Use of organic amendment and endomycorrhizal fungi for steel slags phytostabilization

PhD : Mathieu Scattolin
Supervisors : Olivier Faure, Fernando Pereira, Steve Peuble, Frédéric Paran

Saint-Etienne School of mines
158, cours Fauriel CS 62362, 42023 Saint-Étienne Cedex 2

Phytostabilization assays processed on a slag heap located at steel mill Industeel ArcelorMittal in Rive-de-Gier

Aerial view of Industeel-France ArcelorMittal and its slag heap (IGN 2017)

- Sandy texture
- Very high pH (≈ 11)
- No organic matter
- Metals concentration :

Chromium	≈ 2 %
Aluminium	≈ 6 %

Objectives

Developping phytomanagement process conducted during PHYSAFIMM² project

Aerial view of PHYSAFIMM plots

Various amendments :

- Ramial Chipped Wood
- Composted Sludge Sewage
- N/P/K mineral fertilization

Plant assemblages :

- « Regular »
- « Metallophyte »
- No seeding

[2](Bouchardon *et al.*, 2014)

Results obtained from PHYSAFIMM[2]

- Worst case (≈ 1 % vegetation cover)

P9 (NPK/0M) July 2013

- Amendment :

N/P/K mineral fertilization

- Plant assemblage :

No seeding

- Best case (≈ 95 % vegetation cover)

P5 (CSS/M2) July 2013

- Amendment :

Composted Sludge Sewage

- Plant assemblage :

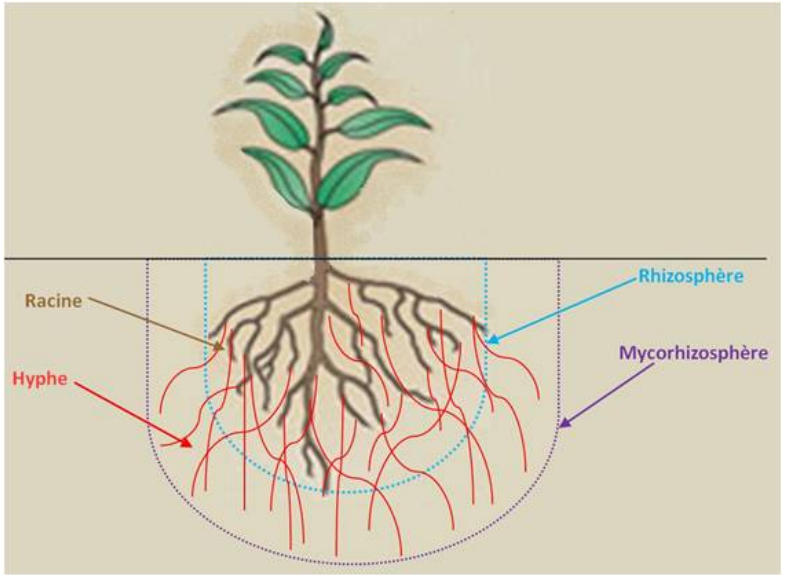
« Metallophyte » with mostly
Poaceae (*Festuca arundinacea*)
Fabaceae (*Melilotus officinalis*)

[2](Bouchardon *et al.*, 2014)

Bio-augmentation assay

- Using Arbuscular Mycorrhizal Fungi inoculate (AMF)

  - Essential nutrients uptake improvement (Meier *et al.*, 2012)
  - Tolerance to environmental constrains (Orlowska *et al.*, 2010)
  - Resistance to pathogenic organisms (Firmin *et al.*, 2010)
  - Chromium immobilization in hyphal tissues and limitation of translocation in plants aerial parts (Wu *et al.*, 2016)



Scheme illustrating mycorrhizal symbiosis (http://www.esitpa.org)

Organic amendment and bio-augmentation

Problematics :

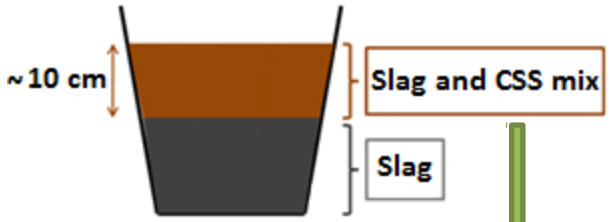
- Effect of CSS on mycorrhizal ability of *Rhizophagus irregularis* ?

