ACADÉMIE d'AGRICULTURE de FRANCE

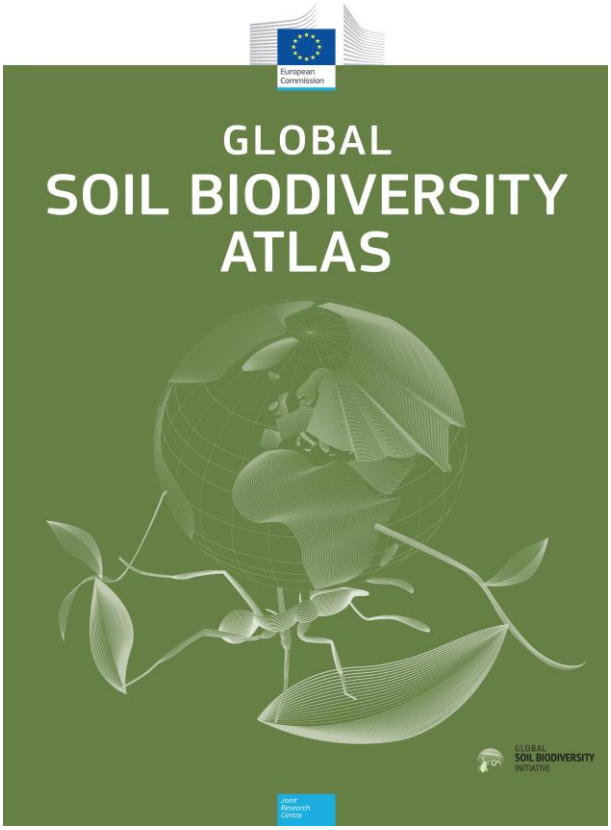
European Commission

French Academy of Agriculture & European Commission Symposium

Launch of the Global Soil Biodiversity Atlas in France

28 November 2016 – 9am30 to 5pm30

Organisators **:** **Jean-Luc Chotte** IRD
Philippe Lemanceau INRA (French Academy of Agriculture)
Alberto Orgiazzi JRC, European Commission



Program
Abstracts and short biographies of the speakers

Académie d'agriculture de France
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General presentation

Soils are the living epidermis of the planet that supports the production of food and fiber, clean water and air, all contributing to human health. Soil organisms, ranging from microscopic bacteria and protists to earthworms, beetles and moles, work together to carry out vital tasks in natural and managed ecosystems that allow life on Earth. They are key drivers of nutrient transformations and cycling; their impact on decomposition and soil structure regulates soil organic matter dynamics, soil carbon storage and greenhouse gas emissions; the symbiotic interactions driven by mycorrhiza and nitrogen fixing bacteria enhance the magnitude and efficiency of nutrient acquisition; while biological control of pest and pathogens is provided by their natural predators and parasites thus contributing to plant and human health. Unfortunately, the extremely variegated communities that inhabit the soil are increasingly threatened by irresponsible uses of the land.

In response to the urgent challenges associated with the sustainable management of soils and the preservation of life within them, a swift collective action has been taking place among scientists of different disciplines, backgrounds and experiences. A first remarkable achievement towards this direction was the publication of the first-ever Global Soil Biodiversity Atlas. Released in May 2016, the Global Soil Biodiversity Atlas, a collaborative effort of the European Commission's Joint Research Centre and the Global Soil Biodiversity Initiative, presents the first overview of soil biodiversity for both managed and natural soils on a global scale. The Atlas is a significant international scientific effort with contributions from more than 120 experts from 26 different countries. The rapid advances in new technologies, such as molecular tools, and information and communication technologies, facilitated the collective effort that resulted in the Global Soil Biodiversity Atlas, but it would have still been incomplete without the global collaborations that fostered new syntheses and understanding of the importance of soil organisms across the globe.

The eight main chapters of the Atlas cover all aspects of soil biodiversity, from taxonomy, geographical distribution and ecosystem service to threats, interventions and policies related to soil biodiversity. The book was conceived to target not only general public and policy makers but also researchers and technicians. More than 800 images, more than 50 maps and hundreds of informative boxes drive the readers through an incredible journey into soil life. The Global Soil Biodiversity Atlas represents a starting point that will contribute to make people aware of the importance and beauty of organisms living in the soil and to help soil life to raise the attention and respect that it deserves.

The present symposium aims at launching in France this unpreceded Atlas. This will represent an opportunity to present European and world initiatives on soil biodiversity and to illustrate advances in knowledge, study strategy, monitoring of soil microbes and fauna in a variety of environments by European and World experts, some of them having contributing to the Atlas.

Chairmen **:** **Dominique Job,** directeur de recherche émérite au CNRS, Laboratoire mixte CNRS/Bayer CropScience, UMR CNRS 5240, Lyon ; Académie d'Agriculture (Sciences de la vie)

Daniel Tessier, directeur de recherche honoraire à l'INRA, Académie (interactions milieux-être vivants)

Program

- **9:45-10:00.** *Welcoming*
  Gérard Tendron, Permanent Secretary of the Academy of Sciences.
- **10:00-10:15.** *Introduction*
  Karmenu Vella, European Commission, Commissioner Environment, Maritime Affairs and Fisheries (pre-recorded video message)
- **10:15-10:30.** *Symposium presentation*
  Jean-Luc Chotte, Philippe Lemanceau, Alberto Orgiazzi, Symposium organizers

1 Atlas presentation

- **10:30-11:00.** *Presentation of the Global Soil Biodiversity Atlas*
  Alberto Orgiazzi, Coordinator of the Atlas, JRC Ispra, European Commission

2 Progresses in the study strategies of soil biodiversity

- **11:00-11:30.** *Basic study and exploitation of soil microbiota following a metagenomics approach*
  Pascal Simonet, CNRS Lyon, France
- **11:30-12:00.** *Development of metabarcoding for soil fauna*
  Arjen de Groot, Wageningen University Research, The Netherlands
- **12:00-12:30.** *Data base management and bioinformatics*
  Urmas Kõljalg, University of Tartu, Estonia

