Biodiversité Microbienne des Sols : du territoire national aux agriculteurs

Soil Microbial Biodiversity : from French National Territory to Farmers

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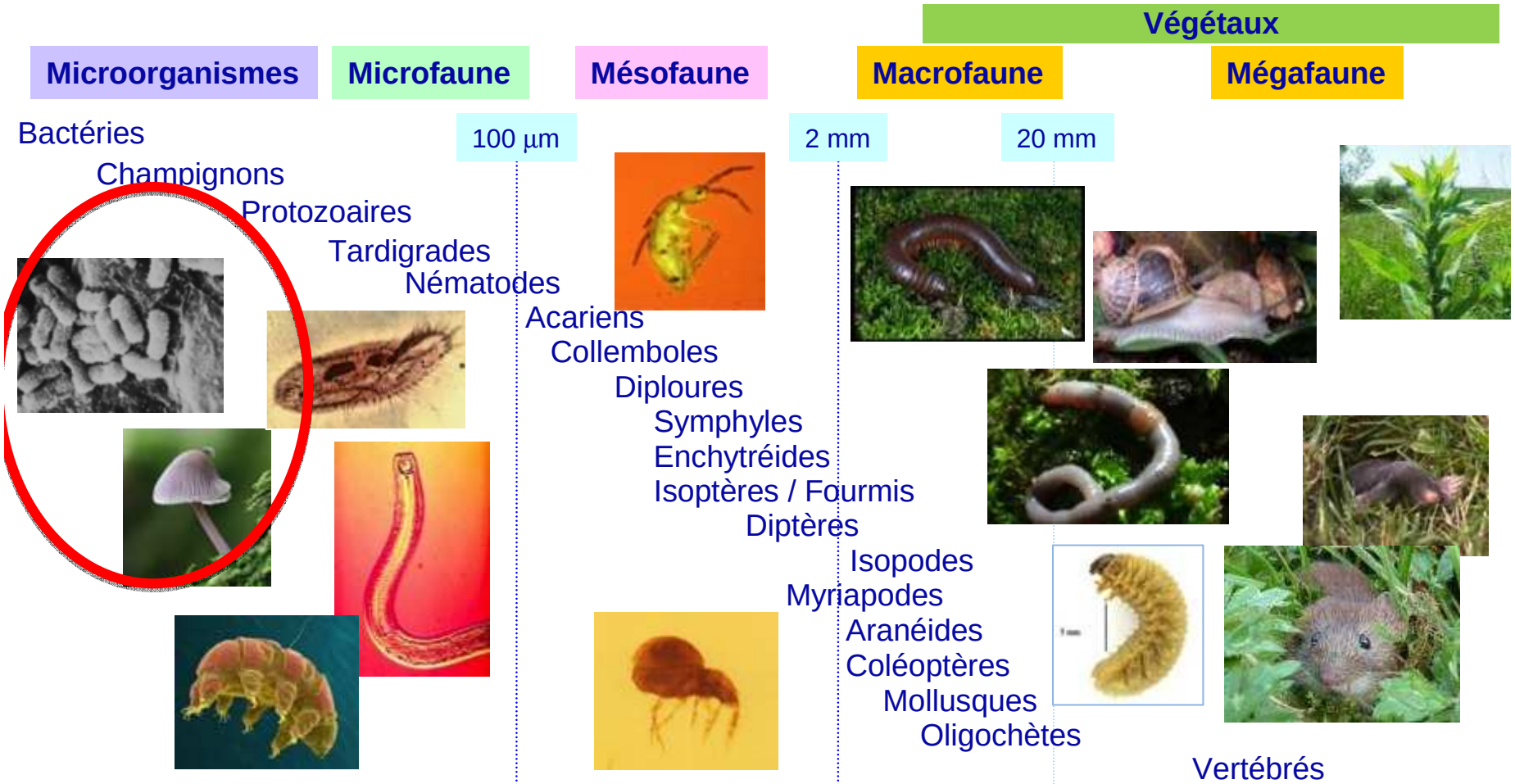
INRA UMR Agroécologie, Dijon

Launch of the Global Soil Biodiversity Atlas in France,
28th November 2016

Soil is a living matrix !!!

from micro- to macroorganisms

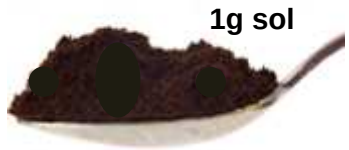


Modifié d'après Swift et al. (1979)

Microorganisms are key players of soil functioning and relevant indicators of soil quality

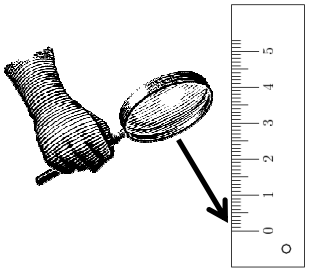
Huge abundance and diversity

10^9 bacteria
10^6 species

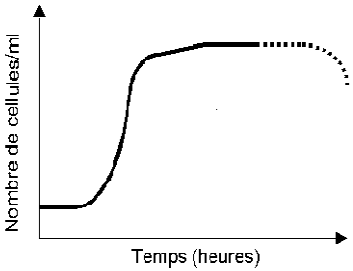


10^6 fungi
10^3 species

Important fitness



Small size

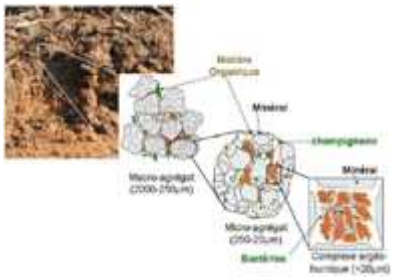


Small Generation Time

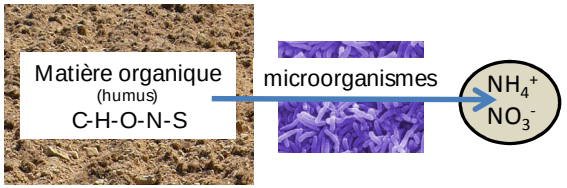
High genome plasticity

Rapid response to environmental modifications

Involved in numerous soils functions

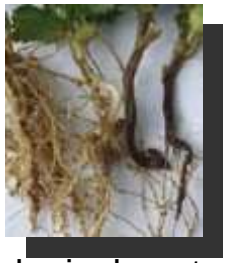


Soil structure



Organic matter mineralisation, Carbon recycling, nutriments

Soil detoxification

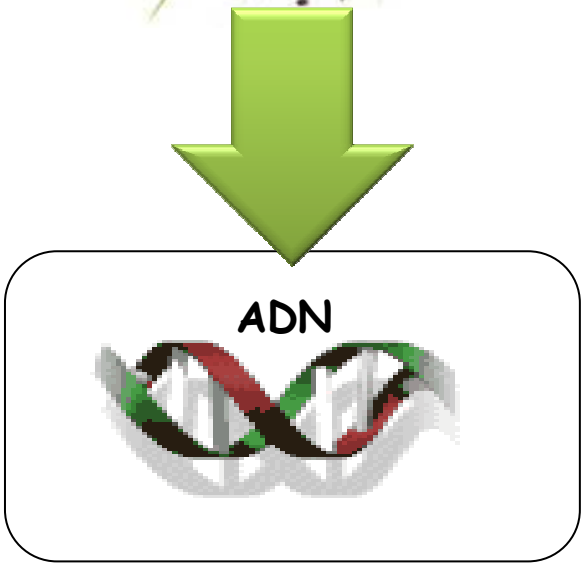


Biological control of pathognens

How to characterize soil microbial diversity?

A new way: Molecular Microbial Ecology !

Soil

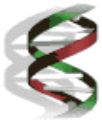


Abundance
Genetic / Taxonomic and Functional Diversity

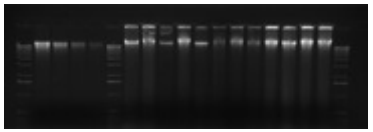
Molecular tools

Soil

DNA

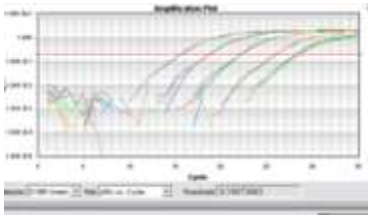


DNA yield



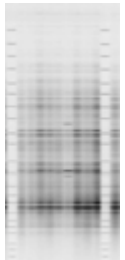
Molecular Microbial Biomass

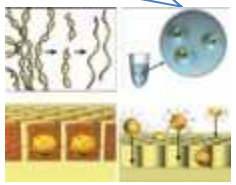
qPCR 16S/18 rDNA



Bacterial density
Fungal density
Ratio Fungy / Bacteria

DNA fingerprint





Taxonomic inventory
High throughput sequencing

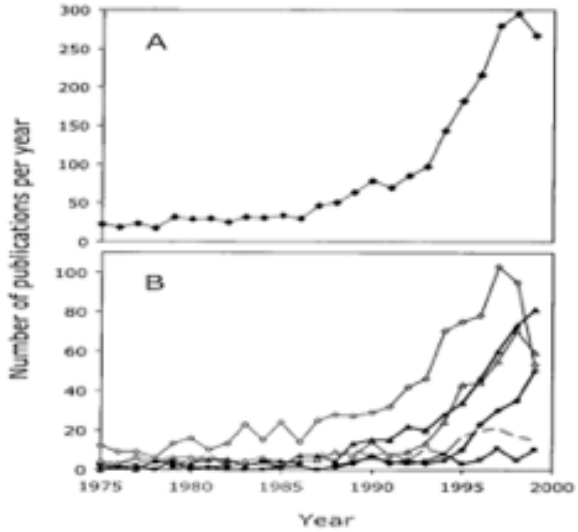
Genotyping

Microbial abundance

Genetic structure
Diversity index
Taxonomic Composition

Plateforme GenoSol INRA
Exploring the microbial world
To better protect our environment

Exponential increase of the number of studies dealing with microbial diversity in natural ecosystems

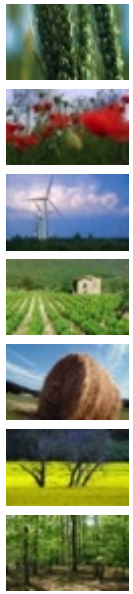


Morris et al., 2002

- Statement: most of studies are locally specific of a site
  - Lack of genericity
    - Lack of knowledge on the spatial distribution of microorganisms

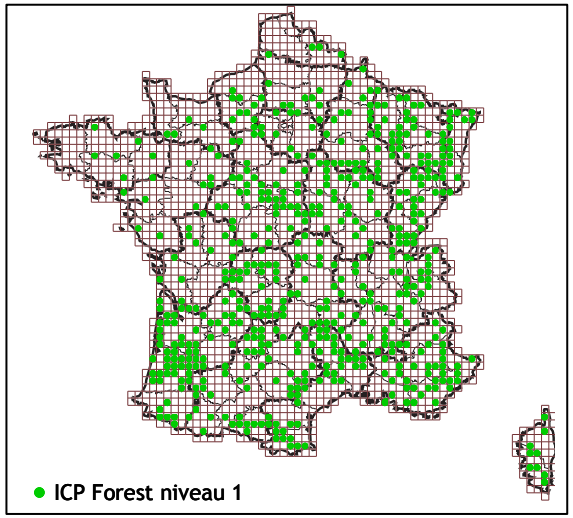
Need to develop studies on a broader spatial scale

