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▶ **To cite this version:**

Guillaume Echevarria, Alan Baker, Jean-Louis Morel, Antony van Der Ent, Vivian Houzelot, et al.. Agromining for nickel: a complete chain that optimizes ecosystem services rendered by ultramafic landscapes. 13th SGA Meeting "Mineral Resources in a Sustainable World, Society for Geology Applied to Mineral Deposits (SGA). DEU., Aug 2015, Nancy, France. hal-01263575

HAL Id: hal-01263575
https://hal.science/hal-01263575

Submitted on 27 Jan 2016

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Agromining for nickel: a complete chain that optimizes ecosystem services rendered by ultramafic landscapes

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Abstract. Serpentine (i.e. ultramafic) outcrops in Europe cover more than 10,000 km^2 and have a low-fertility and low-productivity, making them unattractive for traditional agriculture. Many of these areas are slowly abandoned by local farmers, with rural exodus and landscape closure. However, ultramafic landscapes have the potential to provide multiple ecosystem services and can contribute to Europe's goals towards insuring food security, production of renewable raw materials and renewable energy. Phytomining (Agromining) cultivates plants that are able to accumulate trace metals from metal-rich soils and transport them to the shoots (>1%), which can then be harvested as a bio-ore to recover highly valuable metals, e.g. nickel (Ni). Nickel agromining can offer an eco-efficient alternative to classical pyro- or hydrometallurgical processes, as well as providing biomass for local energy production.
Phytomining agroecosystems can lead to better soil resource efficiency and can offer a fully integrated, new agromining agriculture that could cover thousands of km^2 in Europe and benefit local communities with a sustainable rural development.

Keywords. Phytomining, Life Cycle Assessment, Hyperaccumulator plants, Fuel crops, Hydrometallurgy, Agroecology

1 Introduction

Serpentine (i.e. ultramafic) outcrops are biodiversity hotspots, especially the larger ultramafic areas. Serpentine soils can be stressful environments for plant growth and the plant communities in these areas often present a high number of endemic species, which have evolved both morphological and physiological adaptations differentiating them from the flora of adjacent geological substrates. Serpentine agricultural soils are generally characterised by low fertility and productivity, making them unattractive for agriculture (Bani et al., 2015). As a consequence, many of these areas are slowly abandoned by local farmers. The adjacent steep or rocky slopes have never been cultivated and usually host the highest number of endemic species. Ultramafic flora includes unusual plant groups (hyperaccumulators), which are able to accumulate extremely high concentrations of Ni in their aerial biomass.

2 Nickel Phytomining

The worldwide demand for Ni is experiencing an unprecedented growth under current industrial and economic pressures. However, technologies are lacking to exploit unweathered primary sources (ultramafic soils) in which Ni is present at significant contents (1 500-4 000 mg kg^{-1}), but where its extraction by conventional mining processes is economically unviable. Hyperaccumulator plants are cultivated to accumulate trace metals from soils and transport them to shoots, which can then be harvested (Chaney et al., 2007; van der Ent et al., 2015). Yields have been optimized, and up to 120 kg Ni ha^{-1} is currently produced in field plots in Europe (Bani et al., 2015a, 2015b). Hydrometallurgy from hyperaccumulator ash (after combustion and energy production) can produce Ni-based chemicals (e.g. Ammonium Nickel Sulfate Hydrated with a purity of more than 99%) worth up to

$20 000 per ton in a purified form (Barbaroux et al., 2012; Zhang et al., 2014). Therefore, the production of high value-added Ni products, around a thousand tons per year from combined phytomining and hydrometallurgy offers a high potential of profitability. Phytomining has been developed and optimized from field agronomy in both north America and Albania to full metallurgical process and brought to pilot scale.

3 A new concept: agromining for metals

Agromining is a more integrated concept than phytomining (van der Ent et al., 2015) with the aim of optimizing ecosystem services of ultramafic regions at landscape level after. Agromining is a complete design of new agroecological cropping systems and associated metallurgical chain (including recycling of process by-products in crops). Carrying out a complete Life Cycle Assessment of the agromining chain, it is designed to optimize i) Provisioning services (green Ni products, fuel biomass for local communities), ii) supporting and regulating services (amelioration of soil quality and productivity for agriculture, ensuring the conservation of rare and endangered species, Stimulating populations of pollinating insects, enhancing carbon storage in ultramafic landscapes and iii) cultural services (maintaining agricultural communities in ultramafic landscapes, improve landscape quality, stimulate tourism).