12:30-13:30 Free lunch

3 Biodiversity and soil functioning

- **13:30-14:00.** *Diversity and functions of soil macrofauna in West Africa: Case study of termites and ants in Cote d'Ivoire and Burkina Faso.*
  Souleymane Konate, University Nangui Abrogoua, Cote d'Ivoire
- **14:00-14:30.** *Soil biodiversity and geochemical cycles*
  Alain Brauman (IRD), Jean Trap (IRD), Claude Plassard (INRA), Jean-Luc Chotte (IRD), Eric Blanchart (IRD), Montpellier, France
- **14:30-15:00.** *Exploration of microbial biodiversity and functions in forest ecosystems: a focus on temperate regions*
  Stéphane Uroz, INRA Nancy, France

4 Knowledge applications of soil biodiversity to sustainable soil management

- **15:00-15:30.** *Soil microbial diversity: national territory to farmers*
  Lionel Ranjard, INRA, Dijon, France
- **15:30-16:00.** *Nematode biodiversity and bioindicators*
  Cécile Villenave, ELISOL Environnement, Montpellier, France
- **16:00-16:30.** *Soil biodiversity and ecosystem services*
  Patrick Lavelle, IRD, CIAT, Cali, Colombia

5 European & world initiatives of soil biodiversity characterization

- **15:45-16:15.** *FP7 large-scale European project EcoFINDERS*
  Philippe Lemanceau, INRA, Dijon, France
- **16:15-16:45.** *Global Soil Biodiversity Initiative*
  Wim van der Putten, NIOO, Wageningen, The Netherlands

4 Conclusions-prospects

- **16:45-17:00.** *Conclusions and prospects*
  Philippe Lemanceau & Francis Martin, INRA, Dijon & Nancy

Gérard Tendron

Perpetual secretary of the Agricultural Academy of France
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Gérard Tendron, agronomist, honorary general engineer of agricultural, water and forestry engineering has got a professional career essentially based at the Forests National Office, at the Ministry of the Environment and at the Ministry of Agriculture. He got involved in the reflections of balance between agriculture, forests and wildlife, the economic development of the forest-based industries, the management of agricultural and forestry land included in the European network Natura 2000, the forestry management in outer-urban environment and the ethics from the relationship between man and animal at the Agriculture Academy. He undertook to continue upgrading the Agriculture Academy in terms of organization and operating involving his peer and implementing new means of communication and publication to value his works. He's been president of the Society of Friends and Philanthropists of the Castle of Fontainebleau since 2013.

Karmenu Vella

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Introduction

There is the need to recognise the importance of soil biodiversity for food production, water and regulation, climate change, and for the wider biodiversity and ecosystem objectives. The continuous degradation of soil at global and EU level needs to be addressed through applying appropriate policies in line with the 7th Environment Action Programme (EAP), the Sustainable Development Goal (SDG) target on "land degradation neutrality" by 2030, as well as the EU biodiversity target of restoring 15% of degraded ecosystems by 2020. In particular there is the need to see that agriculture can contribute towards soil protection through more sustainable farming practices.

Karmenu Vella is the European Commissioner for Environment, Fisheries and Maritime Affairs. He was born in Malta on June 1950. Mr Vella graduated in Architecture and Civil Engineering, and later obtained a Master of Science in Tourism Management from University of Sheffield. He was first elected to Parliament in 1976 and continued to be was re-elected in the elections that followed for nine consecutive times. During his political career he has been appointed Minister for Public Works, Minister for Industry and Minister for Tourism twice. Mr Vella had also held various senior posts in the private sector.

Jean-Luc Chotte

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Symposium presentation

Jean-Luc CHOTTE is en senior scientist at IRD (Institut de Recherche pour le Développement), France. His research topic deals with the impact of climate and land use changes on soil organic matter dynamics (stocks and fluxes). As a soil ecologist, he has a special interest in the role of soil biota (macrofauna, mesofauna, microorganisms) and their interactions in organic carbon dynamics in soils. His research promotes the role of soil biota as key players in agro-ecosystem functioning and in soil and land rehabilitation. From 1996 to 2004 he was posted in Sénégal and conducted in depth field studies on means to enhance soil carbon stock in different agro-systems from semi arid to humid ecosystems. He has been involved in international projects. He co-chaired the 3rd International Scientific Conference on "Climate Smart Agriculture" (2015). To date he has published about 90 publications in the fields of Soil Sciences and Soil Ecology. Since 2011 he is the Director of join Unit "Functional Ecology & biogeochemistry of soils & agro-ecosystems". He is the focal point for IRD in the 4P1000 initiative. Since the last COP 12 of the UNCCD convention he is Vice-Chair of the Committee for Science and Technology of the convention and member of the Science and Policy Interface.

Recent papers

- Sall S. N., Ndour N. Y. B., Diedhiou-Sall S., Dick R., Chotte J.L. Microbial response to salinity stress in a tropical sandy soil amended with native shrub residues or inorganic fertilizer. Journal of Environmental Management, 2015, 161, p. 30-37. ISSN 0301-4797
- Herrmann L., Chotte J.L, Thuita M., Lesueur D. Effects of cropping systems, maize residues application and N fertilization on promiscuous soybean yields and diversity of native rhizobia in Central Kenya. Pedobiologia, 2014, 57 (2), p. 75-85. ISSN 0031-4056
- Chotte, JL., Diouf M.N., Assigbetsé K., Lesueur D., Rabary. B., Sall S.N. (2013. "Unexpected similar stability of soil microbial CO2 respiration in 20-year manured and inunmanured tropical soils. Environmental Chemistry Letter, DOI 10.1007/s10311-012-0388-9
- Bernard L, Chapuis-Lardy L, Razafimbelo T, Razafindrakoto M, Pablo A, Legname E, Poulain J, Brüls T, O'Donohue M, Brauman A, Chotte J.L.. and Blanchart E 2012 Endogeic earthworms shape bacterial functional communities and affect organic matter mineralization in a tropical soil. ISME Journal 6, 213-222.