Microbial biogeography

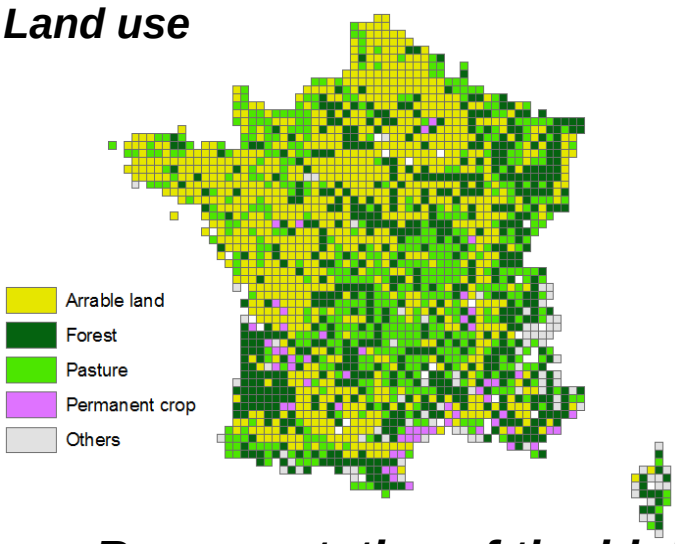


French Soil Quality Monitoring Network (RMQS)

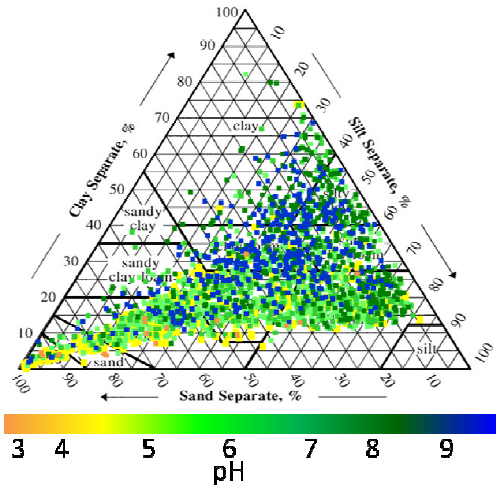
Sampling grid of French soils: 16 kmx16km for all the territory ⇒ 2200 sites



Land use

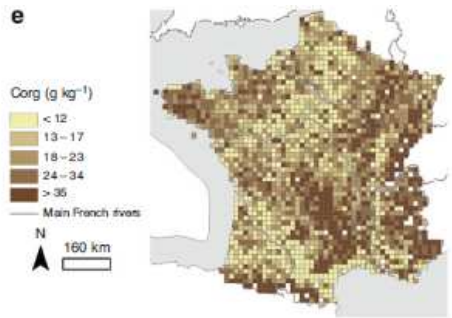


Texture



Representative of the high variability of land use and soil characteristics of France

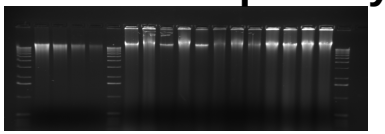
Cartography of soil quality only based on physico-chemical parameters:
- texture, pH, Corg tot, Norg, Ca, Na, Mg, ETM, …
- plant cover, geomorphology, climatic conditions, land-use, etc…



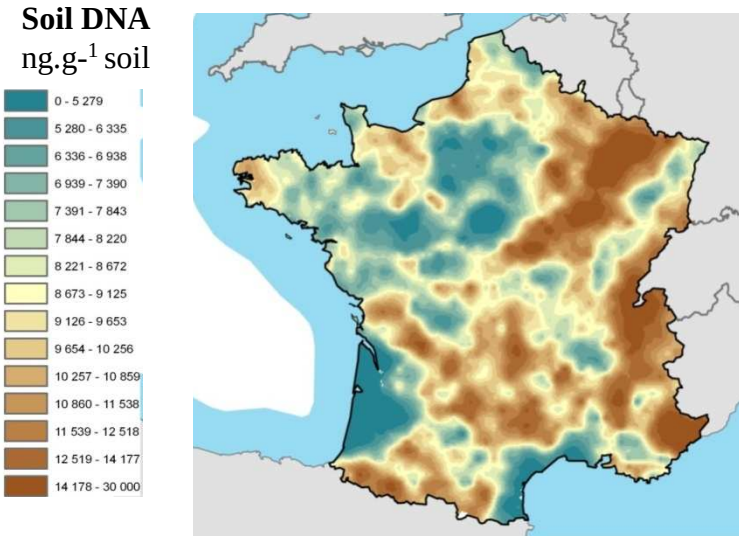
Characterization of microbial communities (ECOMIC-RMQS)

Financé par ANR

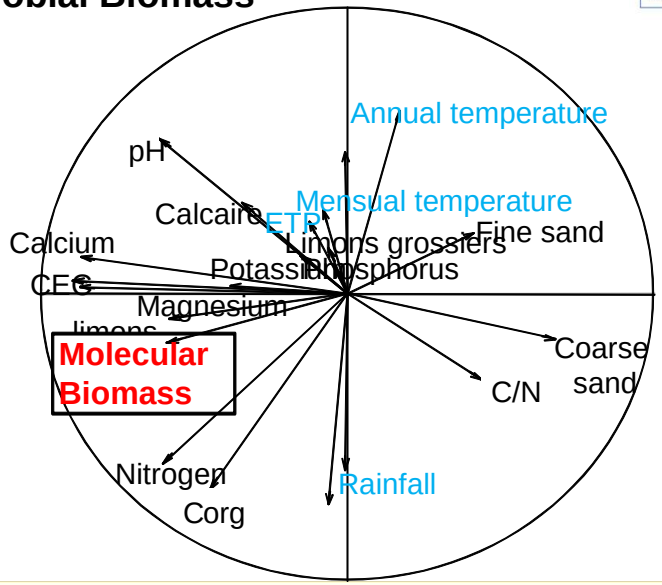
Soil DNA quantity

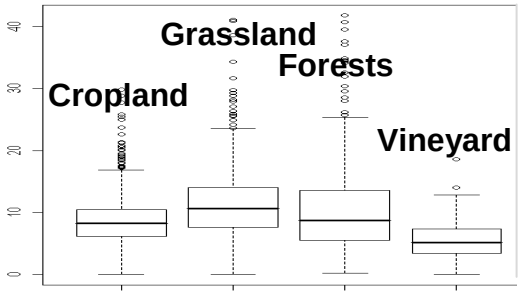


Molecular Microbial Biomass



Mapping of soil molecular microbial biomass





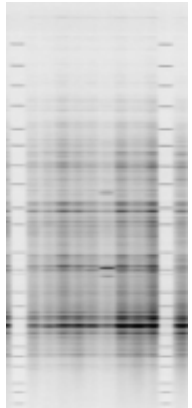
Texture, CEC > Corg, N, pH, C/N
>>> Climatic parameters

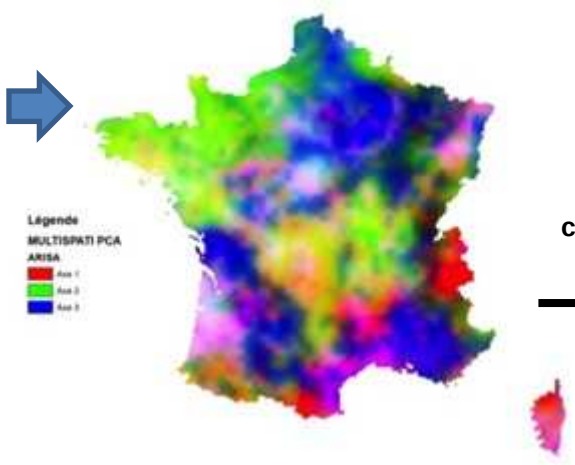
Grasslands > Forests > Croplands>>
Vineyards / Orchards

Agroécologie Dijon Unité de Recherche

Dequiedt et al., 2011, Global Ecology and Biogeography

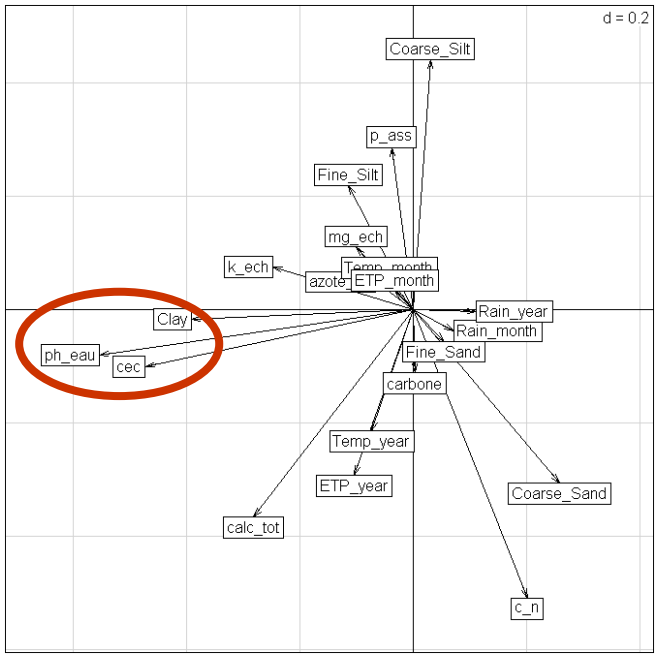
Biogeographical structure of microbial communities





ARISA **Mapping of soil bacterial communities based on structure variations**

Coinertia with soil characteristics



- **Opposite regions→ Regional differences** in terms of **composition**

- **Spatial structures → Ecological regions with more or less variability** (« diversity »)

pH and texture are strongly correlated with structure variations

Climate is less correlated compared to soil characteristics

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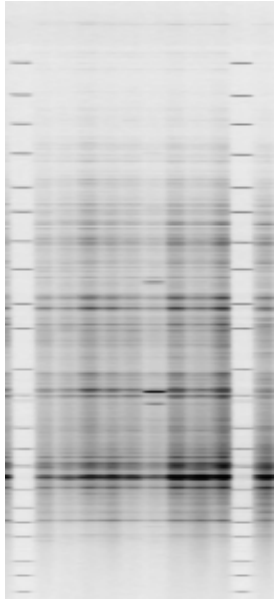
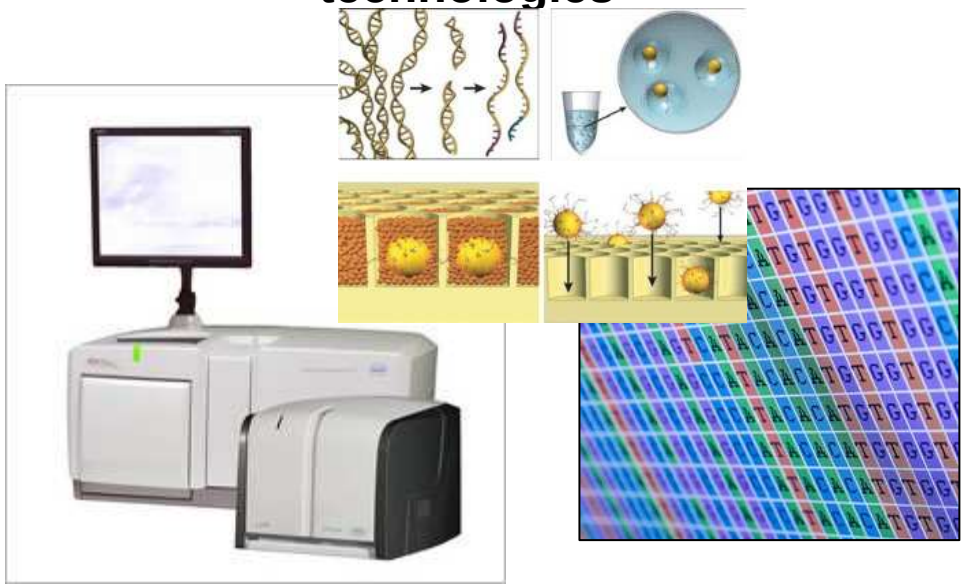
Dequiedt et al., 2009, Environ. Microbiol. Rep.

