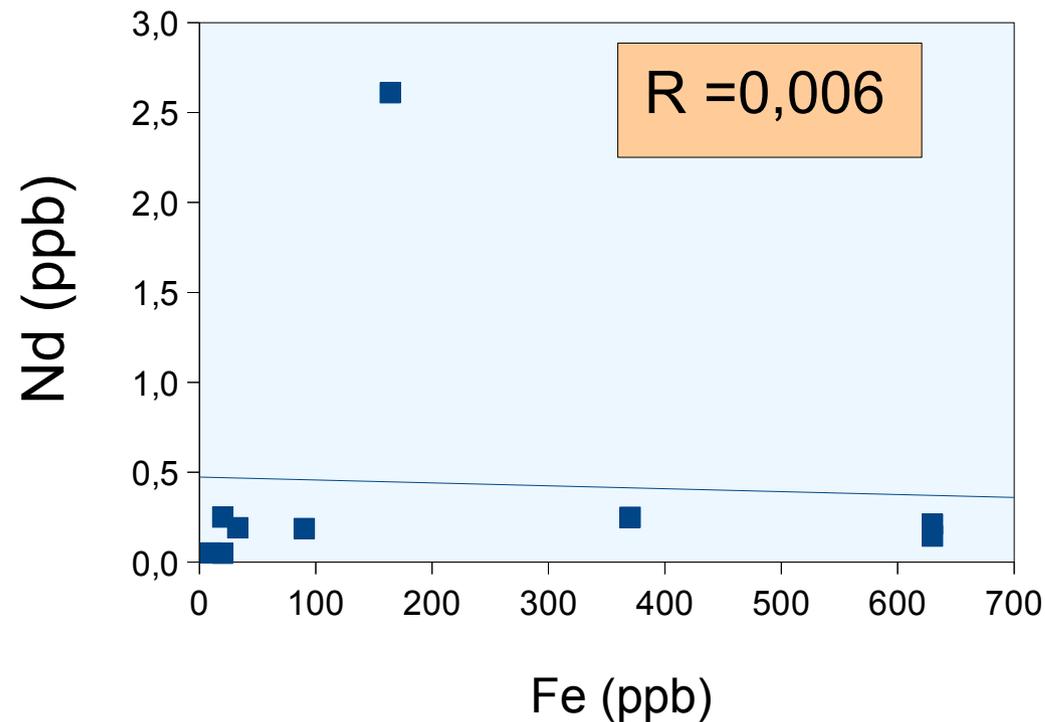
Sol



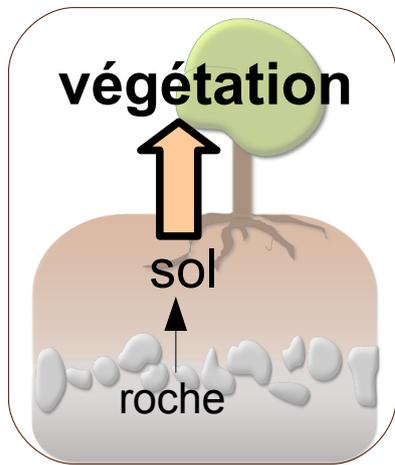
Eau du sol



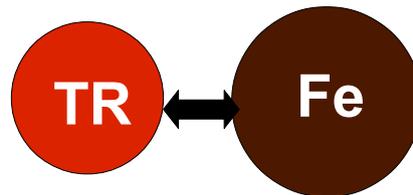
Eau du sol



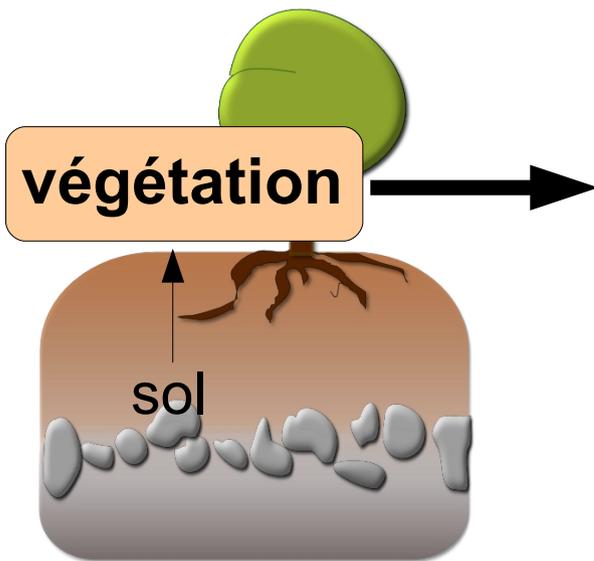
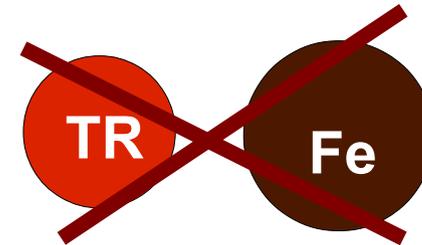
Normalisation : corrélation avec le fer



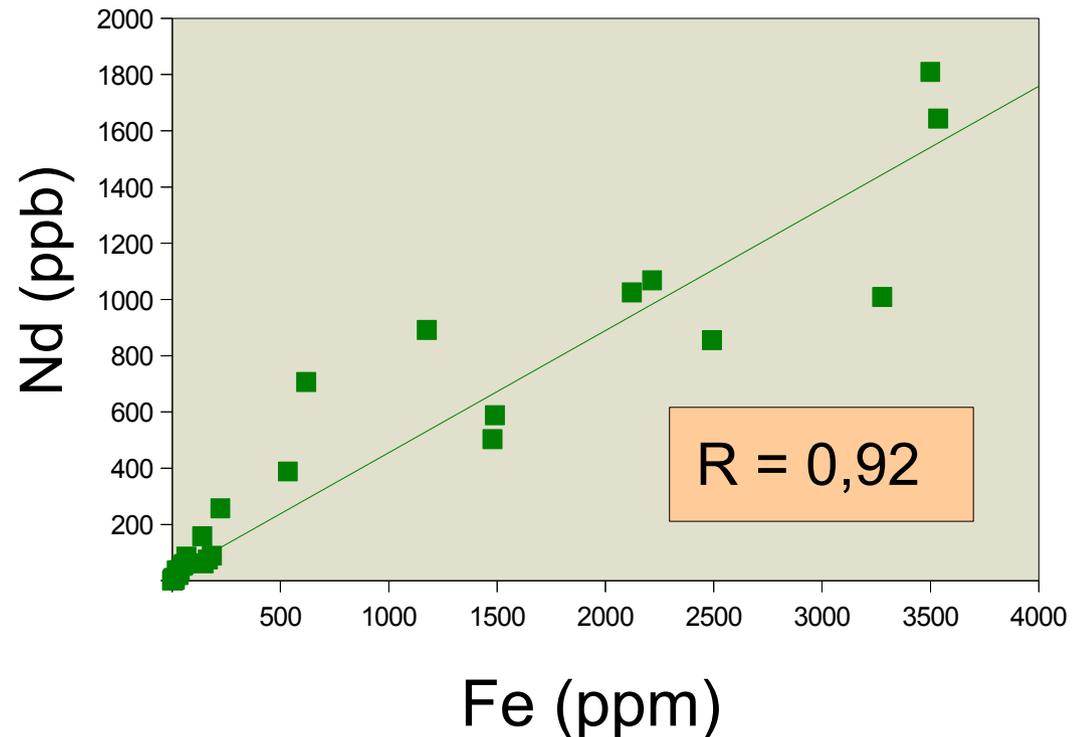
Sol et végétation

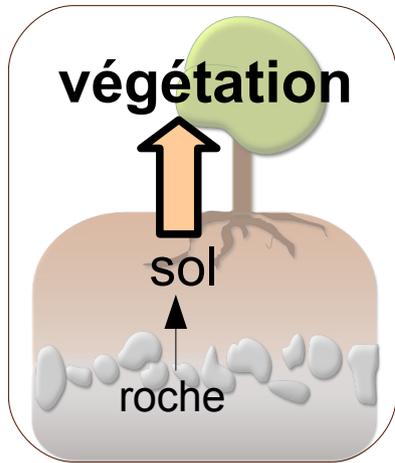


Eau du sol



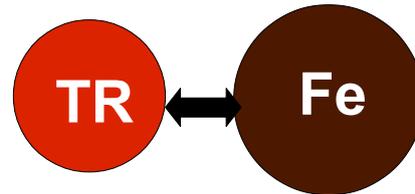
Végétation



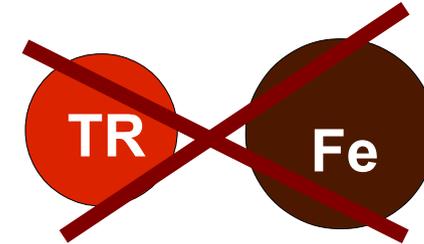


Normalisation

Sol et végétation



Eau du sol

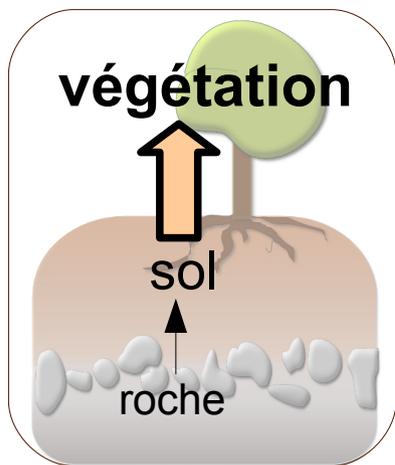


+

Spectre de l'eau du sol différent de celui du sol et de la végétation

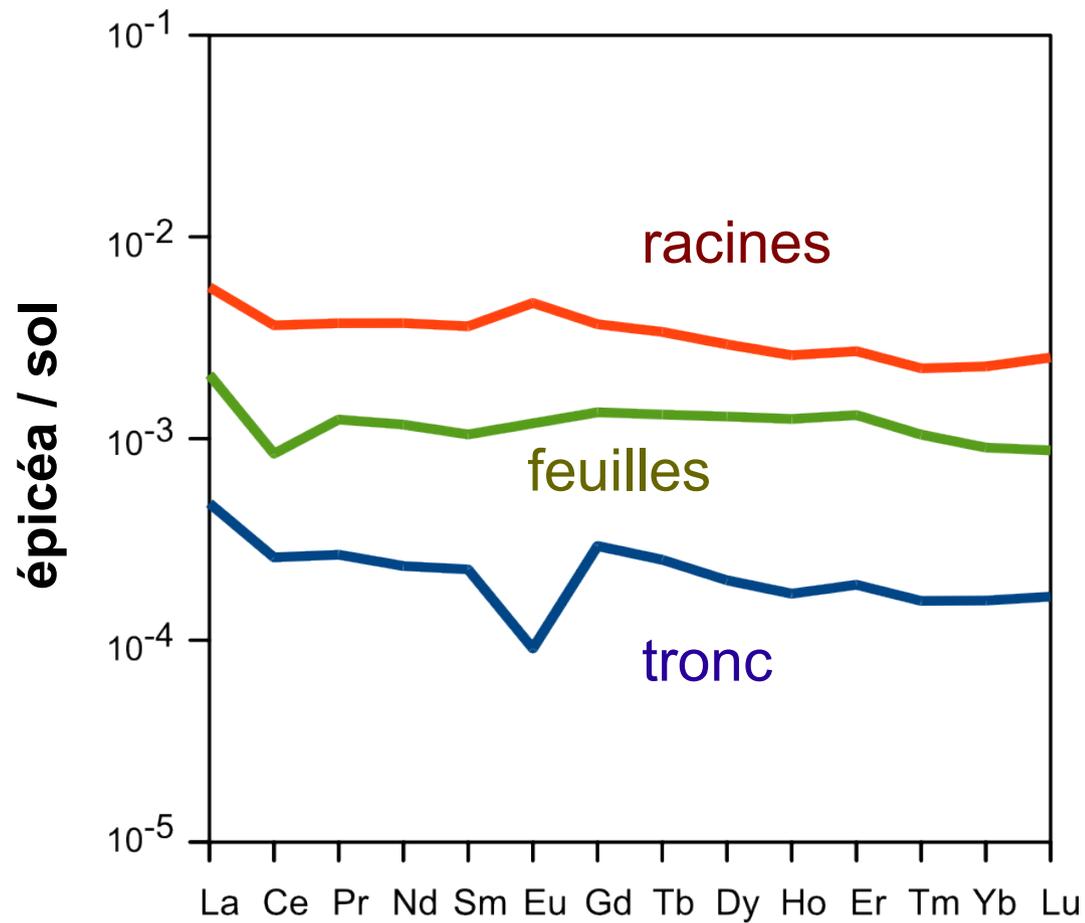


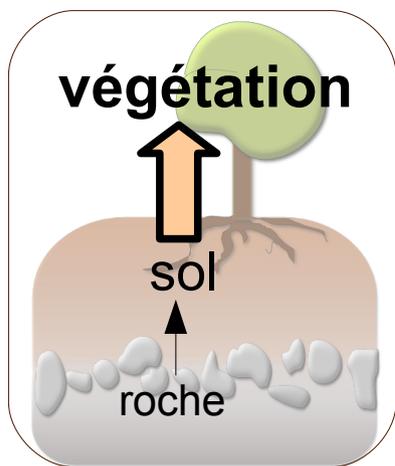
Choix d'une normalisation au sol



Spectre de la végétation

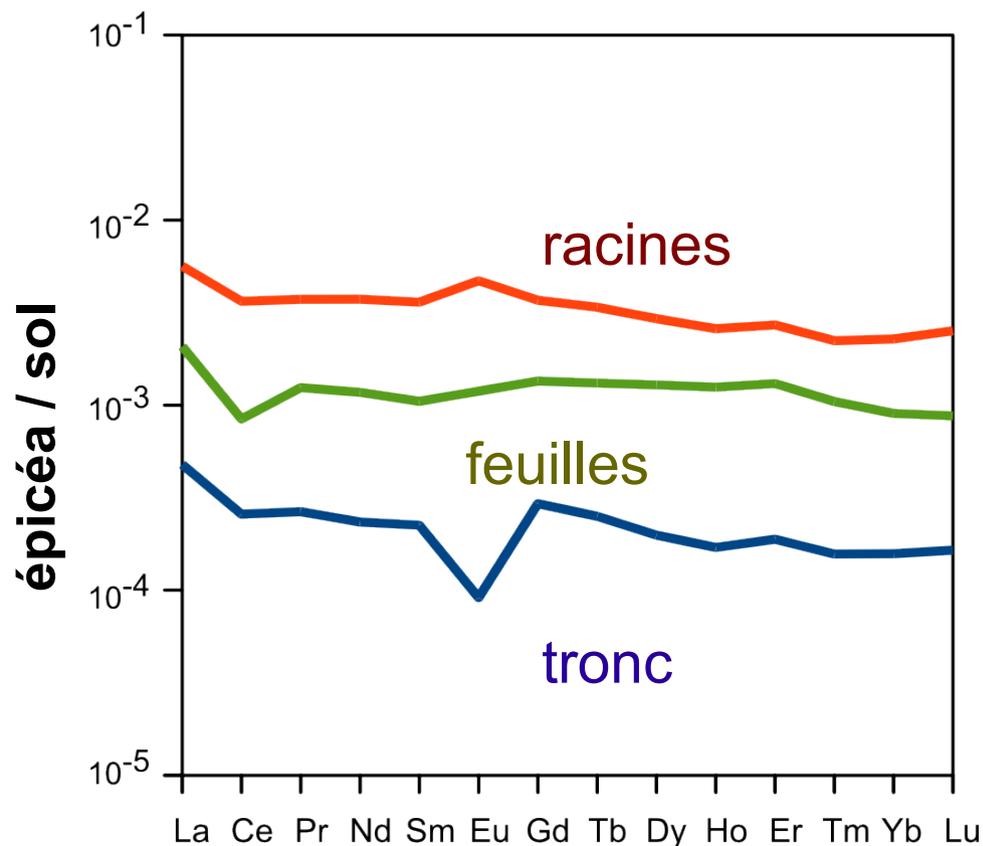
Au sein d'un arbre



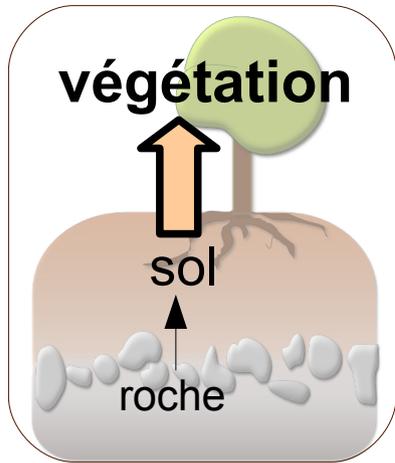


Spectre de la végétation

Au sein d'un arbre



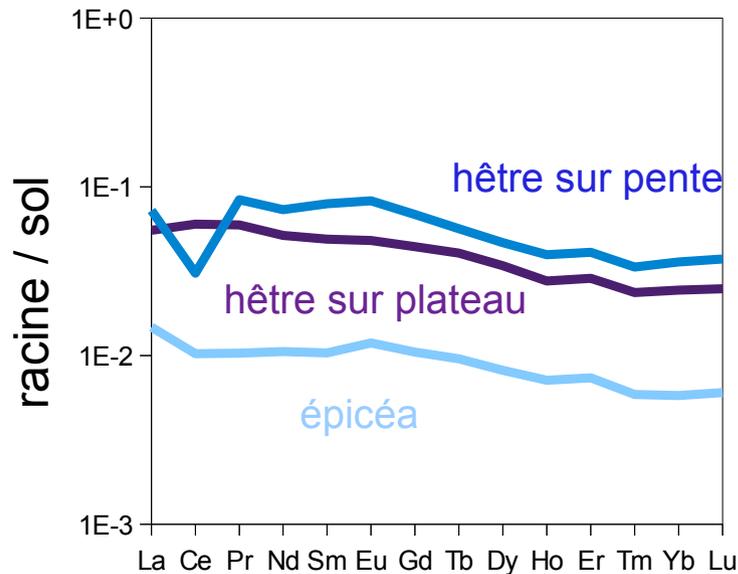
Fractionnement proche pour racines / feuilles / tronc d'un même arbre



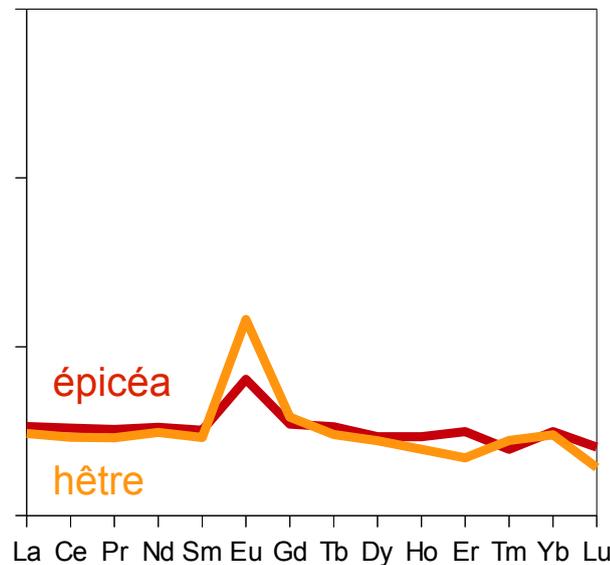
Spectre de la végétation

Comparaison des différents sites

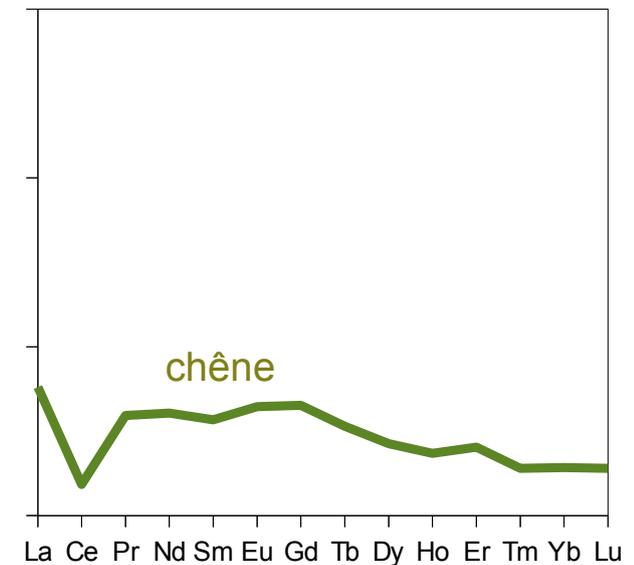
site sur calcaire

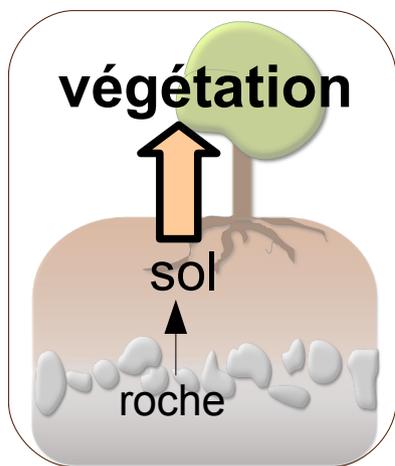


site sur granite



site sur carbonatite



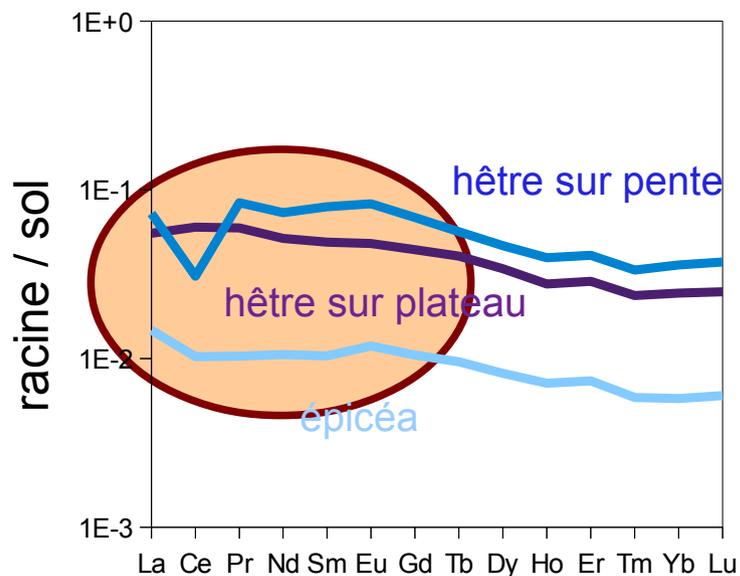


Spectre de la végétation

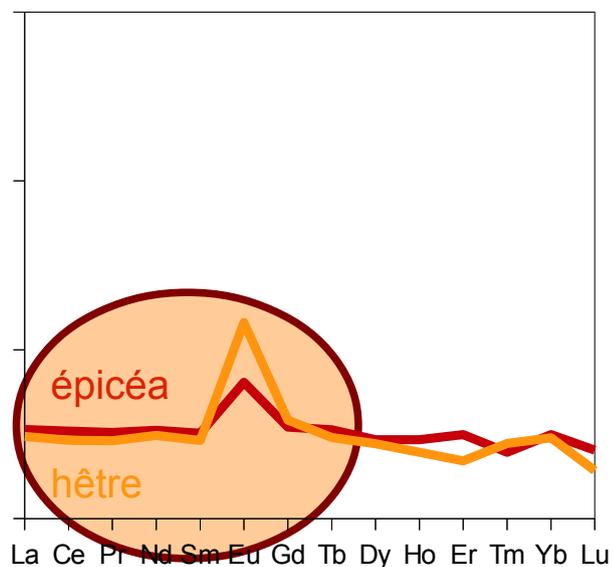
Comparaison des différents sites

Enrichissement en TR légères

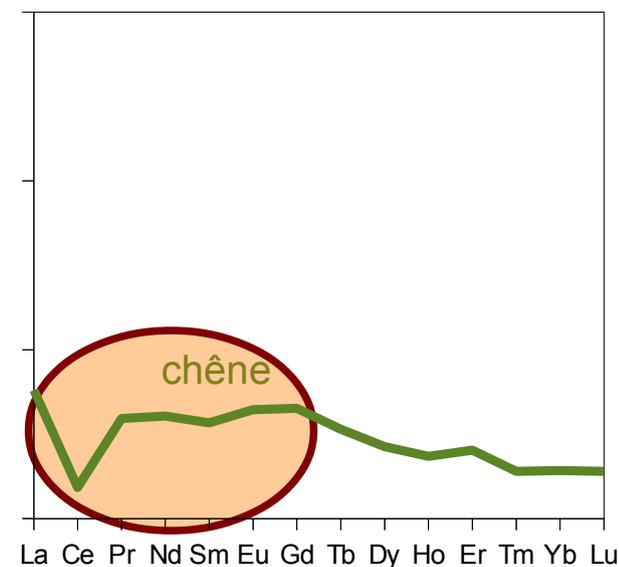
site sur calcaire



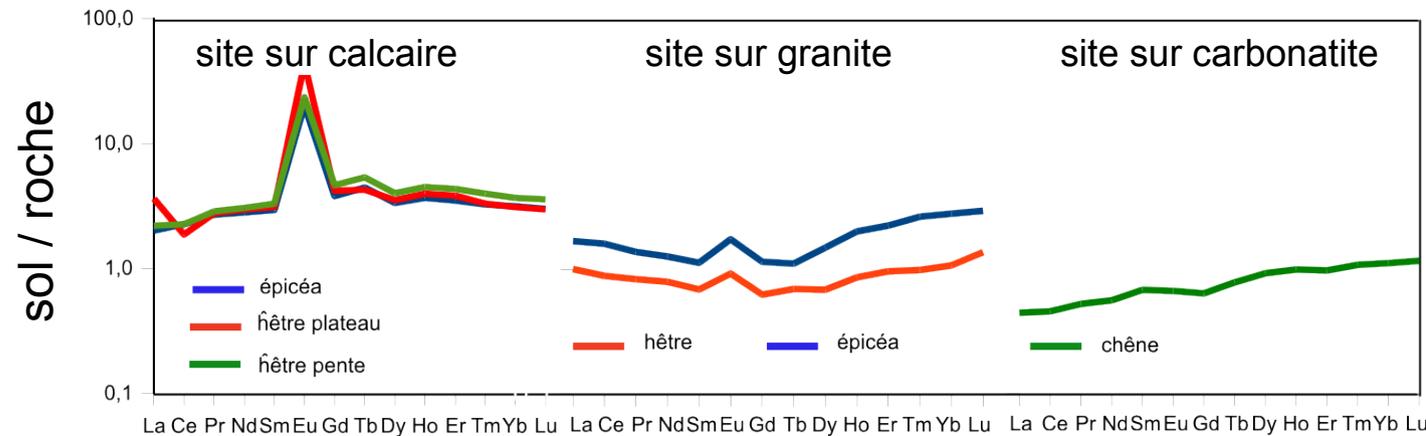
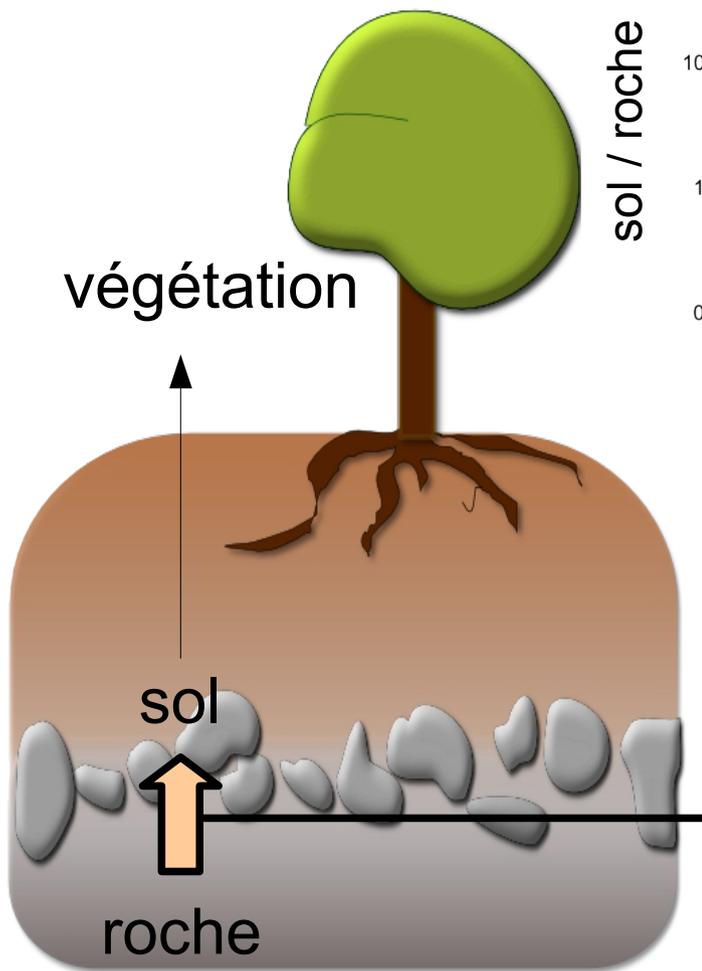
site sur granite



site sur carbonatite



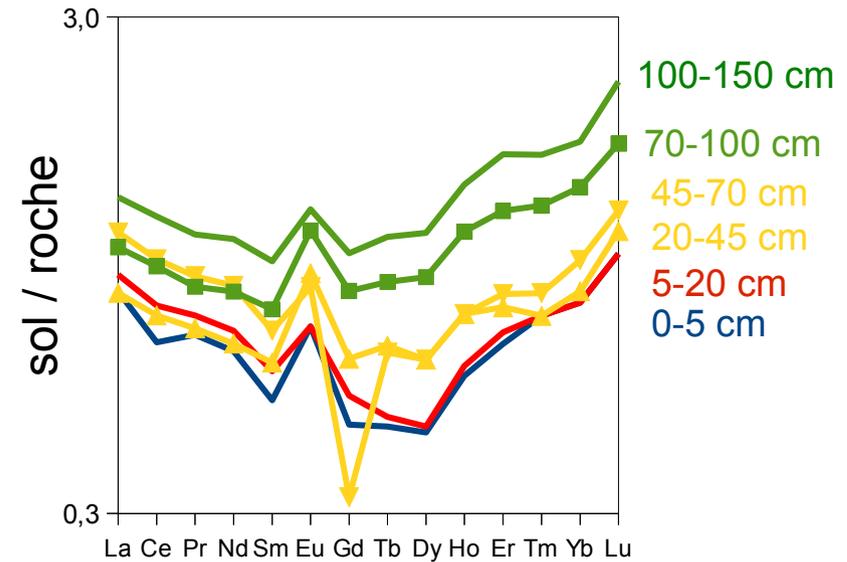
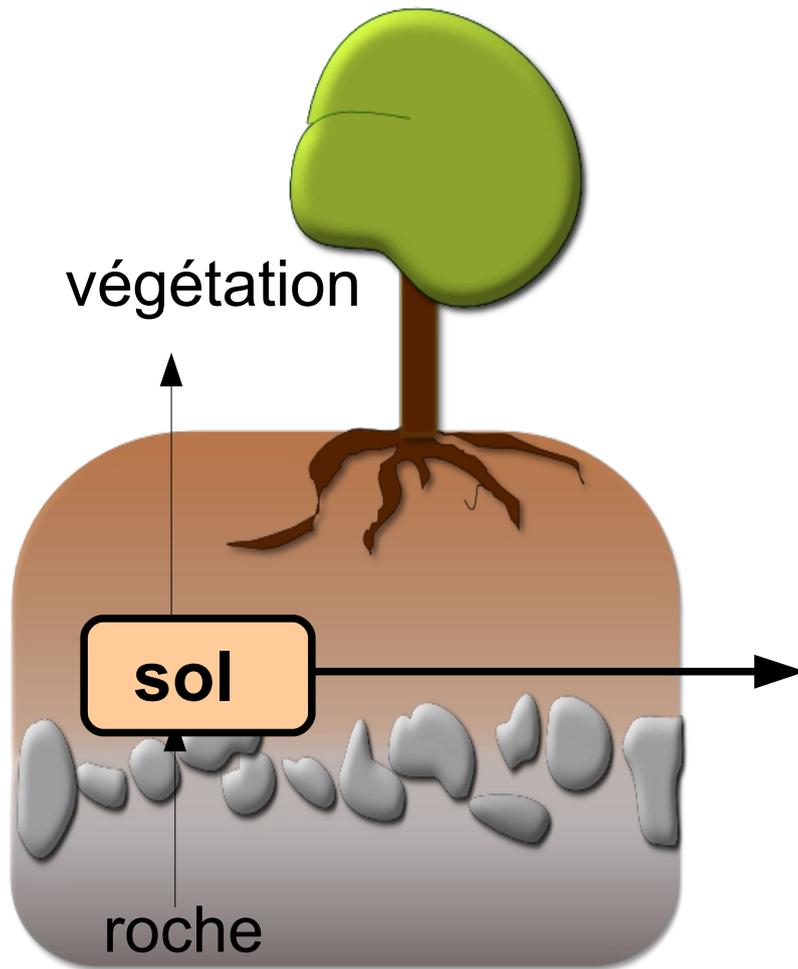
Récapitulatif : transfert roche-sol



**Facteurs de transfert
différents entre les sites**

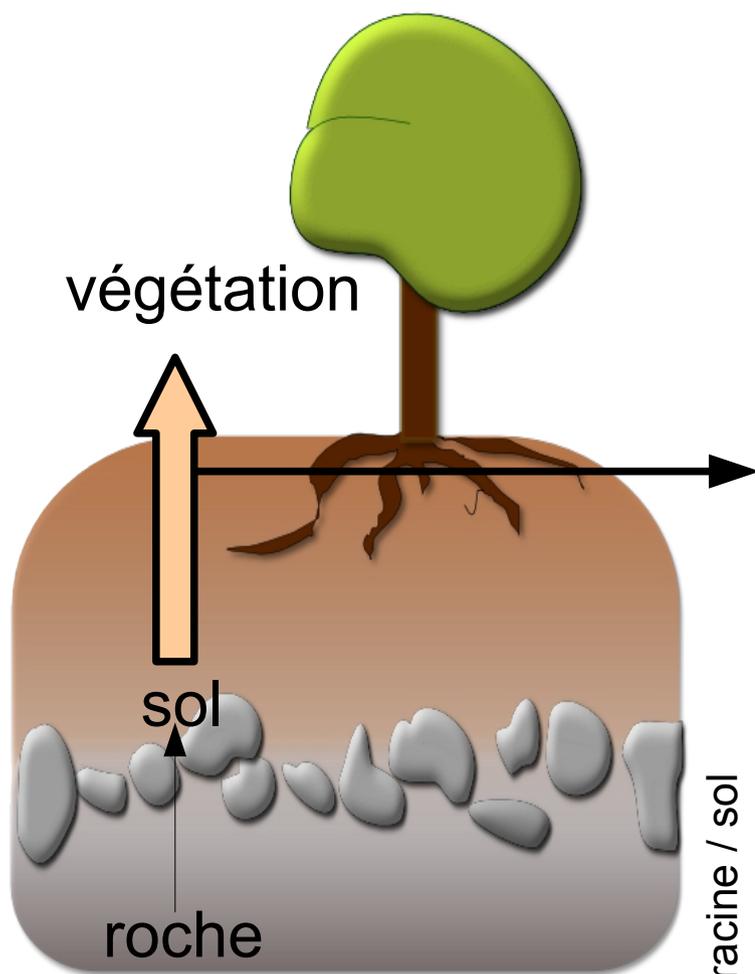
**Fractionnement identique au
sein de chaque site**