Alberto Orgiazzi

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Let's talk about the 1st ever Global Soil Biodiversity Atlas

Alberto's scientific interest is devoted to the fields of biology and biotechnology, with a particular interest in molecular biology and soil metagenomics. His PhD project was aimed at the analyses of soil biodiversity by means of next-generation sequencing technologies (metabarcoding-based approach). While doing his PhD, he spent time at AGROSCOPE (Zurich, Switzerland) and at the University Claude Bernard Lyon I (Lyon, France). Alberto completed his PhD cycle in 2012.
In 2013 he joined the European Commission's Joint Research Centre (JRC) as a post-doctoral researcher. His 3-years projects dealt with

- *the development of the first Global Soil Biodiversity Atlas in collaboration with the Global Soil Biodiversity Initiative (www.globalsoilbiodiversity.org) and*
- *the assessment and mapping of potential threats to soil biodiversity across Europe as part of the FP7 EU project EcoFINDERS.*

In May 2016 Alberto returned to the JRC as temporary scientific officer to work on

- *the assessment of soil biodiversity and the ecosystem services that it provides at European scale,*
- *the development of a European soil biodiversity database,*
- *the assessment of potential threats to soil biodiversity at global scale, and*
- *development of specific measures to protect soil organisms.*

Recent papers

- Orgiazzi, et al. 2016. Global Soil Biodiversity Atlas. European Commission, Publications Office of the European Union, Luxembourg. 176 pp.
- Orgiazzi et al. 2016. A knowledge-based approach to estimating the magnitude and spatial patterns of potential threats to soil biodiversity. *Science of the Total Environment*, 545-546,11-20.
- Orgiazzi et al. 2015. Soil biodiversity and DNA barcodes: opportunities and challenges. *Soil Biology and Biochemistry*, 80, 244-250.
- Orgiazzi et al. 2013. 454 Pyrosequencing analysis of fungal assemblages from geographically distant, disparate soils reveals spatial patterning and a core mycobiome, *Diversity*, 5, 73-98.
- Orgiazzi et al. 2012. Unravelling soil fungal communities from different Mediterranean land-use backgrounds. *PLOS ONE*, 7, e34847

Pascal Simonet

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Basic study and exploitation of soil microbiota following a metagenomics approach

The strong cultivation bias affecting soil bacteria can be circumvented by modern alternative approaches including metagenomics or single cell genomics. I will show how these metagenomic datasets can be used to estimate and compare the functional potential of microbial communities from various environments with a special focus on antibiotic resistance genes. However, metagenomic datasets can also in some cases be partially assembled into longer sequences representing microbial genetic structures for trying to correlate different functions to their co-location on the same genetic structure. Metagenomics can also be used to exploit the genetic potential of environmental microorganisms. I will present an integrative approach coupling *rrs* phylochip, high throughput shotgun sequencing and hybridization of soil metagenomic DNA clones spotted on high density membranes. The inserts of positive clones are sequenced, DNA assembled and annotated leading to identify new coding DNA sequences related to genes of interest with a good coverage but a low similarity against closest hits in the databases confirming novelty of the detected and cloned genes.

Pascal Simonet *leads a research group at ECL (Ampère lab, CNRS) to investigate the evolution potential of bacteria in environments such as the soil and the plants. This included the general objectives of determining the involvement of horizontal gene transfers (HGT) in the adaptation and evolution of bacteria to new environments. Studies focused mainly on natural genetic transformation and conjugation. These objectives lead the group to develop soil DNA extraction methods and they were among the first to investigate environmental bacteria with metagenomic approaches including for investigating the fate of DNA released by genetically engineered organisms and the possibility that recombinant DNA, and particularly antibiotic resistance genes transforms indigenous bacteria. This led the group to investigate the natural occurrence and the fate of antibiotic resistance genes in the environment and their potential to be transferred to pathogens. The group also demonstrated a potential transforming effect on soil bacteria of lightning-generated electrical conditions. Pascal Simonet has numerous responsibilities including as a member of the French committee "Haut Conseil des Biotechnologies" (HCB) and as an editor for Research in Microbiology and as a member of the editorial board of The ISME Journal. He has co-authored over 150 scientific papers and was invited more than 100 times to give key note lectures or oral presentations in international conferences in the last 15 years. He organized several international and national congresses including "Bageco" Lyon, 2005.*

Recent significant papers:

- Nesme J., (46 authors), Simonet P. 2016. Back to the Future of Soil Metagenomics. *Frontiers in Microbiology*, 7:73.
- Nesme J., Simonet P. 2015. The soil resistome: a critical review on antibiotic resistance origins, ecology and dissemination potential in telluric bacteria. *Environmental Microbiology*, 17, 913-930.
- Nesme J, (*et al.* and) Simonet P. 2014. Large scale metagenomic-based study of antibiotic resistance in the environment. *Current Biology*, 24, 1096-1100.
- Delmont T.O., (*et al.* and) Simonet P., Vogel T.M. 2015. Reconstructing rare soil microbial genomes using *in situ* enrichments and metagenomics. *Frontiers in Microbiology*, 6, 358.
- Delmont TO, (*et al.* and), Simonet P., Vogel T.M. 2012. Structure, fluctuation and magnitude of a natural grassland soil metagenome. *The ISME Journal*, 6, 1677-1687.

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Development of DNA metabarcoding tools for soil fauna

Characterization of the huge soil faunal diversity still relies heavily on the slow and expert-dependent morphological identification. This hampers our ecological understanding of spatial and temporal diversity of many faunal groups, as screening many samples at high taxonomic detail is not a realistic proposition. DNA-based approaches, such as high-throughput DNA metabarcoding, potentially solve this issue. Within the EU FP7 project EcoFINDERS, a large effort has been spent to develop such tools.. Here, I will show results of direct comparisons between different strategies: conventional morphological identification, as well as DNA metabarcoding based on either animals that were removed from the soil or direct soil DNA extracts. Furthermore, I will show some examples of how these tools can be applied to advance our ecological understanding of soil food webs and dispersal patterns.