- Effects of CSS and AMF on vegetation:

- plant biomass production ?
- Cr accumulation in vegetation ?
- plant nutritional statu ?

Experimental design

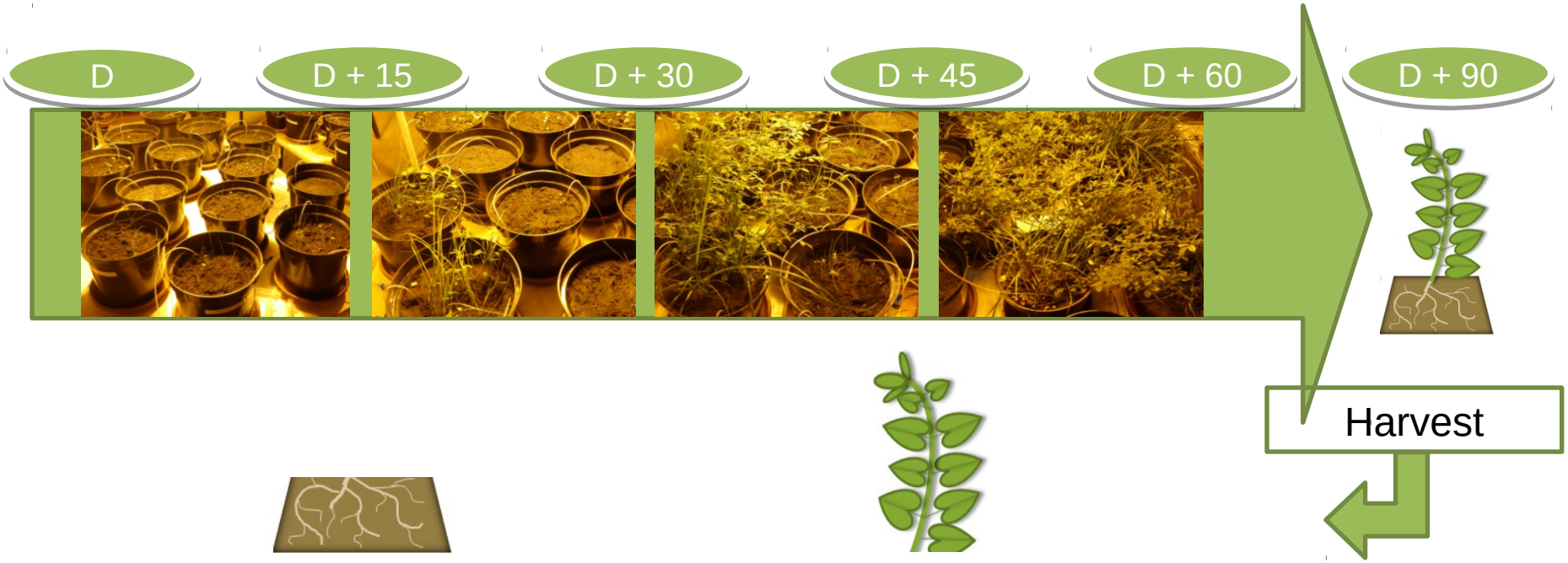
- Two factors (CSS and Ri) tested at two levels :



CSS quantity	AMF inoculation	Treatment
60T/ha (CSS60)	No (Ri0)	CSS60 - Ri0
60T/ha (CSS60)	Yes (Ri)	CSS60 - Ri
120T/ha (CSS120)	No (Ri0)	CSS120 - Ri0
120T/ha (CSS120)	Yes (Ri)	CSS120 - Ri

Experimental design

- Pots culture lasted 3 months :