Récapitulatif : accumulation dans les sols

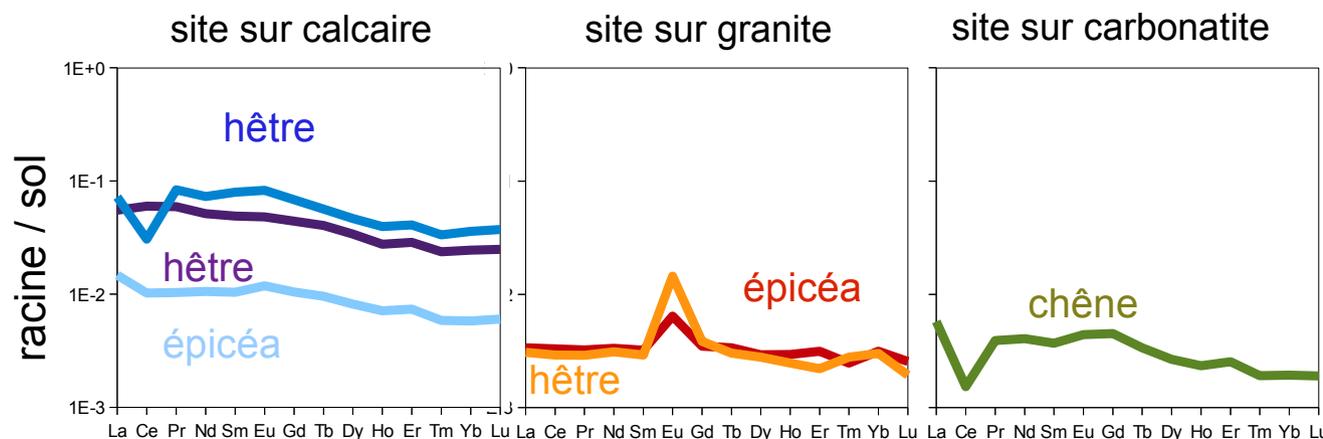


Enrichissement en TR lourdes
Concentrations plus importantes en profondeur

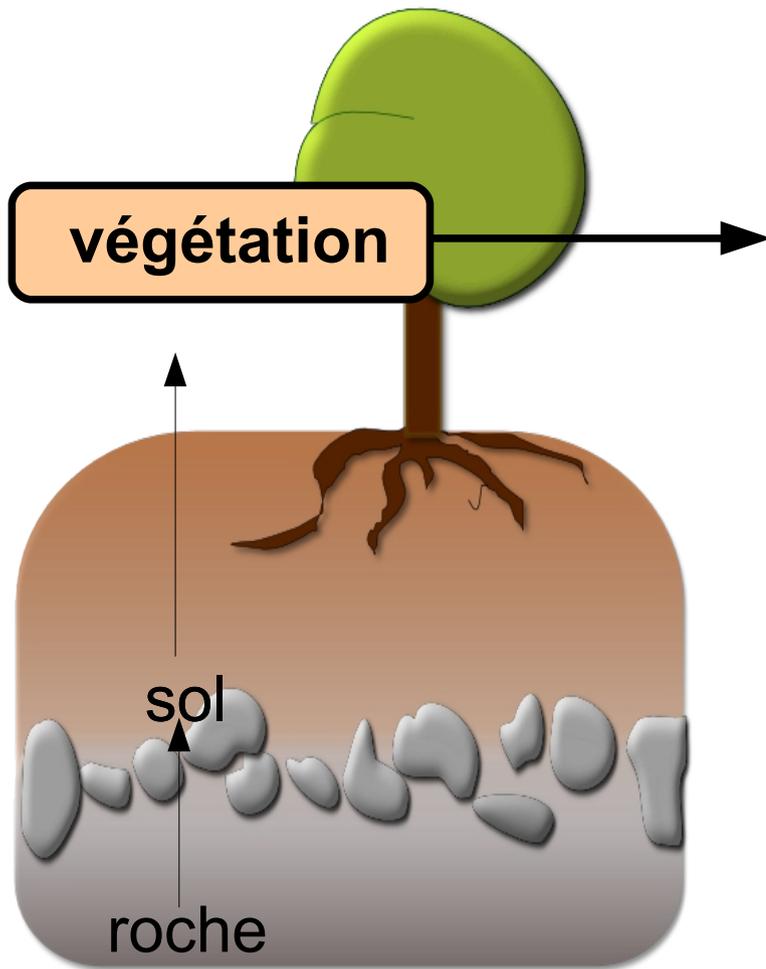
Récapitulatif : transfert vers la végétation



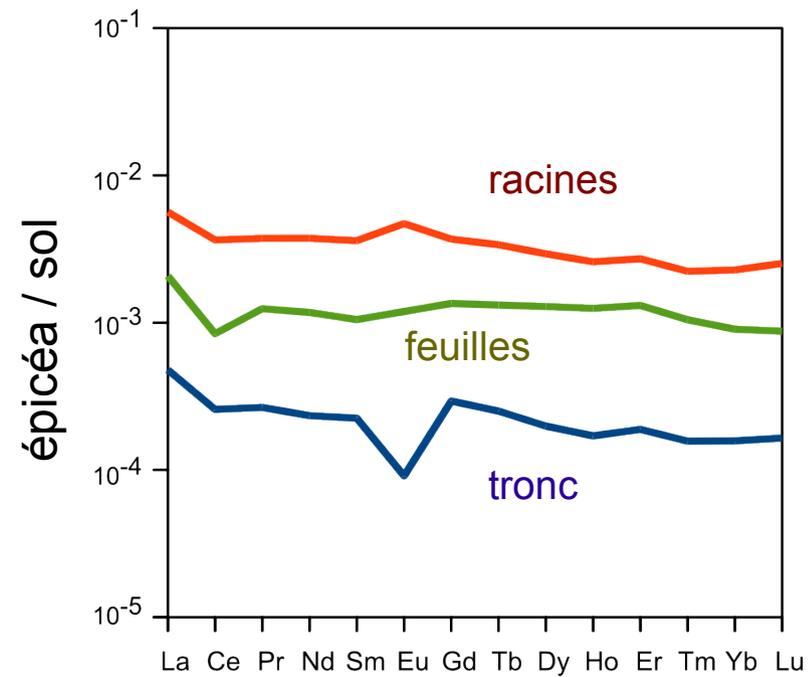
**Absorption préférentielle
des TR légères**



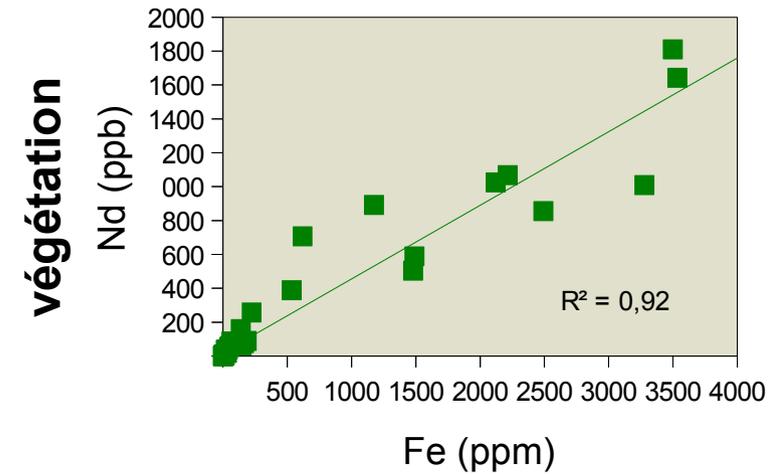
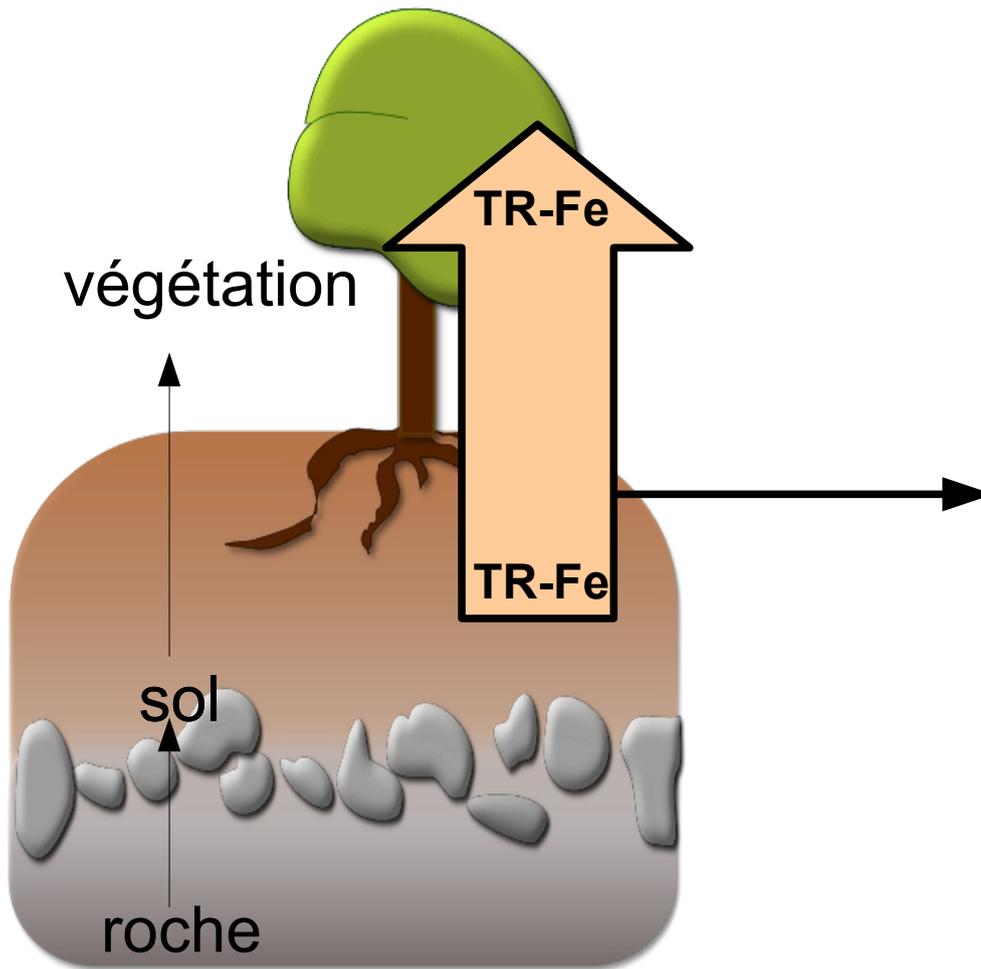
Récapitulatif : accumulation dans la végétation



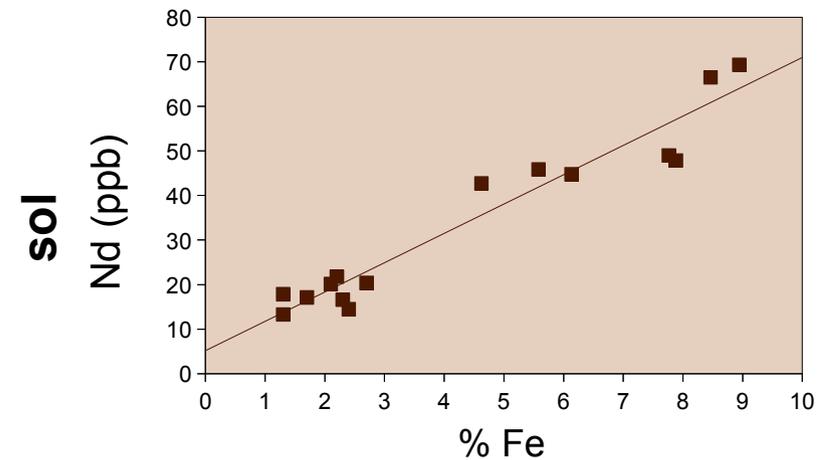
[TR] : racines > feuilles > tronc



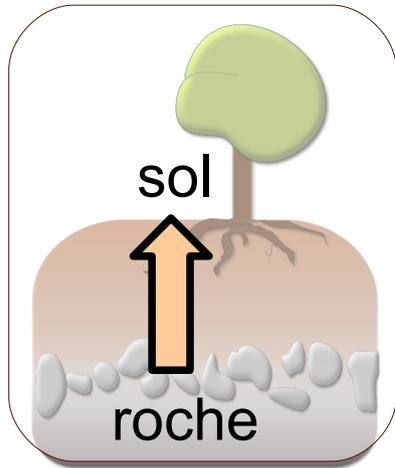
Récapitulatif : corrélation TR-Fe



Corrélation TR-Fe dans les sols et dans la végétation (racines / tronc / feuilles)

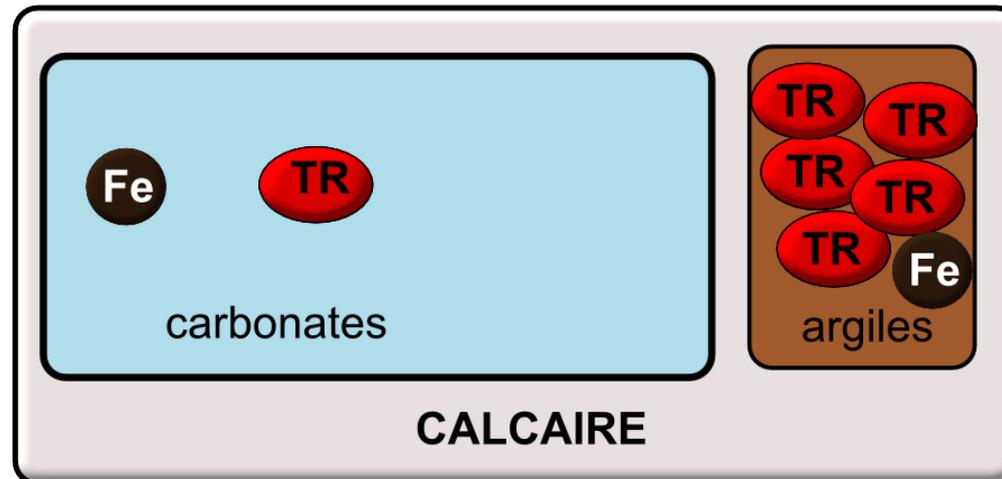


Transfert roche-sol

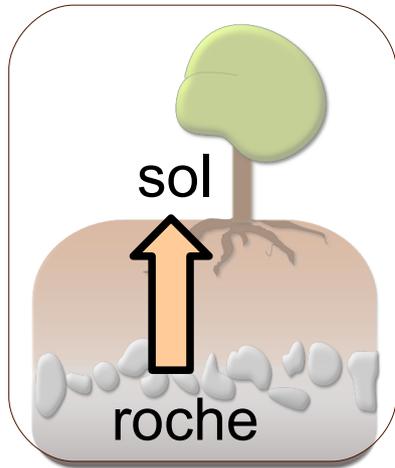


Facteurs de transfert différents entre les sites

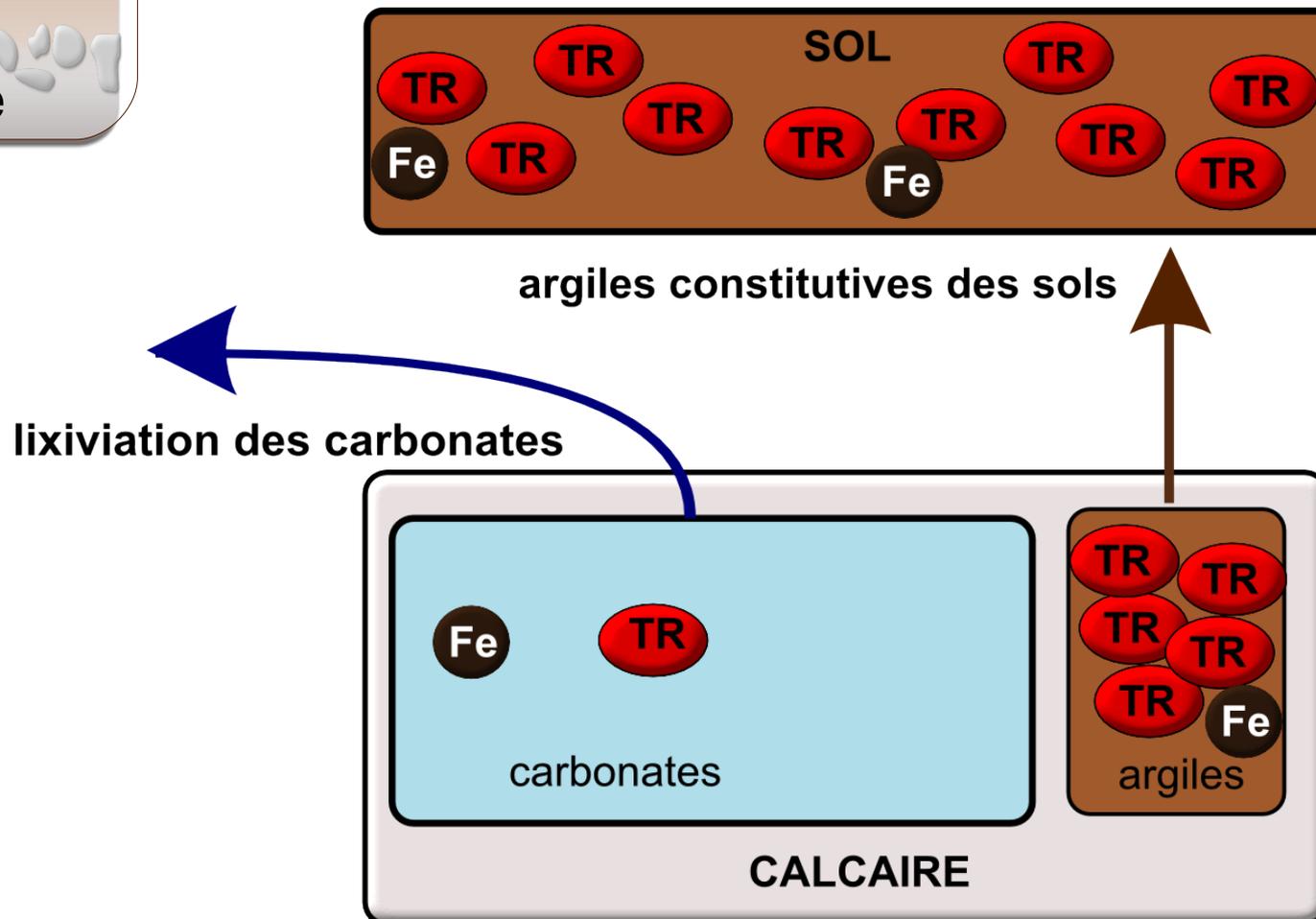
exemple du site calcaire



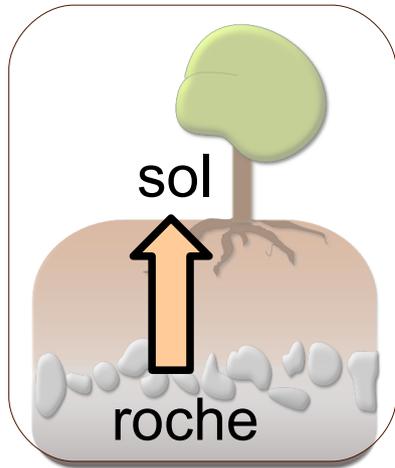
Transfert roche-sol



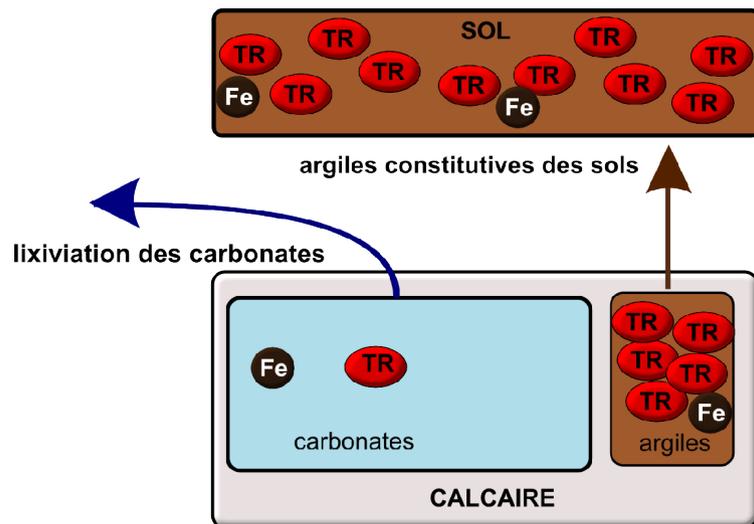
Facteurs de transfert différents entre les sites



Transfert roche-sol

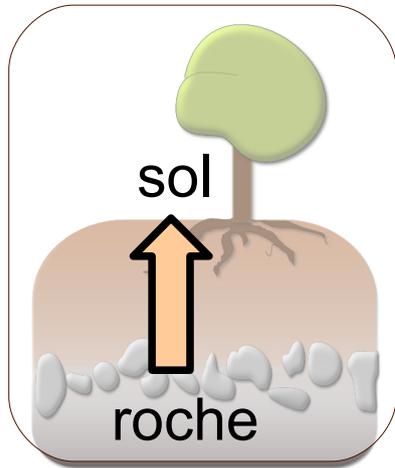


Facteurs de transfert différents entre les sites



Facteurs de transfert liés à la minéralogie de la roche

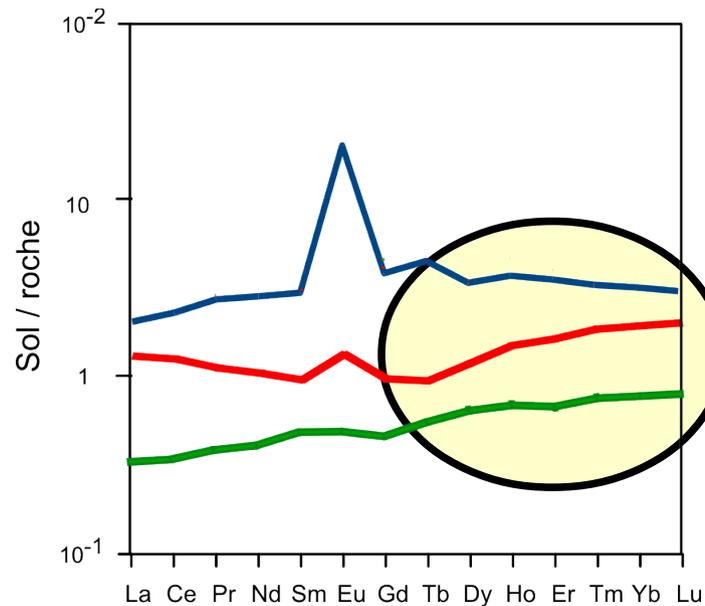
Transfert roche-sol



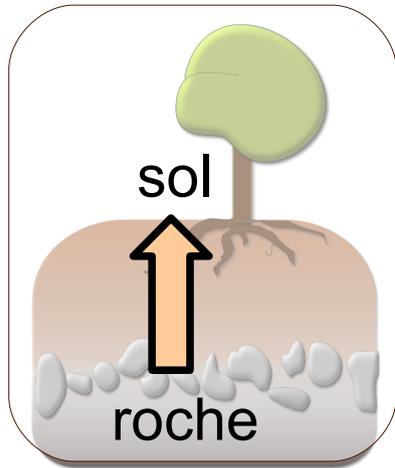
Facteurs de transfert liés à la minéralogie de la roche

mais :

Enrichissement en TR lourdes identique dans les sols des 3 sites



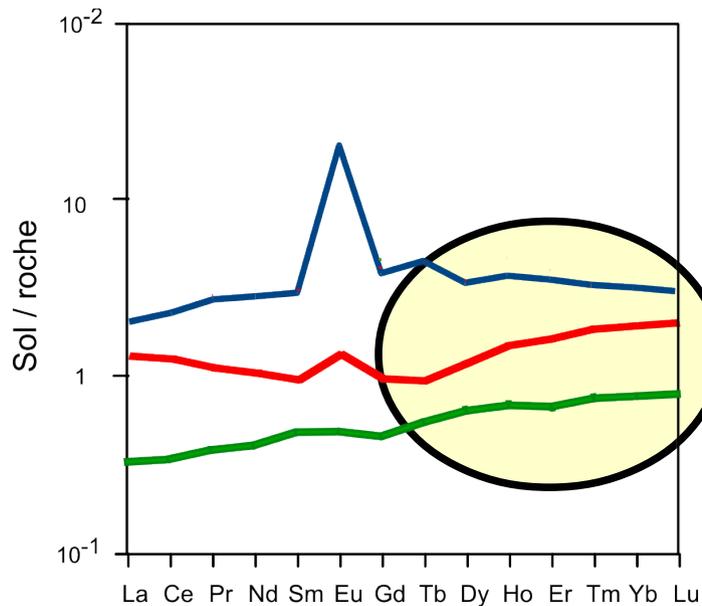
Transfert roche-sol



Facteurs de transfert liés à la minéralogie de la roche

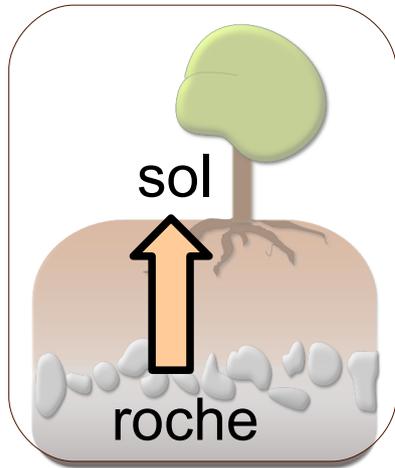
mais :

Enrichissement en TR lourdes identique dans les sols des 3 sites

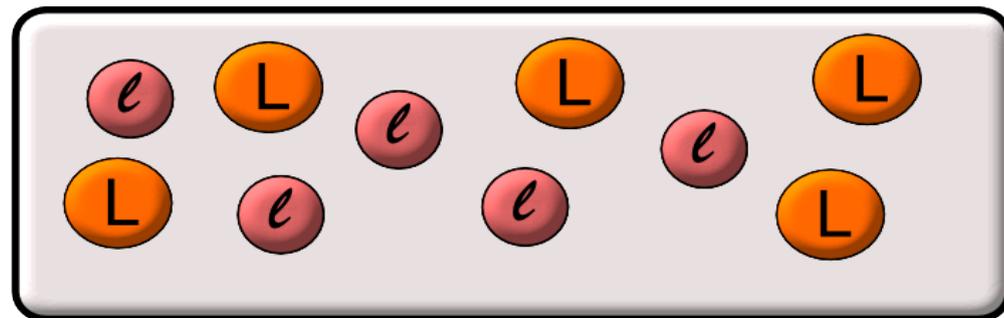


Contrôle par un constituant commun des sols

Transfert des roches au sols

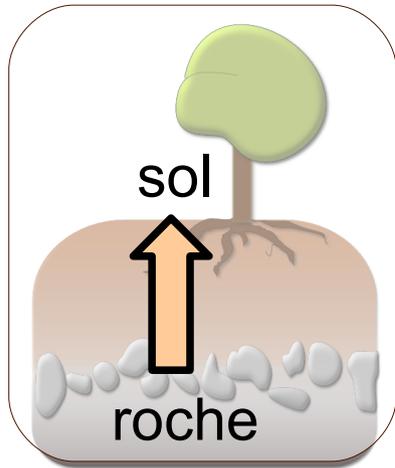


Transfert préférentiel des TR lourdes



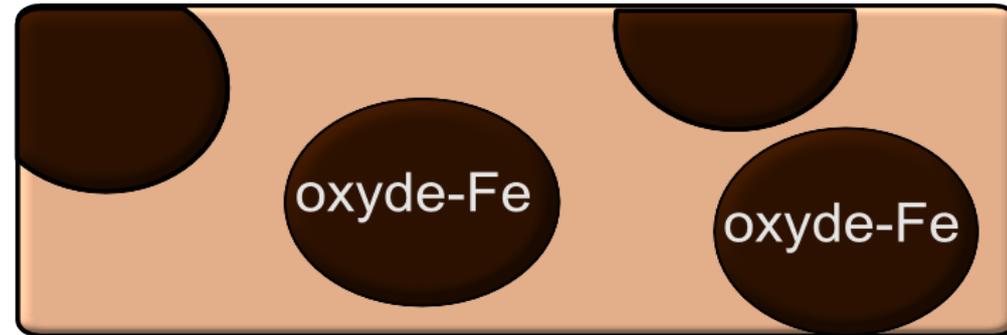
ROCHE

Transfert roche-sol

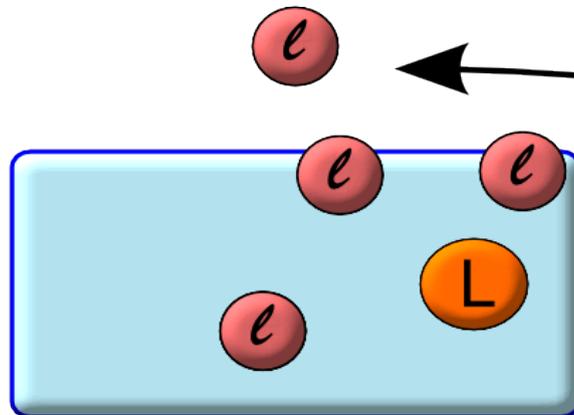


Transfert préférentiel des TR lourdes

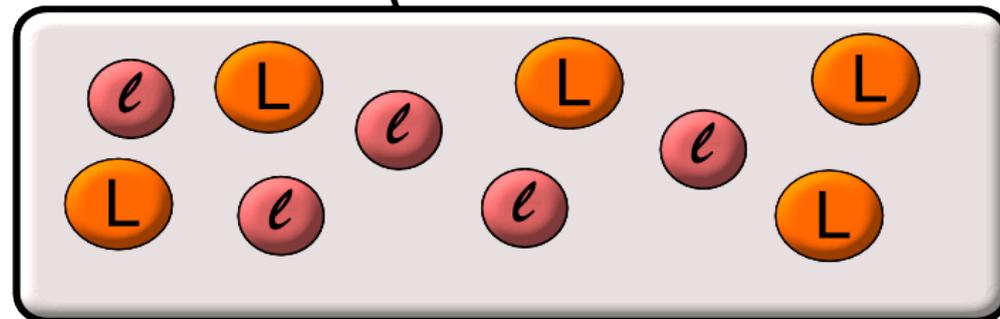
SOL



lixiviation TRI

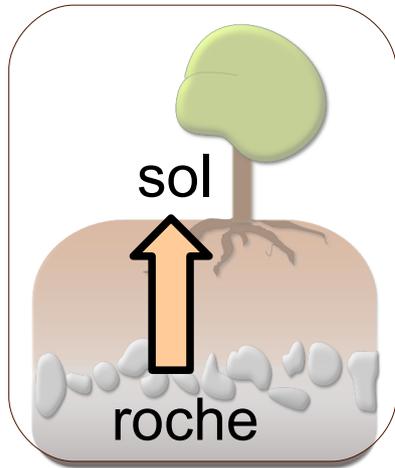


cours d'eau



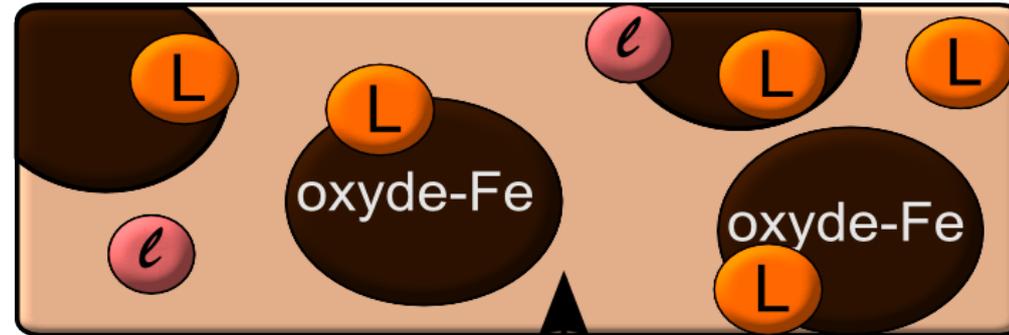
ROCHE

Transfert roche-sol



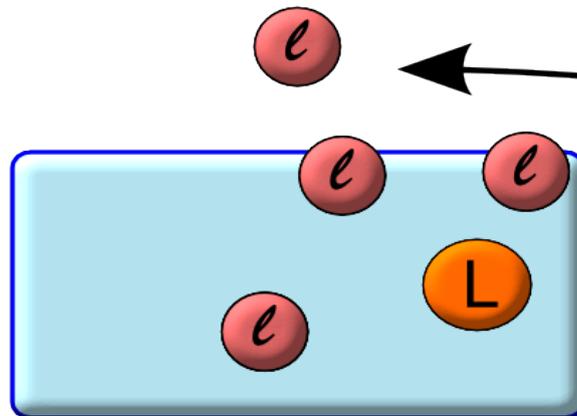
Transfert préférentiel des TR lourdes

SOL



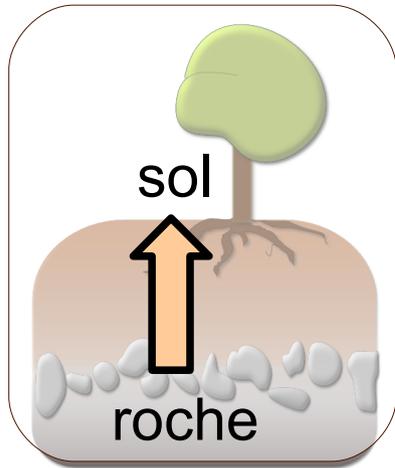
accumulation TRL

lixiviation TRI

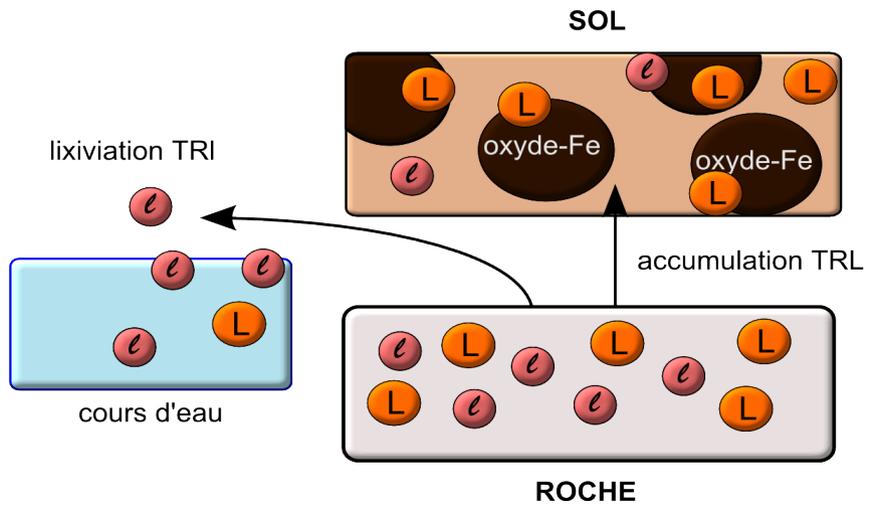


ROCHE

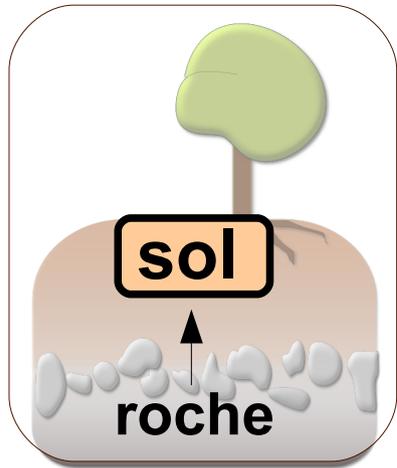
Transfert roche-sol



Transfert préférentiel des TR lourdes

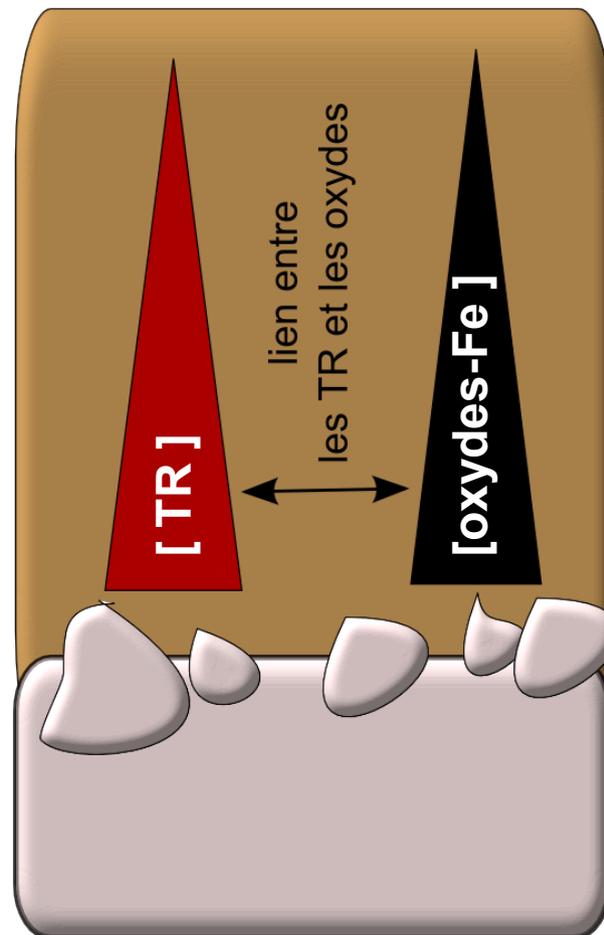


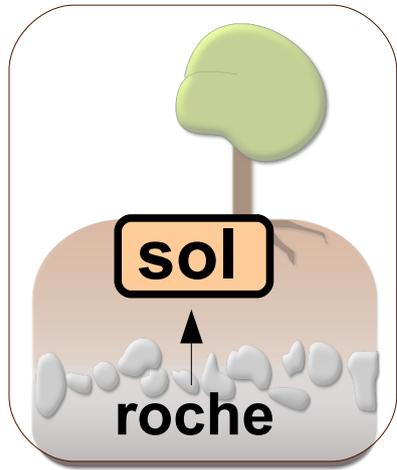
Rôle important des oxydes dans la répartition verticale des TR