MetaTAXOMIC-RMQS project: from Genotyping to Sequencing

Genotyping



High-throughput sequencing technologies



Genetic structure

Taxonomical Inventory
(several thousands of species / soil)

True estimation of diversity
Identification of agro-ecological populations of interest (pathogens, etc…)

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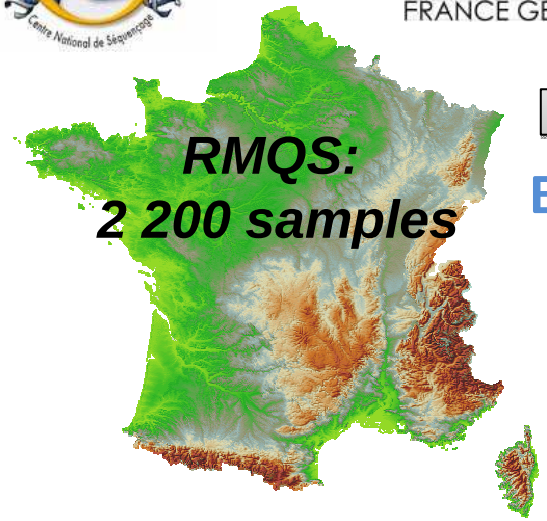
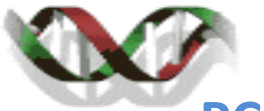
The MetaTAXOMIC-RMQS project



Extraction

DNA



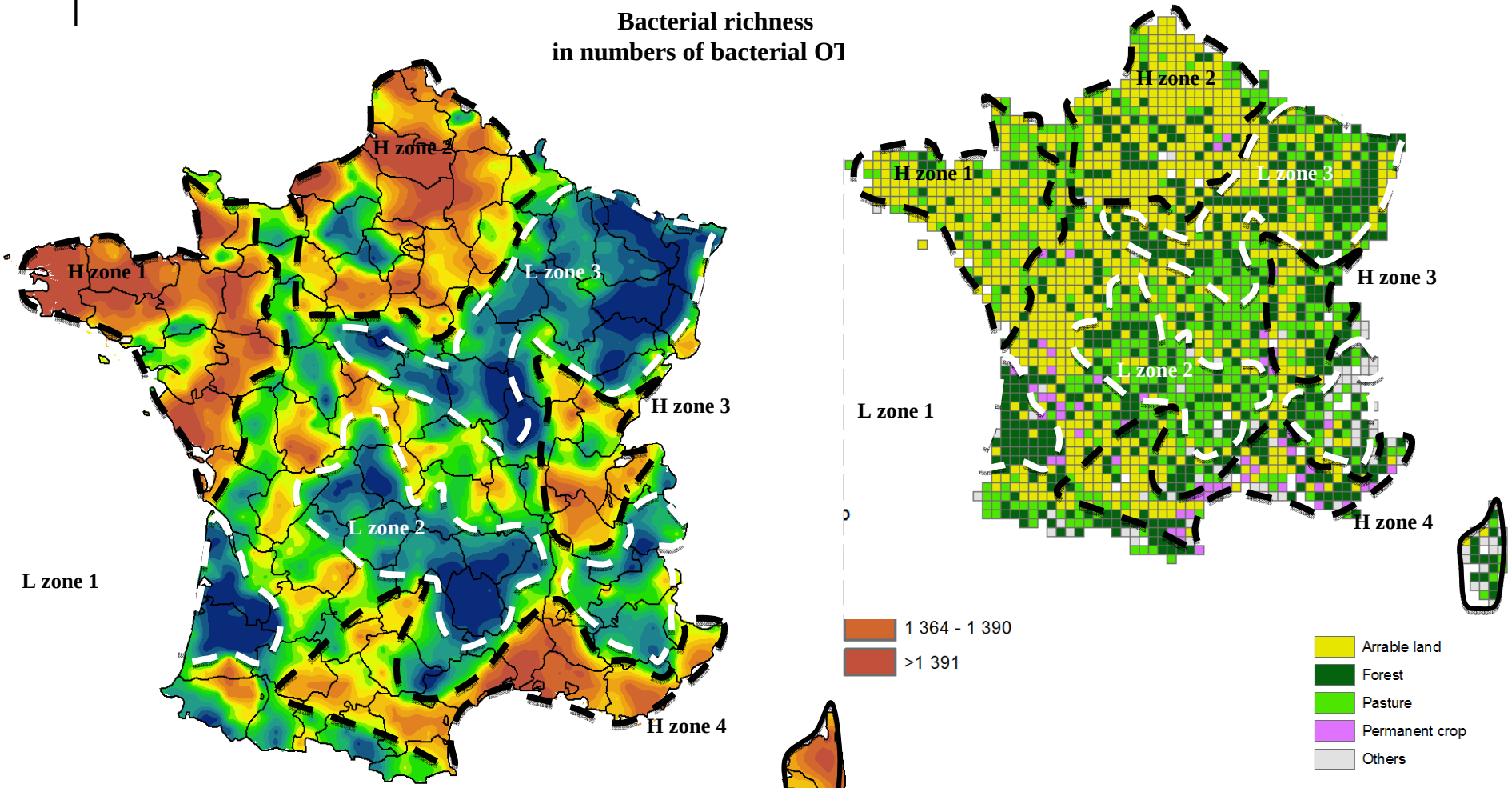
PCR Amplification

PCR products

Sequencing

About 75 Millions of raw reads

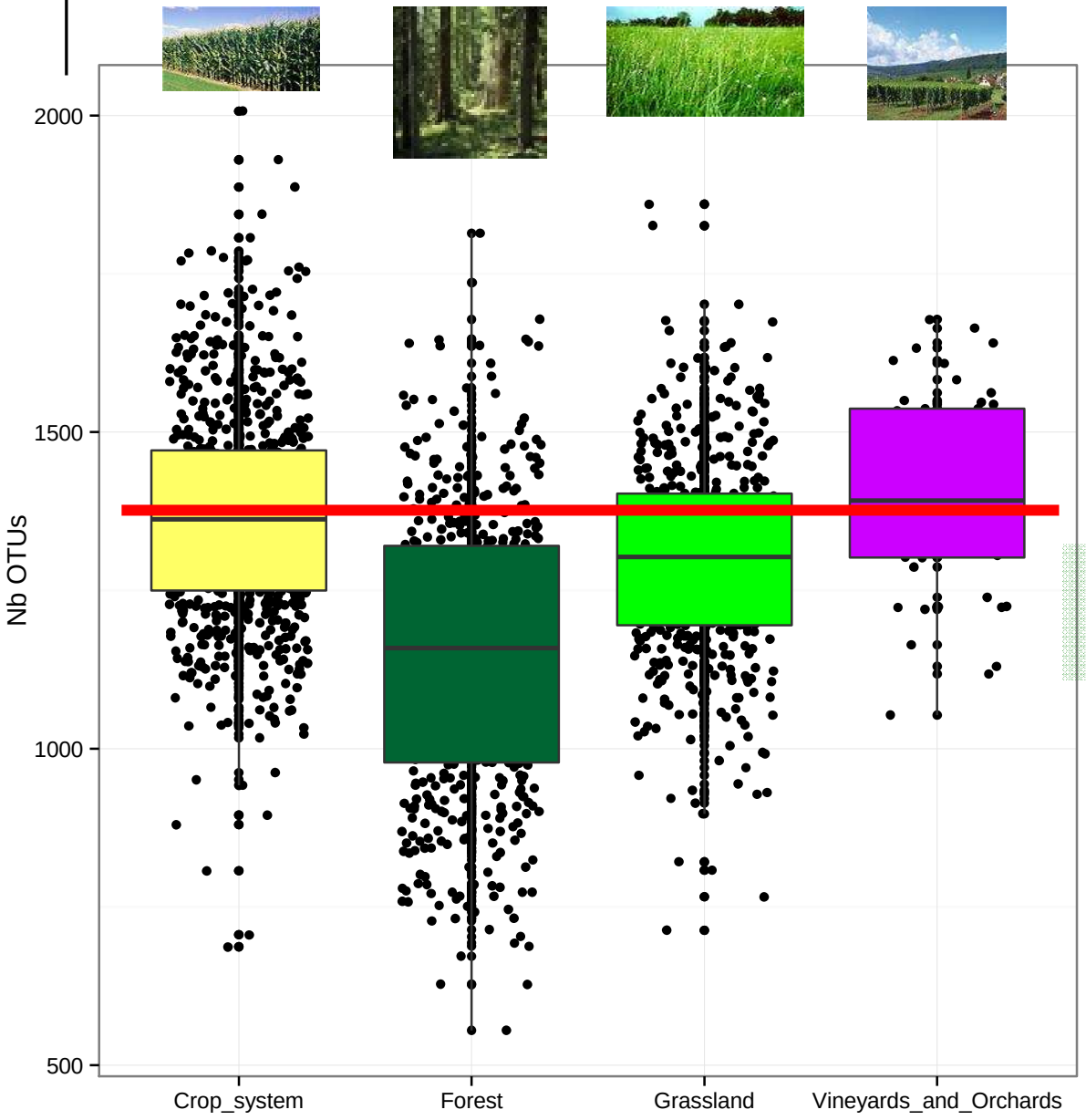
Mapping of soil bacterial diversity on the scale of France



- **Clear regional differences based on the bacterial diversity**
- **Bacterial diversity** seems to be **strongly linked** to land use (forest, grassland, crops…).

Terrat et al., 2016, in prep.

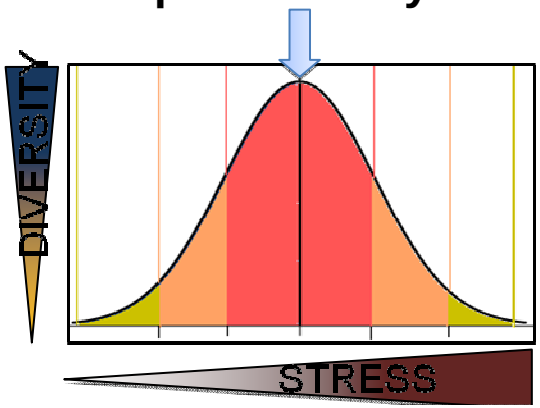
Relationship between bacterial diversity and land use.