As a molecular ecologist at Wageningen Environmental Research (Alterra), Arjen de Groot uses DNA-based tools to answer a broad range of applied questions related to nature management.
Besides conservation genetics (genetic viability of endangered populations) source tracking, this involves species recognition and biodiversity monitoring via DNA (meta)barcoding. Arjen is involved in various projects testing new high-throughput sequencing tools for a wide screening of eukaryotes in soils, as well as in water and air samples. A recent example is the development of metabarcoding tools for soil fauna within the EU FP7 project EcoFINDERS. The molecular lab of Wageningen Environmental Research specializes in the use of environmental DNA (eDNA) and other animals materials found in the field to study animals in their environment without disturbance.
Arjens main ecological interests focus on the understanding of the role of species-specific dispersal and reproduction traits in biodiversity establishment, and optimization of the deliverance of agricultural ecosystem services by insects.

Recent papers

- De Groot G.A., Jagers Op Akkerhuis G.A.J.M., Dimmers W.J., Faber J.H., Charrier X. 2016. Biomass and diversity of soil mite functional groups respond to extensification of land management, potentially affecting soil ecosystem services. *Frontiers in Environmental Science*, 4, 15.
- De Groot G.A., Laros I., Geisen S. 2015. Molecular identification of soil eukaryotes and focused approaches targeting protists and faunal groups using high-throughput metabarcoding. In: Martin F. & Uroz S. (eds.) Microbial Environmental Genomics. Springer: Methods Molecular Biology volume 1399.
- De Groot G.A., Nowak C., Skrbinšek T., Andersen L.W., et al. 2016. Decades of population genetic research reveal the need for harmonization of molecular markers: the grey wolf (*Canis lupus*) as a case study. *Mammal Review*, 46, 44-59.
- De Groot G.A., Hofmeester T.R., La Haye M.J.J., Jansman H.A.H., Perez-Haro MI, Koelewijn HP (2016) Hidden dispersal in an urban world: genetic analysis reveals occasional long-distance dispersal and limited spatial substructure among Dutch pine martens. *Conservation Genetics*, 17, 111-123.
- Geisen S., Laros I., Vizcaino A., Bonkowski M., De Groot G.A. (2015) Not all are free-living: high-throughput DNA metabarcoding reveals a diverse community of protists parasitizing soil metazoan. *Molecular Ecology*, 24, 4556-4569.

Urmas Kõljalg

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Database management and bioinformatics

Species–level classification of life has been a cornerstone of biology for centuries. Most macro-organisms are described soon after discovery, but species of soil biota like prokaryotes, micro-eukaryotes, and fungi often lag far behind in formal description because they are small, extremely diverse, and difficult to cultivate and often lack discriminatory morphological characteristics. In the UNITE database (https://unite.ut.ee) for molecular identification of fungi, we have adopted the species hypotheses concept to provide unique digital object identifiers (DOIs) for all fungal species known from sequence data. Several major microbial identification pipelines, notably QIIME, use the species hypotheses identifiers as a community standardization measure. UNITE provides variety of analysis tools including, for example, massBLASTer for blasting hundreds of sequences in one batch, ITSx for detecting and extracting ITS1 and ITS2 regions of ITS sequences from environmental communities, or ATOSH for assigning your unknown sequences to SHs.

Urmas Kõljalg is a professor in mycology of the University of Tartu, Estonia since 2001. He is also serving as a director of the Natural History Museum of the same university since 2005. His major research area is molecular taxonomy and ecology of fungi and biodiversity informatics. During last fifteen years he has been developing online tools for the data management (http://plutof.com) and for the metabarcoding of fungi (https://unite.ut.ee). He is leading Estonian research infrastructure roadmap project NATARC (http://natarc.ut.ee/en/index.php) and data management workpackage of the 7th framework project EUBON (http://eubon.eu, Building the European Biodiversity Observation Network).

Recent papers

- Kõljalg et al. 2016. Digital identifiers for fungal species. *Science*, 352, 1182−1183.
- Oja et al. 2015. Temporal patterns of orchid mycorrhizal fungi in meadows and forests as revealed by 454 pyrosequencing. *New Phytologist*, 205, 1608−1618, nph.13223/abstract.
- Tedersoo et al. 2014. Global diversity and geography of soil fungi. Science, 346, 1078.
- Tedersoo et al. 2014. Stable isotope analysis, field observations and synthesis experiments suggest that Odontia is a non-mycorrhizal sister genus of Tomentella and Thelephora. *Fungal Ecology*, 11, 80−90.
- Kõljalg et al. 2013. Towards a unified paradigm for sequence-based identification of Fungi. *Molecular Ecology*, 22, 5271−5277.

Souleymane Konate

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Diversity and functions of soil macrofauna in West Africa: Case study of termites and ants in Côte d'Ivoire and Burkina Faso.

African savannas are important and very extended ecosystems of great significance for biodiversity and as a human economic area. Termites and ants represent a very important component of soil biodiversity in West African savannas, delivering essential ecosystem services (by e.g. improving soil water content, soil fertility and carbon sequestration). Our study aims to analyse the diversity and functional roles of these soil organisms along a climatic and anthropogenic gradient in West African savannas, with two case studies in Burkina Faso and Côte d'Ivoire.