Répartition dans les sols rôle des oxydes et du pH

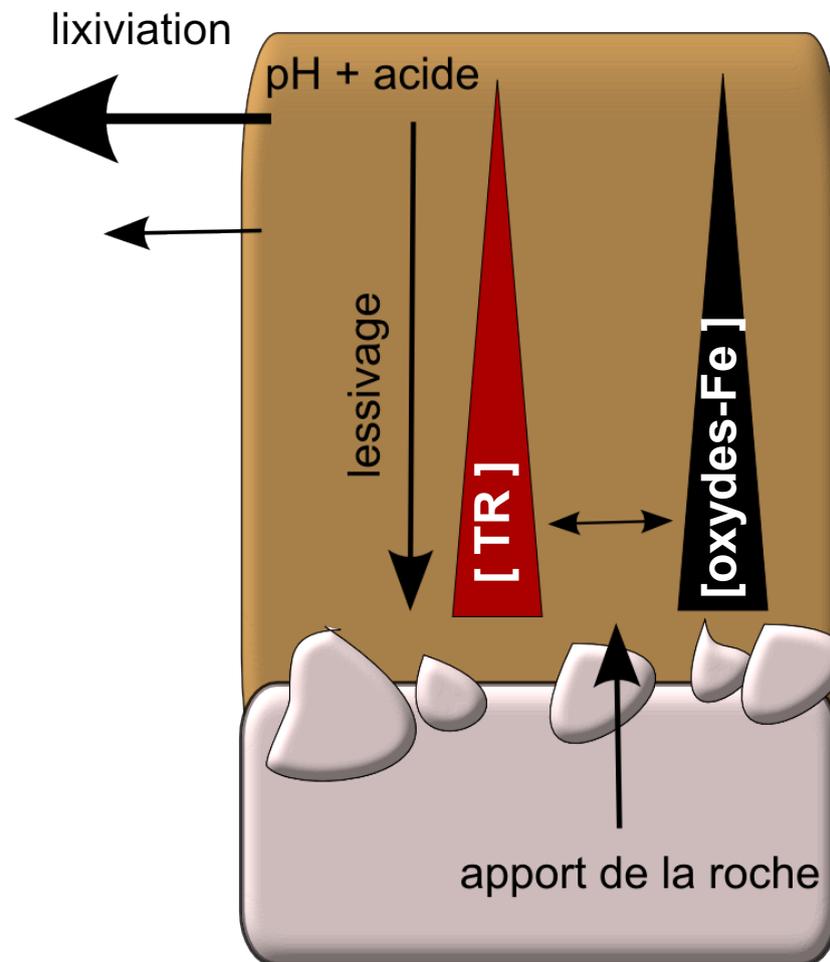
Répartition verticale



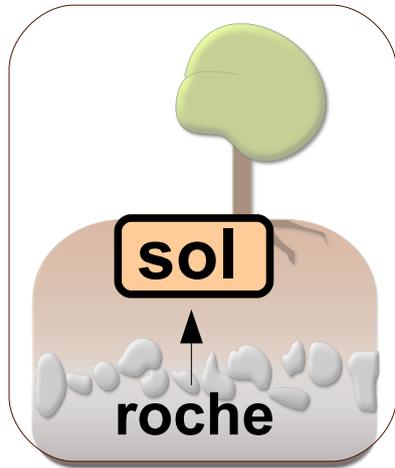


Répartition dans les sols rôle des oxydes et du pH

Répartition verticale

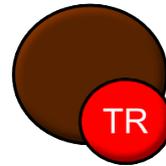


Répartition dans les sols rôle des oxydes et du pH



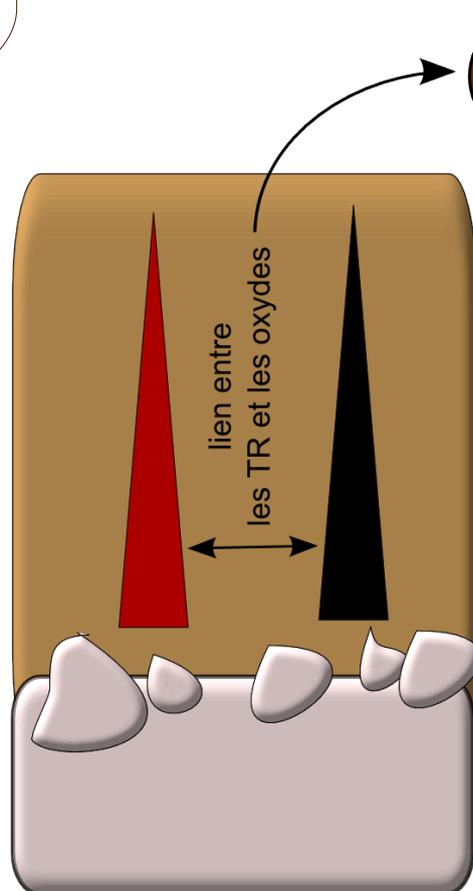
Répartition verticale

oxydes de Fer



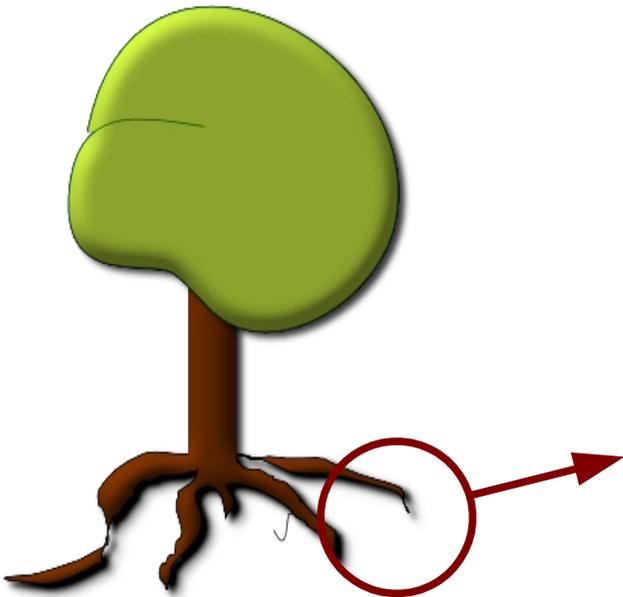
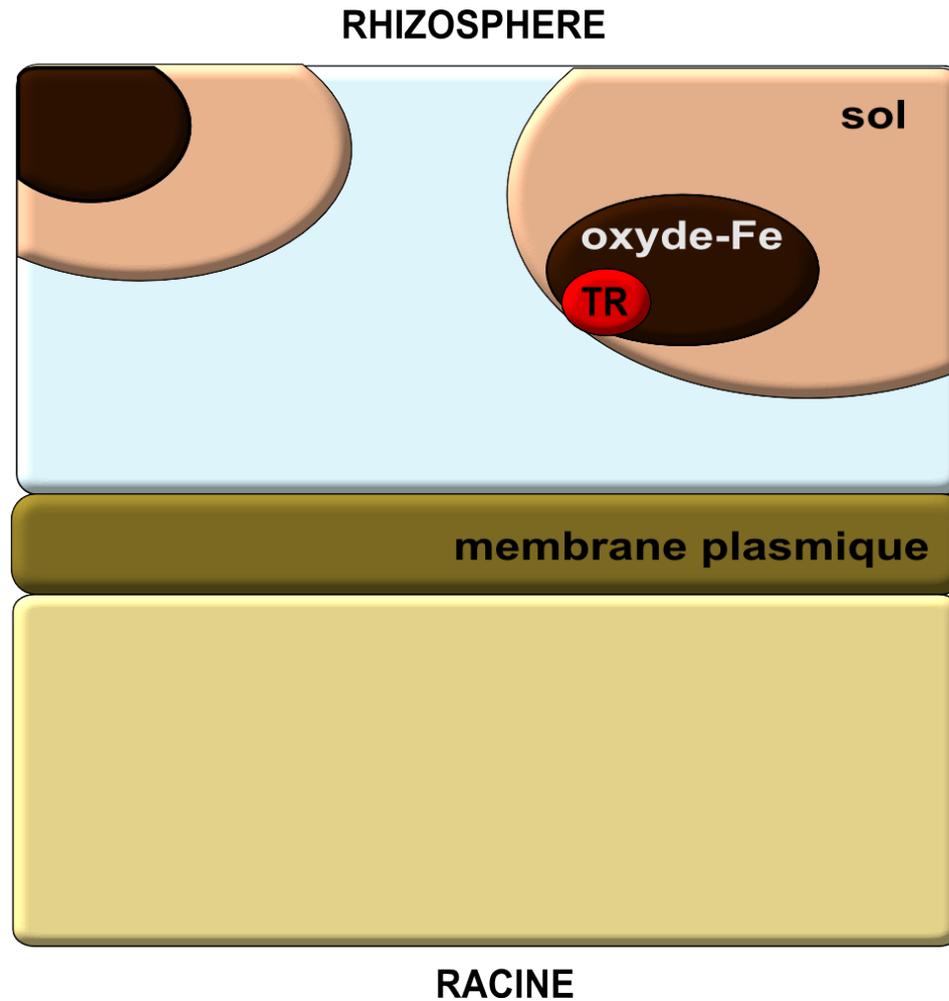
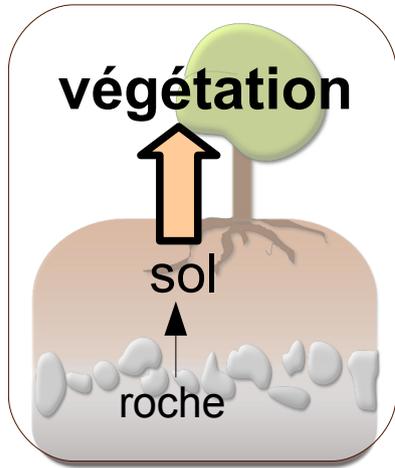
végétation

Corrélation : Fe-TR

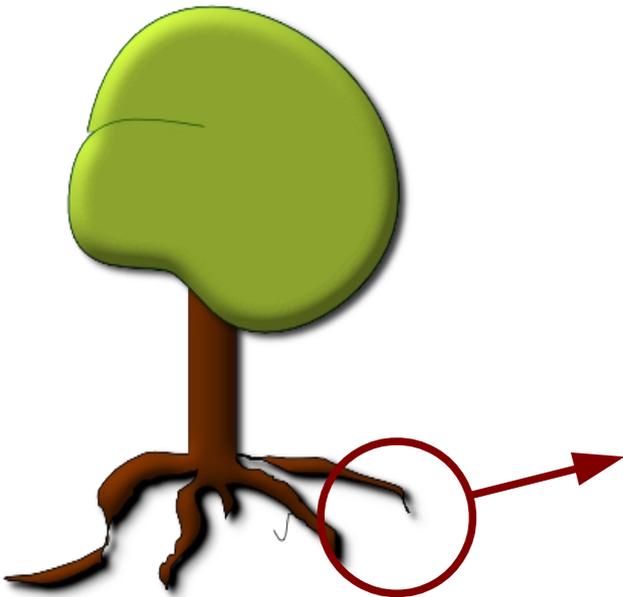
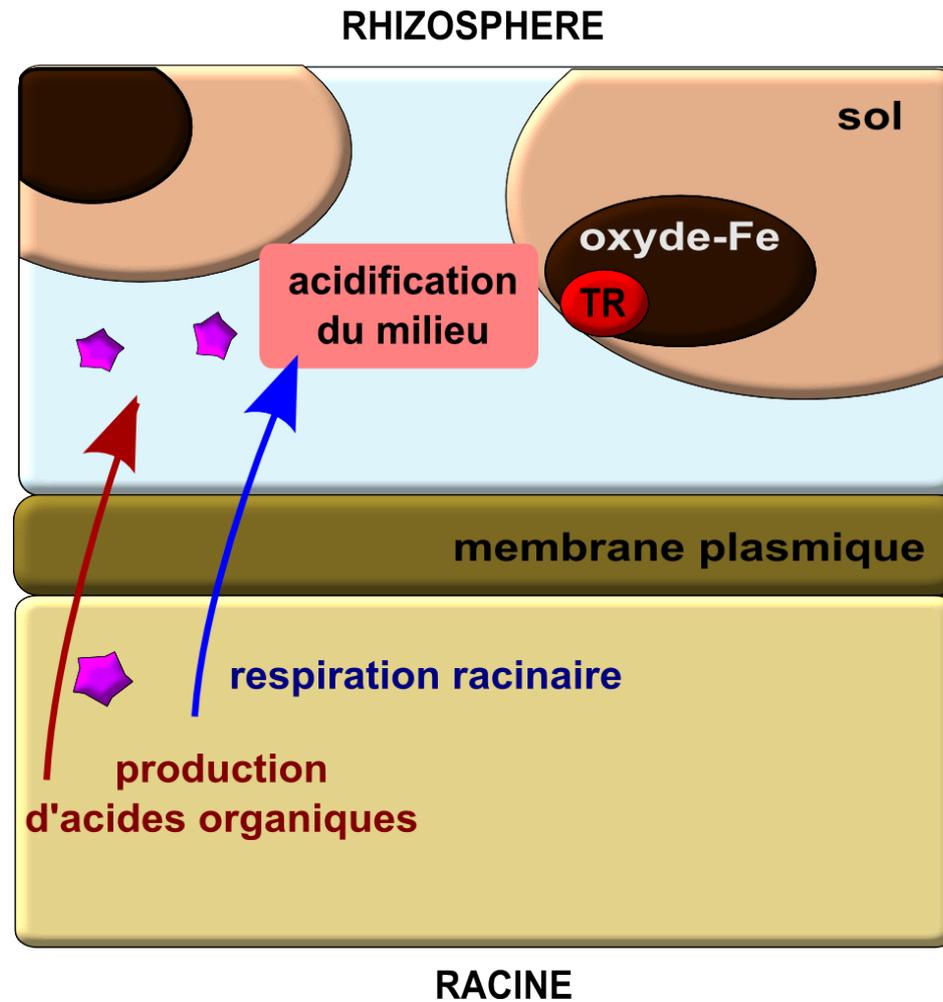
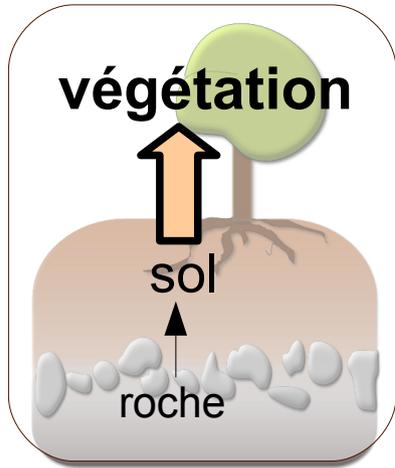


Absorption par la végétation

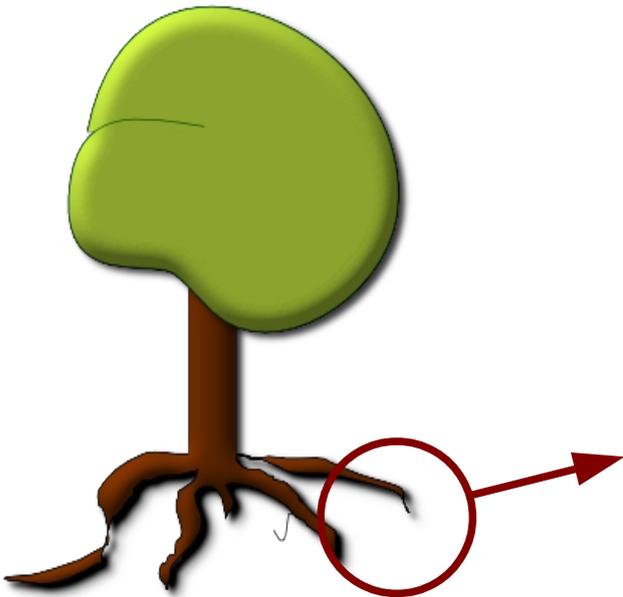
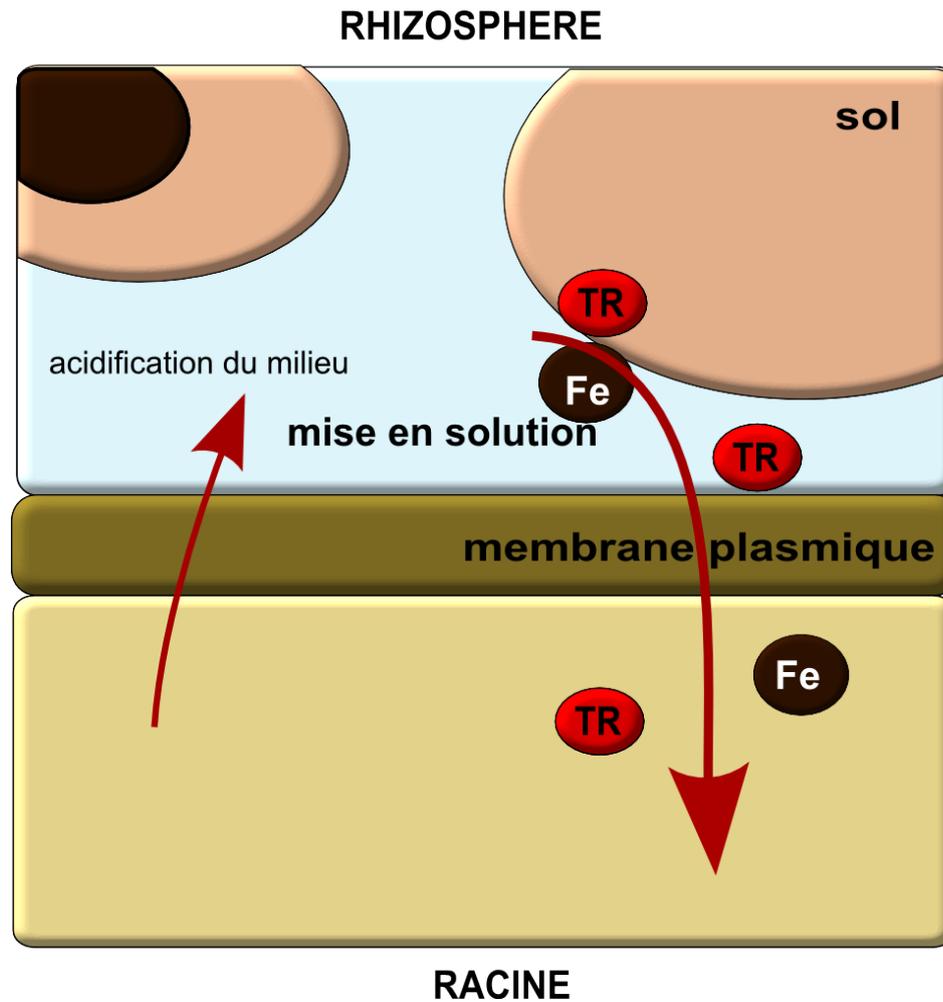
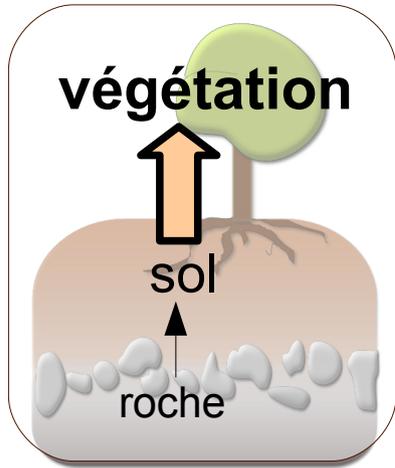
TR-Fe et similitude des spectres de sol et de racines



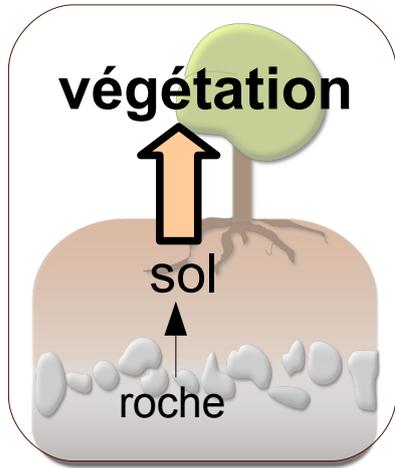
Absorption par la végétation



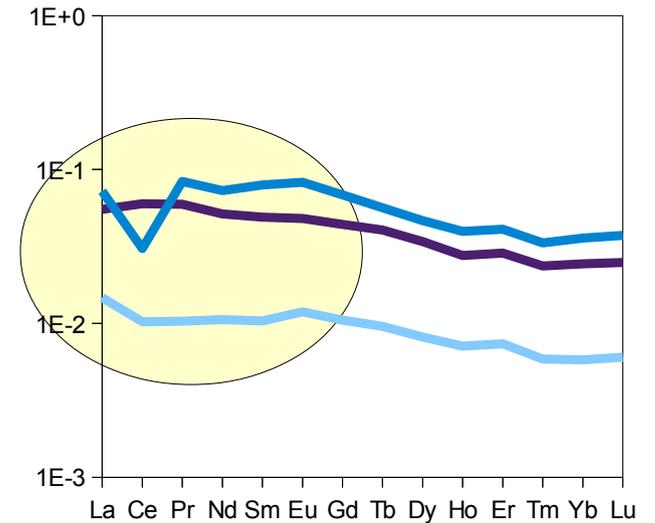
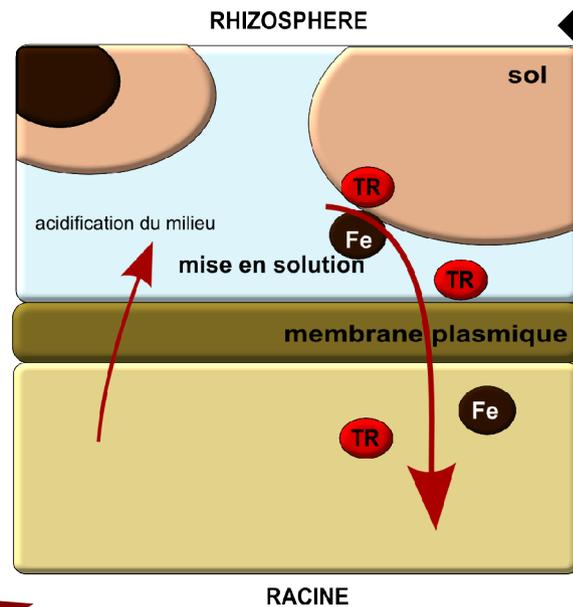
Absorption par la végétation



Absorption par la végétation

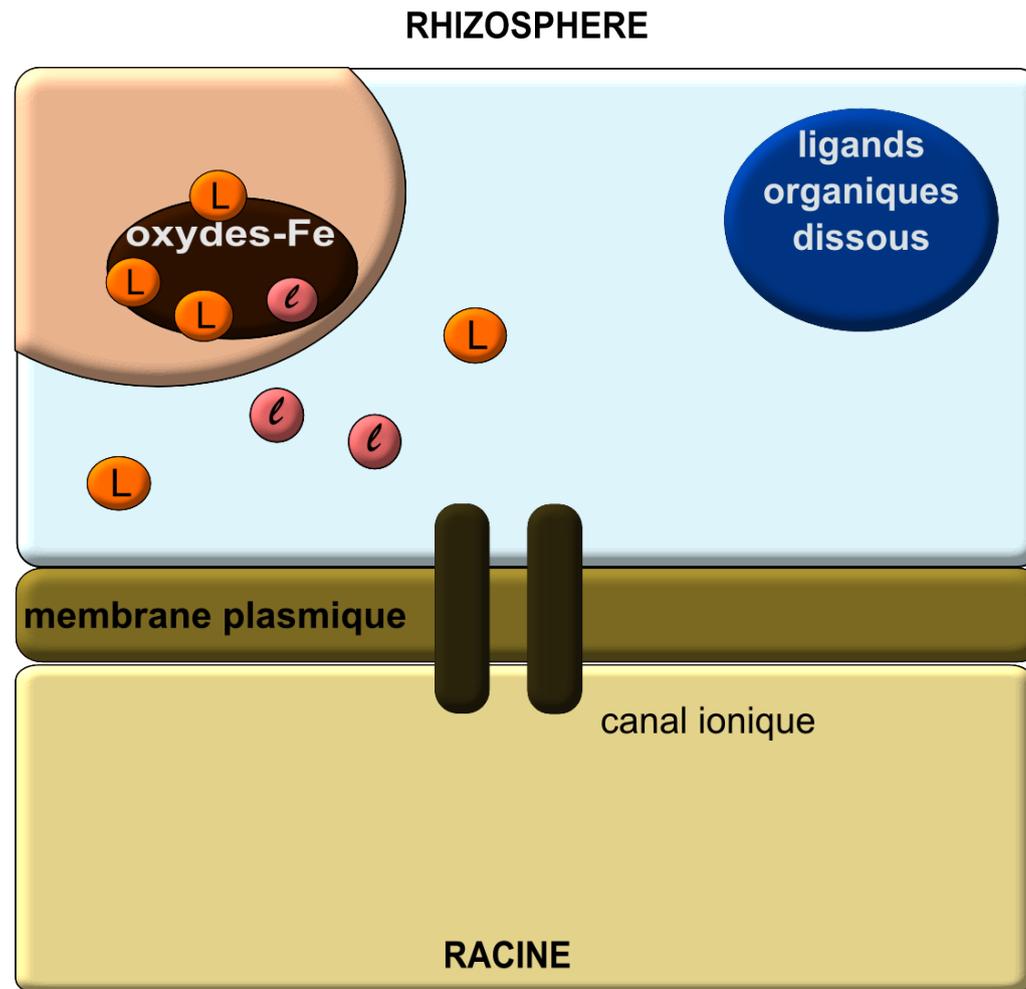
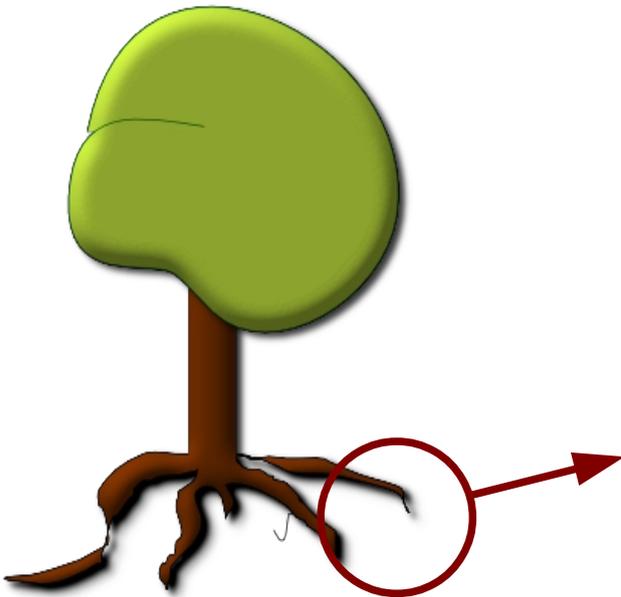
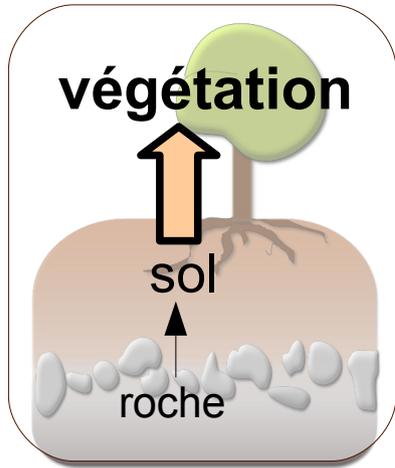


**Absorption
préférentielle
des TR légères**



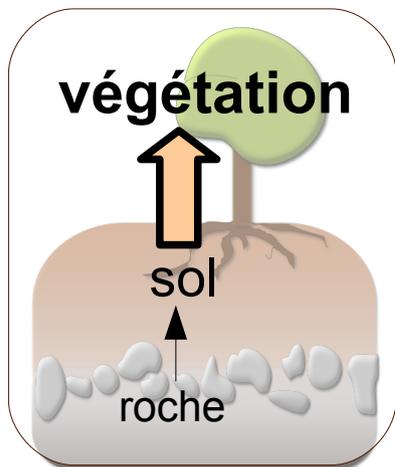
Absorption par la végétation

Absorption préférentielle des TR légères

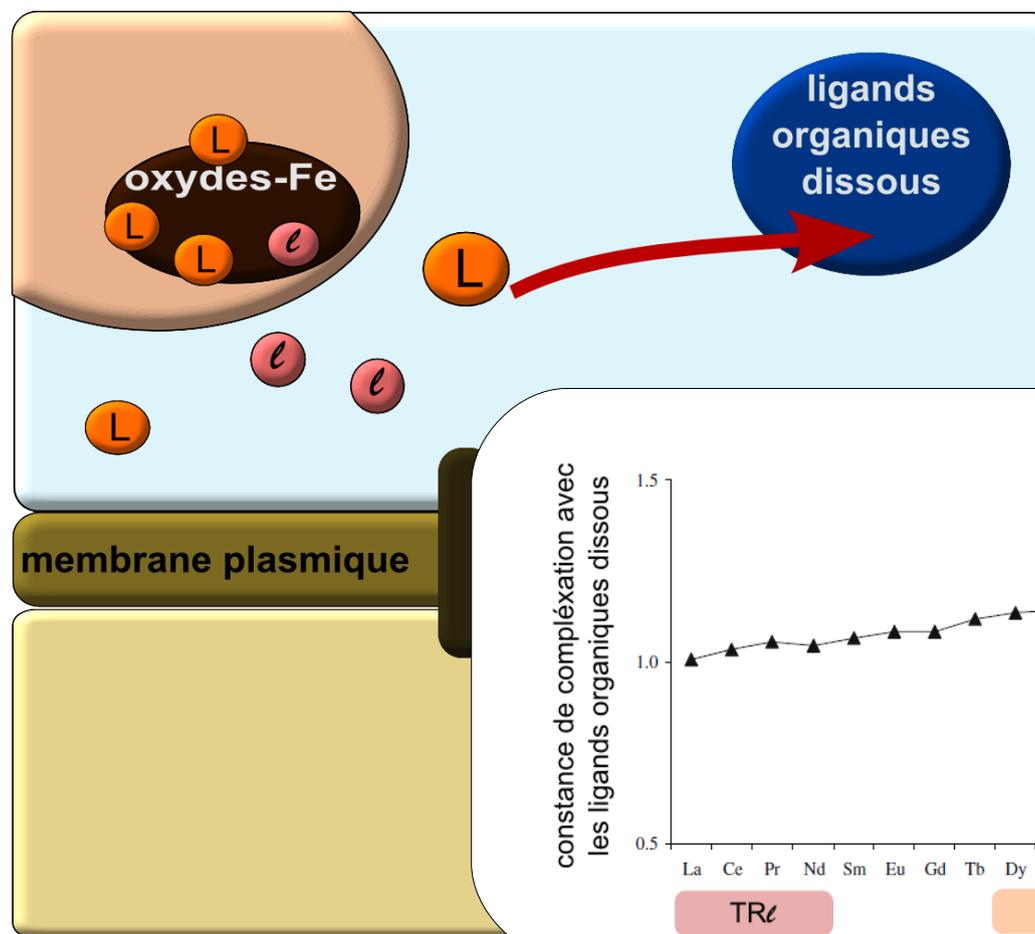


Absorption par la végétation

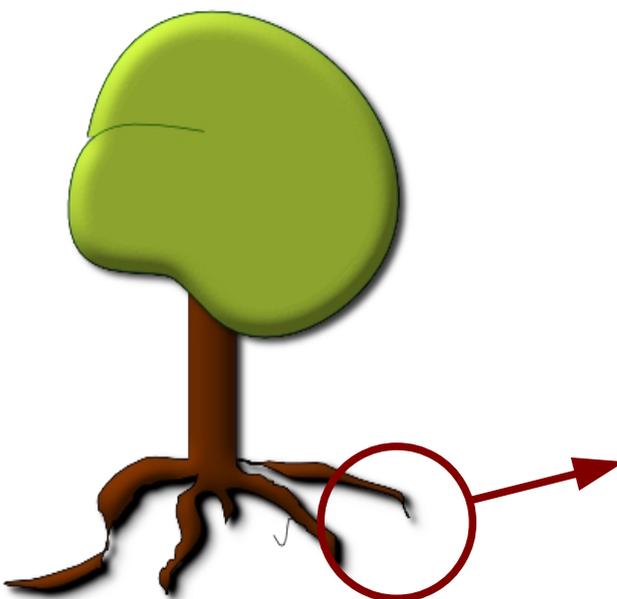
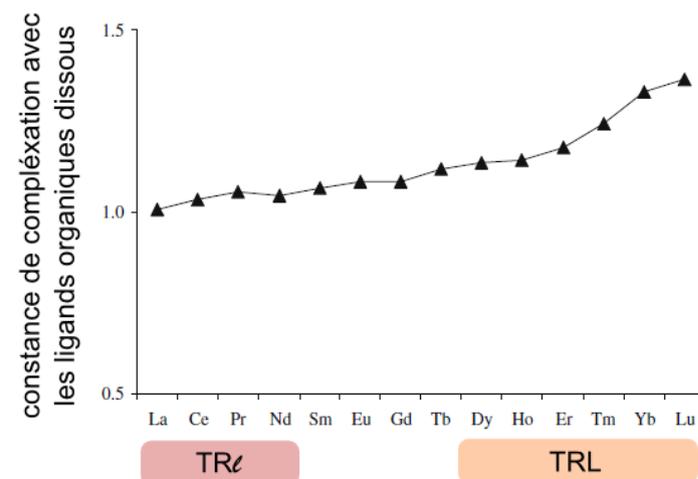
Absorption préférentielle des TR légères