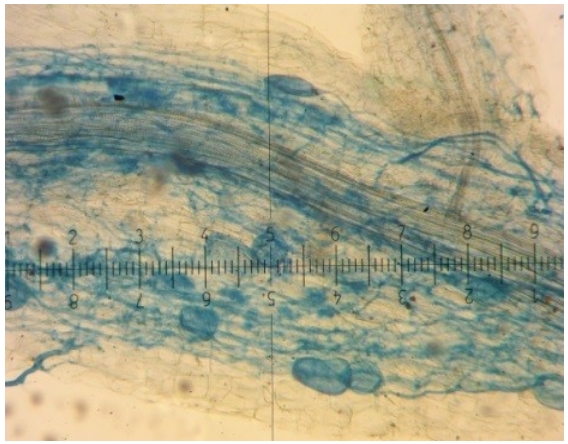
Counting mycorrhizal structures (optical microscopy)

Quantification of major elements and trace elements (ICP-MS/AES)

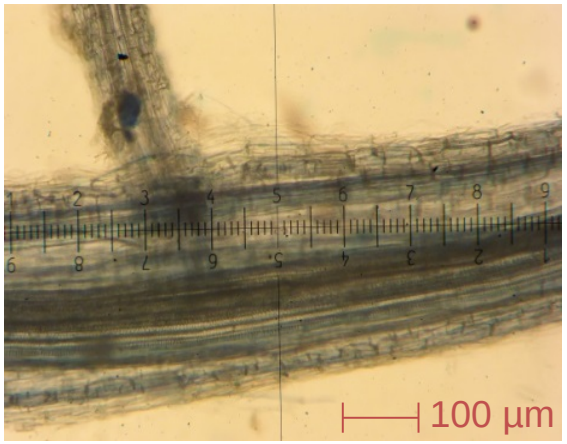
Plants mycorrhizal statu

- Effect of CSS on mycorrhizal ability of *Rhizophagus irregularis* ?

A)



B)



Root fragments of *Melilotus officinalis* mycorrhized (A) or not (B)

Plants mycorrhizal statu

Plant species	Treatment	Mycorrhizal frequency (%)	Mycorrhizal intensity (%)
F. arundinacea	CSS60	47,5 ± 17,8 (bc)	4,9 ± 6,9 (ab)
	CSS120	94,0 ± 10,2 (a)	14,0 ± 10,3 (a)
M. officinalis	CSS60	27,5 ± 10,9 (c)	0,5 ± 0,4 (b)
	CSS120	58,9 ± 22,8 (b)	17,2 ± 15,8 (a)

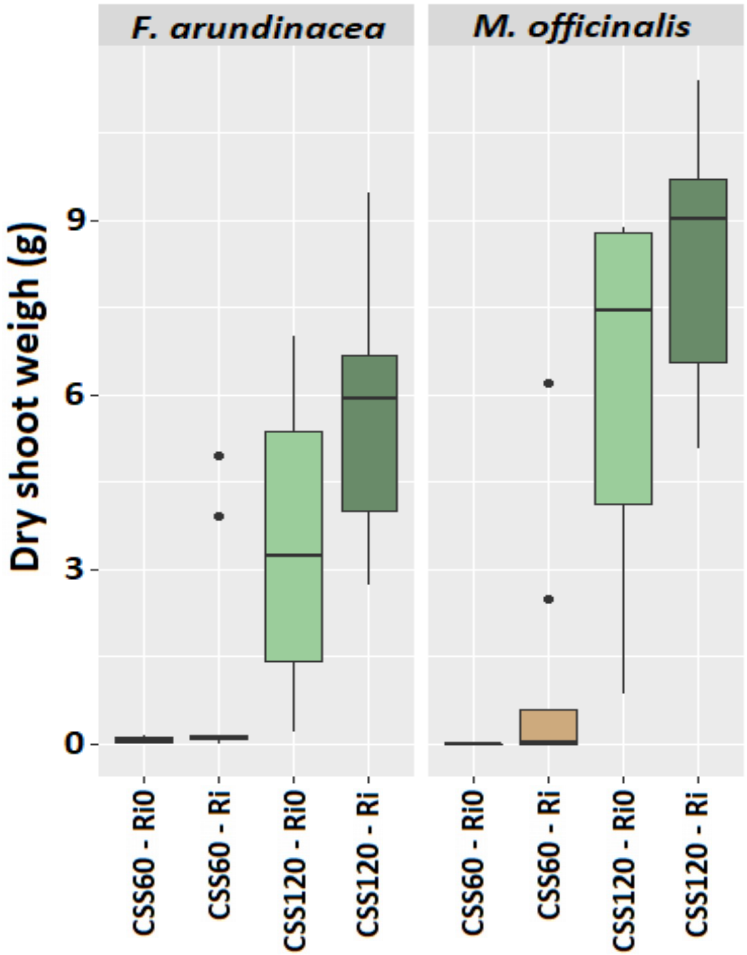
Mycorrhization frequency and intensity were significantly higher for plants grown in CSS120 than in CSS60.