Souleymane Konaté is currently professor in ecology at the University Nangui Abrogoua (Côte d'Ivoire), where he is leading the research unit on Ecology and Biodiversity (within the Research Pole on Environment and Sustainable Development). Souleymane received a Ph.D. in Ecology in 1998 from the University of Paris 6 (Pierre & Marie Curie) in France, and was the winner of 2004 START Young Scientist Award (IGPB-IHDP) in Ecology. Konaté has been director of the Ecological Research Station of Lamto in Côte d'Ivoire for ten years. He has served as Coordinator of the Protected Areas Programme of the International Union for Conservation of Nature (IUCN) for West and Central Africa, and as senior researcher on biodiversity and climate change at WASCAL (West African Science Service Center on Climate Change and Adapted Land Use). He is curently member of international steering committies of several networks and programs like JRS Biodiversity Foundation and GLP (Global land Project, IGBP-Future Earth). He has published more than 40 papers and 20 book chapters, mainly on ecology of soil macrofauna (termites and ants). During the last 15 years he took a leading position in integration of science and society by organizing scientific activities, synthesis and knowledge bundling and dissemination on tropical biodiversity related questions at regional and national levels. One of these achievements is his contribution, as co-editor to the Biodiversity Atlas of West Africa (2010).

Recent papers

- Yéo K., Kouakou L.M.M, Dekoninck W., Ouattara K., Konaté S. 2016. Detecting intruders: assessment of the anthropophilic ant fauna (Hymenoptera: Formicidae) in the city of Abidjan and along access roads in Banco National Park (Côte d'Ivoire). *Journal of Entomology and Zoology Studies*, 4, xx-xx.
- Kaiser D., Tra-Bi C. S., Yéo K., Konaté S., Linsenmair K.E. 2015. Species richness of termites (Blattoidea: Termitoidae) and ants (Hymenoptera: Formicidae) along disturbance gradients in semi-arid Burkina Faso (West Africa). *Bonn zoological Bulletin*, 64, 16–31.
- Koné M., Konate S., Kolo Y., Kouassi K.P., Linsenmair K.E. 2014. Effects of management intensity on ant diversity in cocoa plantation (Oume, centre west Côte d'Ivoire). *Journal of Insect Conservation,* 18, 701-72.
- N'Dri A.B., Gignoux J., Barot S., Konaté S., Dembélé A & Werner P. 2013. The dynamics of hollowing in annually burnt savanna trees and its effect on adult tree mortality. *Plant Ecology*, 215, 27–37.
- Nobre T., Koné N.A., Konaté S., Linsenmair K.E., Aanen D.K. 2011. Dating the fungus-growing termites' mutualism shows a mixture between ancient codiversification and recent symbiont dispersal across divergent hosts*. Molecular Ecology,* 20, 2619-2627.

Alain Brauman

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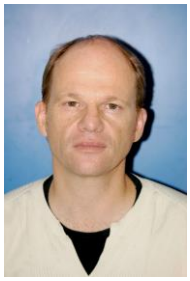

Soil biodiversity and geochemical cycles

Agroecology, the new agriculture paradigm, is based on the intensification of ecological processes, linked to biodiversity and especially soil biodiversity. This implies to better understand the relationship between soil biodiversity and soil functions linked to the provision of ecosystem services. If diversity-functions relationships have been intensively studied for the plant community, these relations remain questionable in the soil ecosystem. The soil inherent complexity is often advocated to explain this trend, however, we could emphasis that (i) soil biota taxonomy is still poorly known compared to most above ground organisms (ii) most of the studies focus on two-sided (one organism, one plant) relationships which does not reflect the whole complexity of the biotic interactions occurring in soils (iii) few studies take into account the underlying mechanisms of these biotic interactions, and (iv) few studies investigate the regulation of the biotic interactions by the abiotic components.

In this talk, we aim to demonstrate the importance of biotic interactions on nutrient fluxes/cycling, which is one of the main functions associated to soil fertility. Through several examples taken from literature or on-going works of our research team, we will show how the diversity of soil organisms within or between trophic/functional levels (i.e., decomposers, microregulators, soil engineers, plant mutualists) regulate nutrient fluxes and/or plant growth. An implication of this perspective is that processes that decrease soil organism abundance (ex: soil tillage) or modify their habitat are likely to decrease aboveground productivity. Conversely, practices increasing soil functional diversity are likely to increase this productivity.

Alain Brauman, soil ecologist at French Institute for Sustainable Development (IRD), spent most of its career (~20y) in tropical countries (Africa and Asia). First interested by the gut microbiota of insects (such as termite) involved in greenhouse gas emission (CH4 and N_2O), his research is now focusing on the impact of agriculture practices on soil functional biodiversity (microorganism, nematofauna, soil macrofauna) and related soil functions (organic matter degradation, fluxes of N and P, greenhouse gas emission).

Recent papers

- Brauman A., Majeed M.Z., Buatois B., Robert A., Pablo A. L., Miambi E. 2015. Nitrous oxide (N_2O) emissions by termites: does the feeding guild matter?, *Plos One*, 10, 12.
- Trap J., Bernard L., Brauman A., Pablo AL., Plassard C., Ranoarisoa M. P., Blanchart E. 2015Plant roots increase bacterivorous nematode dispersion through nonuniform glass-bead media. *Journal of Nematology*, 47, 296-301.
- Dieng A., Baudoin E., Thioulouse J., Brunet D., Toucet J., Sylla S.N., Brauman A. 2015. Soil organic matter quality, structure and activity of the denitrifiers community as influenced by decaying mulched crop residues. *Applied Ecology and Environmental Research*, 13, 655-675.
- Majeed M.Z., Miambi E., Barois I., Randriamanantsoa R., Blanchart E., Brauman A. 2014. Contribution of white grubs (Scarabaeidae: Coleoptera) to N_2O emissions from tropical soils. *Soil Biology and Biochemistry*, 75, 37-44.
- Blanchart E., Brauman A. 2011. Les ingénieurs du sol : diversité et fonctions. Dossier « Biodiversité : des sciences pour les humains et la nature ». Les dossiers d'Agropolis International, Montpellier.