RHIZOSPHERE

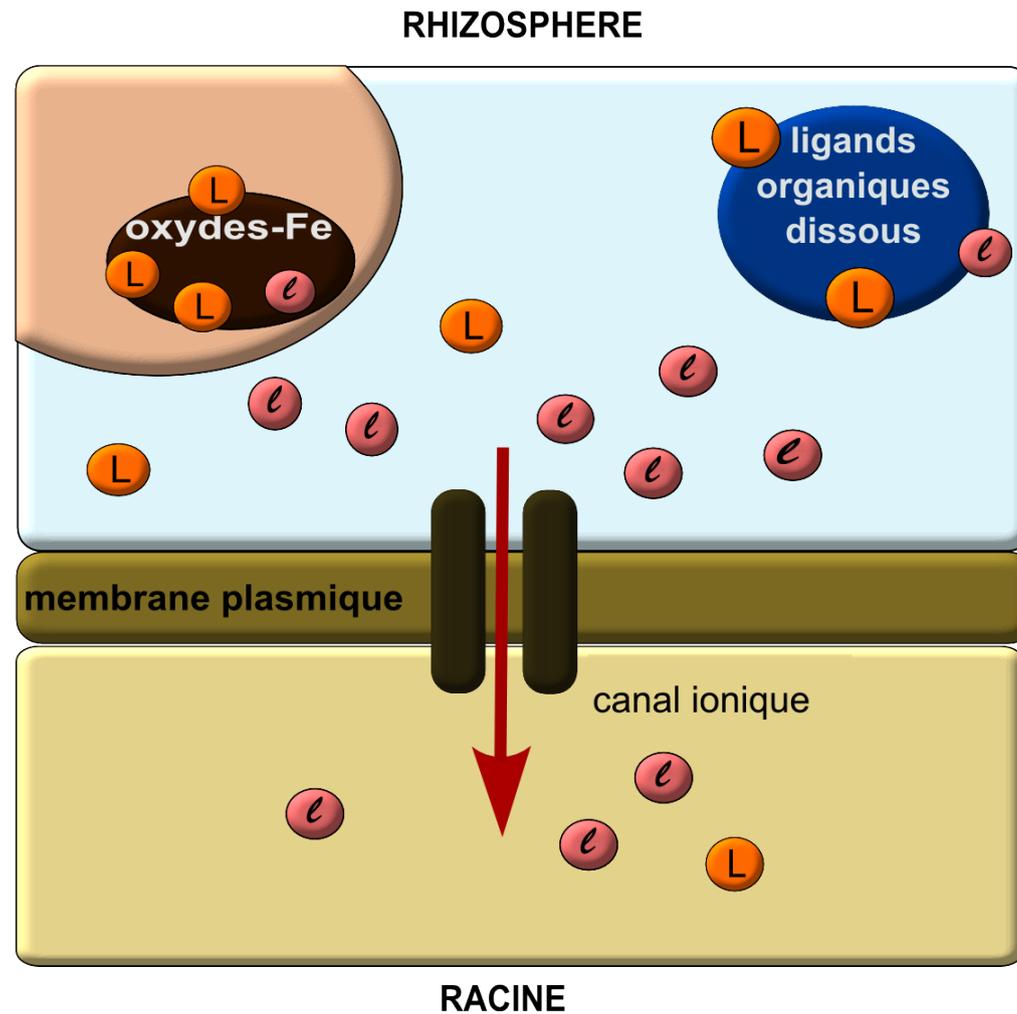
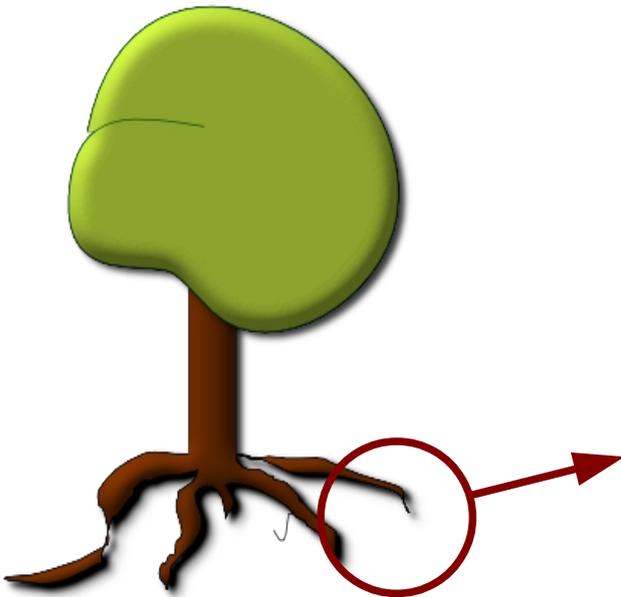
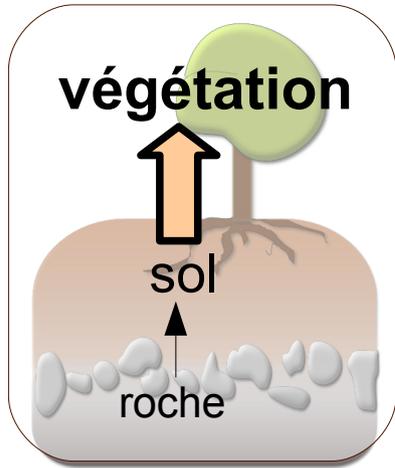


RACINE



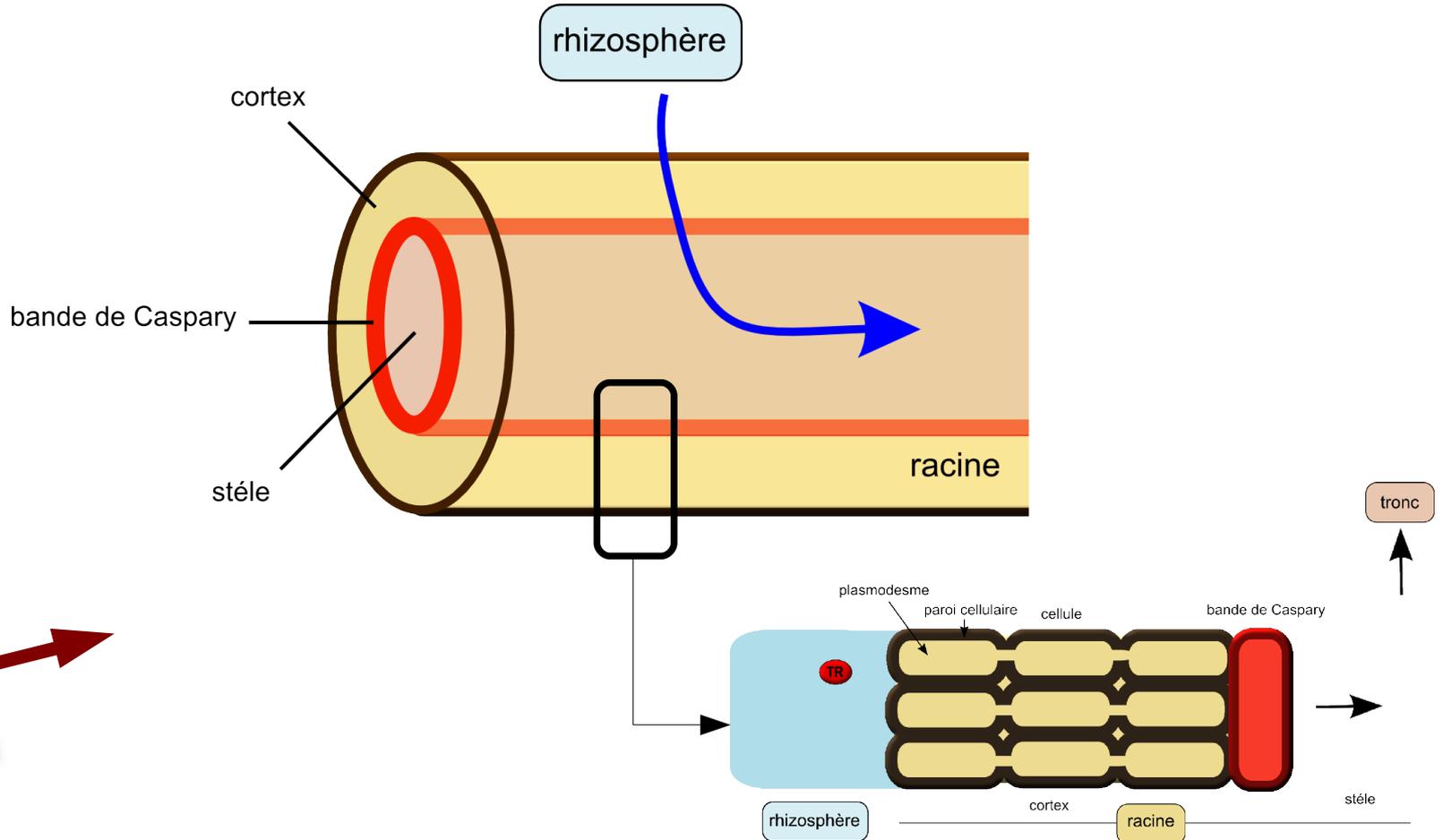
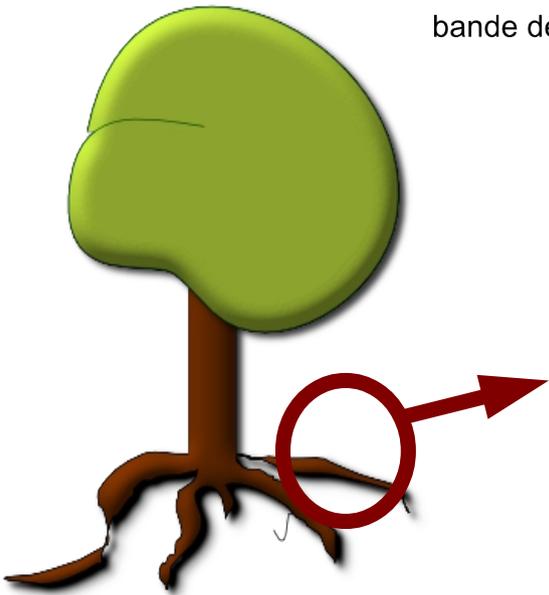
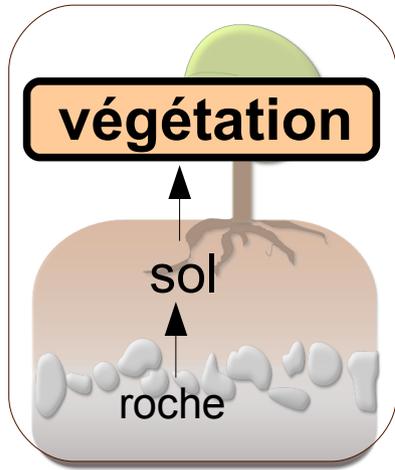
Absorption par la végétation

Absorption préférentielle des TR légères



Transfert dans les racines

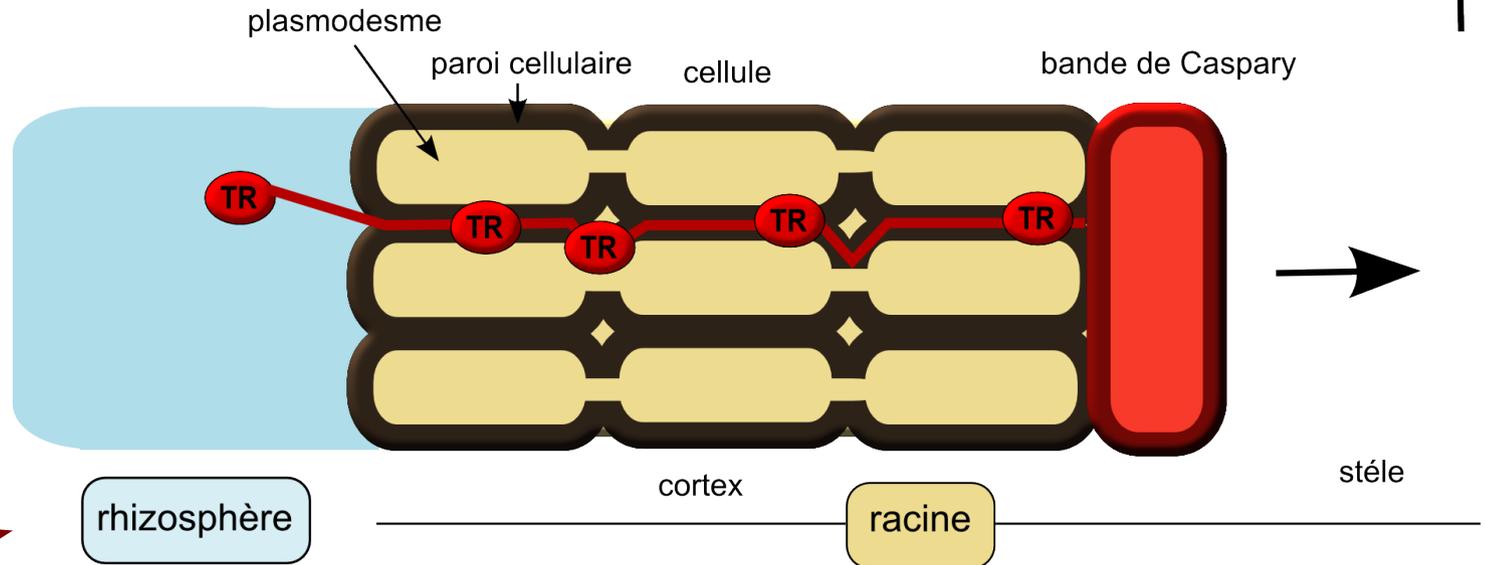
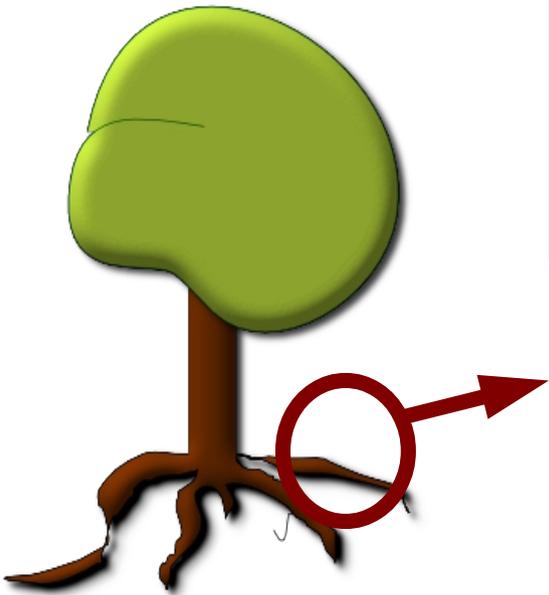
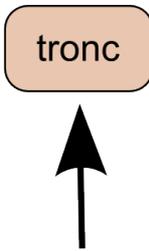
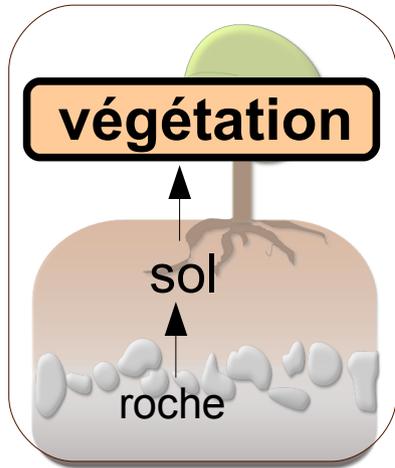
Transfert vers les organes aériens



Transfert dans les racines

Transfert vers les organes aériens

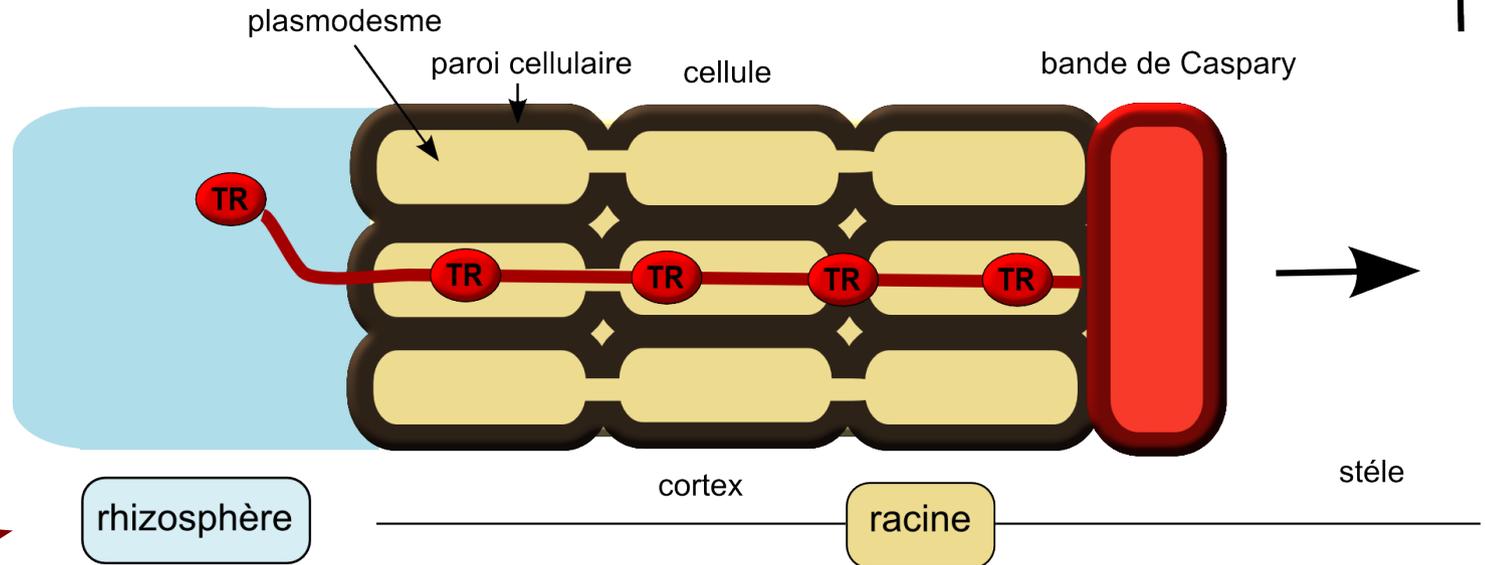
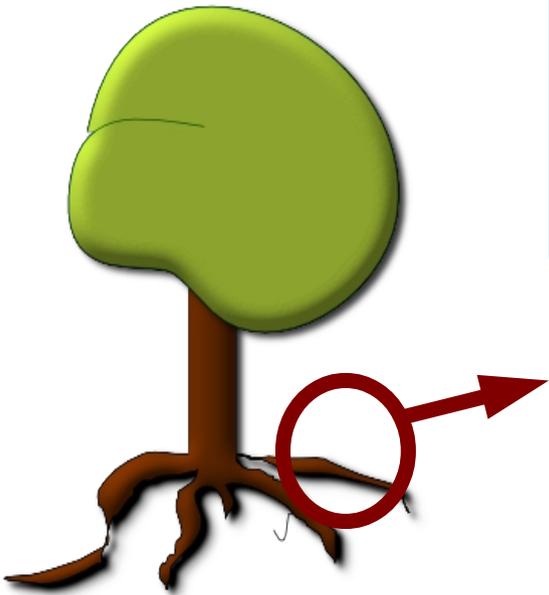
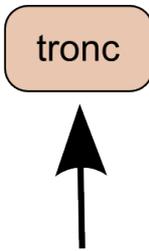
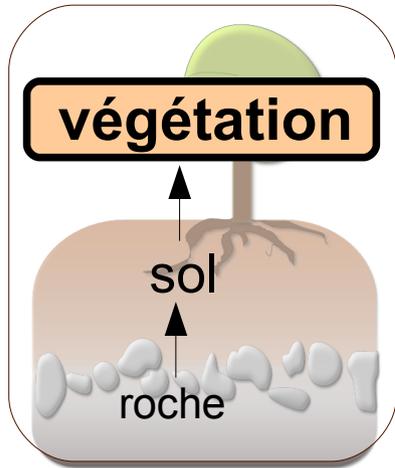
2 voies de transfert : **apoplastique** / symplastique



Transfert dans les racines

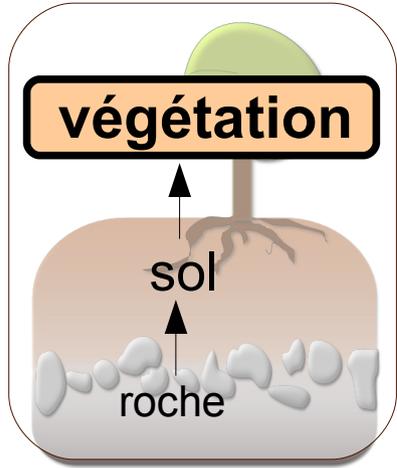
Transfert vers les organes aériens

2 voies de transfert : apoplastique / **symplastique**



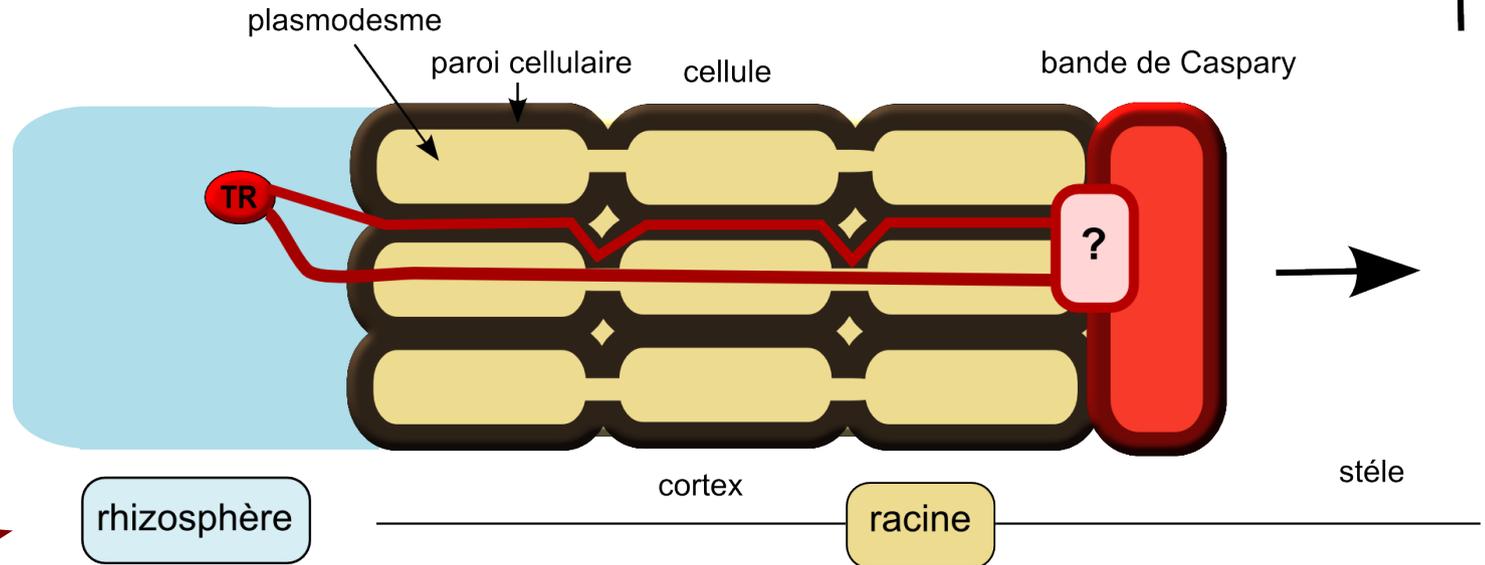
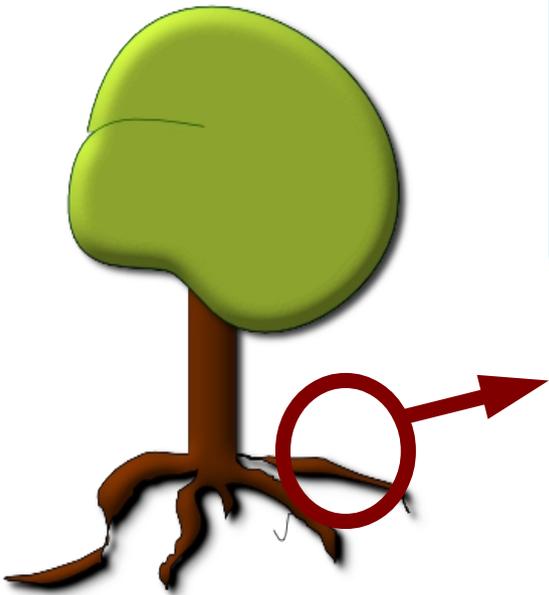
Transfert dans les racines

Accumulation dans les racines



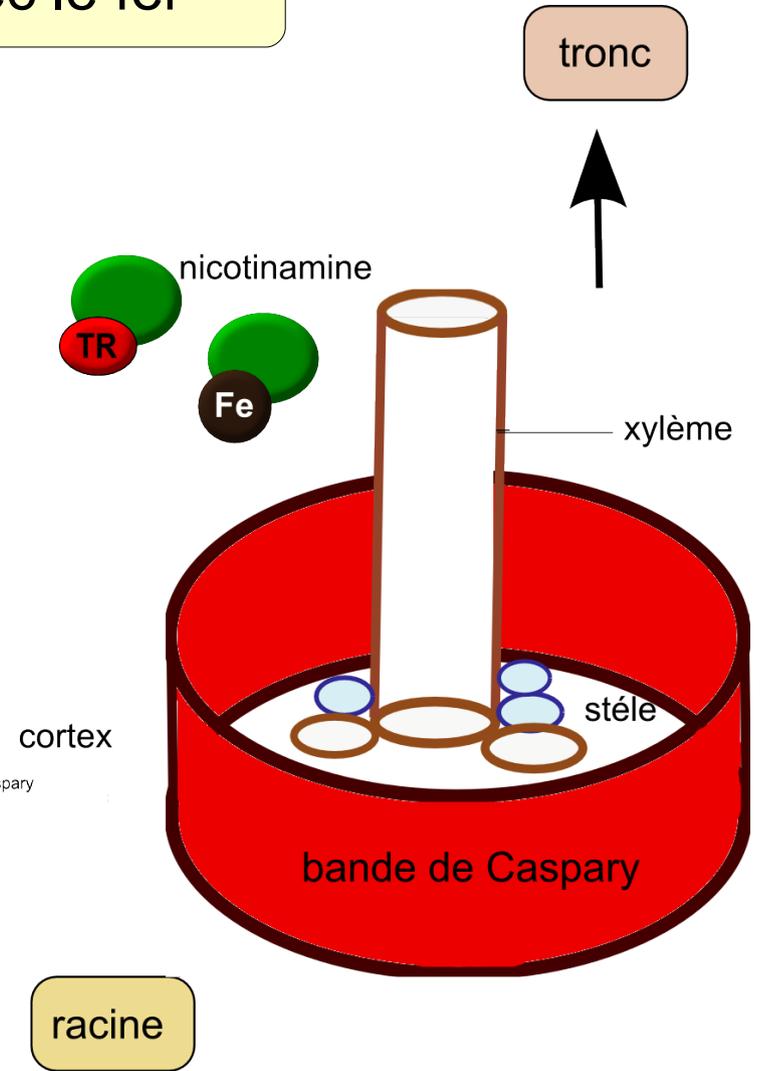
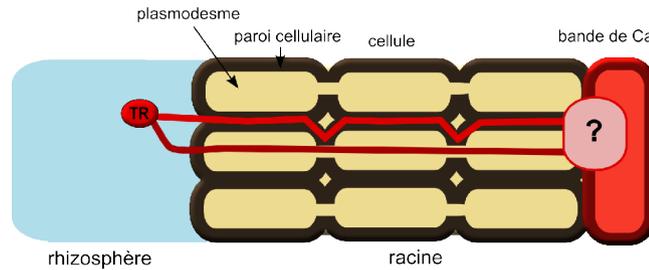
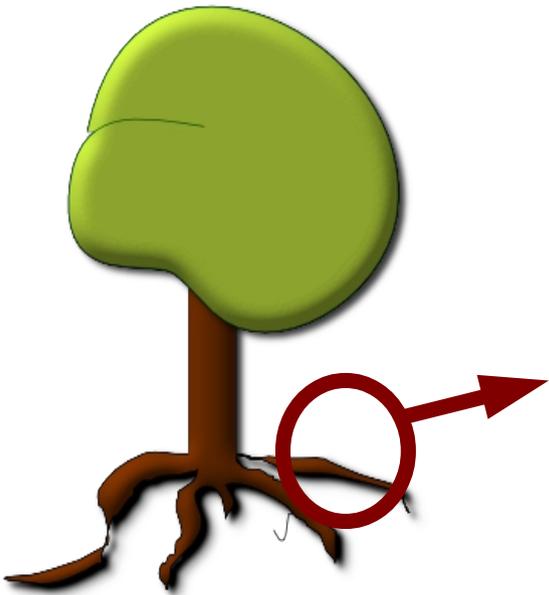
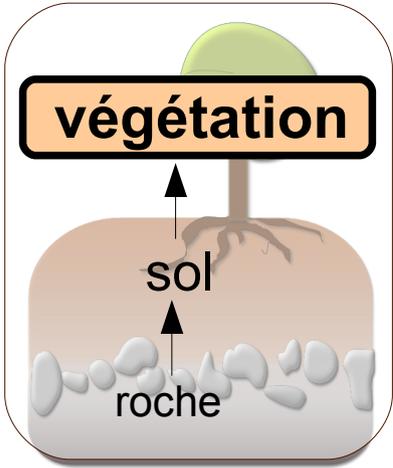
tronc

An arrow pointing upwards from the 'tronc' label towards the main diagram.



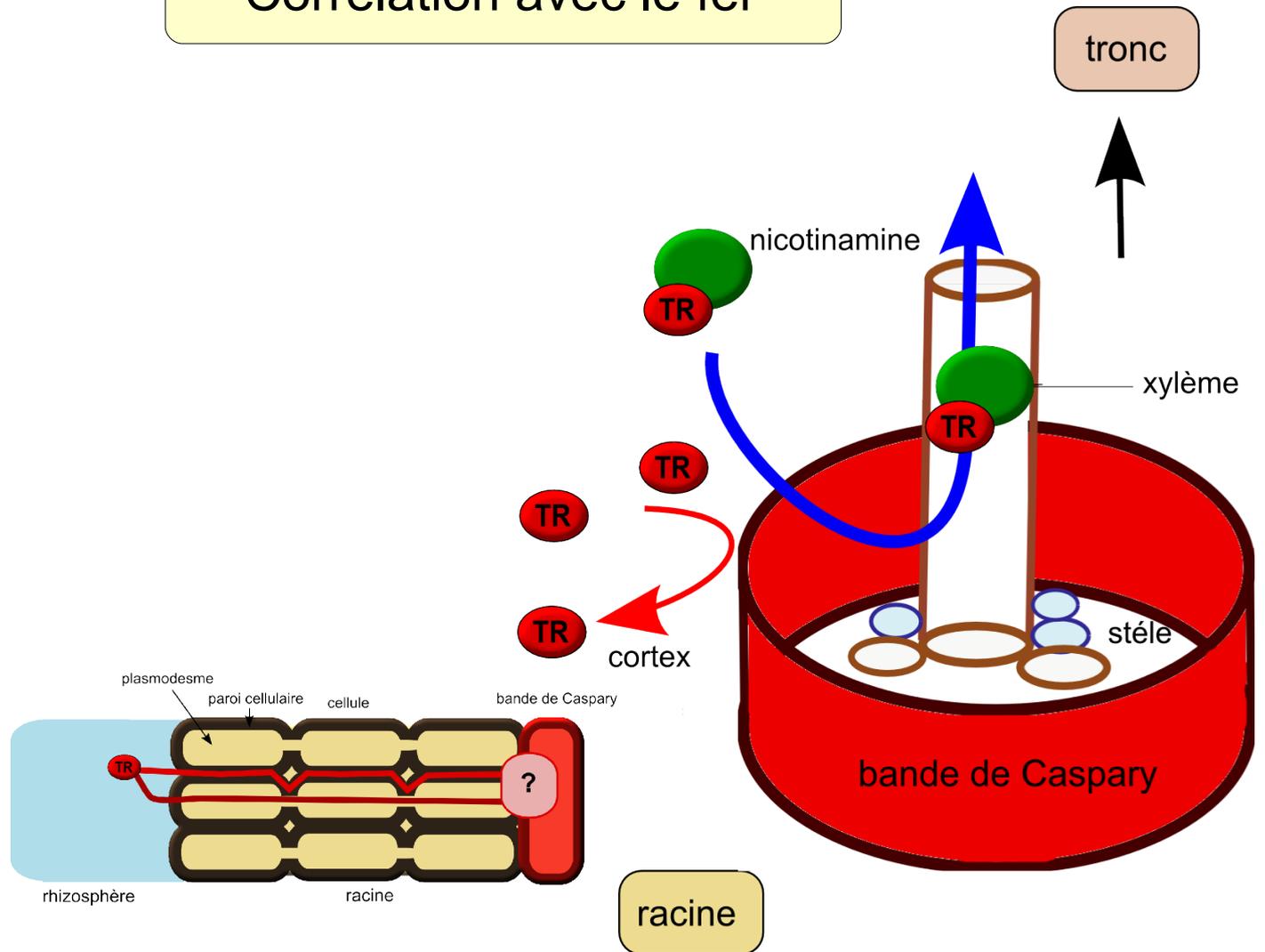
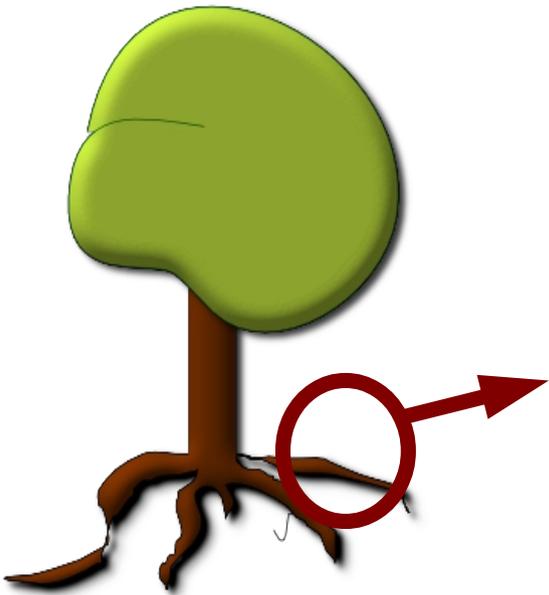
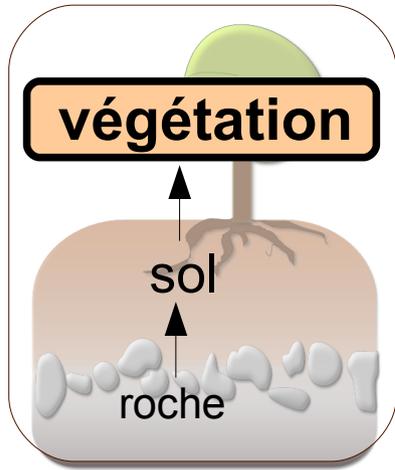
Transfert dans les racines