Fescues showed greater mycorrhizal frequency than Melilots.

Evaluation of plants development

- Effects of CSS and AMF on plants development ?

Evaluation of plants development



Plants grown in CSS60 had very low aerial biomass compared with CSS120 :

- CSS60 | CSS120 p-value < 0.001***

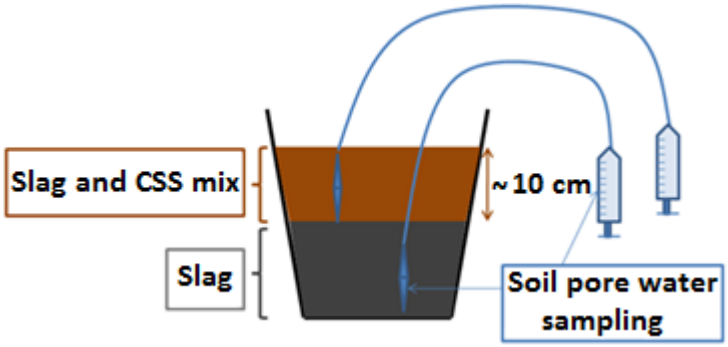
AMF inoculation slightly tend to increase plants aerial biomass in CSS120 :

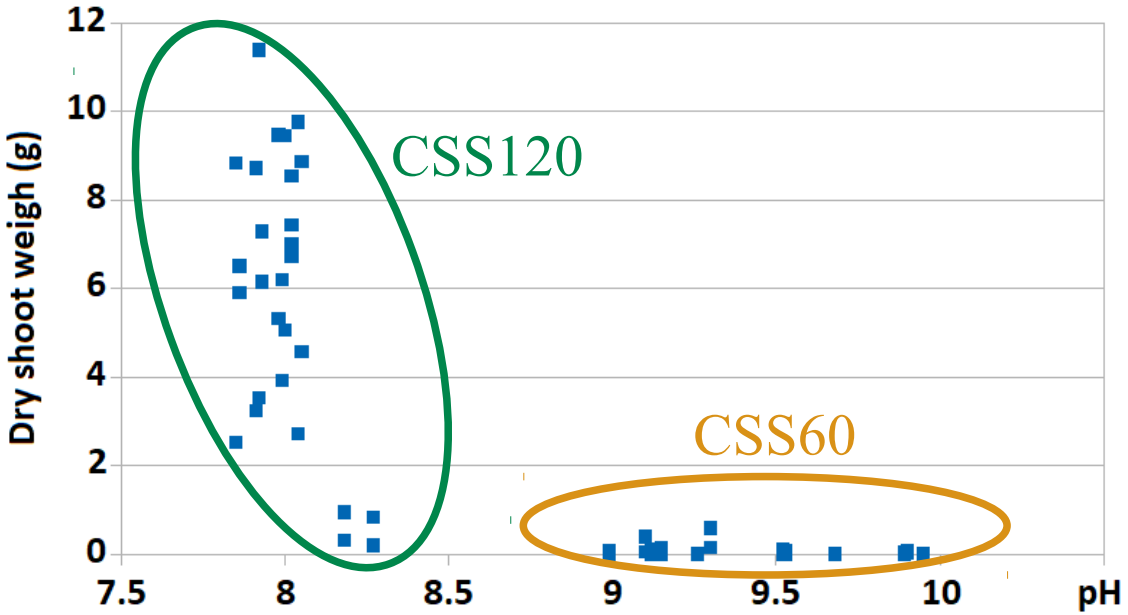
- Fescues : Ri0 | Ri p-value = 0.181
- Melilots : Ri0 | Ri p-value = 0.295