Stéphane Uroz

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http://mycor.nancy.inra.fr/IAM/?page_id=727

Exploration of microbial biodiversity and functions in forest ecosystems: a focus on temperate regions

Forest ecosystems provide several key environmental services such as acting as carbon sinks, protecting biodiversity, protecting soils and providing wood resources. Their worldwide distribution, covering boreal to temperate and tropical regions, allows for the development of complex and distinct ecosystems. However, the distribution of forests is also strongly related to land use history and soil characteristics. Easily manageable soils with high plant nutritional capacity have often been dedicated to crops and grasslands, while nutrient-poor and rocky soils have been abandoned to forests. These specific conditions strongly differentiate forest ecosystems from annual cultures and grasslands, especially as forests are usually non-amended and unploughed.

Forest ecosystems are also characterized by the existence of large perennial plants: the trees. Indeed, trees require decades to centuries of growth to complete their lifecycles or before harvesting. Consequently, their impact on soil parameters and the forest biota is important due to litter deposition, nutrient uptake and root exudation. In this presentation, we will describe the biodiversity of the forest soil biota and especially the forest microbiome (archaea, bacteria, fungi, protists) and how this microbiome is impacted by different environmental factors (tree species, soil type, forestry practices) and how it contributes to the functioning and homeostasis of forest ecosystems.

Stéphane Uroz is a Research Director (DR2) at INRA, Nancy, France since 2015. He received his PhD in Microbial Ecology from the University of Paris XI, Orsay in 2004. His research was focused on the biological stability of the quorum sensing signal molecules. Through fellowships from the French government and European Union Marie Curie programme, he did his research combining classical microbiology, molecular tools, genetic, biochemistry and chemistry in the Interactions Plant Microorganisms lab at the Institute of Plant Sciences (ISV, Gif-sur-Yvette), in Lab of "Sciences de la Terre" at Normal School (ENS, Lyon) and in the Institute of Infections and Immunity at University of Nottingham (Queen's Medical Centre, Nottingham, UK). In 2005, he was hired as Junior Research associate (CR2) in the EFPA department of the National Institute of Agronomic Research (INRA), at the interface between two Units, "Tree microbes interactions" (IAM) and the "Biogeochemical cycles in forest ecosystems" (BEF) to develop a research project on the mineral weathering by bacteria. His interests include bacterial genomics, microbial ecology, environmental genomics and environmental biogeochemistry. His researches focus on the ecology of biotic and abiotic interactions of the forest soil bacterial communities, with the objective to characterize the actors, the mechanims and the related genes.

Recent papers

- Uroz *et al.* 2016. Ecology of the forest microbiome: Highlights of temperate and boreal ecosystems. *Soil Biology and Biochemistry*, In press.
- Uroz *et al.* 2016**.** Specific impacts of beech and Norway spruce on the structure and diversity of the rhizosphere and soil microbial communities. *Scientific Reports*, In press
- Jeanbille *et al.* 2016. Soil parameters drive the structure, diversity and functions of the bacterial communities across a temperate beech forest soil sequence, *Microbial Ecology*, 71, 482-493.
- Uroz *et al.* 2014. Structure and function of bacterial communities in ageing soils: Insights from the Mendocino ecological staircase. *Soil Biology and Biochemistry*, 69, 265-274.
- Uroz *et al.* 2013**.** Functional assays and metagenomic analyses reveals differences between the microbial communities inhabiting the soil horizons of a Norway spruce plantation. *Plos ONE*, 8, e55929.

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Soil microbial diversity: national territory to farmers

My speech will focus on the development of a biogeographical approach to study the spatial distribution of soil microbial community in terms of abundance and diversity on the scale of France. We have reached this goal by the application of molecular tools based on soil DNA extraction and characterization on the 2200 soils of the French national monitoring network. This approach enabled us to draw the biogeographical patterns of molecular microbial biomass as well as bacterial community richness and evenness on the scale of France. By this way we have identified and rank the several ecological processes involved in community assembly as well as the different environmental drivers. In addition, we have also revisited the concept of taxa area relationship for microorganisms at this scale. The set of microbial data obtained from the RQMS survey enabled us to build up the first reference system of soil microbiology on a broad scale. My speech will end with the demonstration that these molecular microbial tools can be operational to diagnose soil quality in an agricultural network of 250 farms distributed across France.

Lionel RANJARD is a research scientist from INRA department "Environment and Agronomy" in the UMR "Agroécologie" INRA Dijon. He takes its position in November 2001 after a PhD in microbial ecology at university Claude Bernard (Lyon1, France) and a post-doctoral position in bacterial genetic. He is the coordinator of numerous scientific programs dealing with microbial biogeography at different spatial scales (from plots to French territory ECOMIC-RMQS project). More recently he has managed scientific programs with the goal to develop an operational set of bio indicators to diagnose agricultural soil quality and evaluate the impact of farming practices (AgrInnov project).

Recent papers

- Horrigue W., Dequiedt S., Chemidlin Prévost-Bouré N., Jolivet C., Saby N.P.A., Arrouays D., Bispo A., Maron P.-A., Ranjard L. 2016. Predictive model of soil molecular microbial biomass. *Ecological Indicators*, 64, 203-211.
- Constancias F., Saby N.P.A., Terrat S., Dequiedt S., Horrigue W., Nowak V., Guillemin J.-P., Biju-Duval L., Chemidlin Prévost-Bouré N., Ranjard L. 2015. Contrasting spatial patterns and ecological attributes of soil bacterial taxa across a landscape. *MicrobiologyOpen*, 4, 518-531.
- Ranjard L., Dequiedt S., Chemidlin Prévost-Bouré N., Thioulouse J., Saby N.P.A, Lelievre M., Maron P.-A., Morin F.E.R., Bispo A., Jolivet C., Arrouays D., Lemanceau P. 2013. Turnover of soil bacterial diversity driven by wide-scale environmental heterogeneity. *Nature Communications*, 4:134.
- Chemidlin Prévost-Bouré N., Dequiedt S., Thioulouse J., Lelièvre M., Saby N.P.A, Jolivet C., Arrouays D., Lemanceau P., Ranjard L. 2014. Similar processes but different environmental filters for soil bacterial and fungal diversity turnover on a widescale. *Plos One*, 9, 11.
- Terrat S., Dequiedt S., Horigue W., Lelievre M., Cruaud C., Saby N., Jolivet C., Arrouays D., Maron P.-A., Ranjard L., Chemidlin Prévost Bouré N. 2015. Improving soil bacterial taxa-area relationships assessment using DNA meta-barcoding. *Heredity*, 114, 468-475.