Corrélation avec le fer

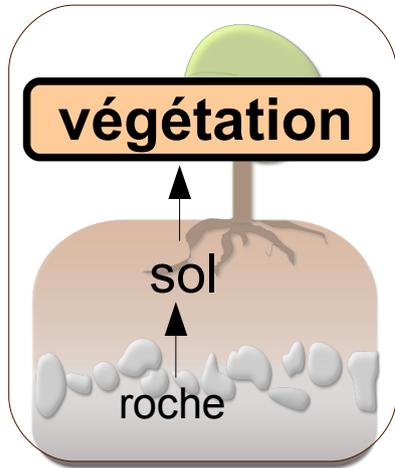


Transfert dans les racines

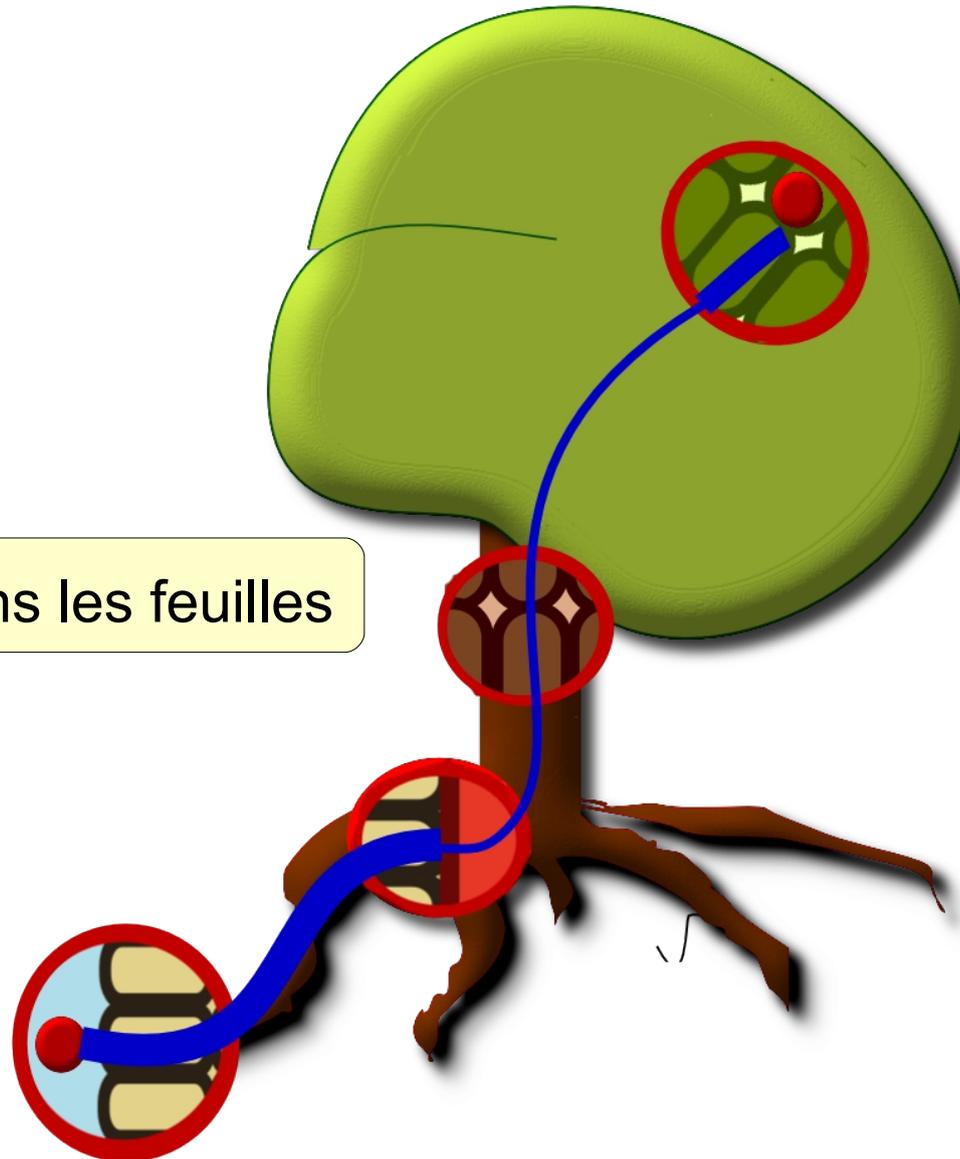
Corrélation avec le fer



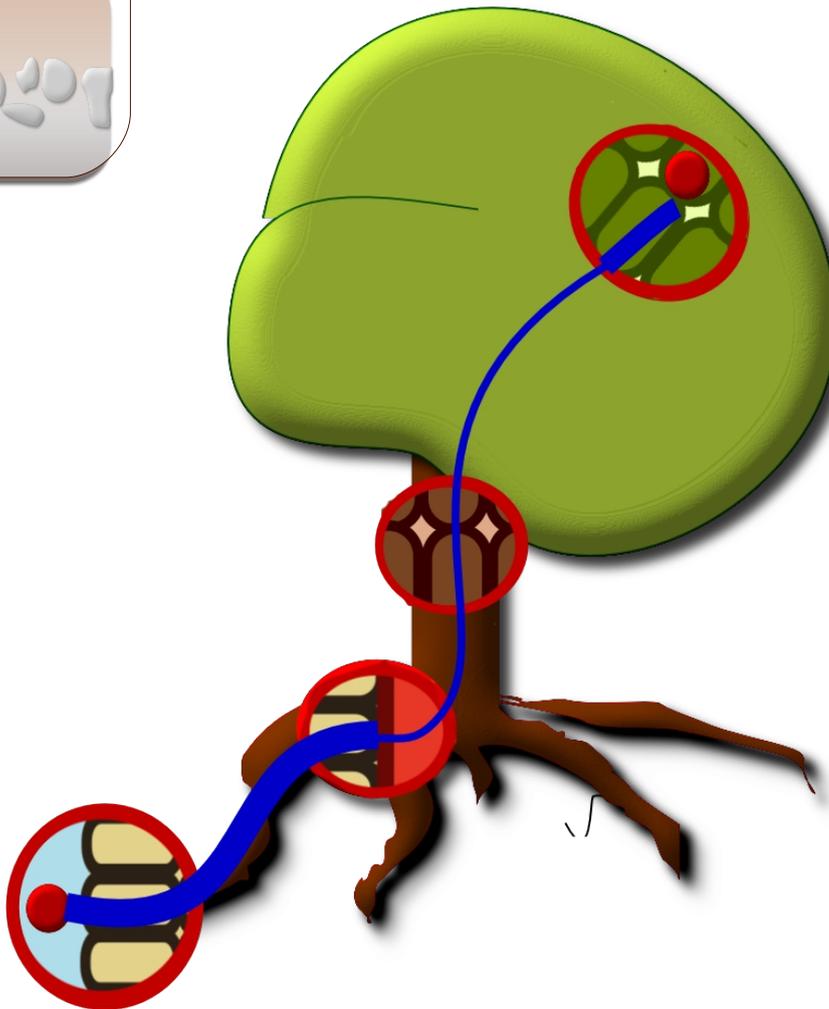
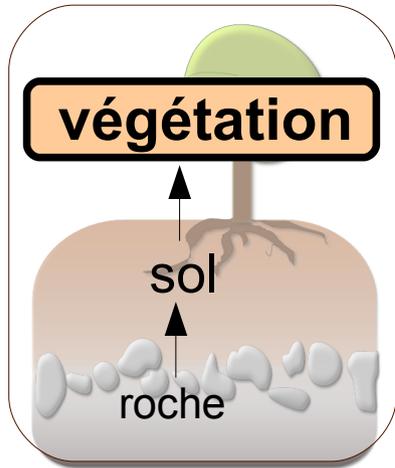
Transfert vers les organes aériens



Accumulation dans les feuilles



Transfert vers les organes aériens



**Accumulation des TR
dans la végétation,
effets ?**



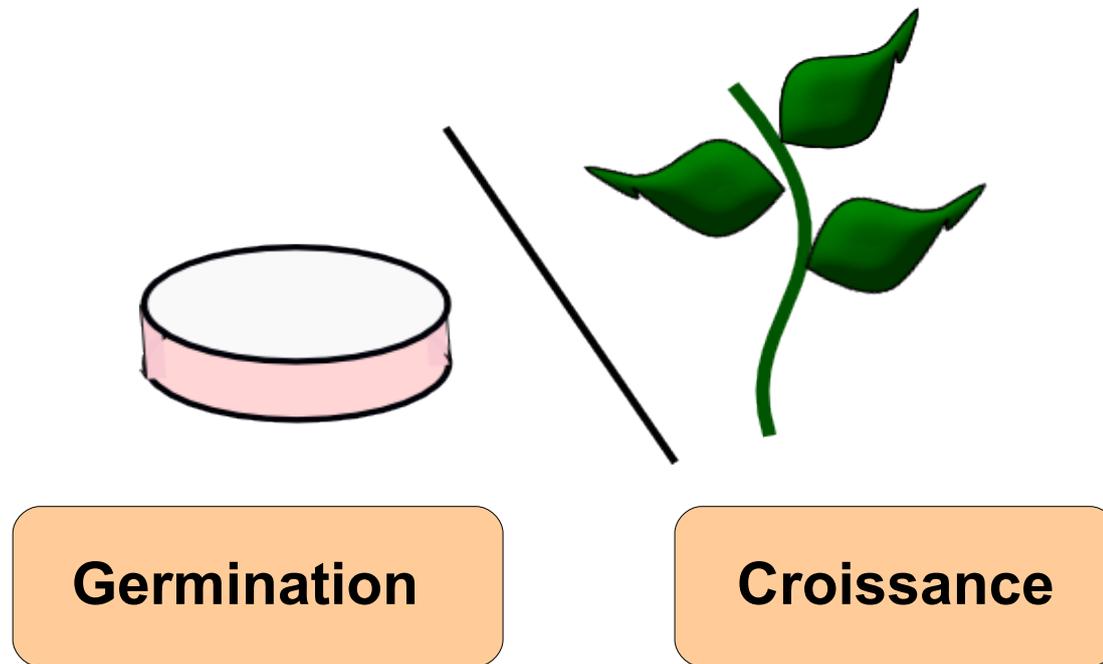
III : Effets des TR sur la physiologie de la plante

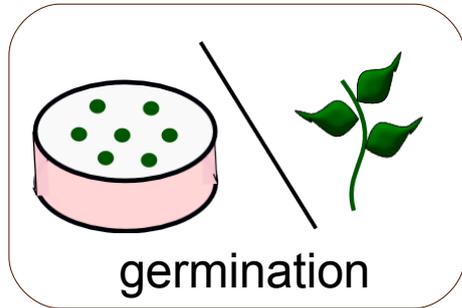
Matériels et méthodes

Résultats : germination
croissance

Discussion

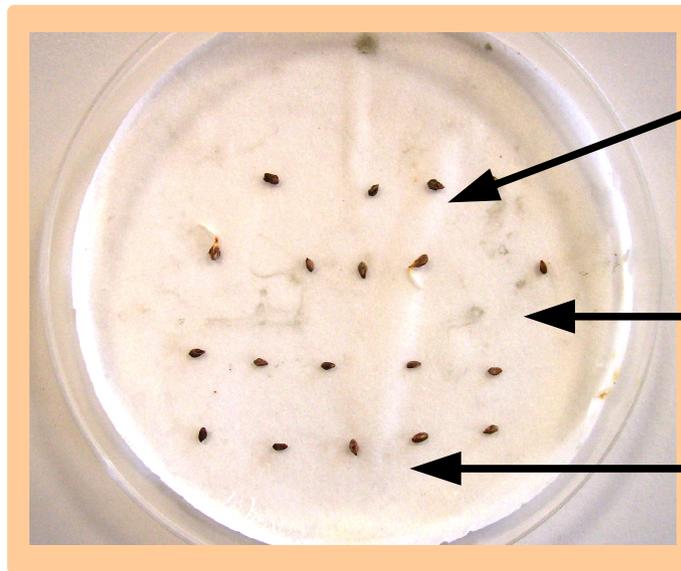
Étude de deux stades de développement





Test de germination

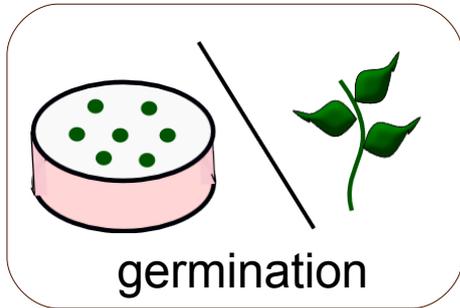
Lanthane, europium, ytterbium
AFNOR X31-210 : essai d'inhibition de la germination de
semences par une substance



50 graines de *Lactuca sativa* pour 7
boîtes pour chaque concentration testée

4 mL de solution de TR

papier filtre



Test de germination

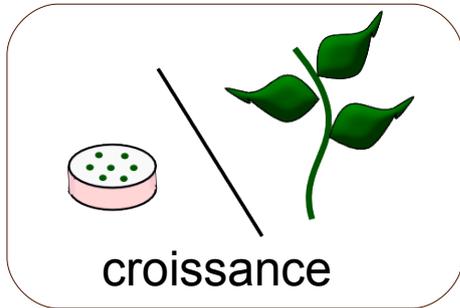
Lanthane, europium, ytterbium et mélange
AFNOR X31-210 : essai d'inhibition de la germination de
semences par une substance



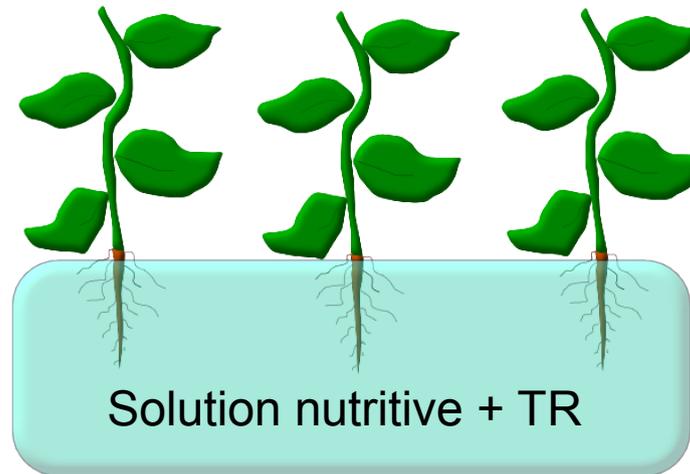
Mesure du taux de germination

Test sur la croissance

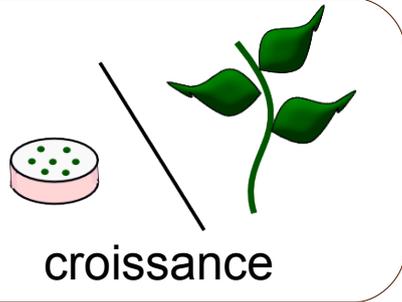
Europium et lanthane



16h de jour / 8h de nuit
24 °C



Test sur la croissance



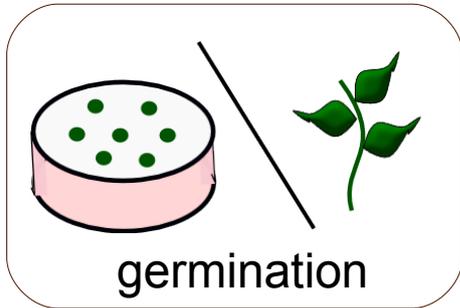
Paramètres étudiés

**Mesures des paramètres physiologiques :
taille et poids des racines et des organes aériens**



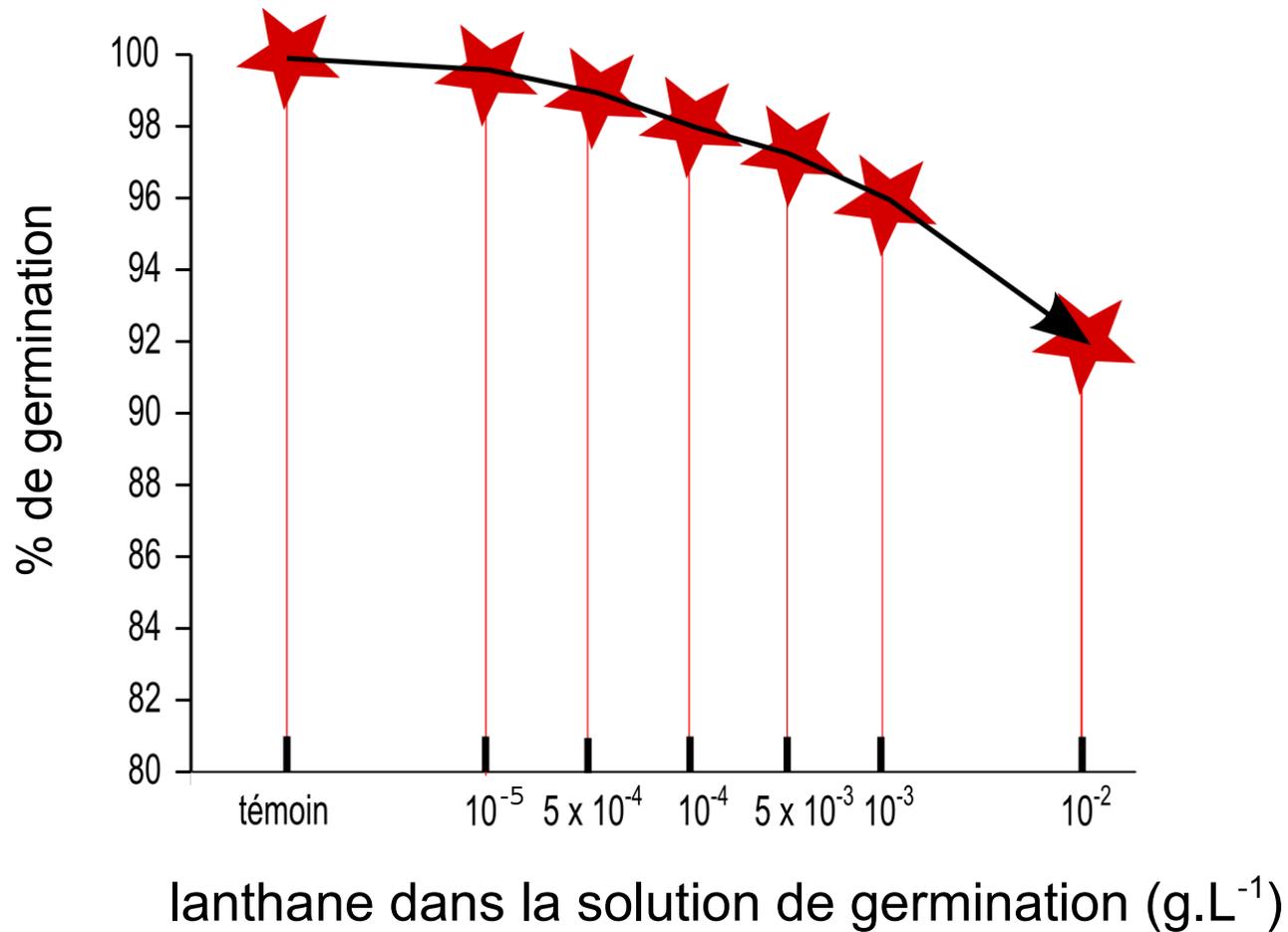
Dosage des concentrations en TR dans chaque organe

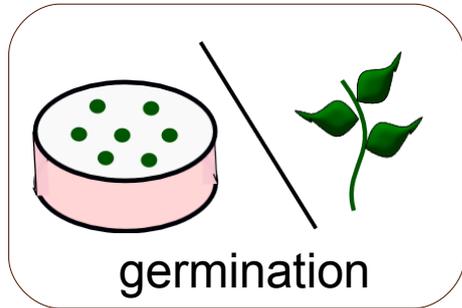




Germination

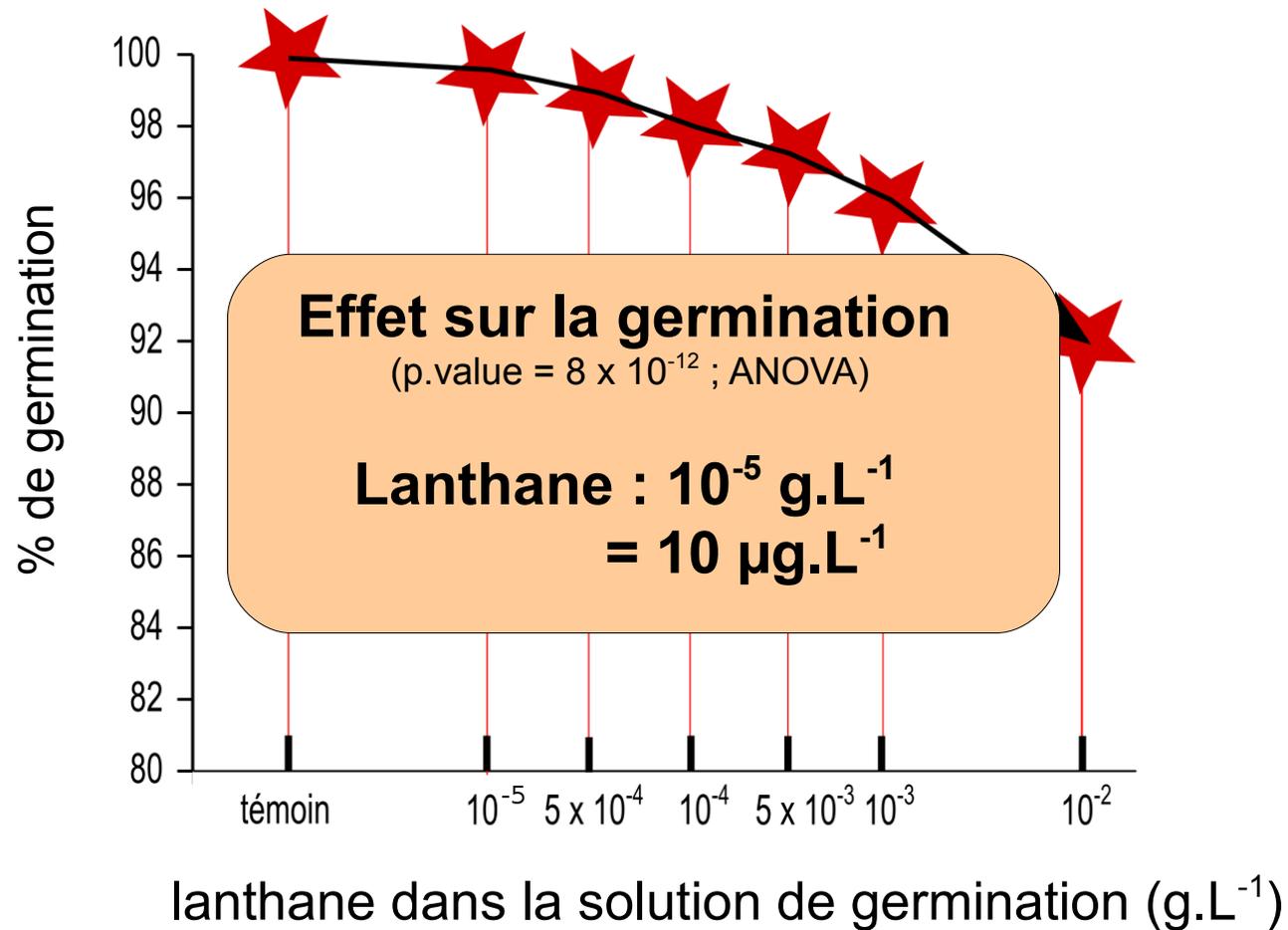
Lanthane

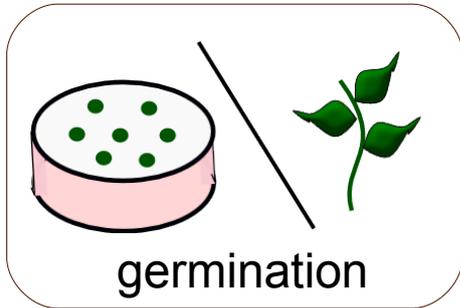




Germination

Lanthane





Germination

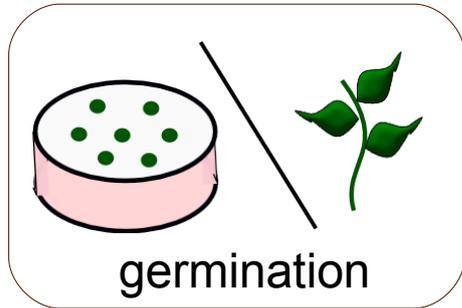
Comparaison des effets pour les TR uniques

lanthane = 10^{-5} g.L⁻¹

europium = 10^{-5} g.L⁻¹

ytterbium = 5×10^{-3} g.L⁻¹

Concentration
d'inhibition identique



Germination

Comparaison des effets pour les TR uniques

lanthane = 10^{-5} g.L⁻¹

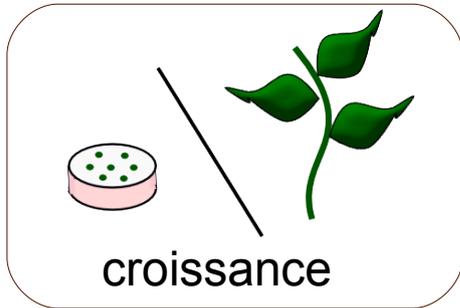
europium = 10^{-5} g.L⁻¹

ytterbium = 5×10^{-3} g.L⁻¹

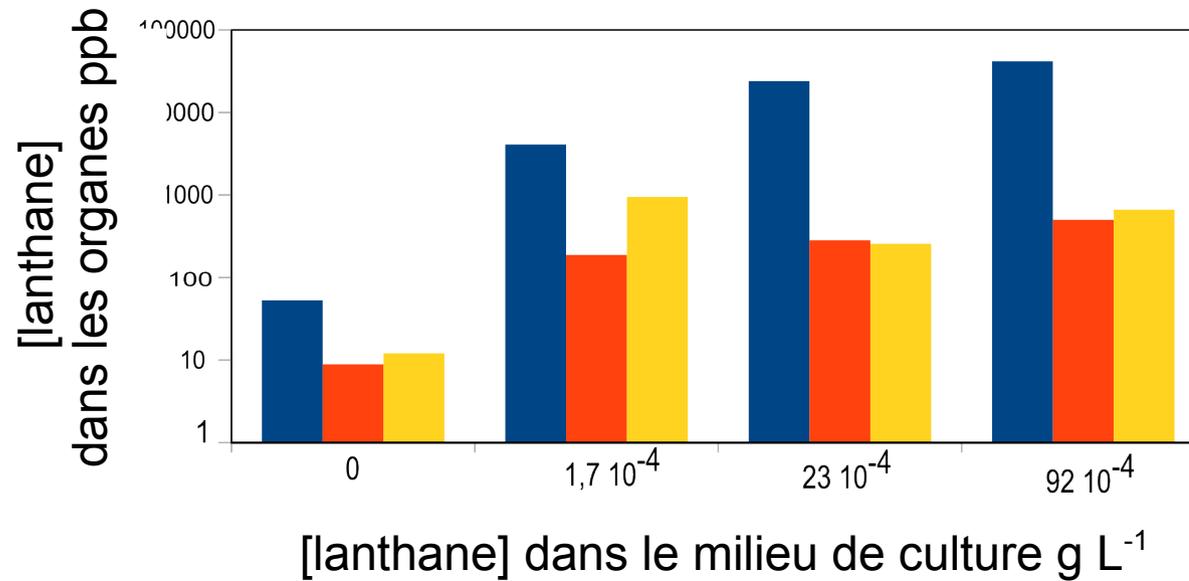
Concentration
d'inhibition identique

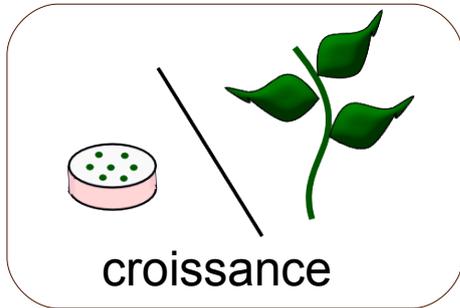
Concentration à effet, plus forte pour l'ytterbium,
que pour l'europium et le lanthane

(p.value = 3×10^{-5} ; ANOVA)



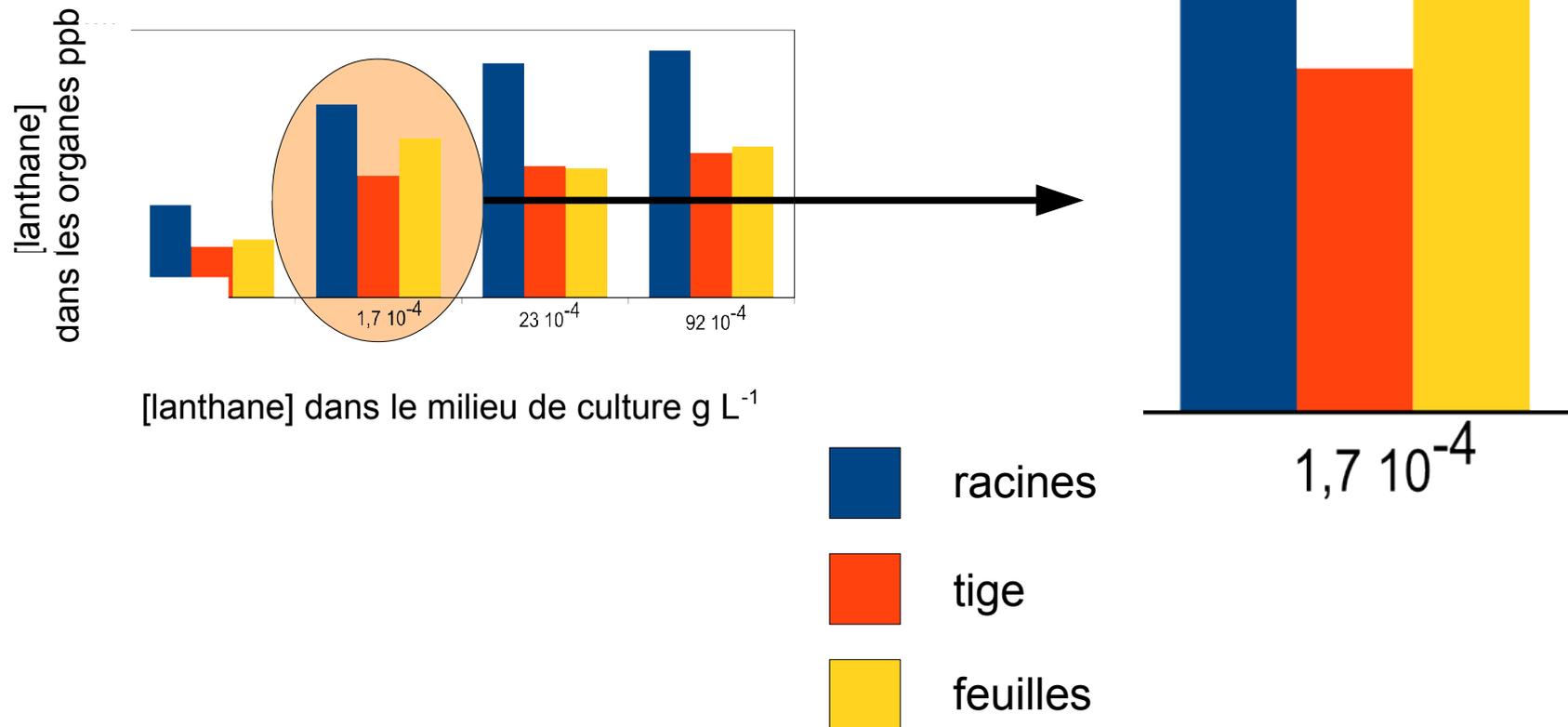
Croissance : répartition des concentrations

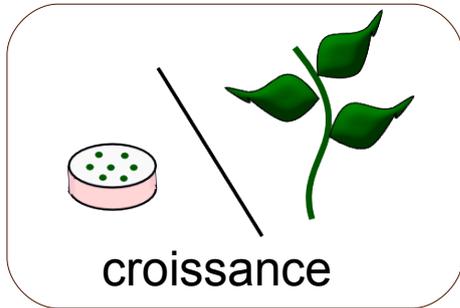




Croissance : répartition des concentrations

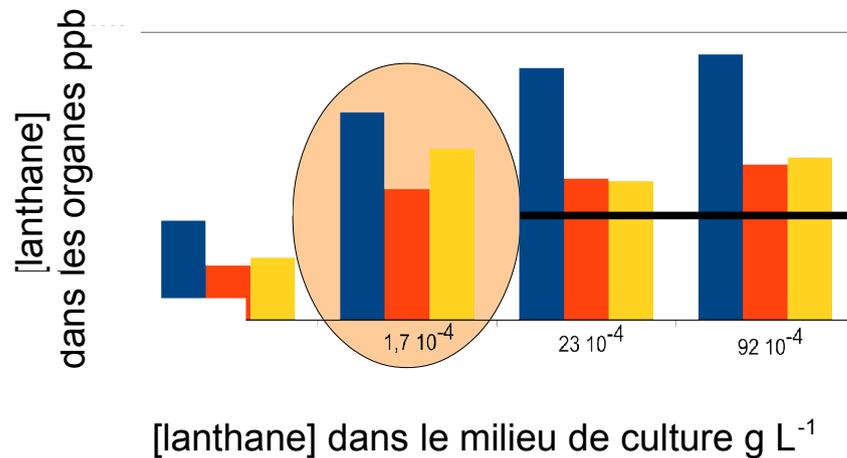
[TR] : racines > feuilles > tige



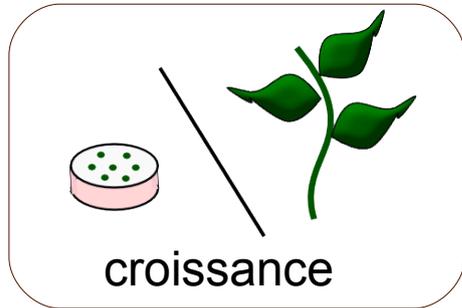


Croissance : répartition des concentrations

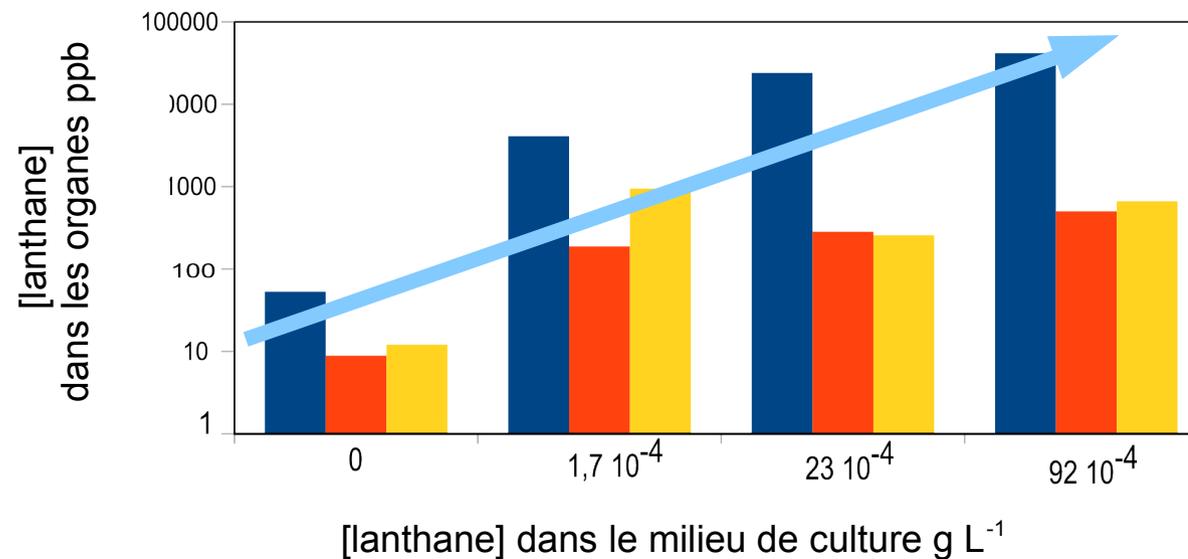
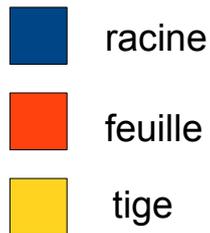
[TR] : racines > feuilles > tige