Melitots did not grown in CSS60 - Ri0

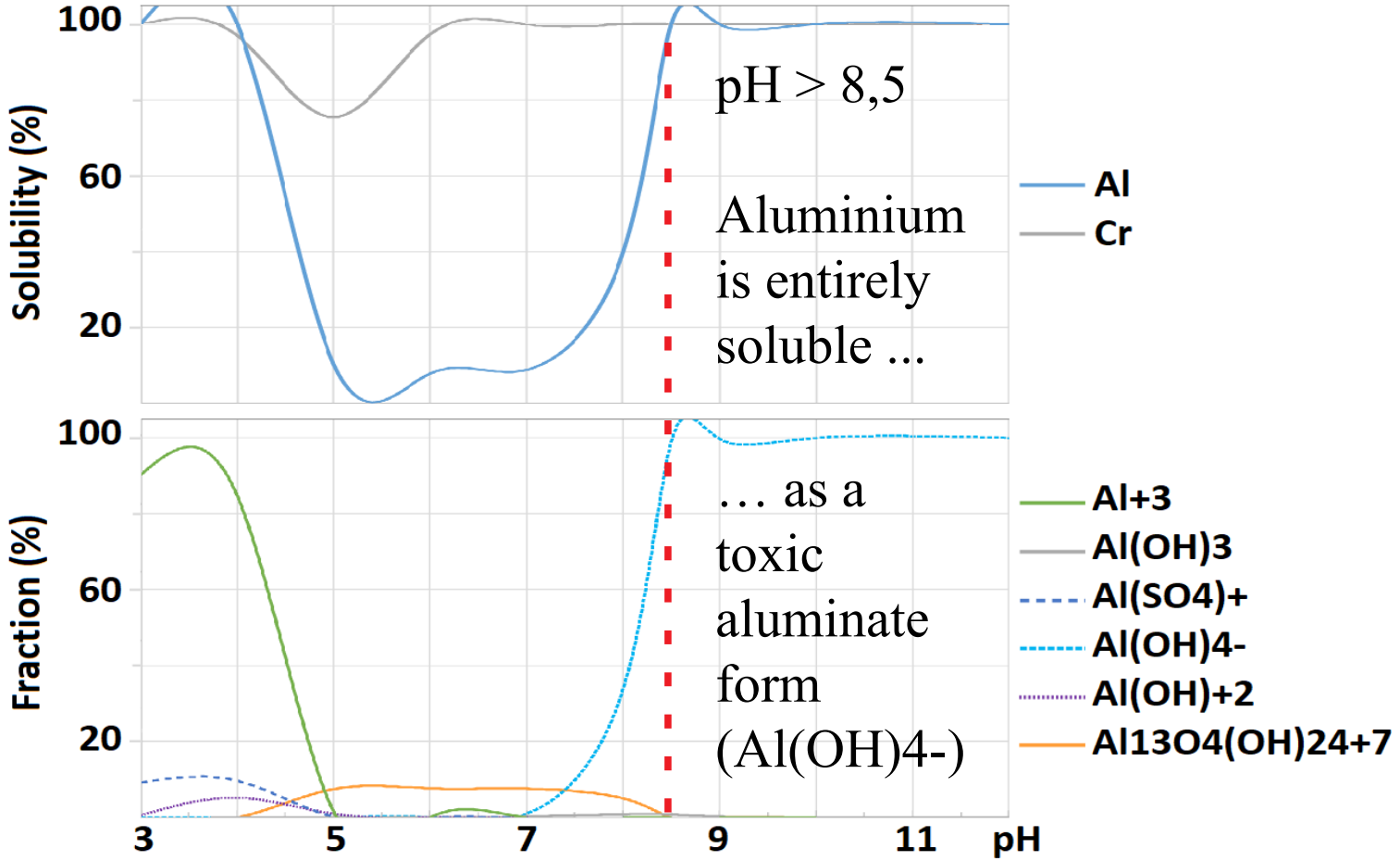
To go a little further

- Why such biomass differences between CSS levels ?