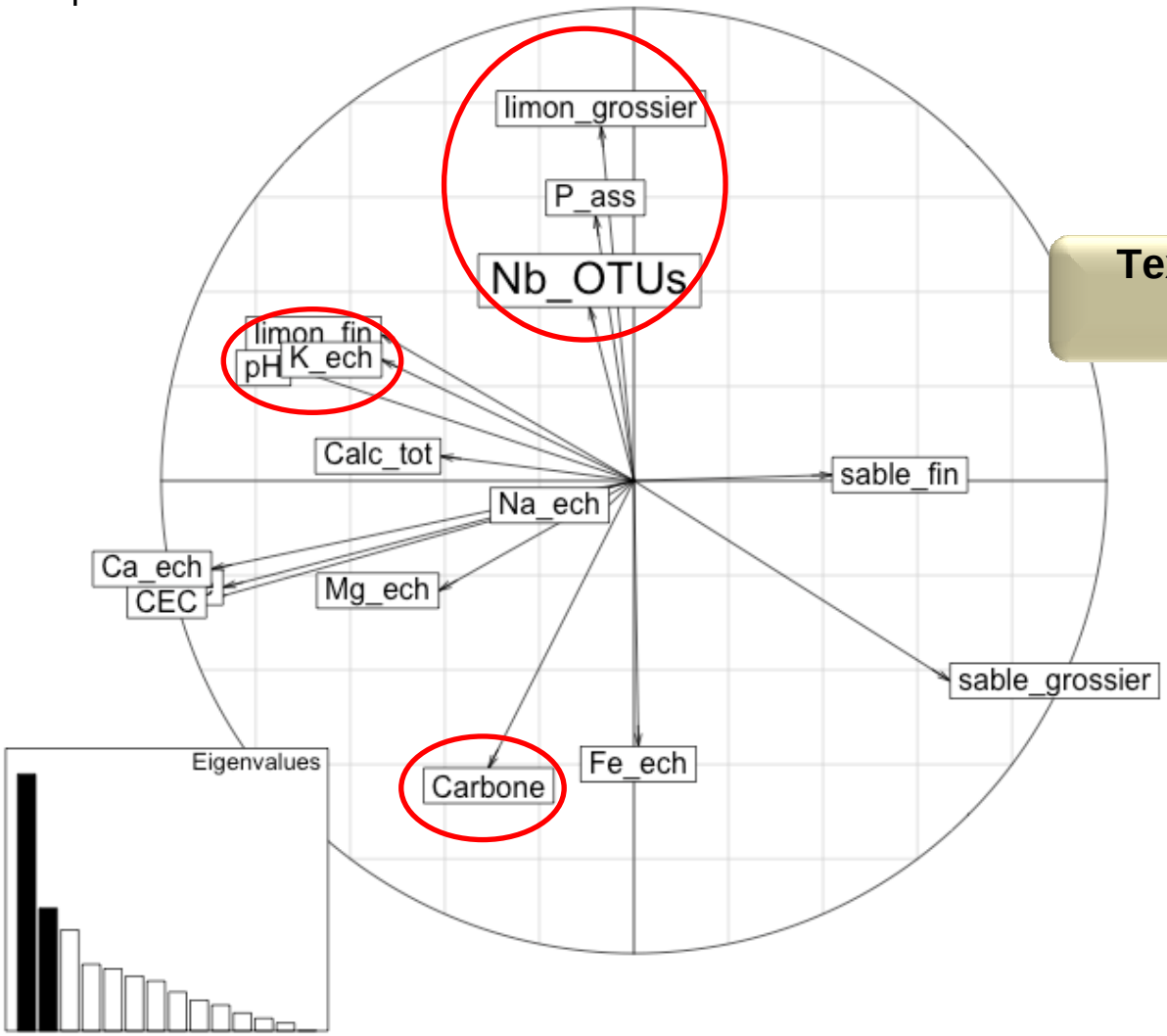
Crops and Vineyards exhibit the most important diversity conversely to forests and grasslands.

Intermediate perturbation stimulates bacterial diversity.

Crops and vineyards



Correlation between soil characteristics and bacterial richness



Texture , C et P are the main drivers

Weak influence of pH

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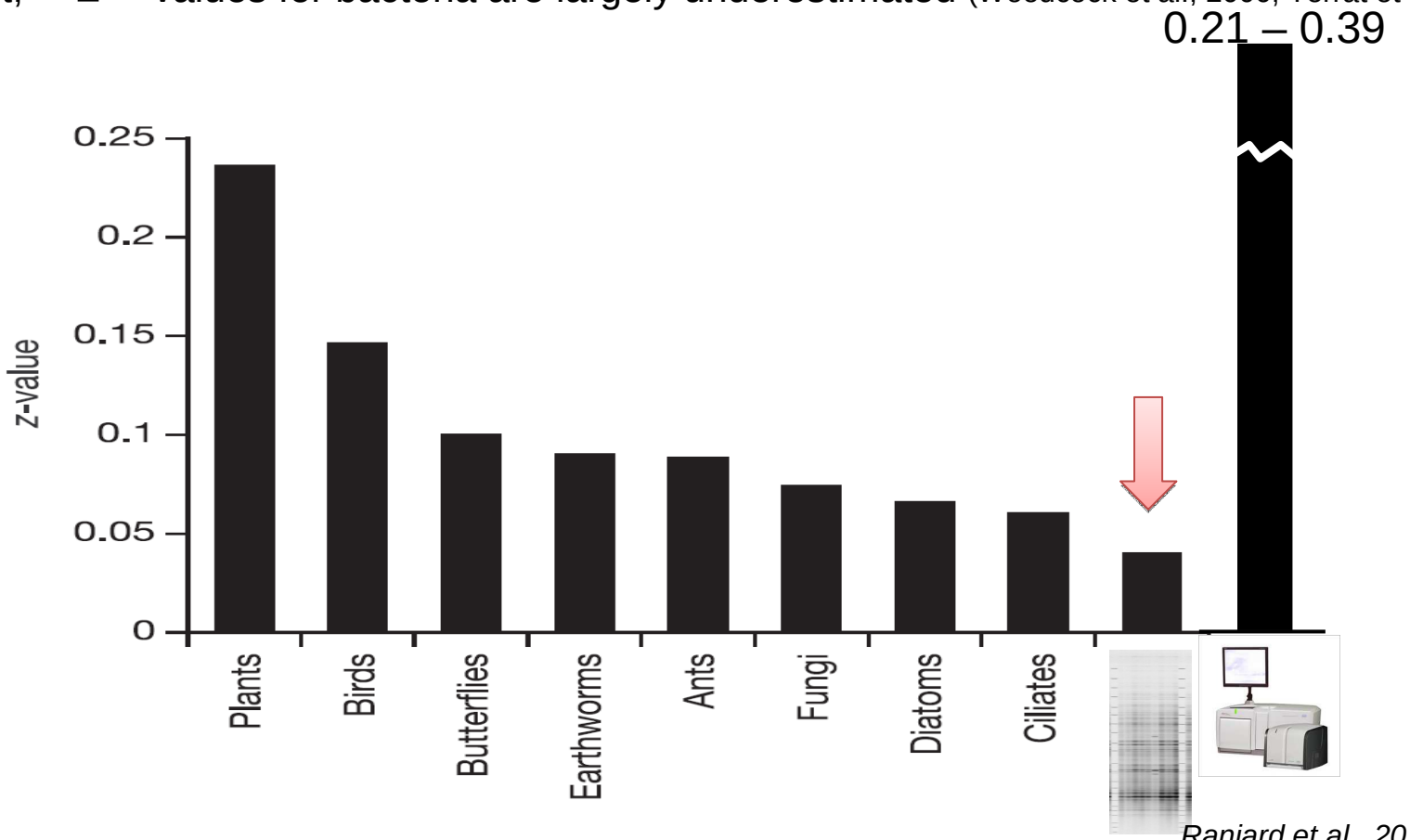
MetaTAXOMIC-RMQS : bacterial taxa-area relationship

- ✓ **Fundamental law in ecology highlighted for microorganisms** (Horner-Devine et al., 2004)
- ✓ **Hypothesis**: the number of detected species increase with the sampling size

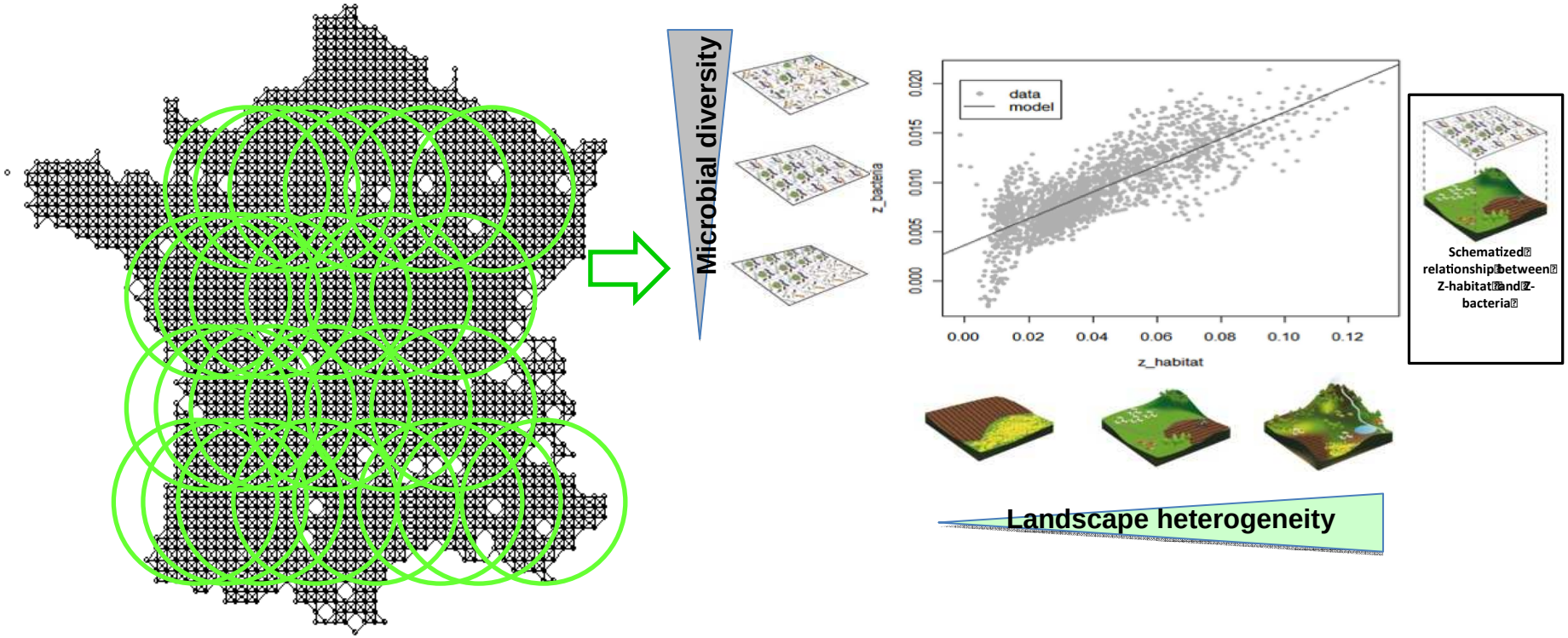
➔ **The turnover (z)** represents the rate at which new species are sampled as the sampling size increased