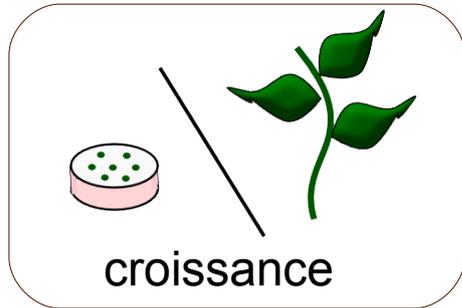


**Répartition :
du milieu naturel = milieu de culture**

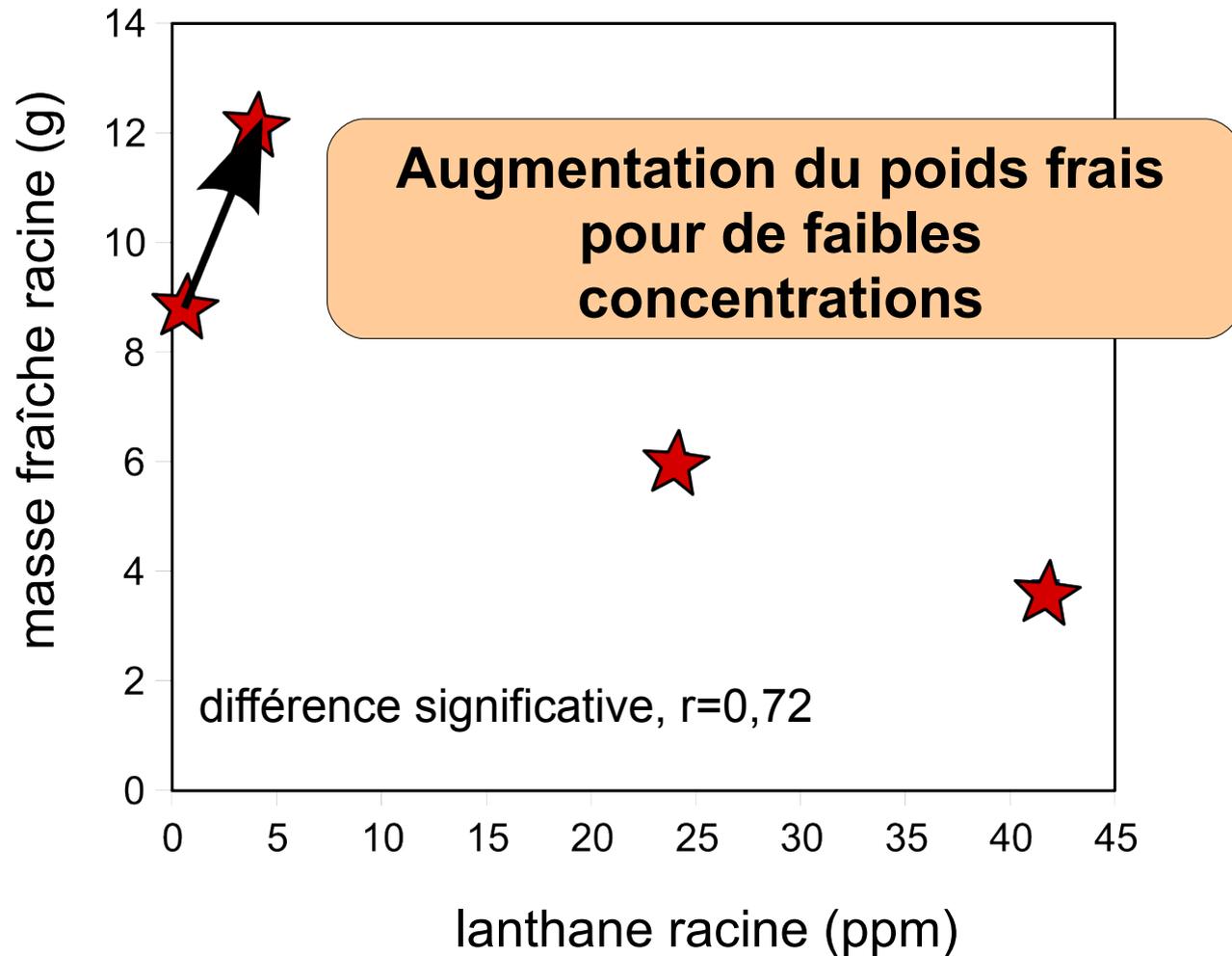


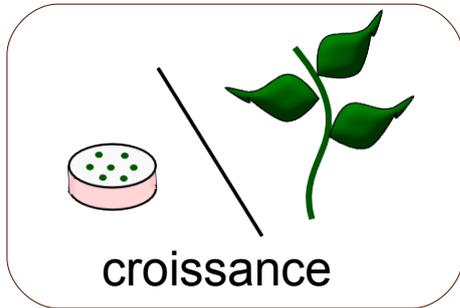
Croissance : lien entre les concentrations des racines et celles et du milieu



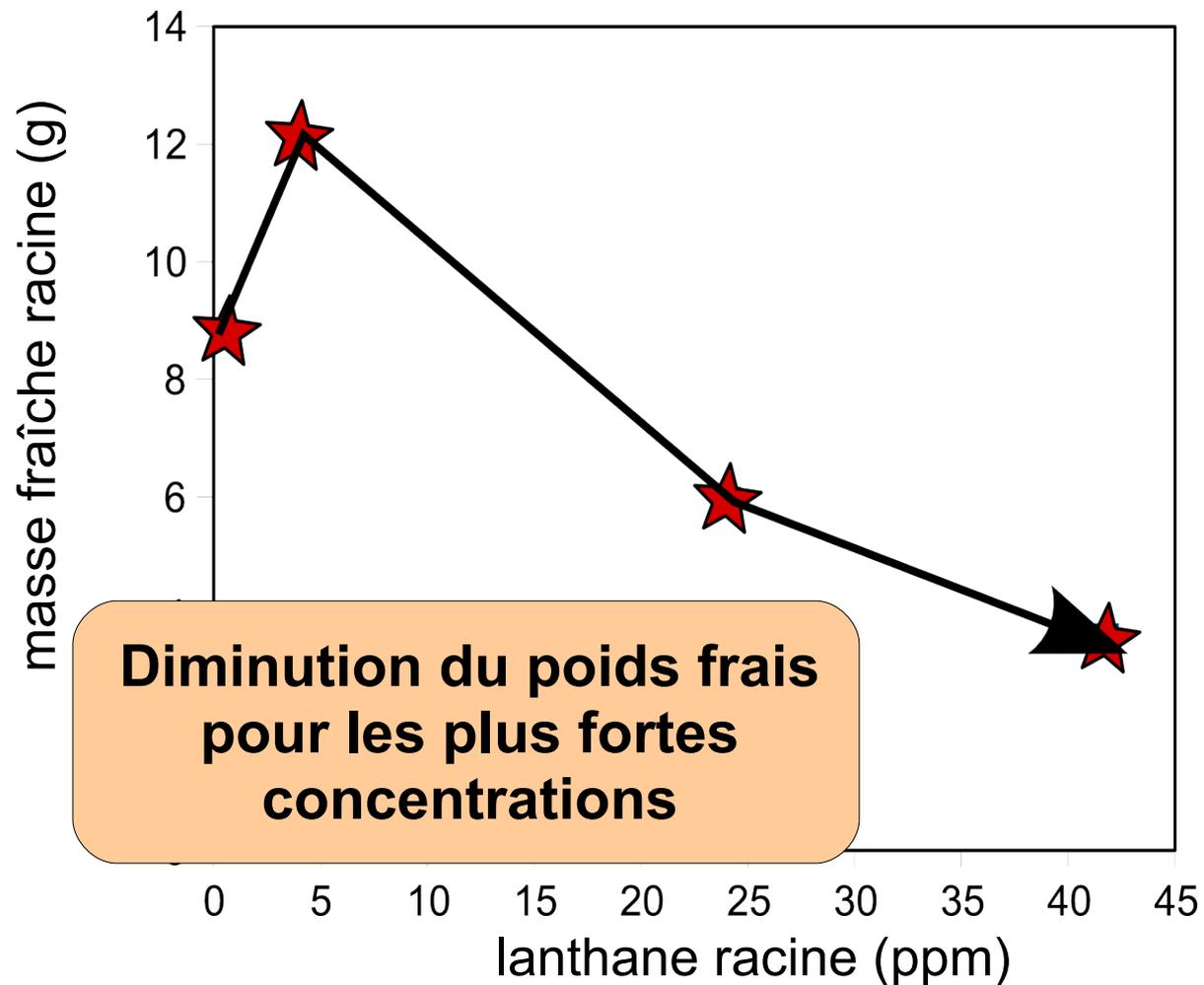


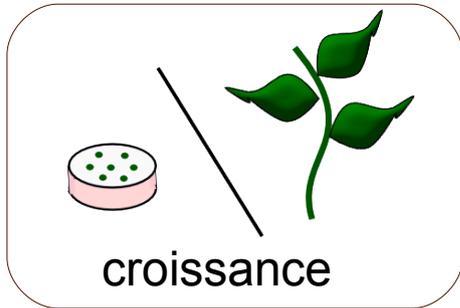
Croissance : effets des concentrations sur les racines



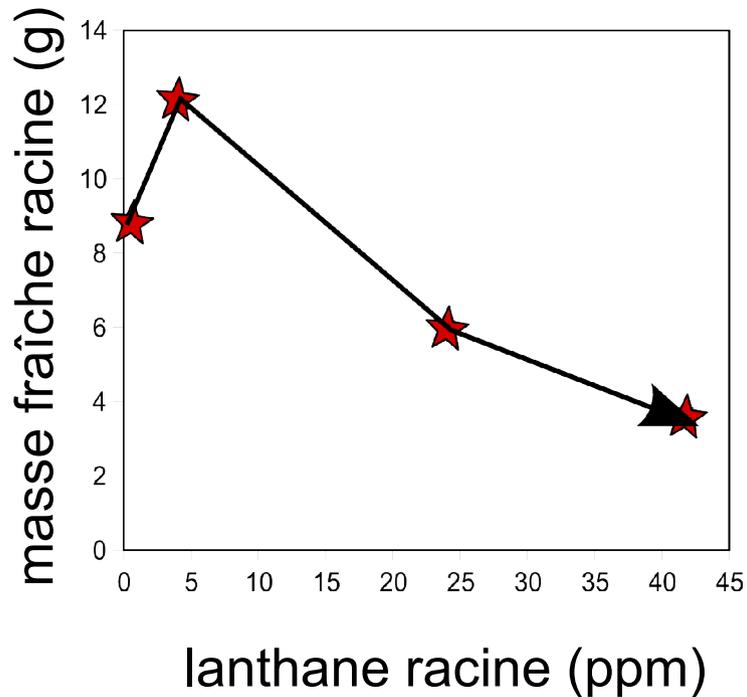


Croissance : effets des concentrations sur les racines



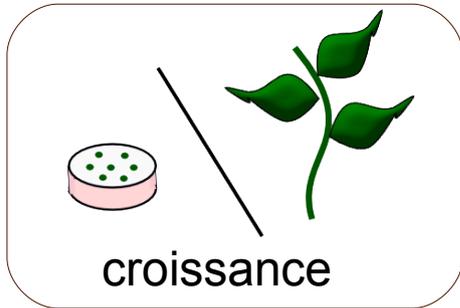


Croissance : effets des concentrations sur les racines

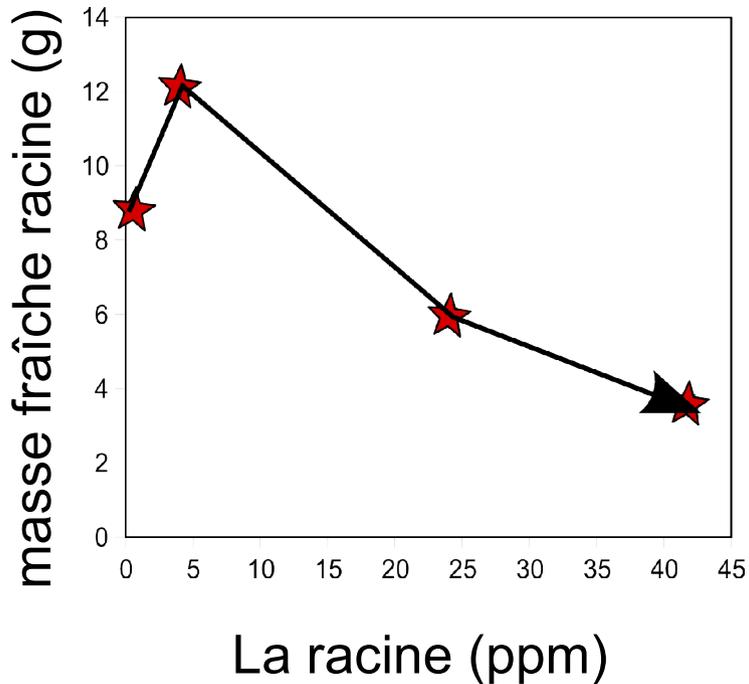


- Effets (+) pour de faibles concentrations
- Effets (-) pour de fortes concentrations

**Résultats identiques
pour l'euprium**



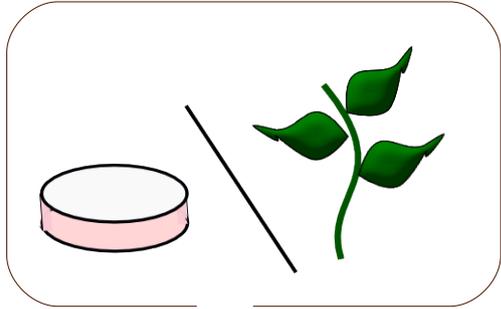
Croissance : effets des concentrations sur les racines



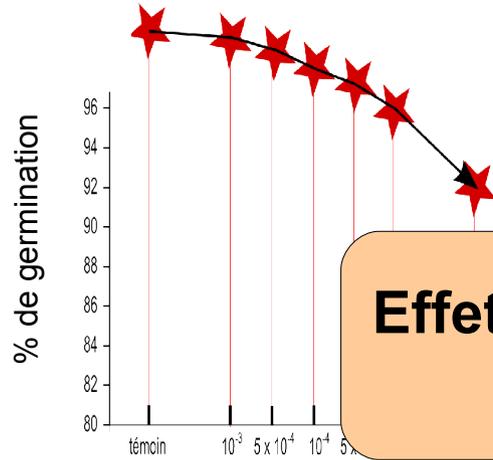
**Résultats identiques
pour l'europlium**

- Effets (+) pour de faibles concentrations
- Effets (-) pour de fortes concentrations

**Peut expliquer les résultats
contradictoires de la
littérature**

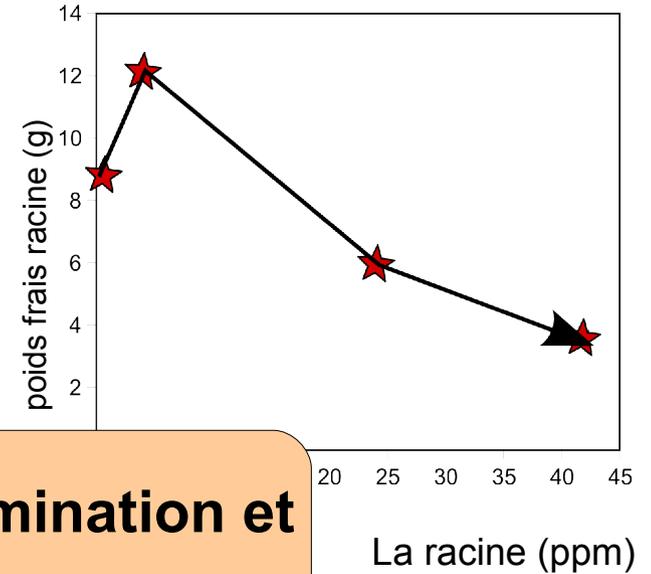


Récapitulatif



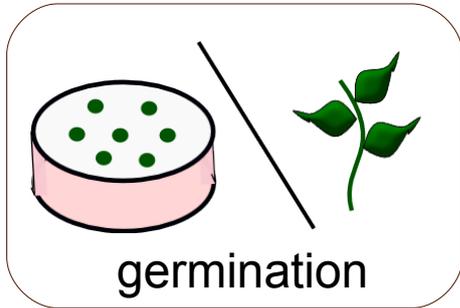
Lanthane dans la solution de germination (g.L⁻¹)

Effet du La, Eu et Yb sur la germination et la croissance



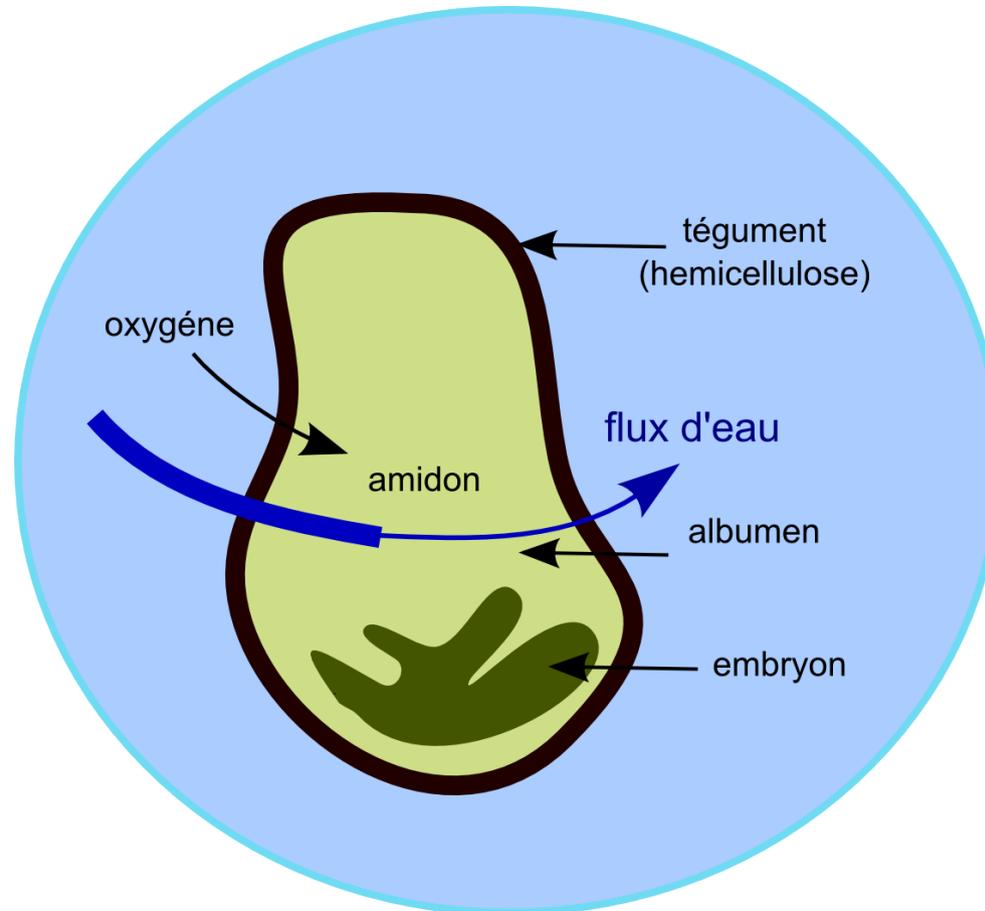
+

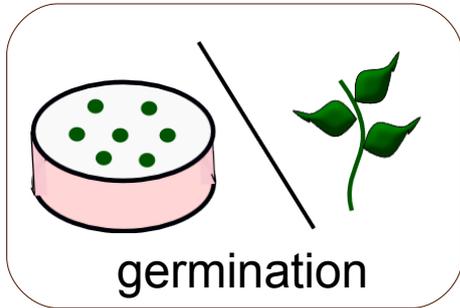
Possible effet sur l'absorption des éléments nutritifs



Absorption de TR par les graines

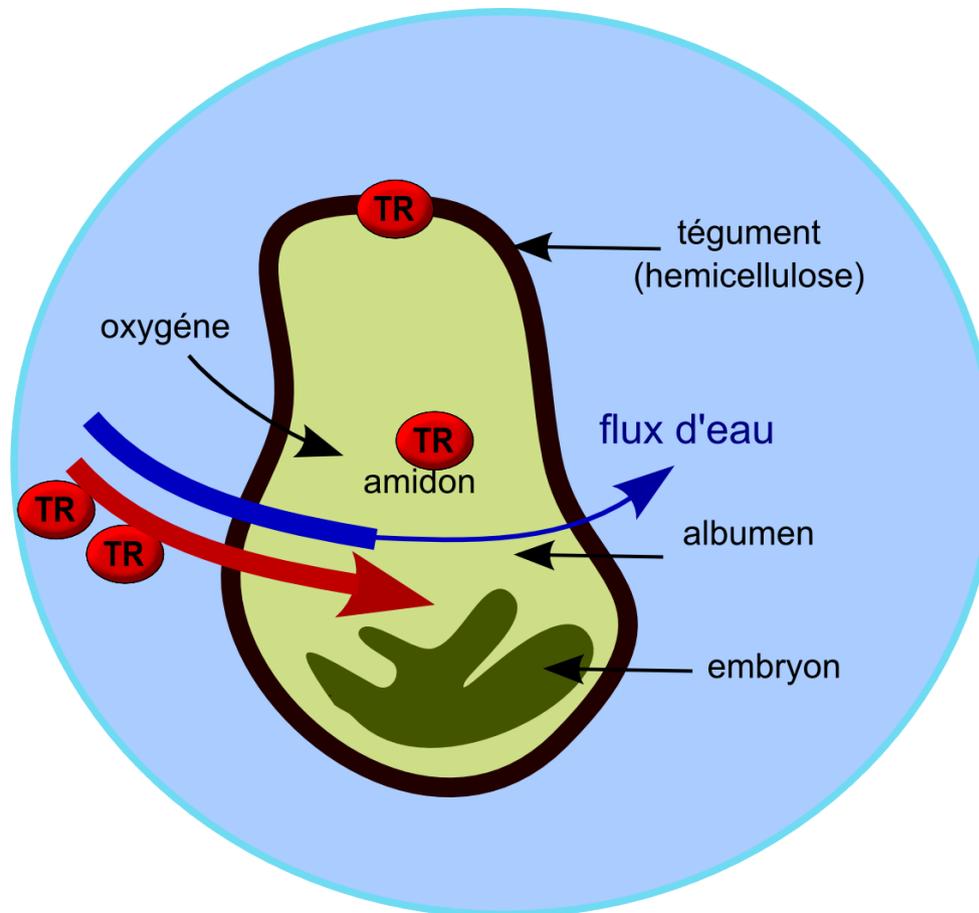
Inhibition de la germination

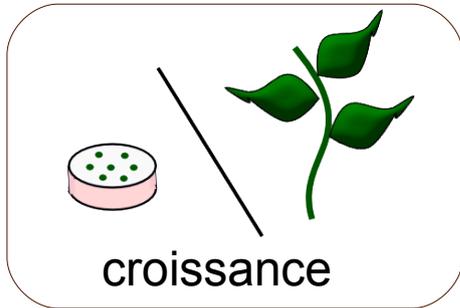




Absorption de TR par les graines

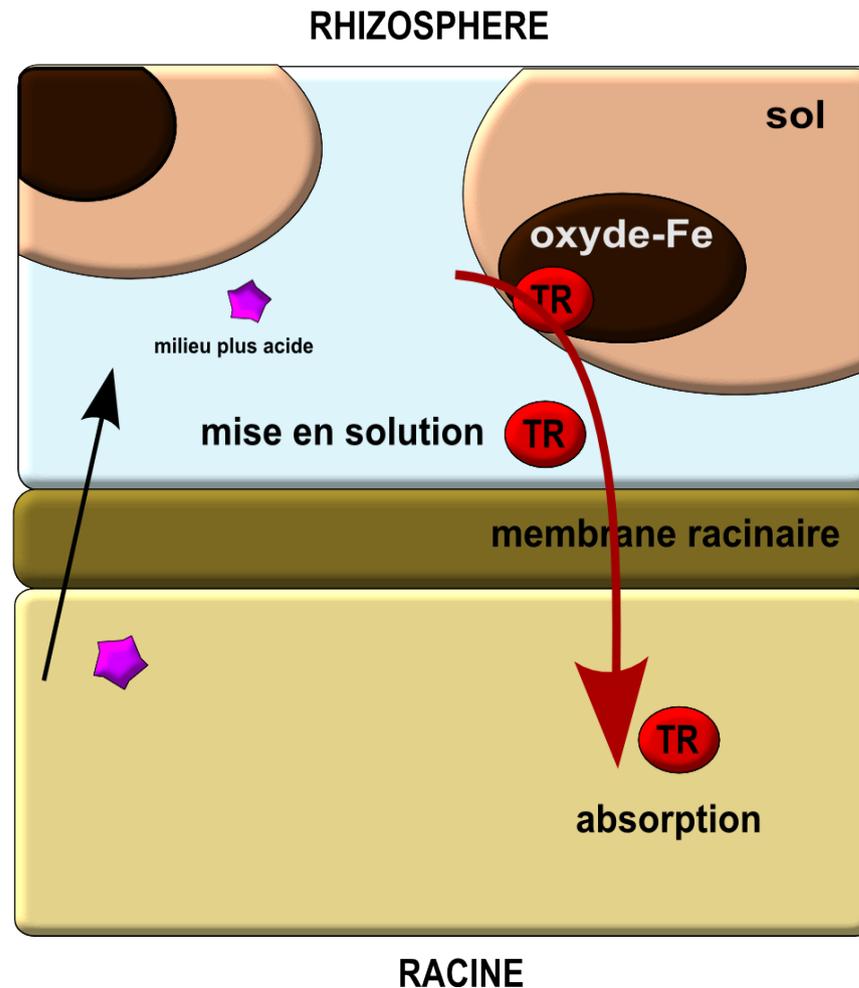
Inhibition de la germination



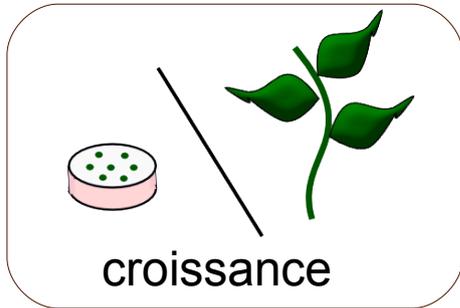


Absorption des TR, effets sur la plante

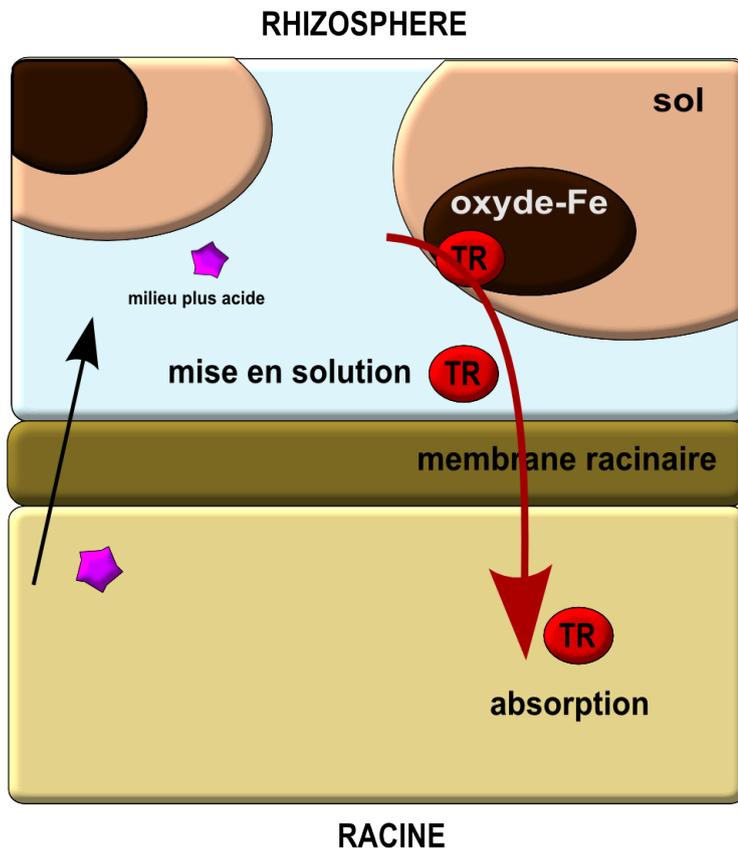
Inhibition de la croissance



Absorption des TR, effets sur la plante

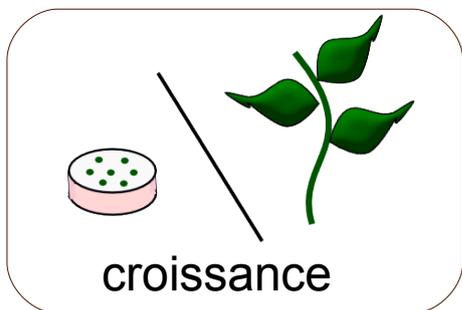


Inhibition de la croissance

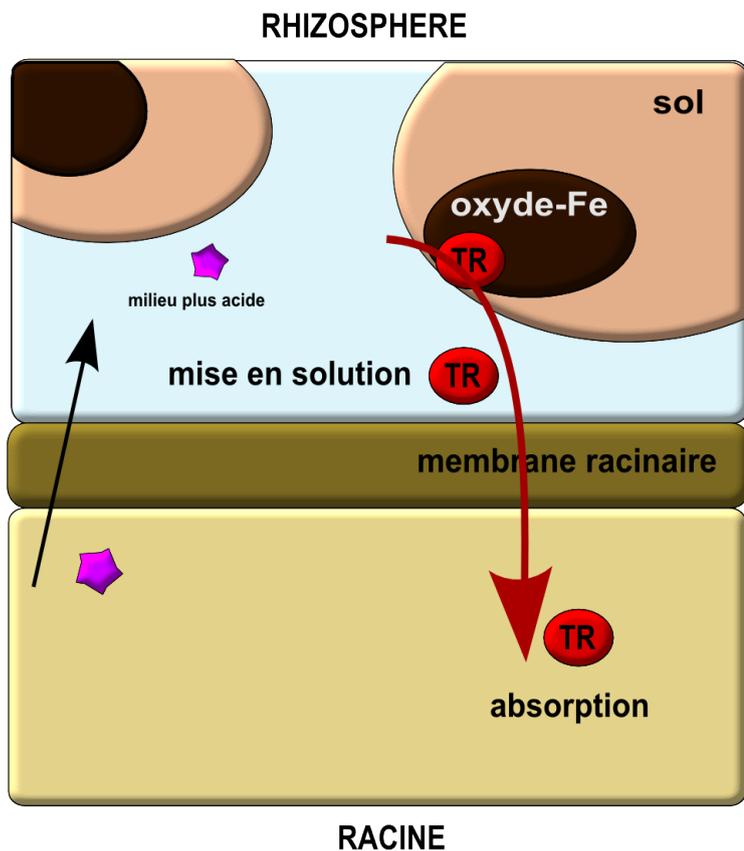


Effet sur les activités enzymatiques

Absorption des TR, effets sur la plante

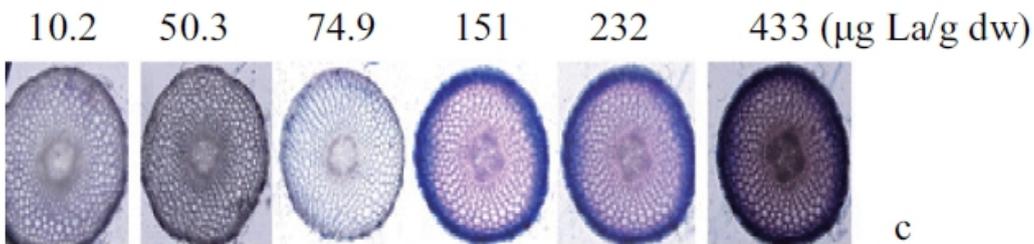


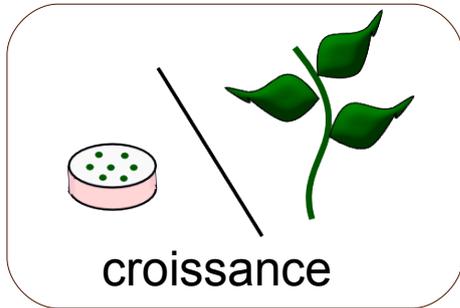
Inhibition de la croissance



Effet sur les activités enzymatiques

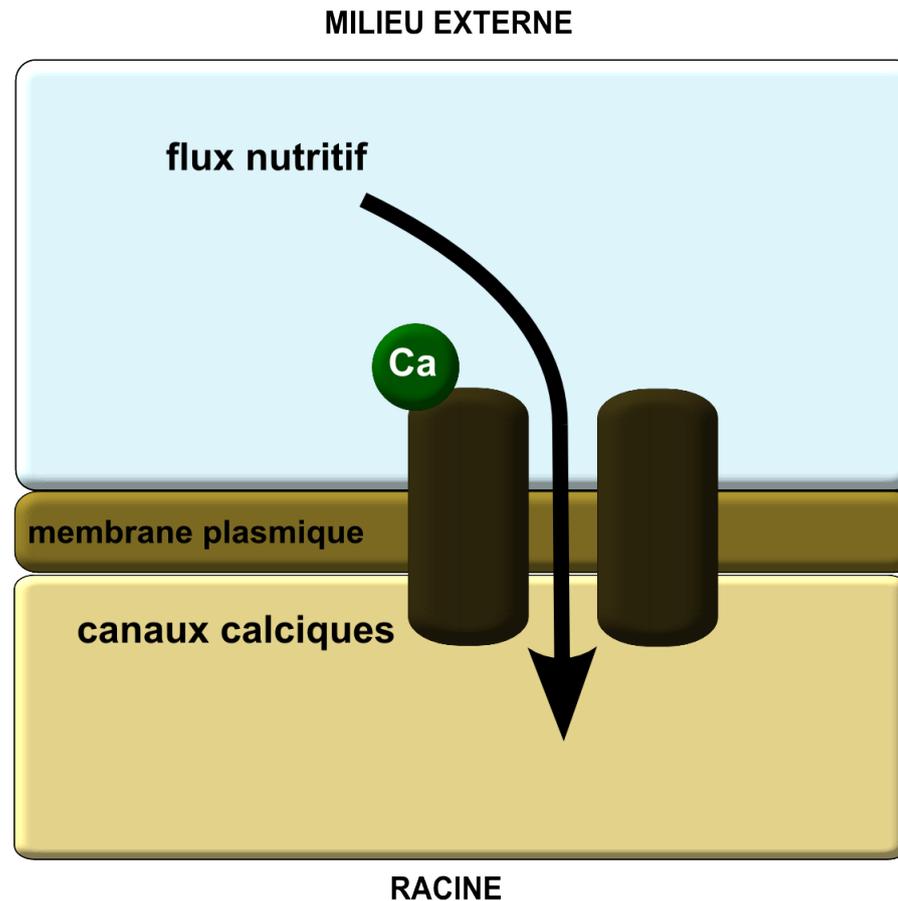
Mort cellulaire

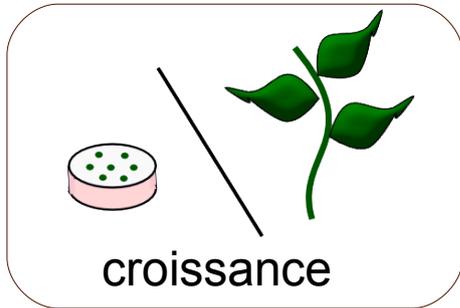




Absorption par le système racinaire et effet

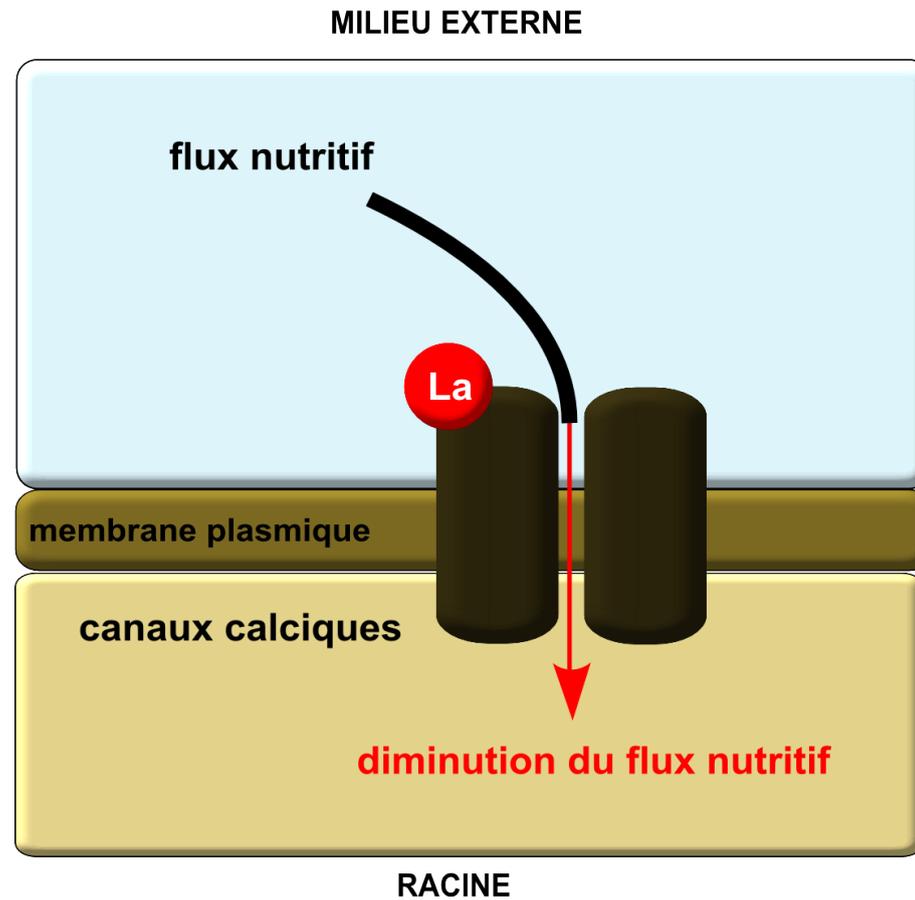
Effets sur l'absorption des éléments nutritifs Fe et Ca