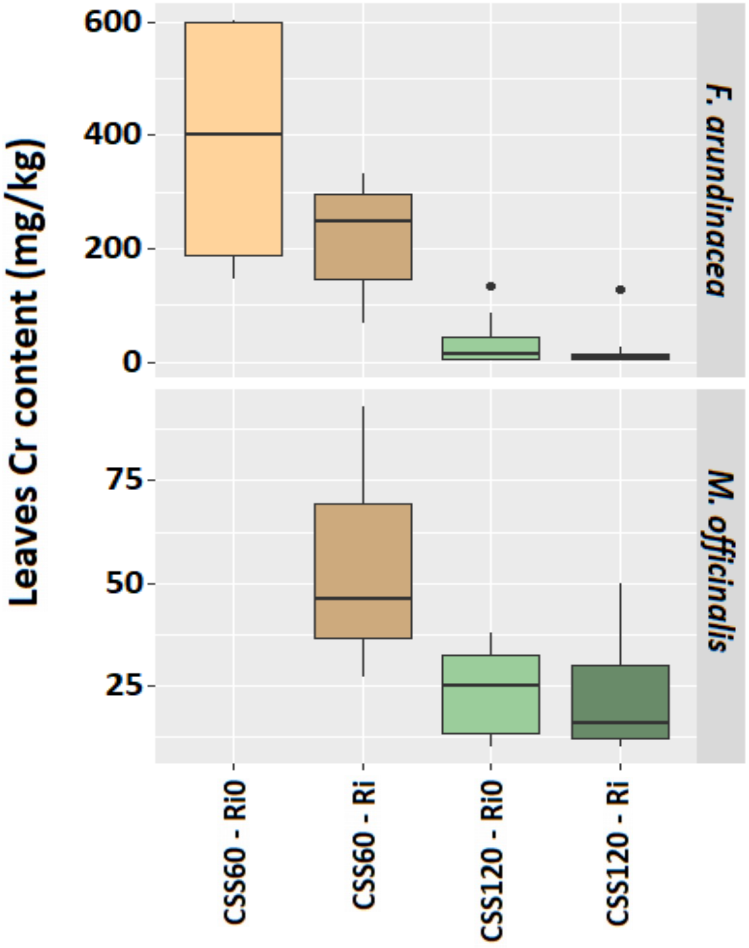
Geochemical modelling run using PhreeqC program



Tracking of leaves elements contents

- Effects of CSS and AMF on metal accumulation and nutritional plants statu ?

Foliar chromium content



Plants grown on CSS60 exhibited higher Cr leaves content compared with CSS120 :