➔ But, **« z »** values for bacteria are largely underestimated (Woodcock et al., 2006; Terrat et al., 2014)



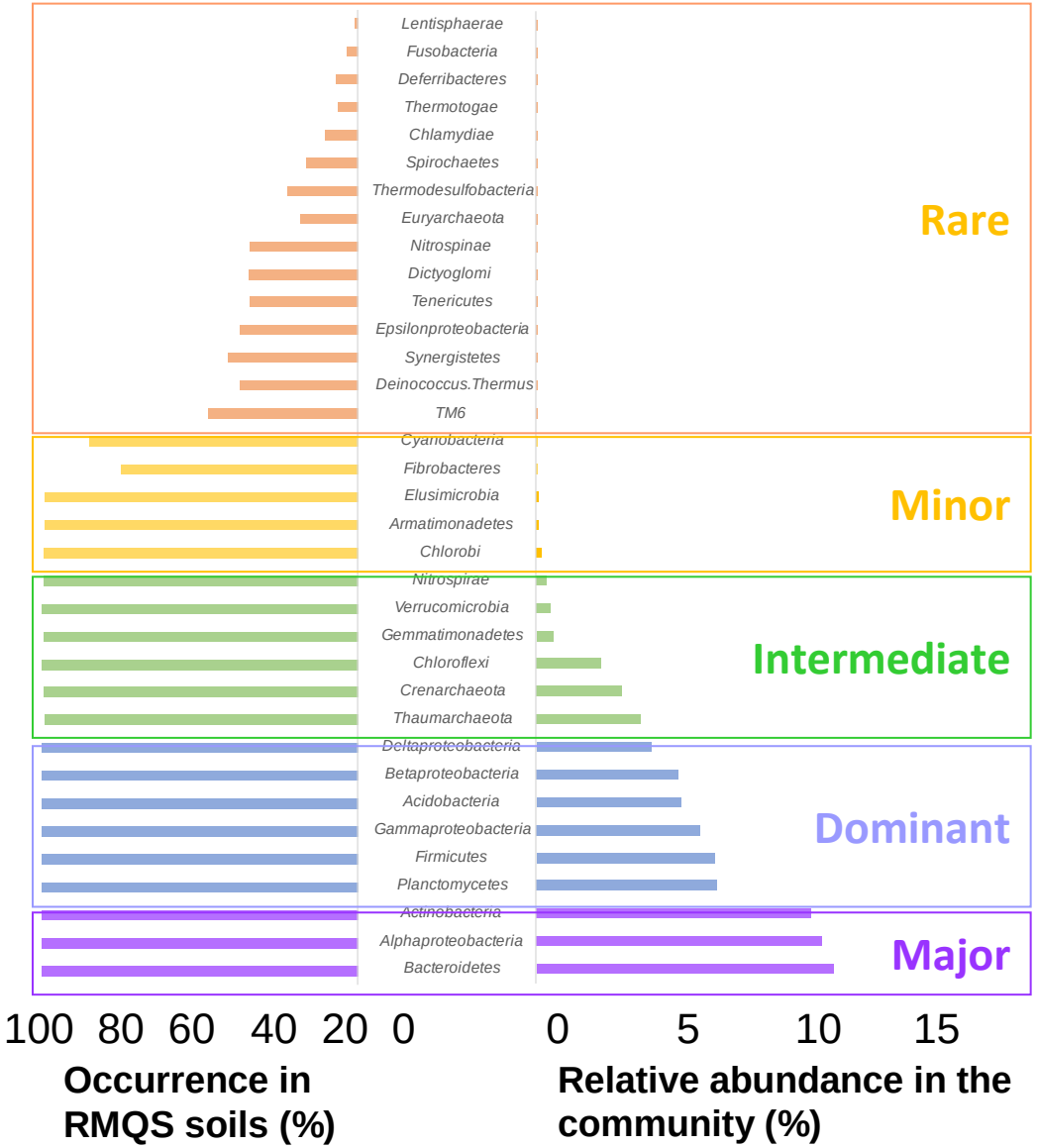
Ranjard et al., 2013 Nature Comm.
Chemidlin et al., 2016, in prep.

Relationships between biodiversity turnover and landscape heterogeniety

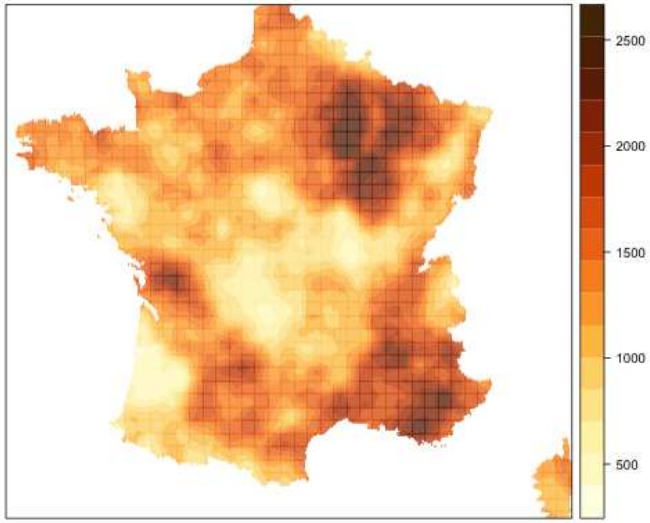


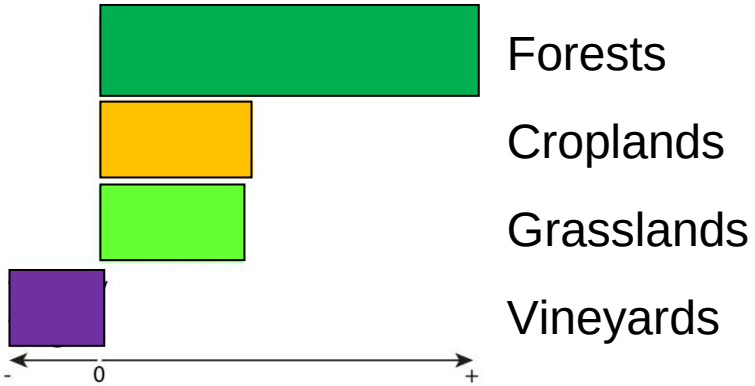
Significant influence of landscape heterogeneity on soil bacterial diversity turnover

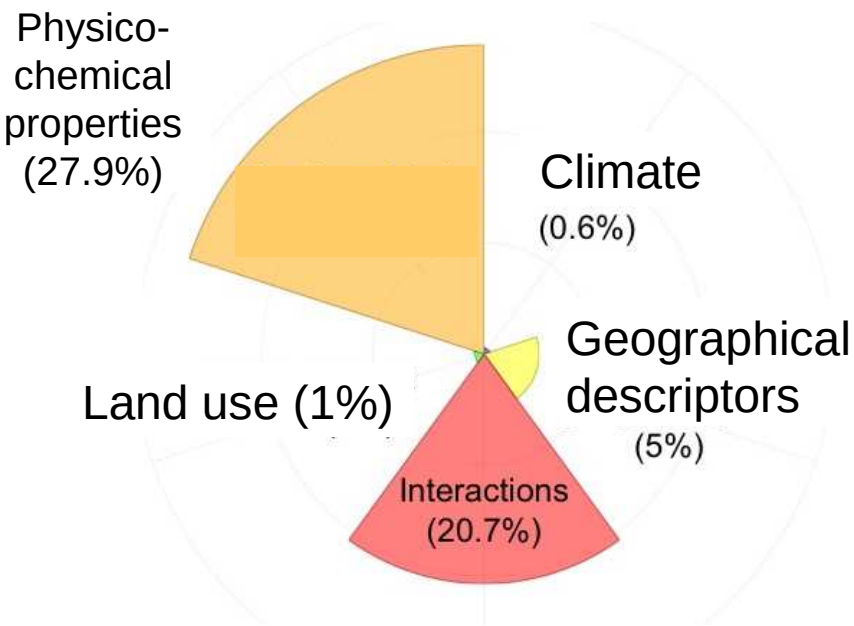
Soil bacterial Taxonomic groups (Phylum level)