3 How to design Agromining in Europe with the objective of optimizing ecosystem services

Europe host large ultramafic outcrops (Figure 1), mainly situated in Iberian and Italian peninsulas, Corsica and the Balkan region (van der Ent et al., 2015). These regions are also home for a large plant hyperaccumulator diversity which can be utilised in agromining projects (Figure 1).

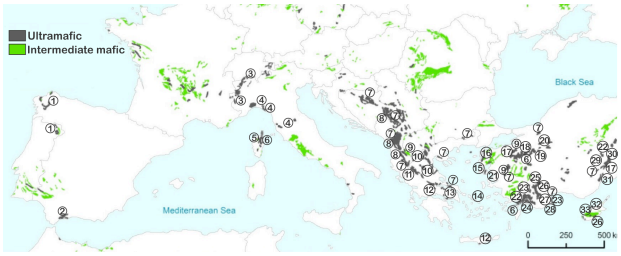


Figure 1. Ultramafic outcrops and Ni-hyperaccumulator taxa occurrence in Europe and western Anatolian peninsula.

Agromining for Ni in Europe should provide adapted cropping systems combining phytomining, food, medicinal or forage crops in such a way so as to restrict the entry of trace metals into the food chain and protect human and animal health. It should at the same time optimise all ecosystem services towards populations, territories and nature (Figure 2). Phytomining systems will be developed throughout the project with the goal of optimising their ecosystem services. Therefore, the Life Cycle Assessment of phytomining will serve as a guideline to organise all research objectives.

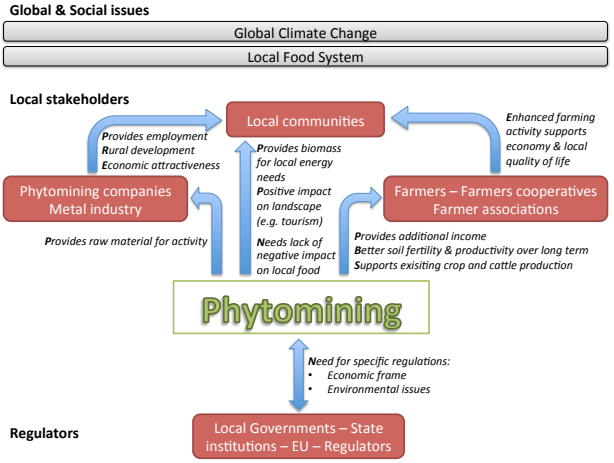


Figure 2. Interactions of agromining activities in ultramafic regions of Europe with local and state stakeholders in the frame of global issues.

The implementation of Ni agromining in Europe should rely on the three following steps in order to optimise ecosystem services rendered by this new agricultural activity:

- Assessment of phytomining at landscape level after complete design of new agroecological cropping systems.
- Establishment of a complete Life Cycle Assessment of the phytomining chain.
- Specific description and optimisation of the following ecosystem services:
    1. Amelioration of soil quality and productivity for agriculture
    2. Supplying industry with a green Ni resource and tailored Pure Ni salts
    3. Producing fuel biomass for local communities
    4. Ensuring the conservation of rare and endangered species by introducing them in new cropping systems
    5. Stimulating and increasing the population of pollinating insects through cropping large surfaces of hyperaccumulator crops
    6. Limiting Ni contents in food products (honey,…)
    7. Enhancing carbon storage in ultramafic landscapes.

4 Conclusions and Perspectives

These technologies are about to be launched at a territory scale thanks to several private initiatives, which are looking for areas to implement phytomining. Phytomining agroecosystems will benefit local communities in terms of rural development and sustainability. Trade-off between provisioning services (food and non-food) will be a key to the success of its implementation in many areas of Europe (e.g. Albania). Setting up agromining research stations in representative

ultramafic areas (i.e. Northwestern Spain and Albania) will help build a generic approach that will be applicable to all ultramafic regions of Europe and the Mediterranean basin. These research centres will act as field demonstrators for farmers but also for public stakeholders, local communities and private stakeholders (capacitation and structuring of the activity). It will also be a basis for future adapted agricultural policies for the economic development of ultramafic regions of Europe.

Acknowledgements

This work was supported by the French National Research Agency through the national "Investissements d'avenir" program, reference ANR-10-LABX-21 - LABEX RESSOURCES21.

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