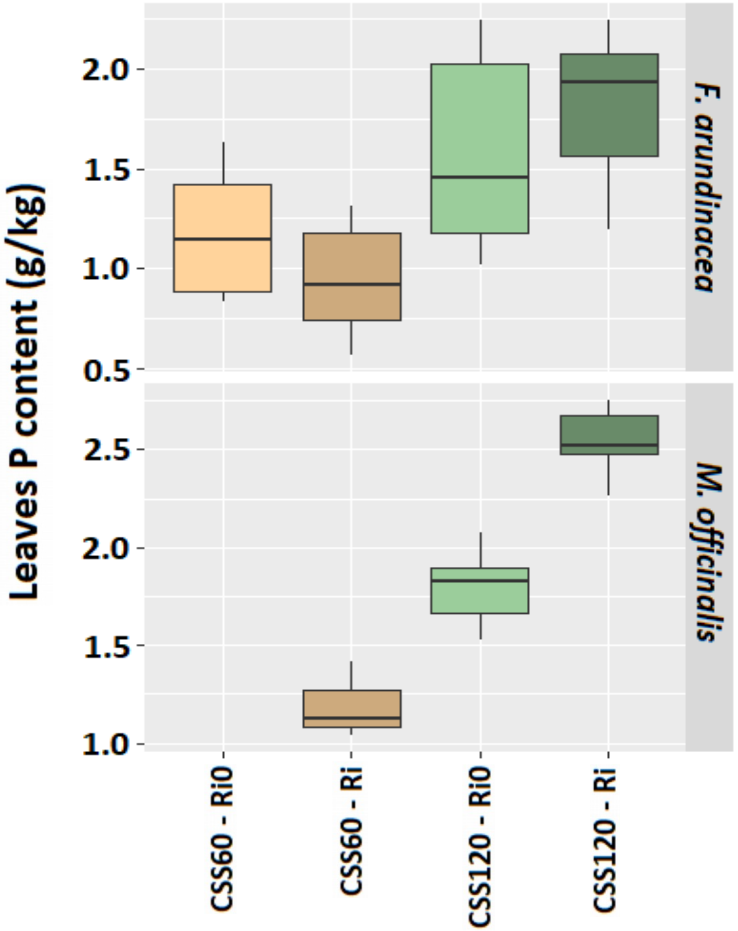
- CSS60 | CSS120 p-value < 0.05 *

In CSS120, AMF inoculation slightly tend to decrease Cr content in leaves of Fescues :

- Fescues : Ri0 | Ri p-value = 0.07

Low Melilots individuals impaired statistical tests

Foliar phosphorus content



P leaves content of Fescues are mostly drive by CSS level :

- Fescues : CSS60 |CSS120 p-value < 0.01**

While in CSS120, foliar P of Melilots responded better to AMF inoculation :

- Melilots : Ri0 | Ri p-value < 0.01**

Conclusion

- Composted Sludge Sewage effects :

  On slag :

  - Improves water retention capacity
  - Reduces pH and phytotoxicity of Al

  On vegetation

  - Drives biomass production and P uptake
  - Limits Cr accumulation

- AMF employment:
  - Leads to roots colonization
  - Can increase biomass production and P uptake by Melilots
  - Slightly decreases Cr uptake by Fescues

References

- Bouchardon J.L., Faure O., Lespagnol G., Moutte J., Guy B., Mimoun D., Graillot D., Paran F., Croze V., Athenol J.D., Ferrando B., Boisson J., Perret S., Hitmi A., Verney P., Moussard Gauthier C., Ledoigt G., Goupil P., Sac C., Mench M.(2014) Physafimm: la phytostabilisation, méthodologie applicable aux friches industrielles, metallurgiques et minières.

- Meier S., Azcón R., Cartes P., Borie F., Cornejo P. (2011) Alleviation of Cu toxicity in Oenothera picensis by copper-adapted arbuscular mycorrhizal fungi and treated agrowaste residue, *Applied Soil Ecology*, **48**:117-124.

- Orłowska E., Orłowski D., Mesjasz-Przybyłowicz J., Turnau K. (2010) Role of Mycorrhizal Colonization in Plant Establishment on an Alkaline Gold Mine Tailing, *International Journal of Phytoremediation*, **13**:185-205.

- Firmin, S., Labidi, S., Fontaine, J., Laruelle, F., Tisserant, B., Nsanganwimana, F., Pourrut, B., Dalpé, Y., Grandmougin, A., Douay, F., Shirali, P., Verdin, A., Lounès-HadjSahraoui, A. (2015) Arbuscular mycorrhizal fungal inoculation protects Miscanthus × giganteus against trace element toxicity in a highly metal-contaminated site, *Science of The Total Environment*, **527**:91-99.

- Wu S., Zhang X., Chen B., Wu Z., Li T., Hu Y., Sun Y., Wang Y. (2016) Chromium immobilization by extraradical mycelium of arbuscular mycorrhiza contributes to plant chromium tolerance, *Environmental and Experimental Botany*, **122**:10-18.

HYPASS

Use of organic amendment and endomycorrhizal fungi for steel slags phytostabilization

Merci de votre attention !