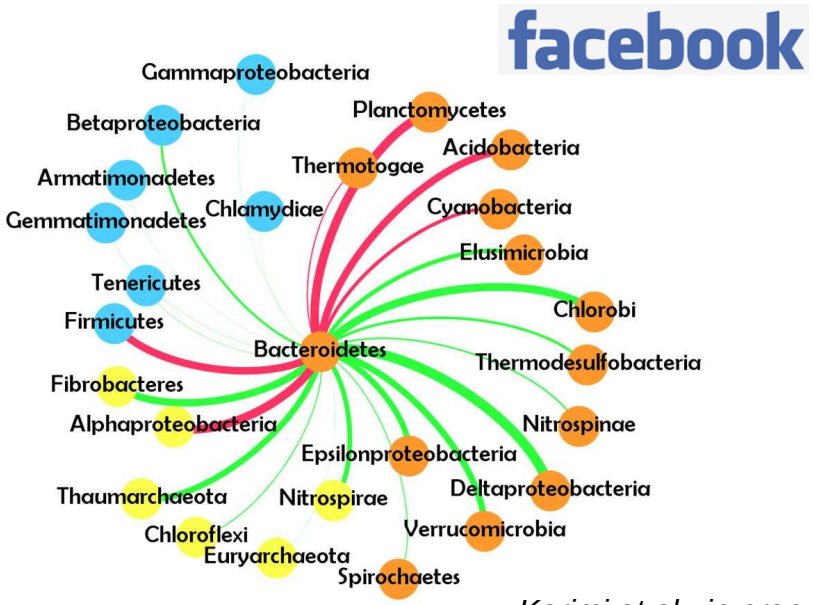


MetaTAXOMIC-RMQS : *Bacteroidetes*



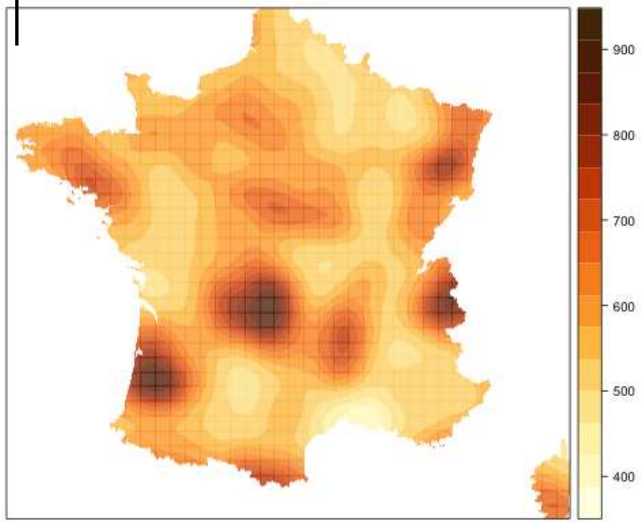


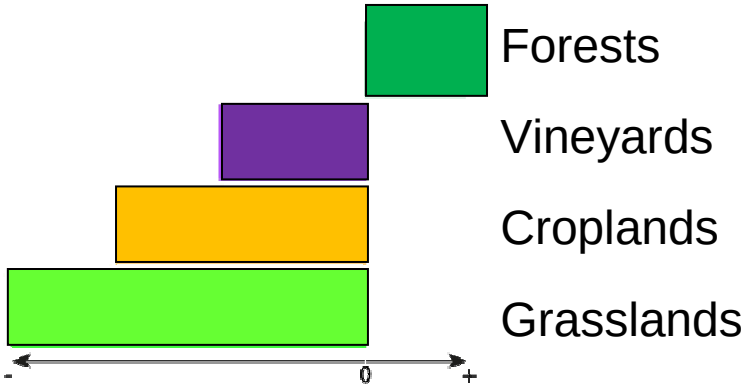


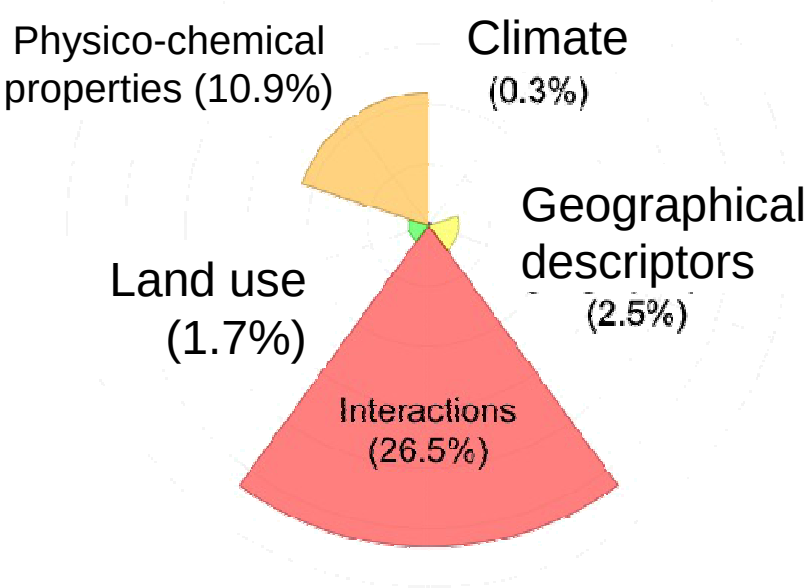


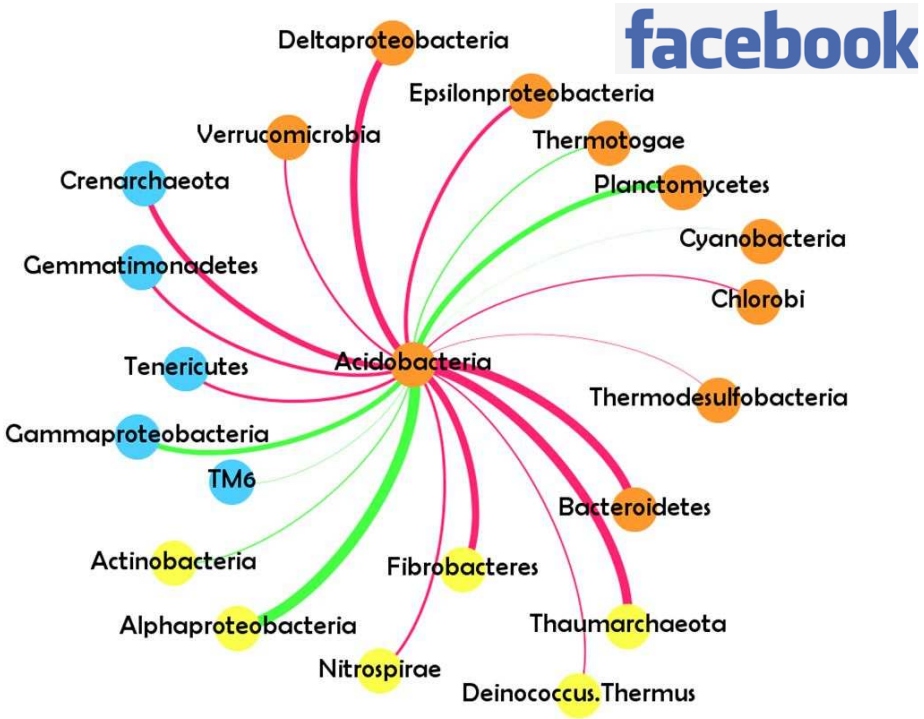
Karimi et al., in prep.

MetaTAXOMIC-RMQS : *Acidobacteria*



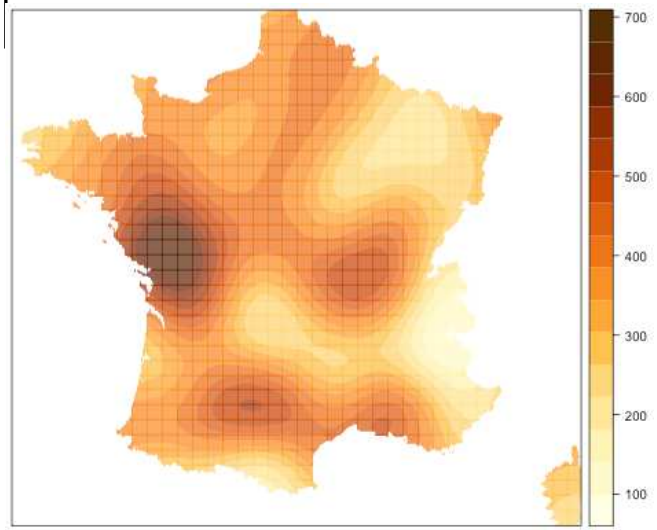


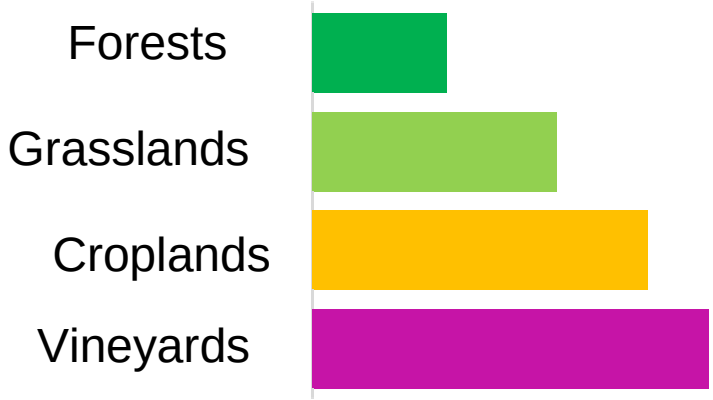


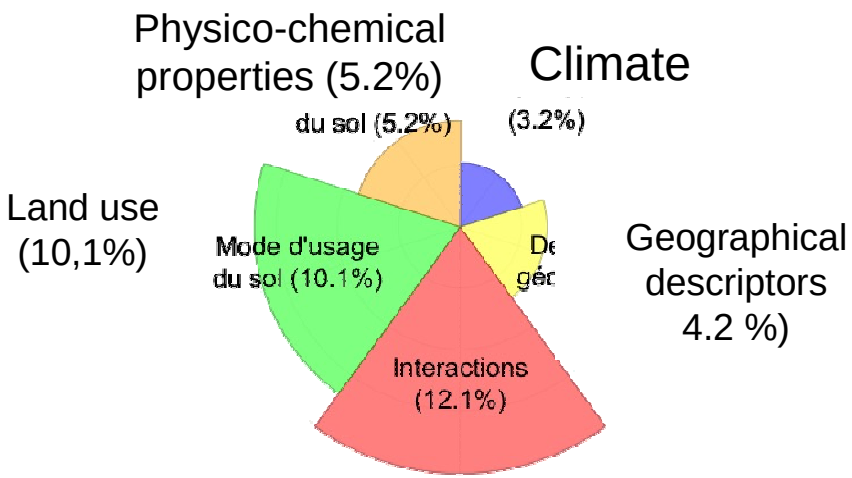


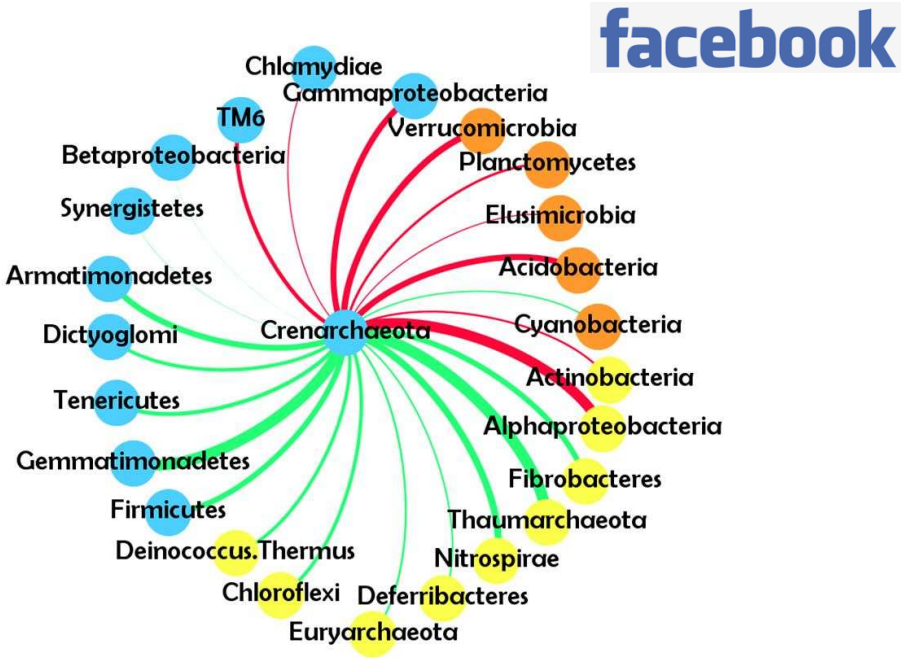
Karimi et al., in prep.