Absorption par le système racinaire et effet

Effets sur l'absorption des éléments nutritifs Fe et Ca

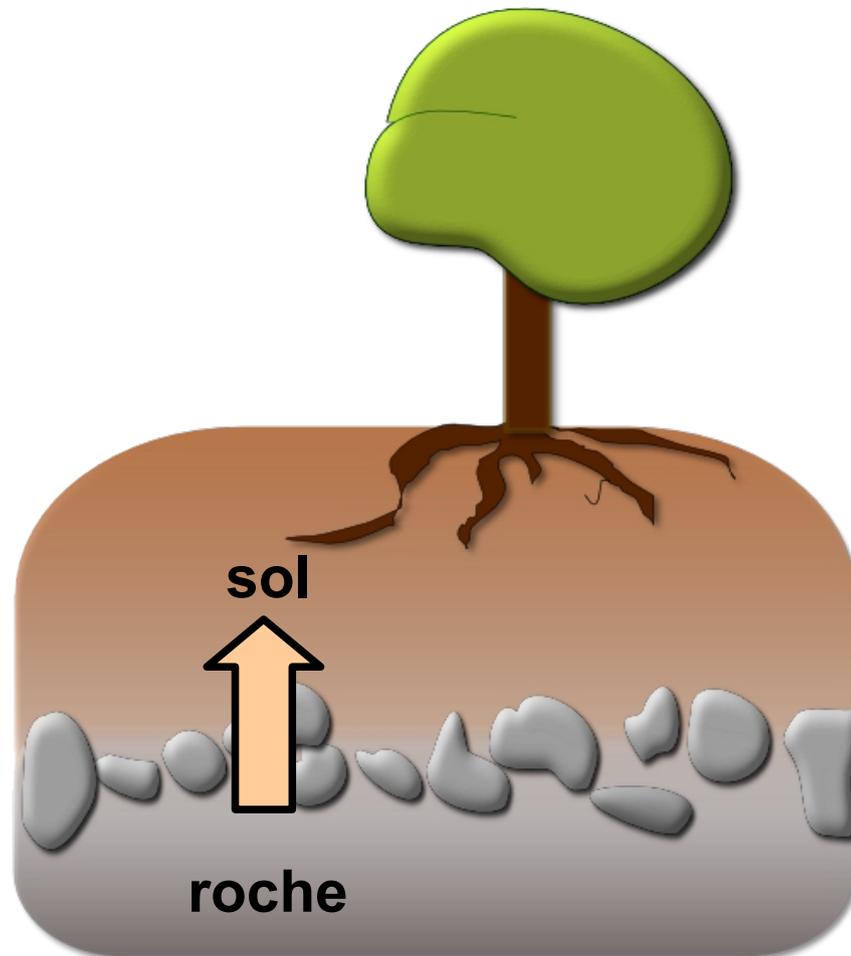


Impact sur la croissance



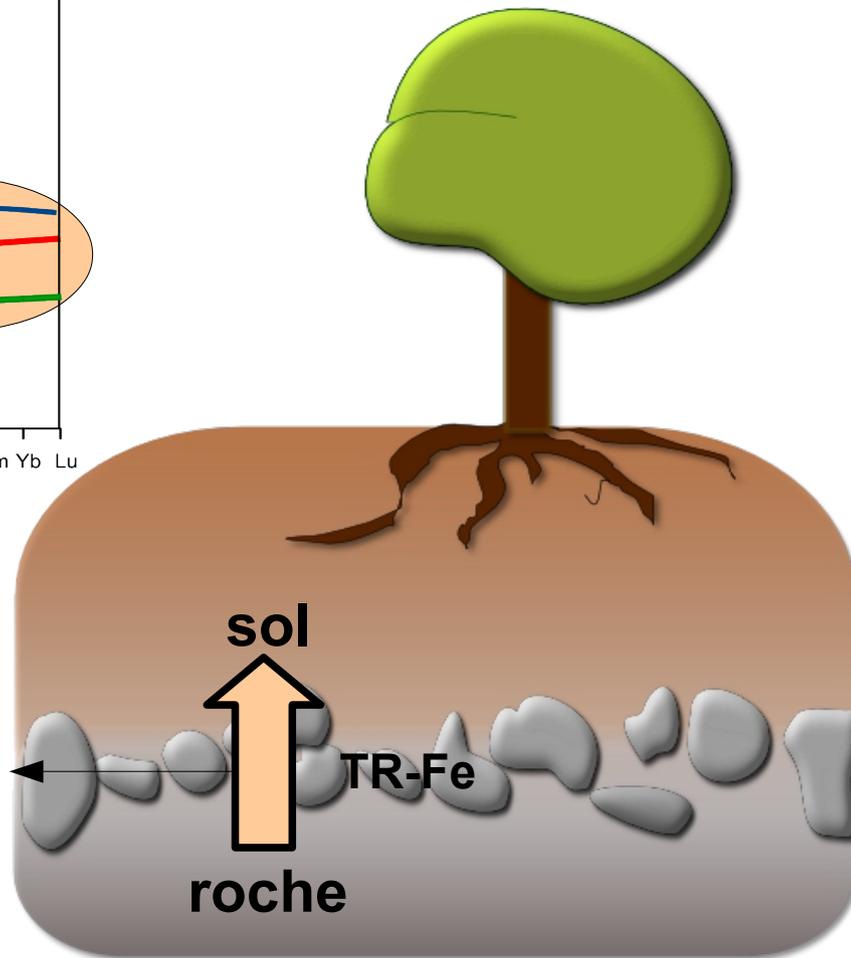
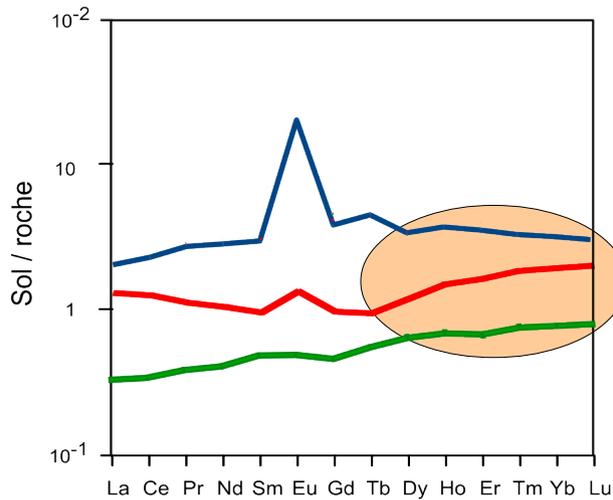
IV : Conclusions et perspectives

Transfert roche -sol



Facteurs de transfert liés à la minéralogie de la roche

Transfert roche -sol



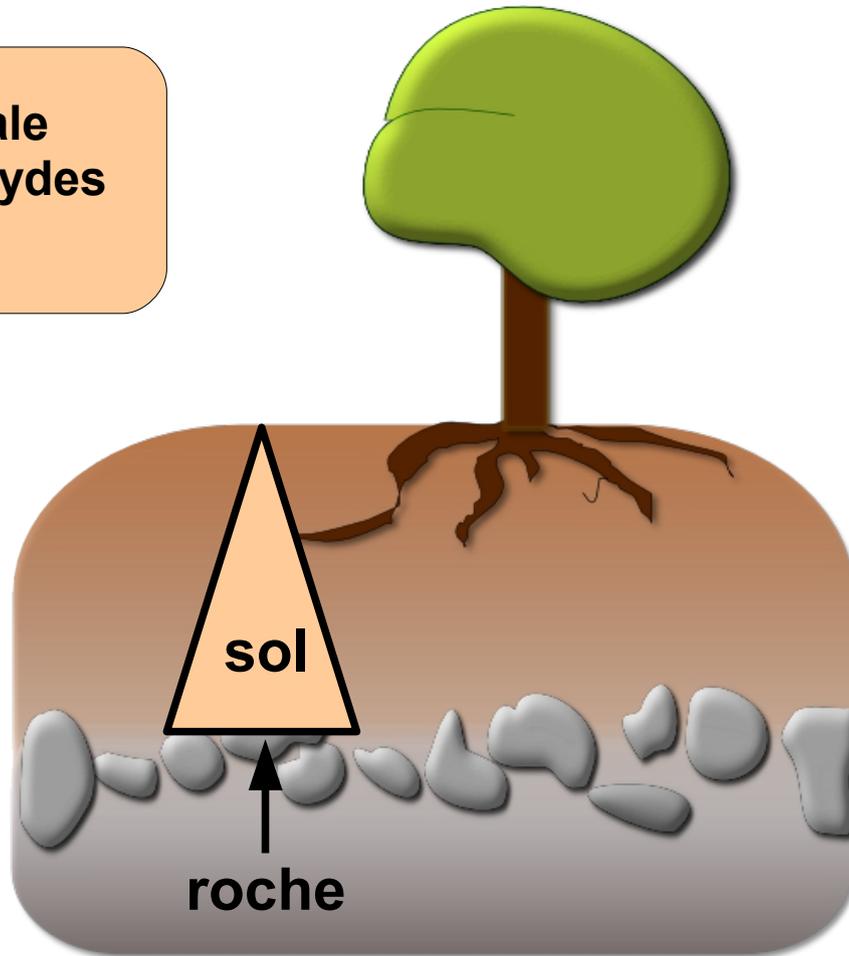
Enrichissement en TRL contrôlé par les oxydes de fer

Facteurs de transfert liés à la minéralogie de la roche

Transfert roche -sol

Répartition verticale
contrôlée par les oxydes
de Fe et le pH

Enrichissement en TR
contrôlé par les oxydes de
fer

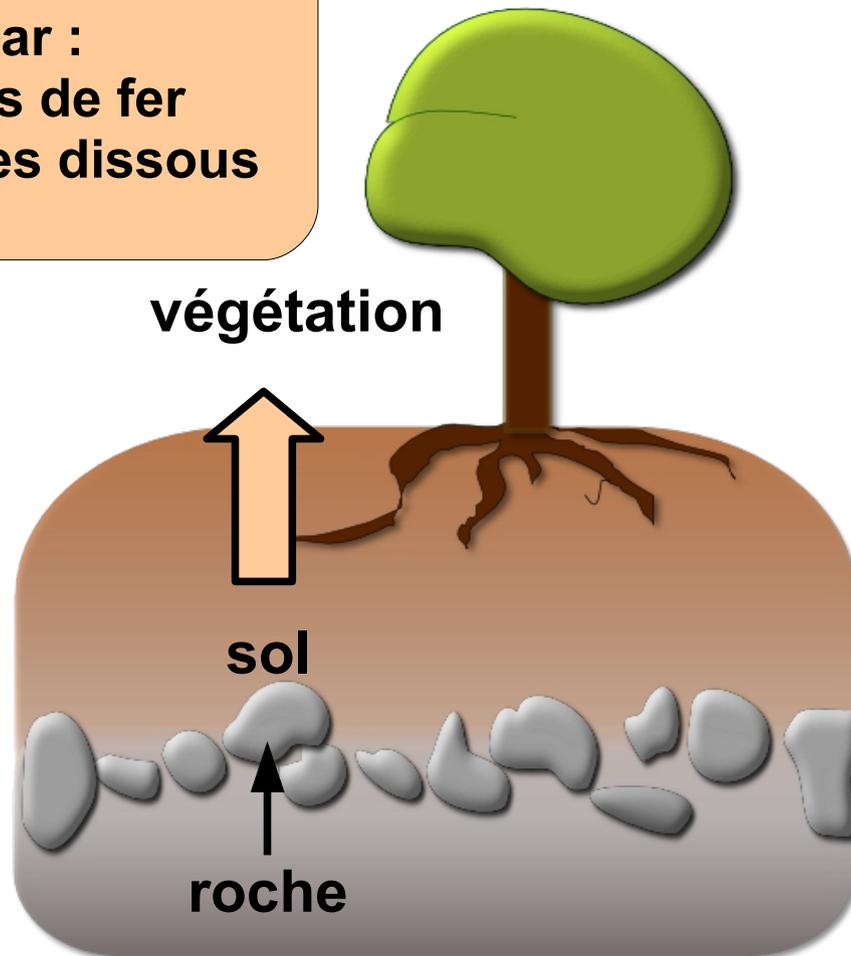


Facteurs de transfert liés à la
minéralogie de la roche

Transfert sol-végétation

Enrichissement en TRI
contrôlé par :

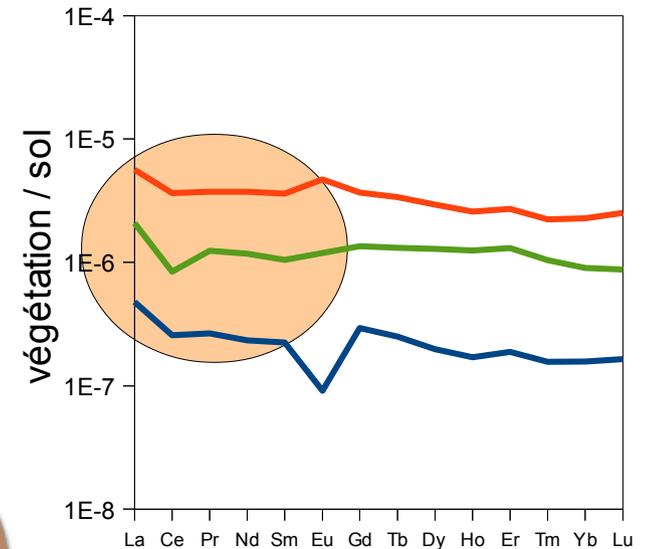
- TRL - oxydes de fer
- TRL - complexes dissous



Répartition verticale
contrôlée par les oxydes
de Fe et le pH

Enrichissement en TR
contrôlé par les oxydes de
fer

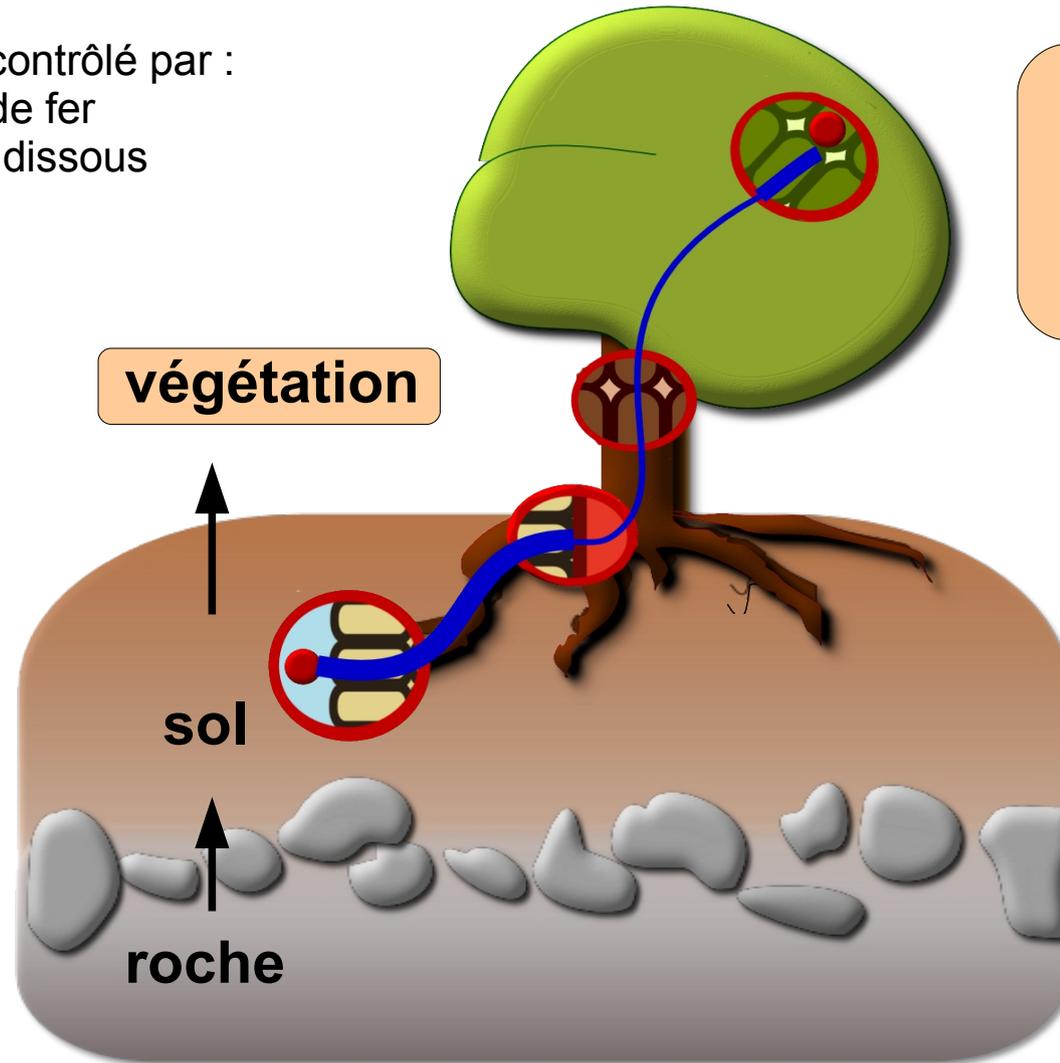
Facteurs de transfert liés à la
minéralogie de la roche



Transfert sol-végétation

Enrichissement en TRI contrôlé par :

- TRL - oxydes de fer
- TRL - complexes dissous



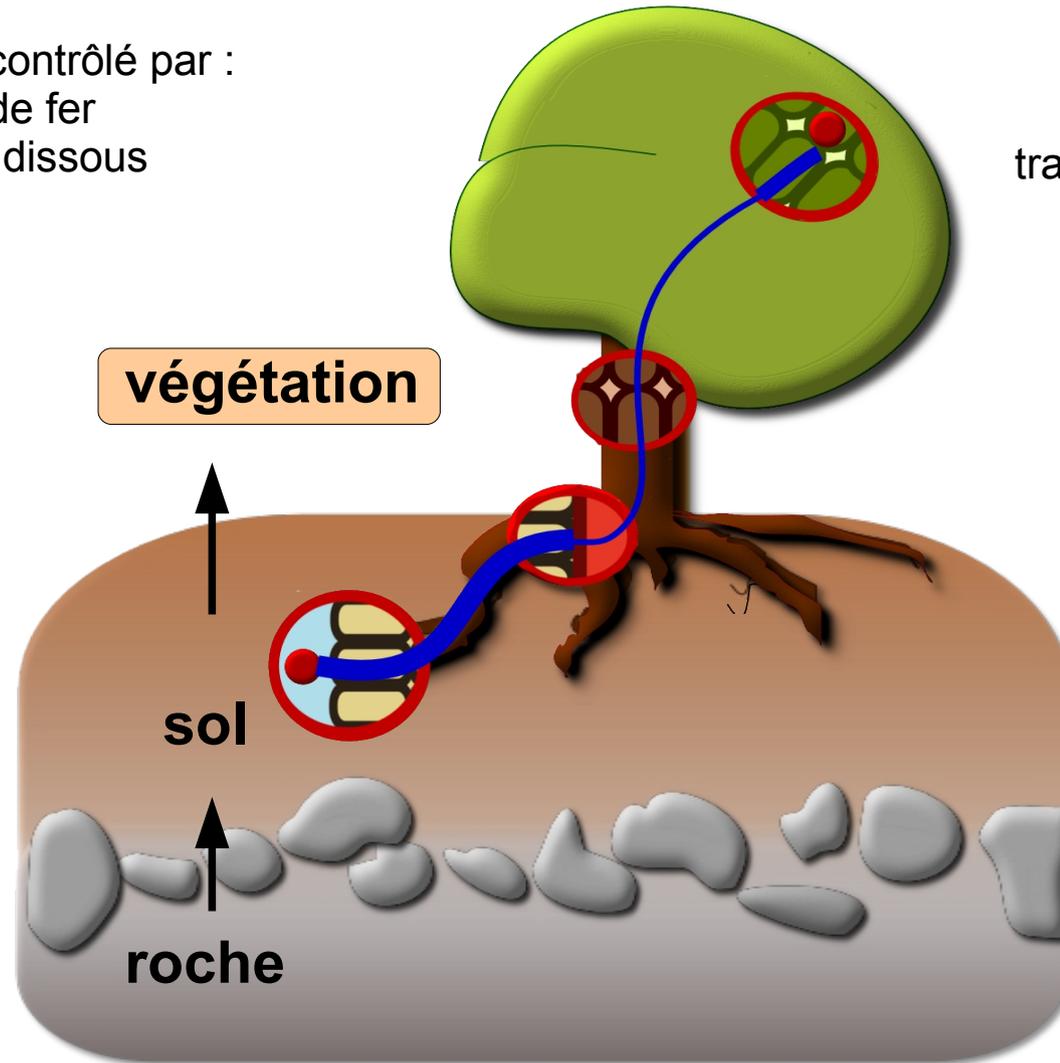
**Absorption et
translocation
liées aux fer**

Accumulation et translocation dans la végétation

Enrichissement en TRI contrôlé par :

- TRI - oxydes de fer
- TRI - complexes dissous

Absorption et translocation liées aux fer



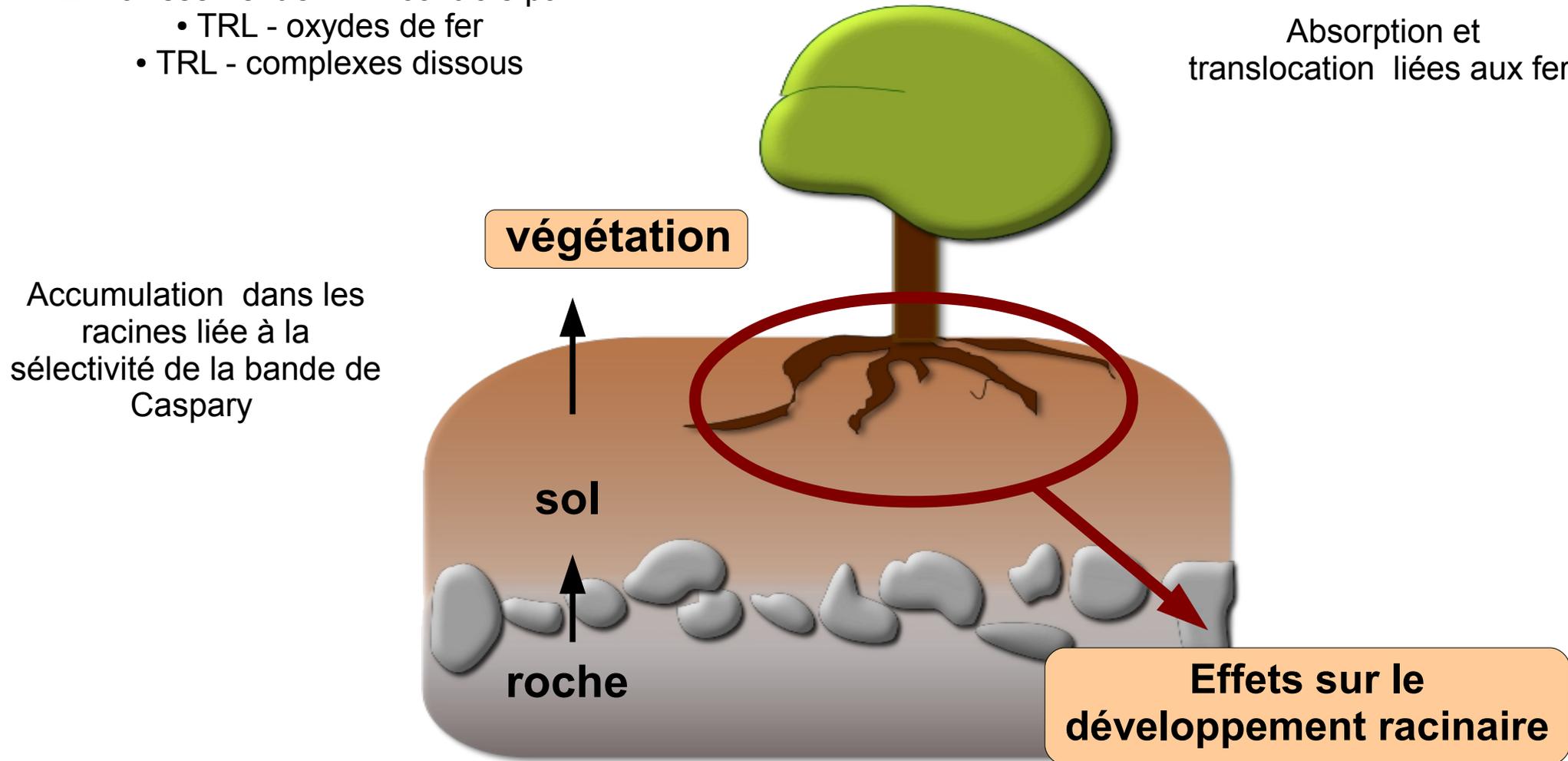
Accumulation dans les racines liée à la sélectivité de la bande de Caspary

Effets sur la physiologie de la plante

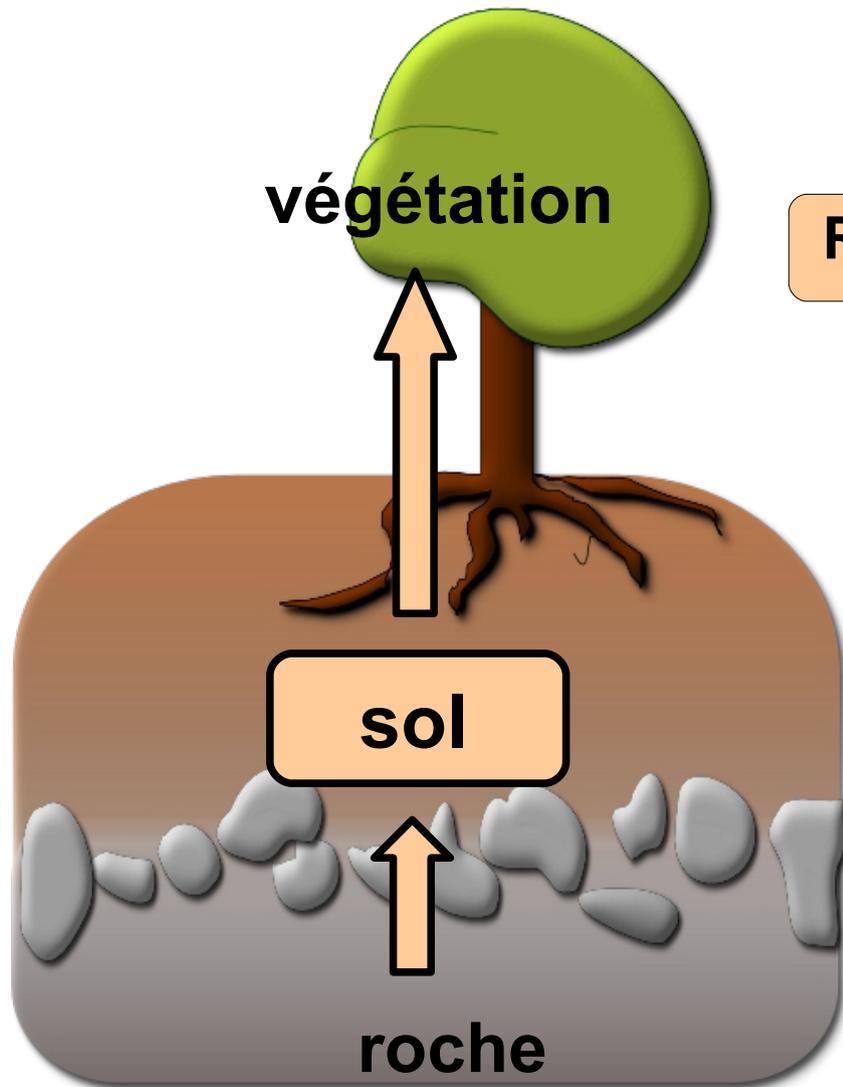
Enrichissement en TRI contrôlé par :

- TRI - oxydes de fer
- TRI - complexes dissous

Absorption et translocation liées aux fer



Perspectives



Facteurs de transfert liés à la minéralogie de la roche

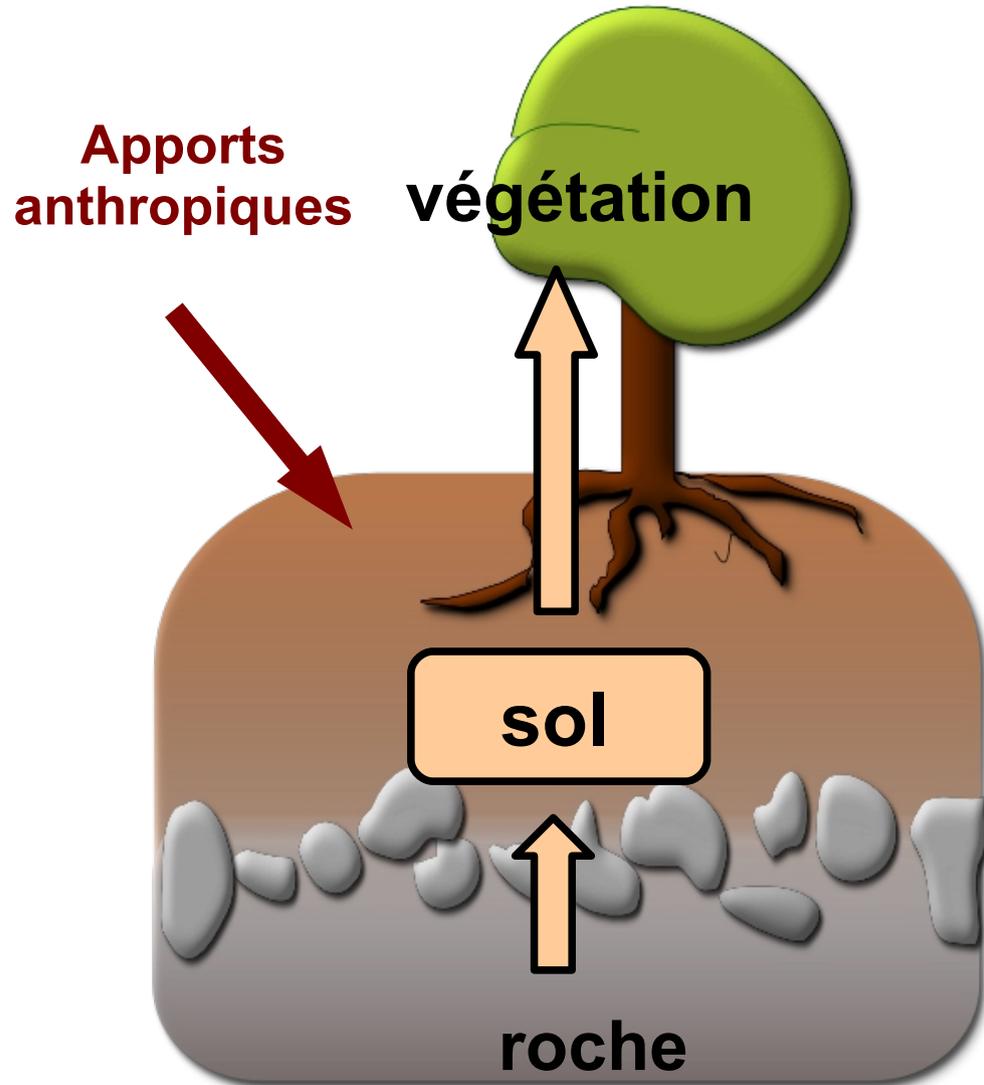
Répartition verticale des TR et TR-Fe



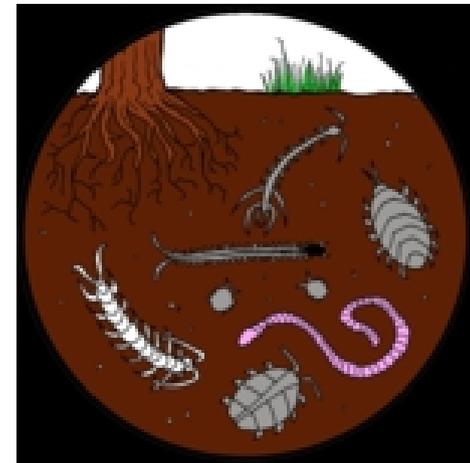
Outil pour l'analyse fonctionnelle des sols



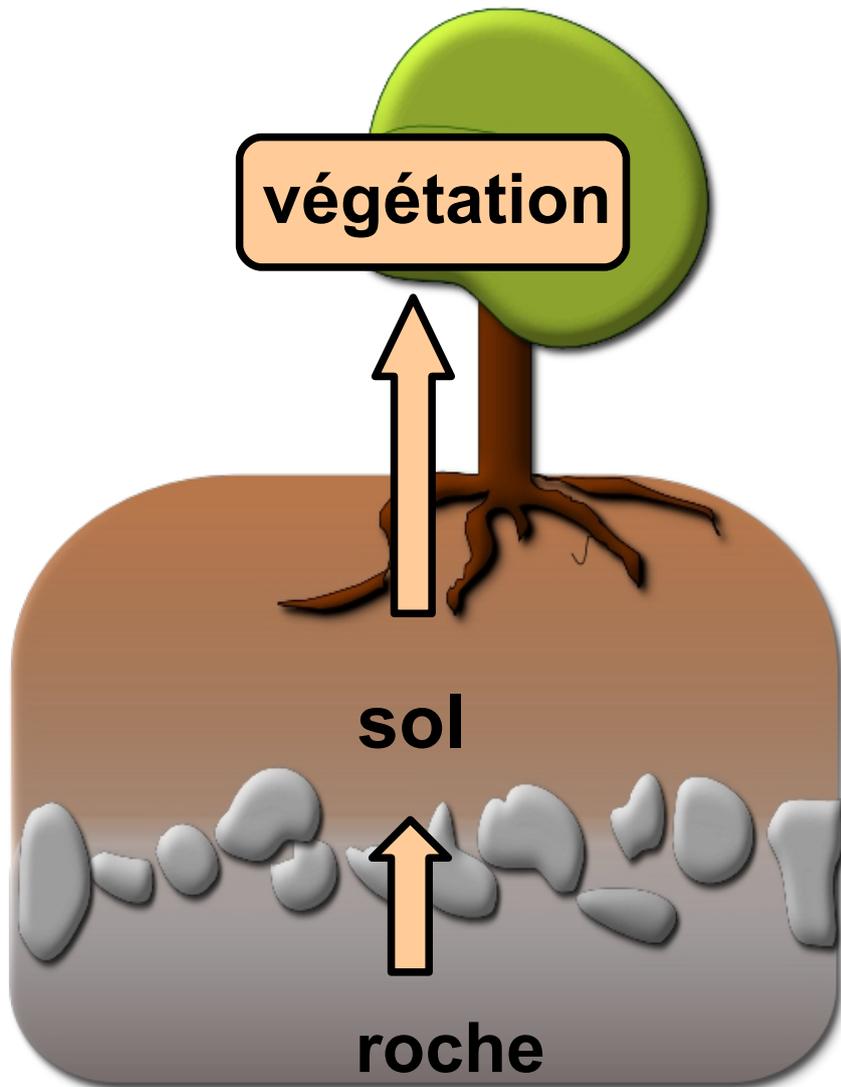
Perspectives



Effet sur l'activité biologique des sols ?