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Nematodes biodiversity and bioindicators

Nematodes are the most abundant metazoa on earth. They are ubiquitous and can be found in all habitats that provide organic carbon sources.

Since the 90's, nematofaunal indices have been developed: they integrate the responses of different taxa and trophic groups to perturbation and, in association with nematode functional group abundances, provide a powerful tool for an *in situ* environmental monitoring of soil.

The advantages of nematodes as bioindicators of soil quality are the ease with which assessments can be made: ease of the soil sampling, ease of community characterisation thanks to the strong relationship between nematode forms and functions which allows morphological identification. Moreover, nematodes vary in sensitivity to pollutants and environmental disturbance; the consistent and known response of taxonomic groups to different forms of environmental perturbation is also an essential factor of success.

Routine analysis of nematode fauna affords assessment of changes of agricultural practices or levels of environmental stress and provides decision criteria for conservation and remediation.

Soil ecologist and agronomist specialized on soil and plant nematodes, experienced in sustainable agriculture and soil fertility with twenty years of professional experience as researcher with the French "Institut de Recherche pour le Développement" (I.R.D.) mainly in Africa and France. She holds a PhD in ecology & plant production, and is agronomist from AgroParisTech (Paris, France)
C. Villenave is co-founder in 2011 of the ELISOL environnement; this company develops and markets tools for monitoring soil quality, based on nematodes as bioindicators. The customers are 1) the managers of sites undergoing decontamination, restoration or preservation and 2) the users of agricultural soils. It is also a laboratory of plant-parasitic nematode analysis (agricultural pests). Research and development is an important part of ELISOL environnement, through this research effort seeks to continuously improve fundamental and applied knowledge in the various fields of application of its soil quality monitoring tools.

Recent papers

- Trap et al. 2016. Ecological importance of soil bacterivores for ecosystem functions. *Plant & Soil*, 398, 1-24.
- Salomé et al. 2016. The soil quality concept as a framework to assess management practices in vulnerable agroecosystems: A case study in Mediterranean vineyards. *Ecologic indicators*, 61, 456–465.
- Henneron et al. 2014. Fourteen years evidence for positive effects of conservation agriculture and organic farming on soil life. *Agronomy for sustainable development*, 35, 169-181.
- Villenave et al. 2013. Nematodes for soil quality monitoring: results from the RMQS BioDiv programme. *Open Journal of Soil Science*, 3, 30-45.
- Cluzeau et al. 2012 Integration of biodiversity in soil quality monitoring: Baselines for microbial and soil fauna parameters for different land-use types. *European Journal of Soil Biology*, 49, 63-72.

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Soil biodiversity and ecosystem services

Soils are self-organized systems within which organisms interact forming a nested suite of discrete scales. Microorganisms form communities and physical structures at the smallest scale (microns), followed by the community of their predators organized in microfoodwebs (tens of microns), the functional domains built by ecosystem engineers (centimeters to meters), ecosystems, and landscapes where the delivery of ecosystem services emerges. The integrity and diversity of the different subsystems at each scale and the quality of their interconnections are a precondition for an optimum and sustainable delivery of ecosystem services. An adequate management of soil biodiversity offers a wide range of options to improve the delivery of such important soil based ES as climate regulation, food production, water and nutrient cycling.

Patrick Lavelle is an Emeritus Professor at Université Pierre et Marie Curie (Paris 6). He is a Soil Ecologist who worked mainly on earthworm ecology and their relationships with other soil organisms and processes. His research has been mainly developed in tropical areas of Africa and America, in natural savannas and rainforests and a large diversity of managed systems, especially in Amazonia. He has developed a general theoretical model of soil function based on the self-organization theory that integrates all biological, chemical and physical processes. After participating in the redaction of the millennium Ecosystem Assessment (coordinating author of chapter on Nutrient Cycling) he is currently working on Ecosystem Services, their determinants and their links to landscapes and societies in Tropical America. As a Director of the Laboratoire d'Ecologie des Sols Tropicaux and UMR BIOSOL at Institut de Recherche pour le Développement, he coordinated 20 projects for French and European donnors and supervised 31 PhD theses. He has published 360 scientific papers (220 in international journals) and published a textbook of Soil Ecology with Alister Spain (Kluwer, 2001).

Recent papers

- Lavelle et al. 2016. Ecosystem engineers in a self-organized soil: a review of concepts and future research questions. *Soil Science*, 181, 91-109.
- Lavelle et al. 2016. Unsustainable landscapes of deforested Amazonia: An analysis of the relationships among landscapes and the social, economic and environmental profiles of farms at different ages following deforestation. *Global Environmental Change*, 40,137–155
- Sanabria C., Dubs F., Lavelle P., Fonte S.J., Barot S. 2016. Influence of regions, land uses and soil properties on termite and ant communities in agricultural landscapes of the Colombian Llanos. *European Journal of Soil Biology*, 74, 81-92.
- Sanabria et al. 2014. Ants as indicators of soil-based ecosystem services in agroecosystems of the Colombian Llanos. *Applied Soil Ecology*, 84, 24-30.
- Jimenez et al. 2014 Dissecting the multi-scale spatial relationship of earthworm assemblages with soil environmental variability. *BMC Ecology*, 14, 26.