MetaTAXOMIC-RMQS : *Crenarchaeota*



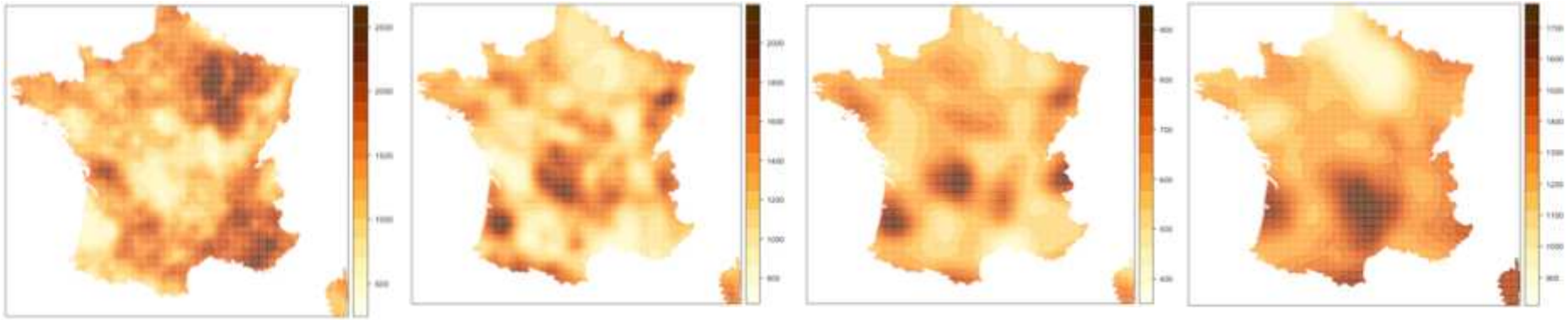




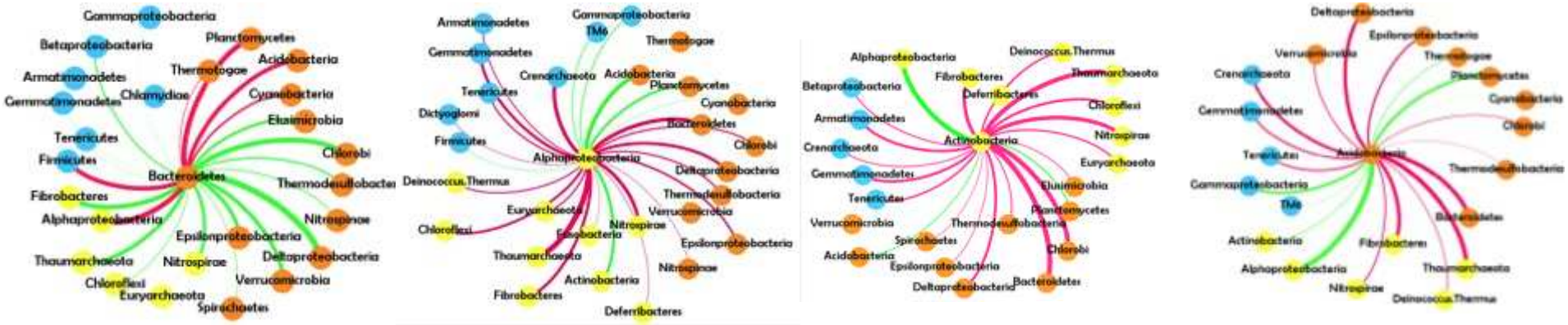


Karimi et al., in prep.

Bacterial distribution and co-occuring interactions



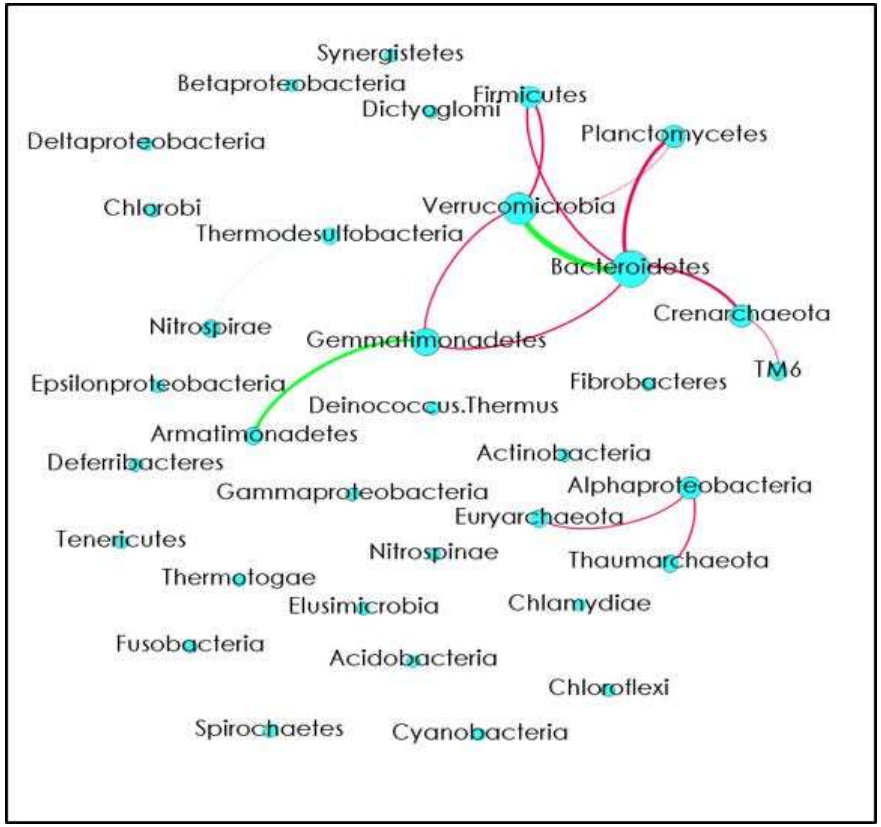
« spotty » « patchy »



Bacterial social network according to land use

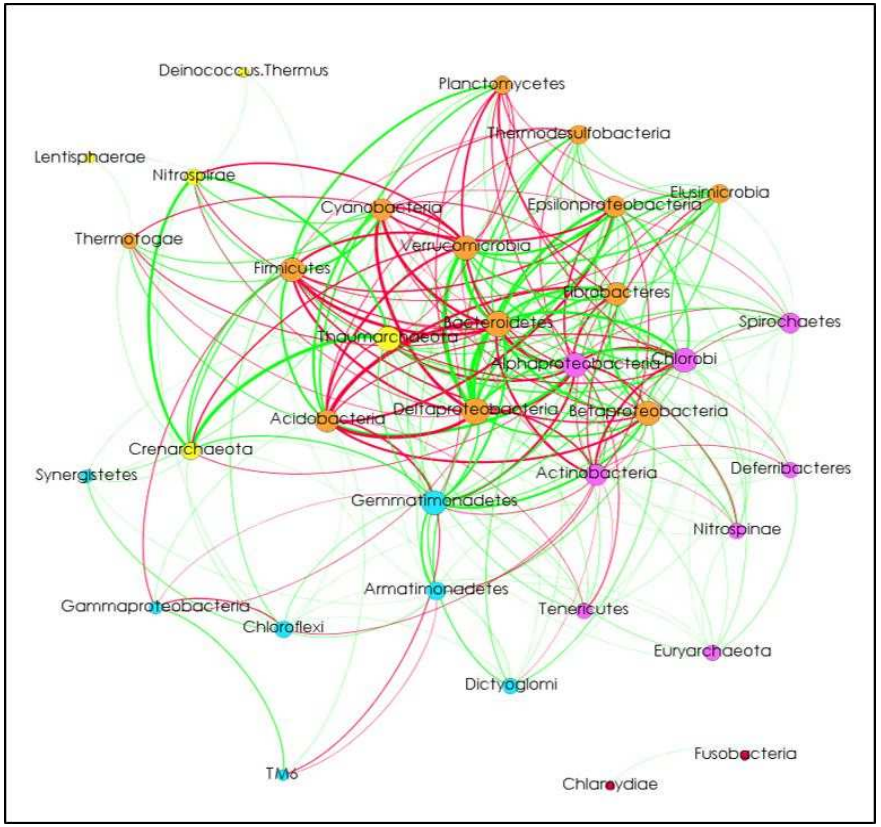
Vineyards

Higher bacterial diversity



Forests

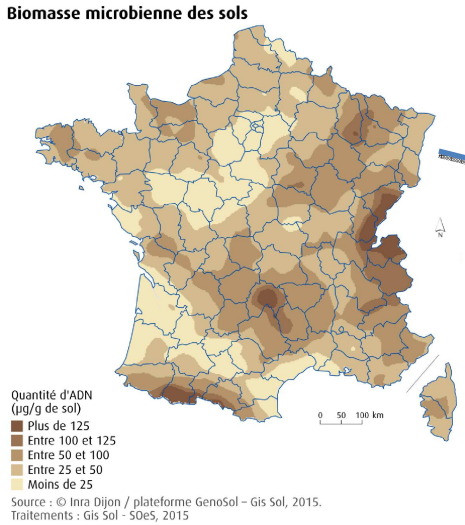
Lower bacterial diversity



From Biogeography to National Soil Quality Indicators

Molecular Microbial Biomass

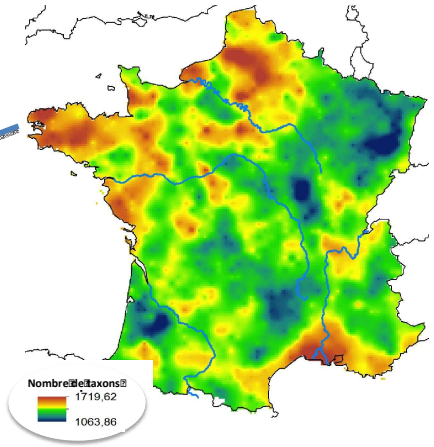
RMQS



« Soil National Indicator »

Dequiedt et al., 2011 Glob Ecol Biogeo

Soil Bacterial Diversity



«Soil National Indicator »

Ranjard et al., 2013 Nature Comm

High influence of soil characteristics
Weak influence of climate
Significant influence of land use

Predictive statistical modells:

$$Y=\beta 0+\sum(\beta jXj+ \beta jX^2j)+\sum\sum \beta jkXjXk+\varepsilon$$

Ecological reference value for a given soil type

Diagnosis of soil biological state

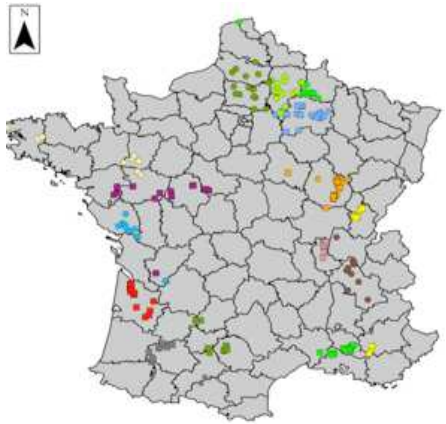
Horrigue et al., 2016 Ecol Indic.

Towards Citizen Project on Soil Biological Quality
CASDAR AgrInnov

To Train
and
Equip Farmers for Soil Biology

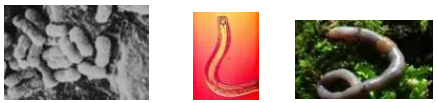
Scientific experts in soil biology ⟷ **Farmers**

National network of 250 farms (crops and vineyards)



Training farmers for soil biology

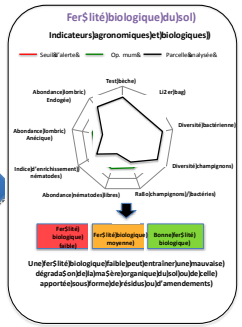
Dashboard of soil bioindicators



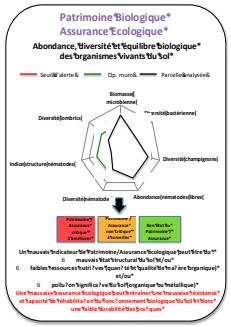
Agricultural soil biological quality diagnosis

Innovative agricutlural practices

Aggregated indicators



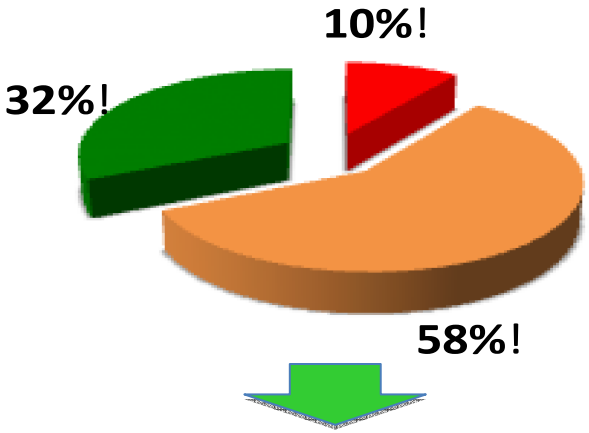
Biological patrimony



Biological fertility

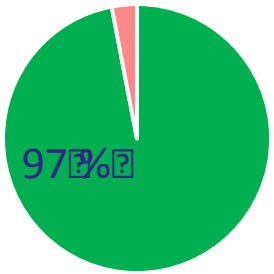
Outcomes

97% !