Perspectives



Enrichissement en TR légères

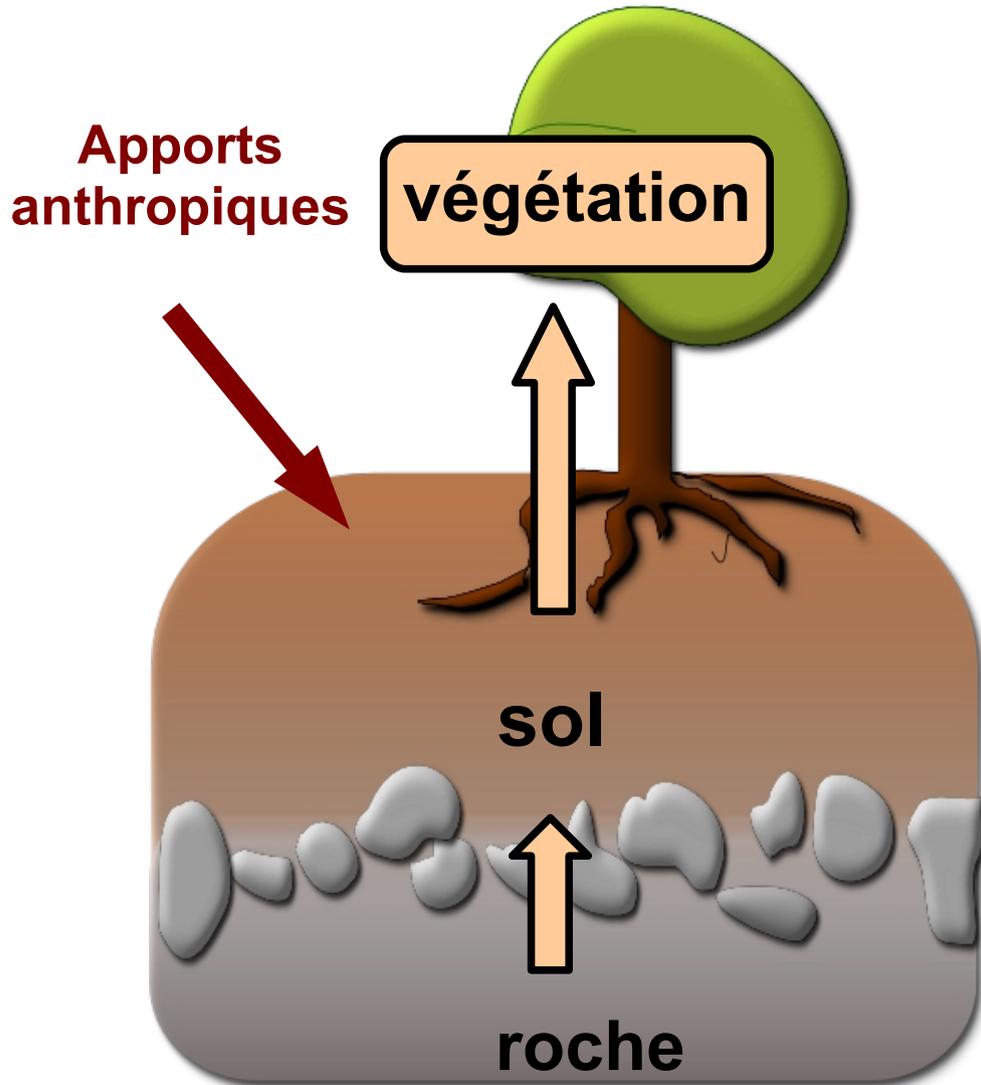


Sélectivité de la plante ?

Fractionnement de la plante ?



Perspectives

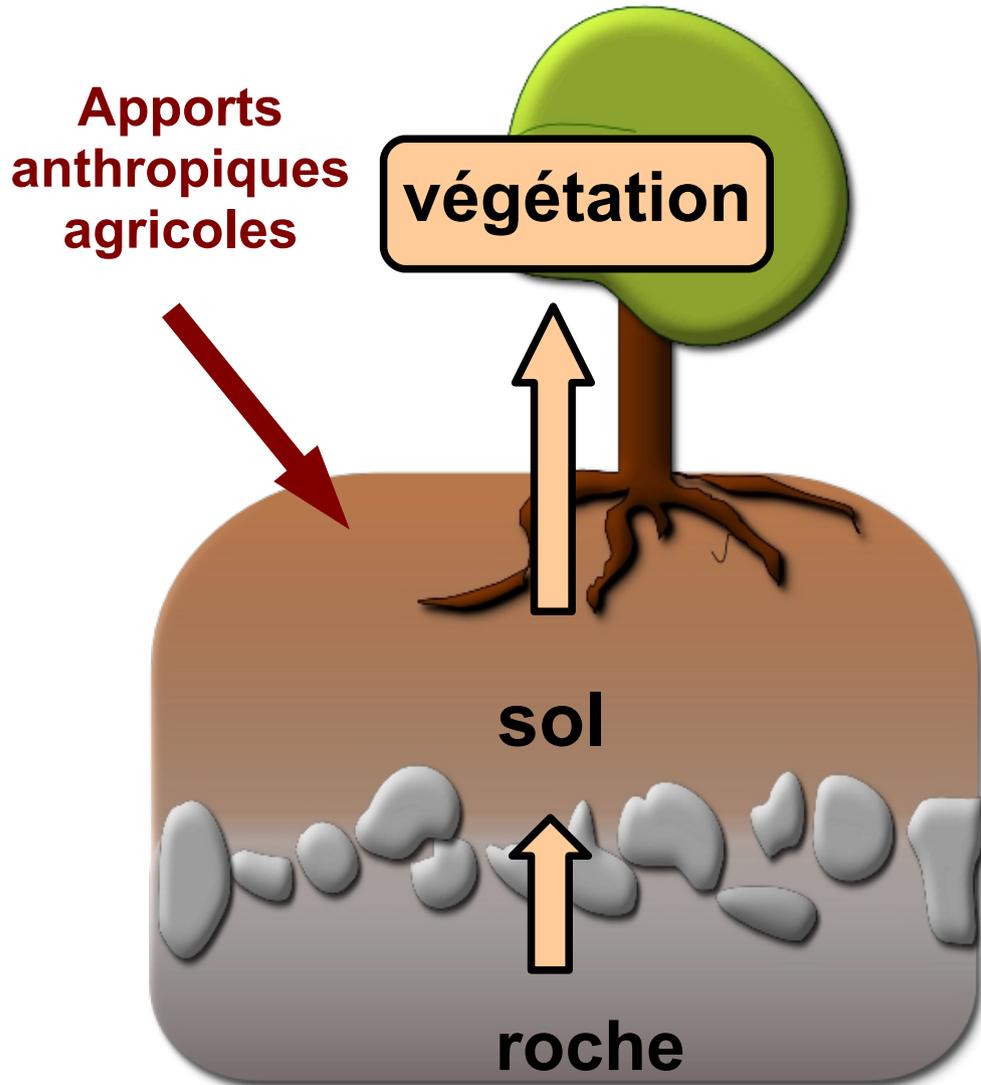


accumulation et effet sur le système racinaire

Impact sur le production primaire des écosystèmes ?



Perspectives



accumulation et effet sur le système racinaire



Risque pour les consommateurs ?

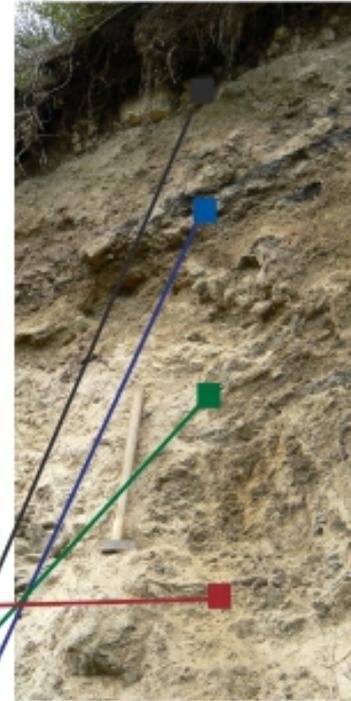
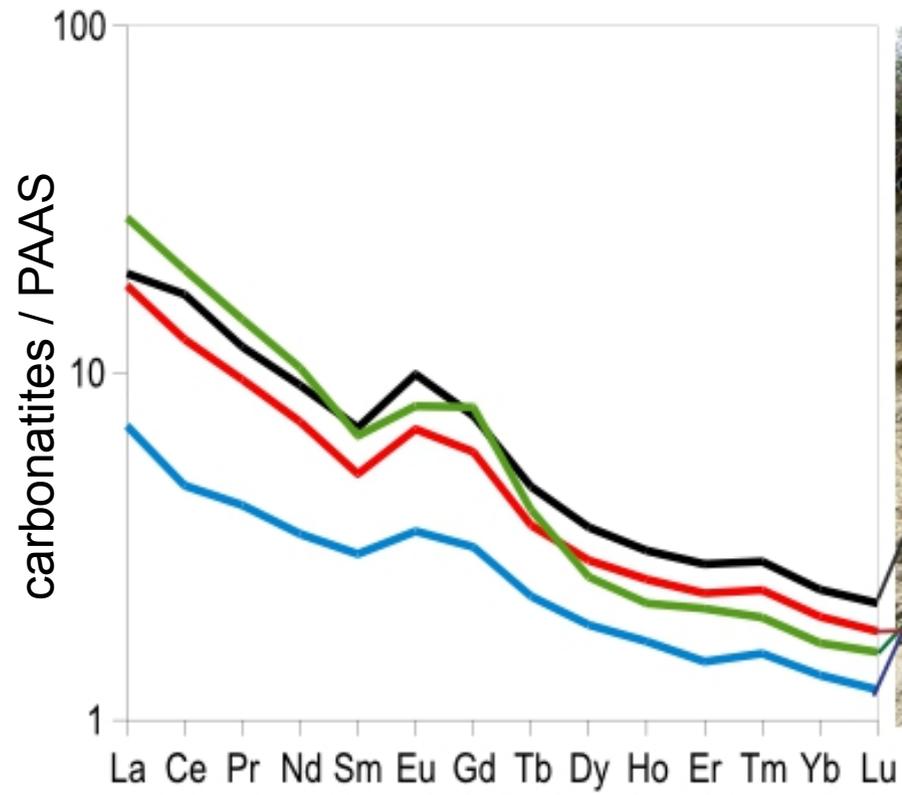
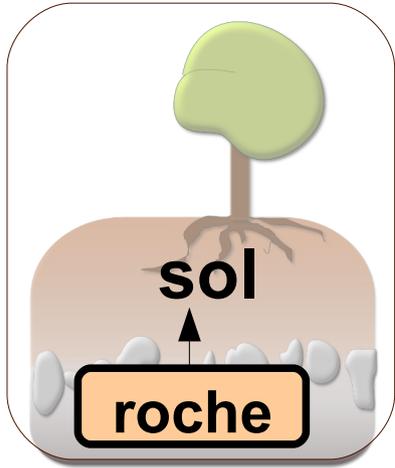




Merci de votre attention

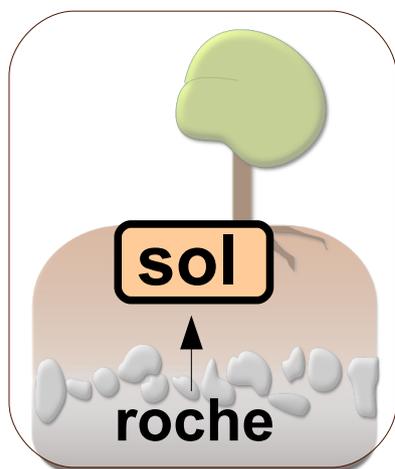
**Financement
Bourse ministère de la recherche
Programme EC2CO INSU-CNRS**

Carbonatite Profil



Répartition dans les sols

Rapport La/Yb selon la profondeur



Calcaire

épicea	La/Yb roche
profondeur cm	
0-12	0,7
0-12	0,7
30-60	0,6

hêtre plateau

profondeur cm	La/Yb roche
0-8	13,9
8-28	14

hêtre pente

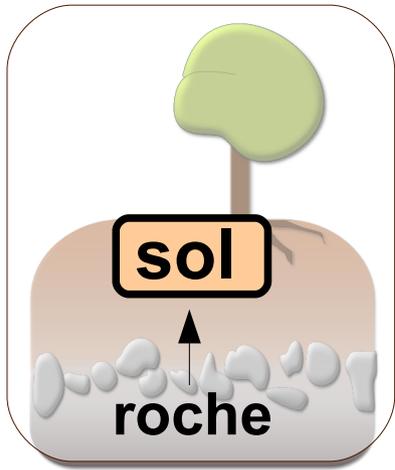
profondeur cm	La/Yb roche
0-21	14
21-38	12

Granite

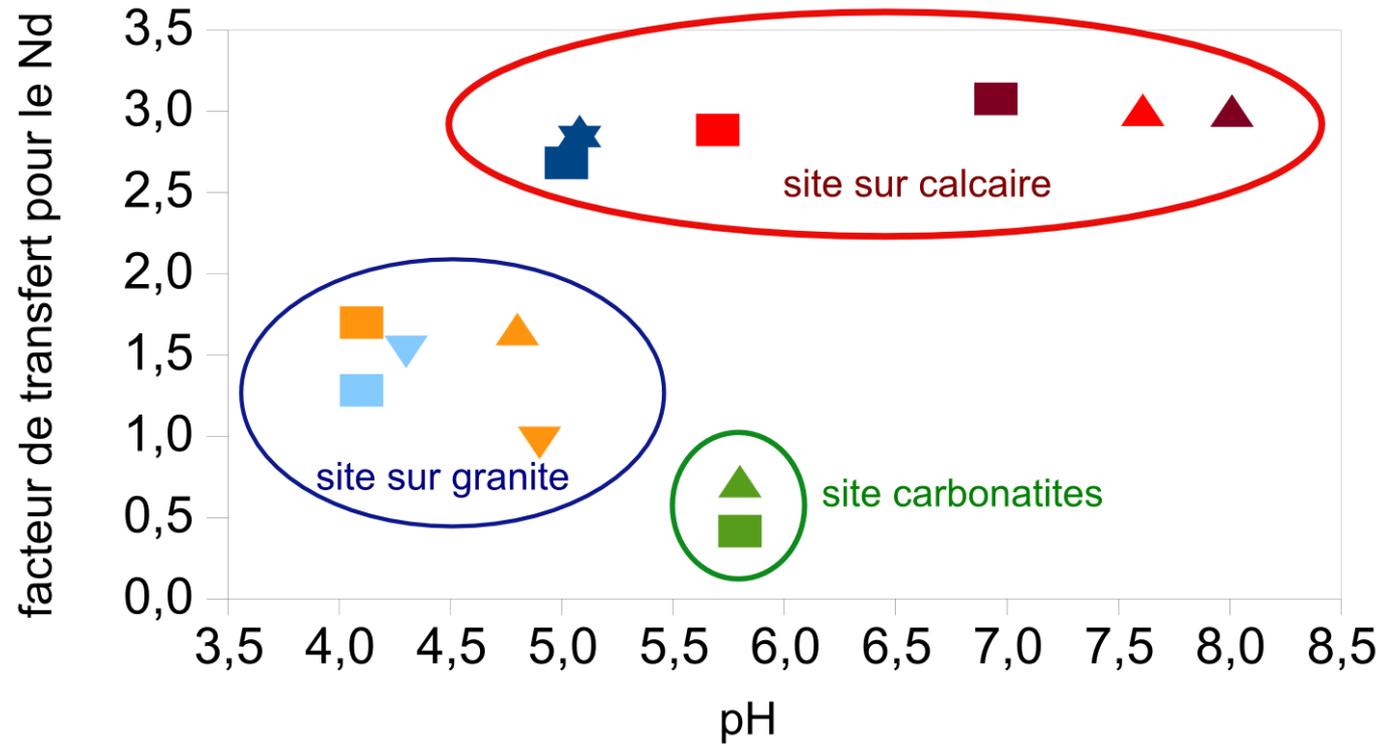
épicea	La/Yb roche
profondeur cm	
0-10	0,64
10-20	0,72
30-40	0,68
50-60	0,64
70-80	0,43
90-100	0,57

hêtre

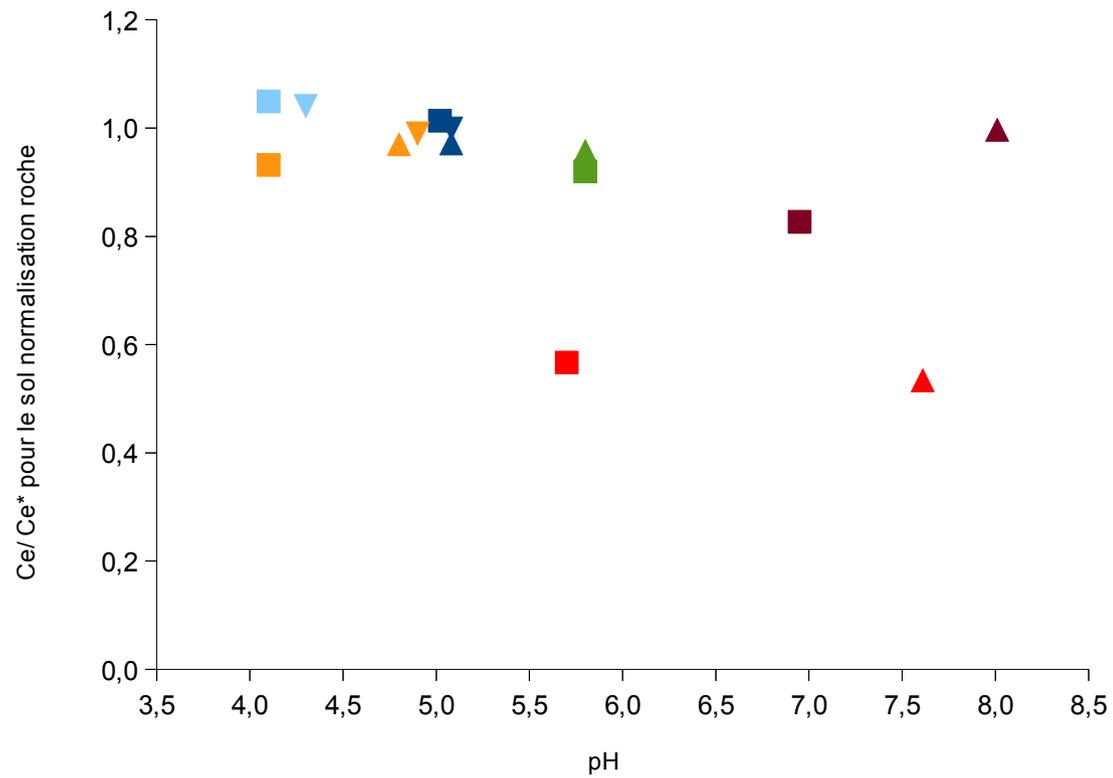
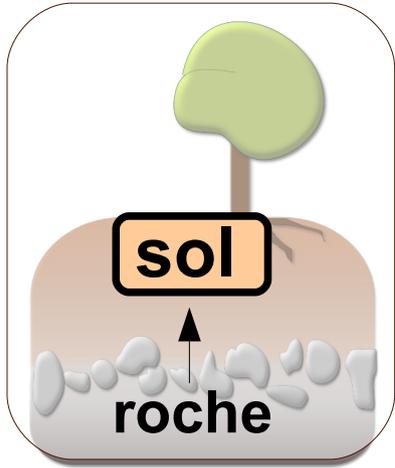
profondeur cm	La/Yb roche
0-5	1,05
5-20	1,14
20-45	1,14
45-70	0,99
70-100	0,77
100-150	0,76



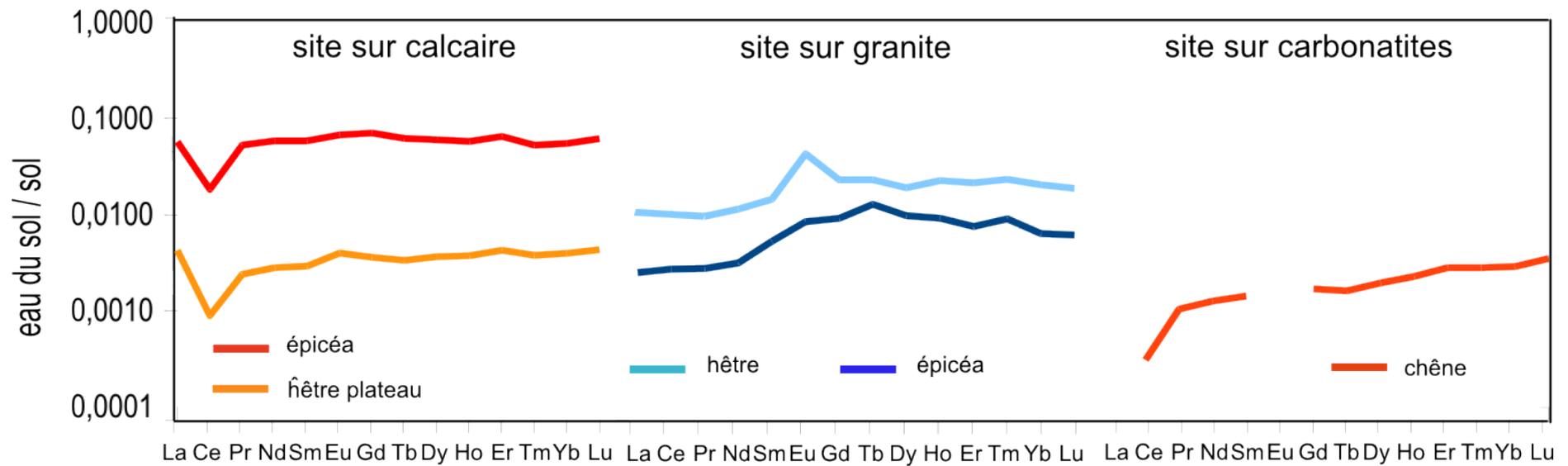
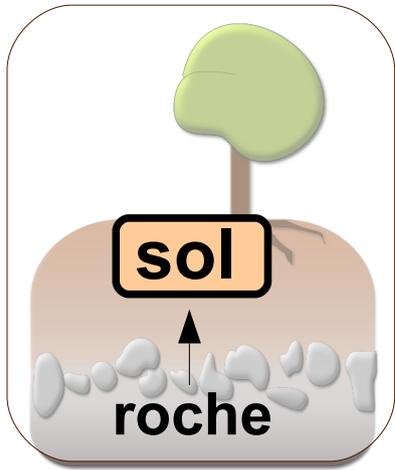
Facteur de transfert et pH



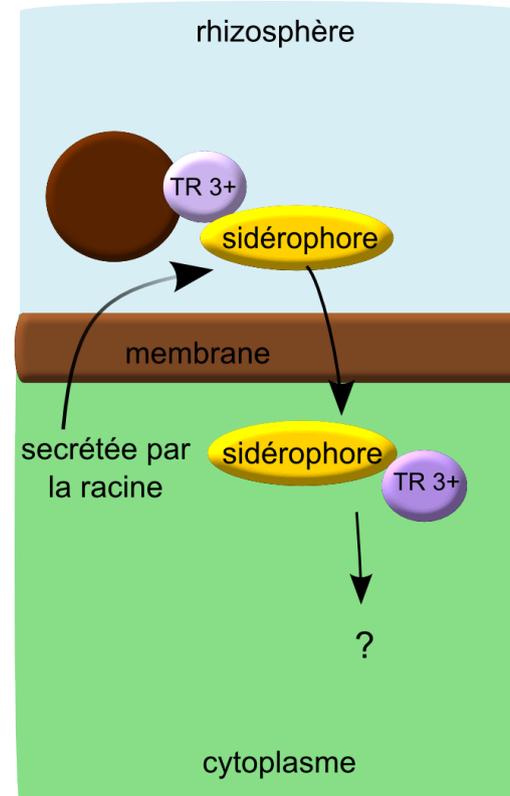
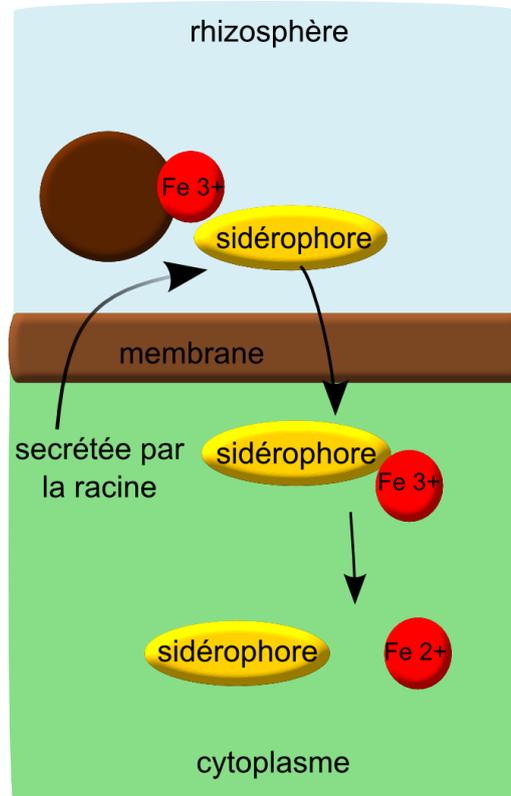
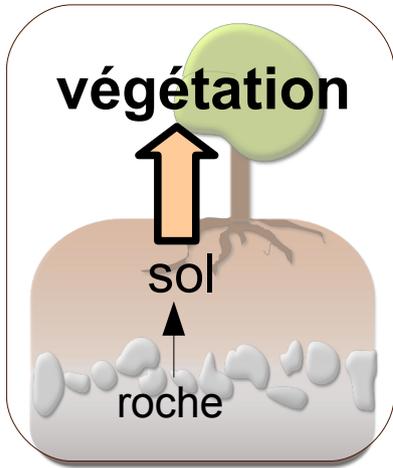
Anomalie en Ce dans les sols



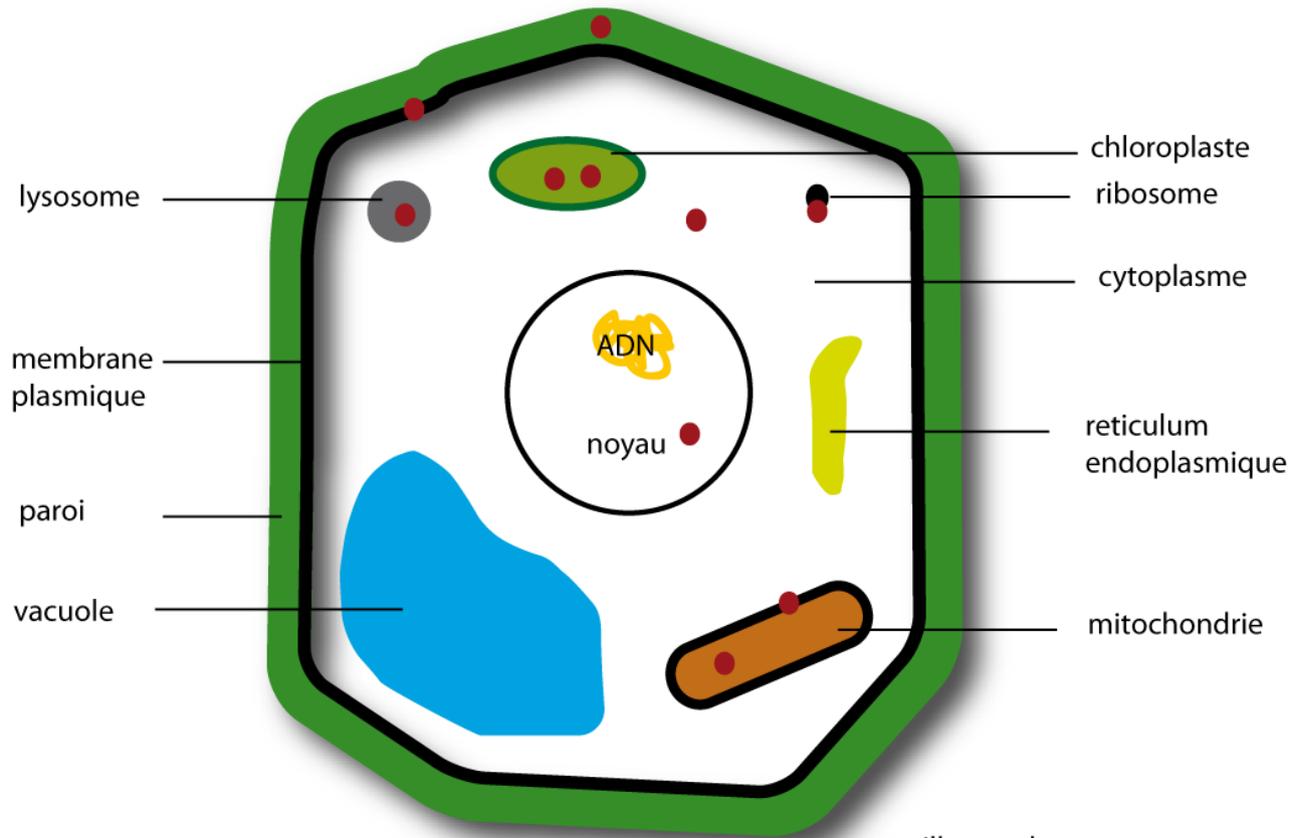
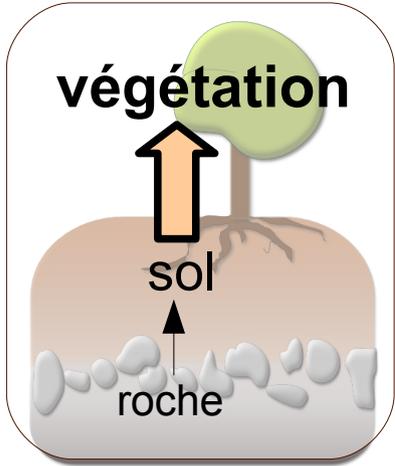
Transfert vers l'eau du sol



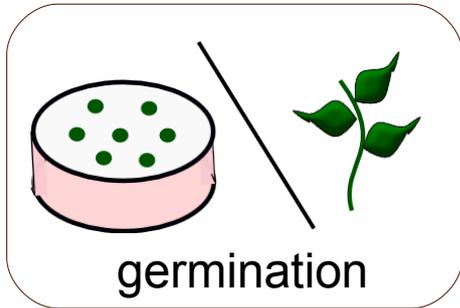
Absorption par la végétation sidérophore



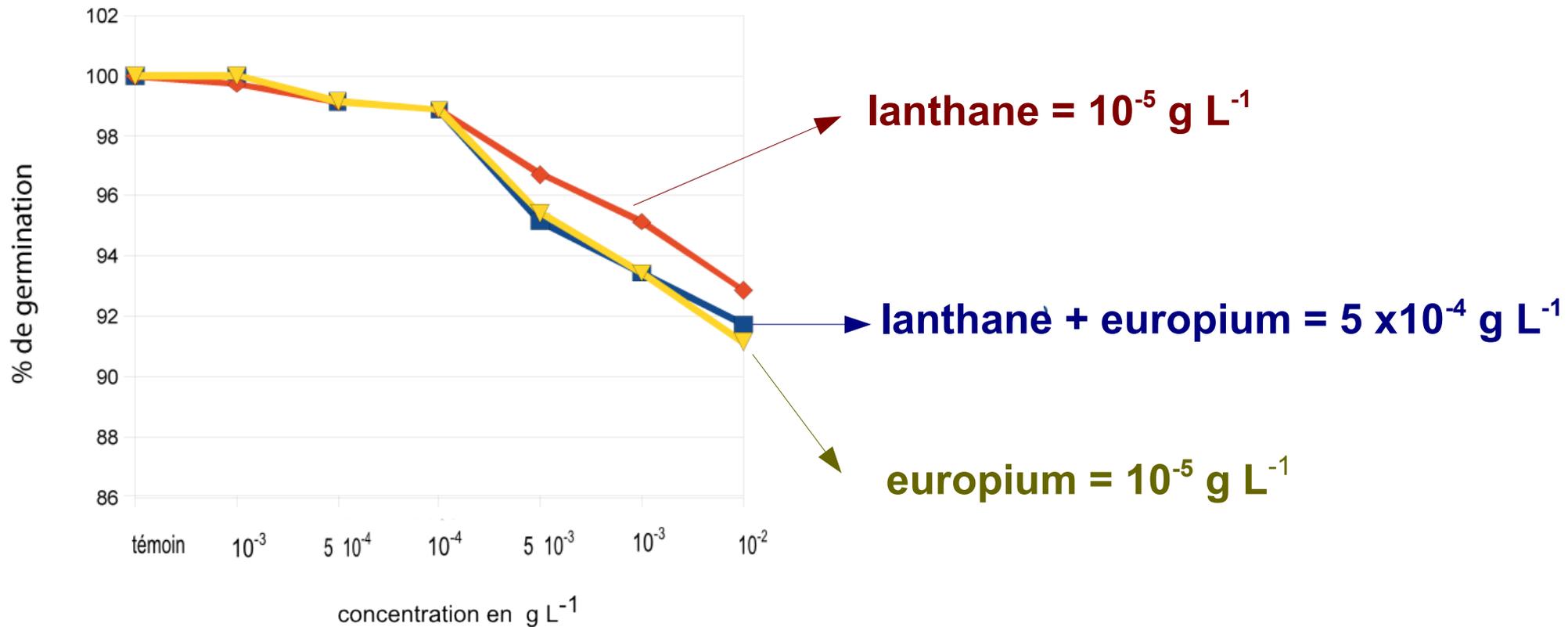
Accumulation dans les feuilles

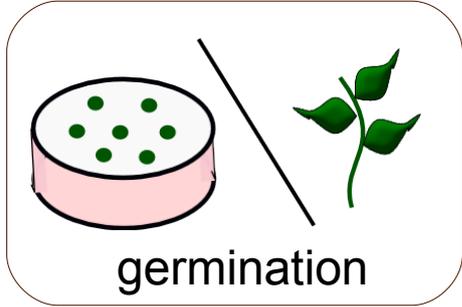


Germination



Comparaison des effets pour les TR
uniques et de la synergie des TR





Germination

Comparaison des effets pour les TR
uniques et de la synergie des TR