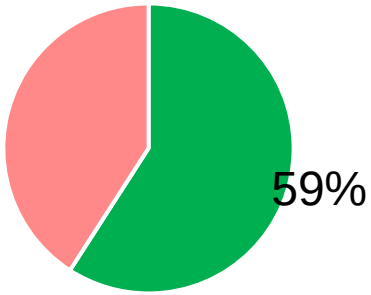


Agricultural soils are not dead !!!

Agricultural Survey: Impact of AgrInnov project on farmers



97% farmers integrate now better soil biology in soil management



59% of farmers have changed their practices

Intercrop management 56%

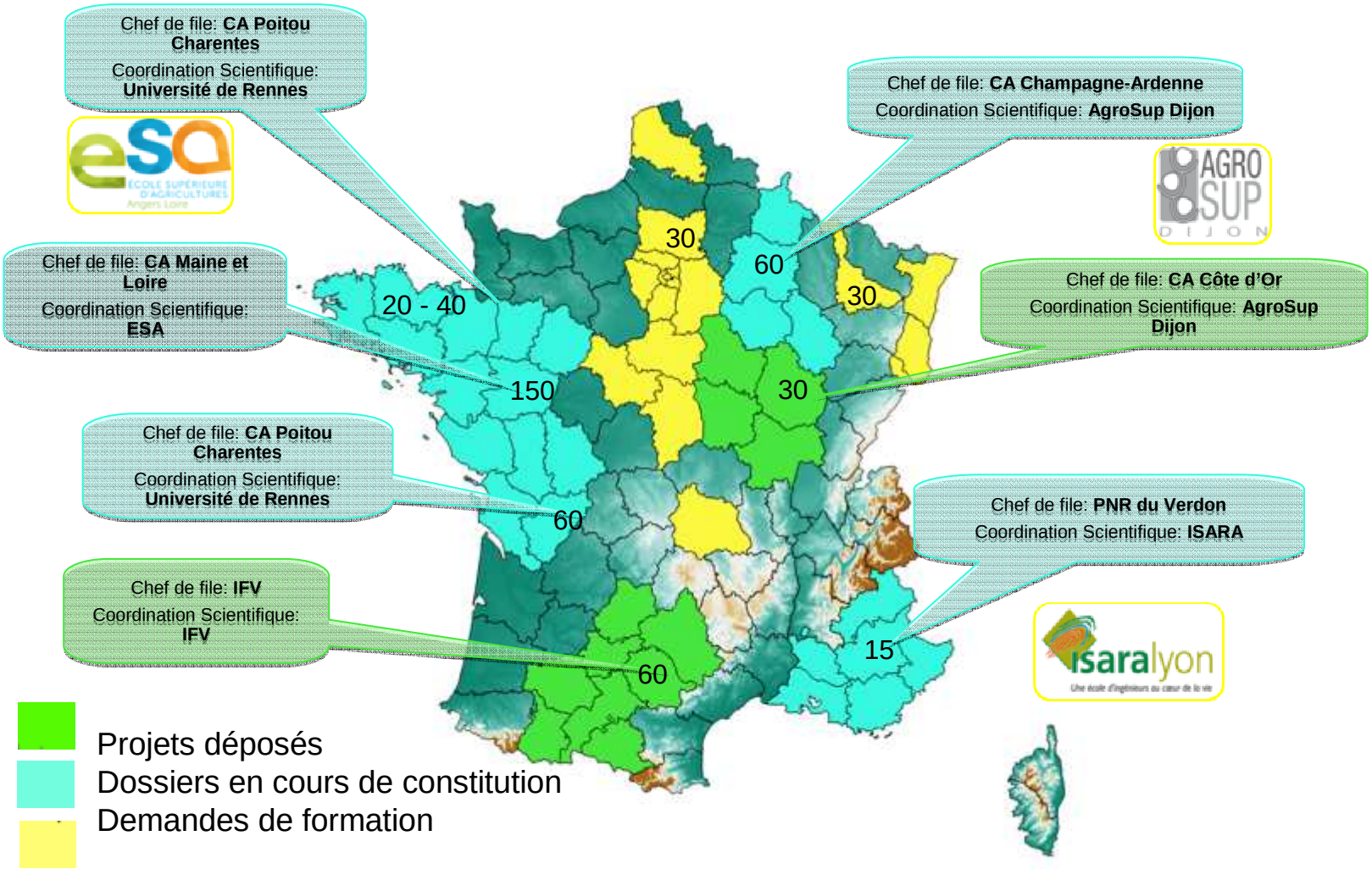
Soil tillage 28%

Reduction of input 23%

Crop rotation 13%

Beyond AgrInnov - REVA

(Network of Experimentation & Monitoring of Agricutlural Innovation)



PIA2-Agriculture Eco-efficiente (ADEME)

Technical Transfer and Industrialisation of Soil Quality Indicators and Development of Agroecological Recommendation

Technical Agricultural Institute and Cooperatives

Public partners

INRA SCIENCE & IMPACT

Agroécologie Dijon

EcoSys

Centre d'Ecologie Fonctionnelle & Evolutive

cnrs

LECA Laboratoire d'Ecologie Alpine

AgroParisTech

Transfer
Tools and Expertise

Private partners

aurea AgroSciences

ARVALIS Institut du végétal

invivo

GenoScreen

SPYGEN

Celesta-lab

ELISOL ENVIRONNEMENT

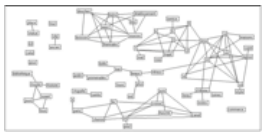
Diagnosis
Recommendation

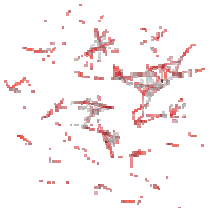
Perspectives

Bacterial Diversity: « Atlas » of French soil bacterial diversity (to be published in 2018)

Fungal Diversity: Spatial distribution and determinism of fungal diversity on the scale of France

Co-occuring network analyses: Relations (synergy, antagonism) between bacterial groups on the scale of France.



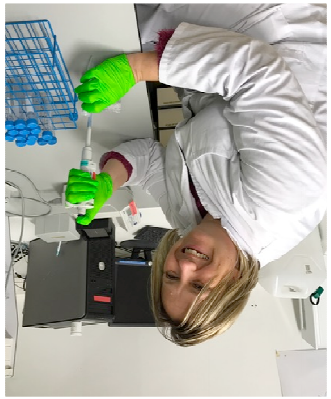


Decipher the link between microbial diversity and functions in soils such as carbon or nitrogen cycling.

To be published in 2017: « *Molecular Microbiology for Environmental Diagnosis* » eds Cuny, Maron, Ranjard.

The ECO-TAXO-MIC Dream team

Sam Dequiedt



Vivi Nowak

Mél Lelievre

Nikos Chemidlin PB

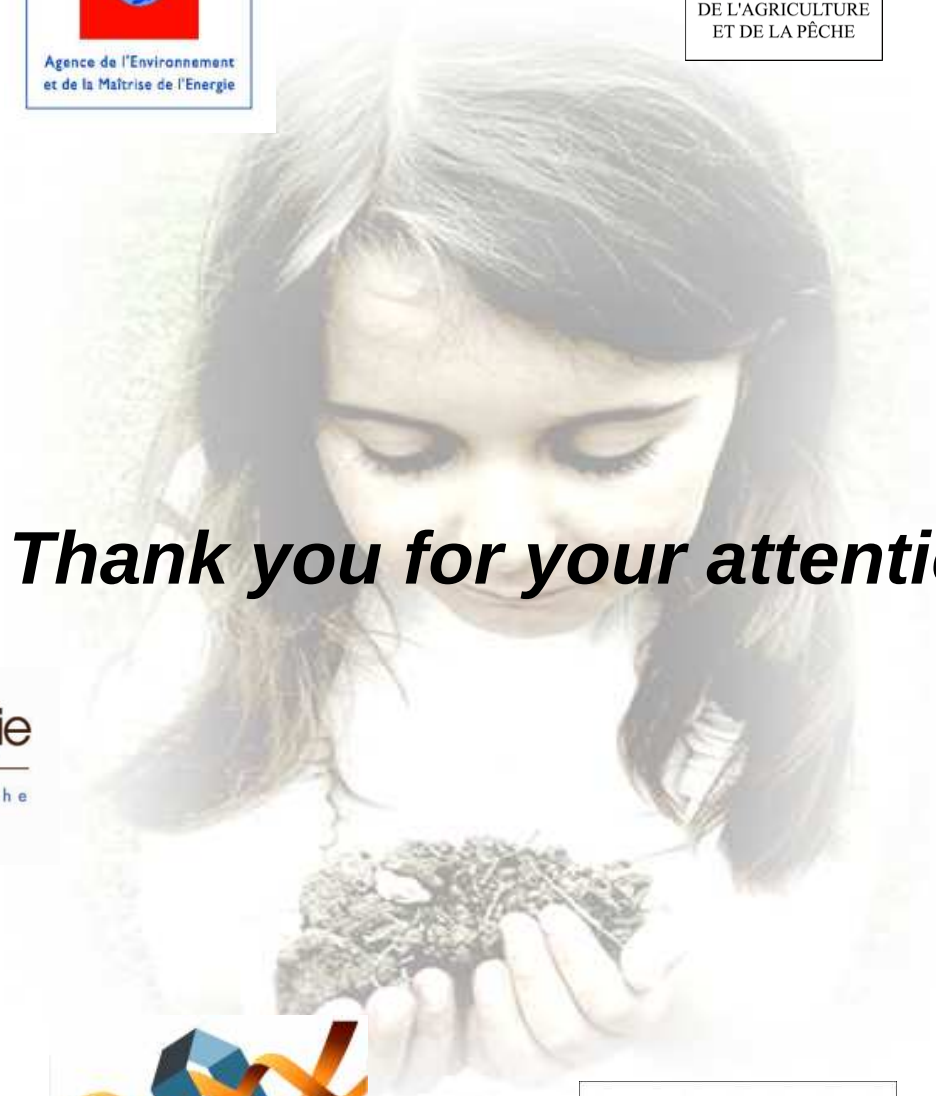
Seb « biogeek » Terrat

Fafa Morin

Walid Horrigue « le président »

Battle « Royal » Karimi

PA Maron



Thank you for your attention