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FP7 large scale European project EcoFINDERS

EcoFINDERS project aimed at providing scientific and technological knowledge on soil biodiversity and functioning in relation with ecosystem services to the European Commission for its Soil Thematic Strategy. Research conducted within EcoFINDERS project has: (i) significantly increased the knowledge of soil biodiversity and soil ecosystem services across Europe, (ii) delivered standardized operating procedures to assess soil biodiversity and services, (iii) proposed a set of cost-effective bioindicators and mapped the threats to soil biodiversity at the European scale, (iv) developed strategies for assessing the economic value of soil biodiversity and ecosystem services, and (v) promoted the importance of soil biodiversity and ecosystem services to policy-makers, stakeholders and public.

Philippe Lemanceau is a senior scientist at the French National Institute for Agricultural Research (INRA). He is a soil microbiologist with a widely recognized expertise in plant-microbe interactions. He has published more than 100 papers and 35 book chapters. He is heading a department on agroecology in Dijon aiming at developing sustainable cropping systems valorizing plant and microbial diversity in order to maintain a high agricultural production delivering at the same time ecosystem services, with a lower use of synthetic inputs. He has been coordinating a large scale program within the 7th framework-program EcoFINDERS aiming at providing the European Commission with information on (i) soil biodiversity across Europe and (ii) relations between biodiversity, functions and ecosystems services according to the variety of European environmental conditions (soil and climate types, land uses).

Recent papers

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- Jones *et al.* 2014. Recently identified microbial guild mediates soil N_2O sink capacity. *Nature Climate Change*, 4, 801-805.
- Lemanceau *et al.* 2015. Understanding and managing soil biodiversity: a major challenge in agroecology. *Agronomy for Sustainable Development*, 35, 67-81.
- Lemanceau *et al.* 2016. Soil biodiversity and ecosystem functions across Europe: A transect covering variations in bio-geographical zones, land use and soil properties. *Applied Soil Ecology*, 97, 1-2.
- Philippot *et al.* 2013. Going back to the roots: the microbial ecology of the rhizosphere. *Nature Reviews Microbiology,* 11, 789-799.
- Ranjard *et al.* 2013. Turnover of soil bacterial diversity driven by wide-scale environmental heterogeneity. *Nature Communications*, 4, 1434.

Wim van der Putten

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Global Soil Biodiversity Initiative

The Global Soil Biodiversity Initiative (GSBI: https://globalsoilbiodiversity.org/) was launched in September 2011 and is open to all those interested in developing a coherent platform for promoting the translation of expert knowledge on soil biodiversity into environmental policy and sustainable land management for the protection and enhancement of ecosystem services. The GSBI is very much a bottom-up initiative from scientists for policy makers, public, and colleague scientists. It organizes numerous outreach activities, including the Global Soil Biodiversity Conference (the first one was in 2015 in Dijon and the second in 2017 in Nanjing) and the Global Soil Biodiversity Atlas. Another large effort is the setting up of a Global Soil Biodiversity Assessment.

Wim van der Putten graduated at Wageningen University in 1984 with a degree in ecology and then moved to the Institute for Ecological Research at Oostvoorne, The Netherlands. In 1989 he gained his PhD and Wageningen University and currently, he is head of the Terrestrial Ecology at the Netherlands Institute of Ecology (NIOO) and extraordinary professor in Functional Biodiversity at Wageningen University. Wim's main interest is in aboveground-belowground multitrophic interactions, plant-soil feedback, succession, (soil) biodiversity, invasions, and climate change-induced range shifts. In 2004, he was awarded a VICI grant in order to study consequences of rapid range shifts due to current climate warming and in 2012 an ERC Advanced grant on community re-assembly under climate warming. In 2015 he was elected member of the Royal Netherlands Academy of Arts and Sciences. Wim has co-authored an overview report on soil biodiversity for the EC DGXI, and is co-editor of both the European and Global Atlases of Soil Biodiversity. He co-founded the Wageningen Centre for Soil Ecology and the Global Soil Biodiversity Initiative (https://globalsoilbiodiversity.org/).

Recent papers

- Bardgett R.D., Van der Putten W.H. 2014. Soil biodiversity and ecosystem functioning. *Nature*, 515, 505-511.
- Tsiafouli M.A., Thébault E., Sgardelis S., De Ruiter P.C., Van der Putten W.H., Birkhofer K., Hemerik L., De Vries F.T., Bardgett R.D., Brady M., Bjornlund L., Bracht Jörgensen H., Christensen S., D' Hertfelt T., Hotes S., Hol W.H.G., Frouz J., Liiri M., Mortimer S.R., Setälä H., Stary J., Tzanopoulos J., Uteseny C., Wolters V., Hedlund K. 2015. Intensive agriculture reduces soil biodiversity across Europe. *Global Change Biology*, 21, 973-985.
- Ramirez, K.S. Döring, M., Eisenhauer, N., Gardi, C., Ladau, J., Leff, J.W., Lentendu, G. Lindo, Z., Rillig, M.C. Russell, D., Scheu, S., St John, M.G., de Vries, F.T., Wubet, T., van der Putten, W.H., Wall, D.H. 2015. Toward a global platform for linking soil biodiversity data. *Frontiers in Ecology and Evolution*, 3, 91.
- Keesstra S.D., Bouma J., Wallinga J., Tittonell P., Smith P., Cerdà A., Montanarella L., Quinton J., Pachepsky Y., van der Putten W.H., Bardgett R.D., Moolenaar S., Mol G., Jansen B., Fresco L.O. 2016. The significance of soils and soil science towards realization of the United Nations sustainable development goals (SDGs). *Soil*, 2, 111–128.
- Wubs E.R.J., van der Putten W.H., Bosch M., Bezemer T.M.B. 2016. Soil inoculation steers restoration of terrestrial ecosystems *Nature Plants*, 2, 1-5.

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Conclusions and prospects

Francis Martin is Distinguished Research Director at INRA, Nancy, France. He earned his doctorates in Plant sciences from Nancy and Paris-Sud Universities. He conducted postdoctoral and sabbatical research at at the University of California Los Angeles (UCLA), CSIRO, Perth, WA, and USDA Atlantic Research Center, PA. He has been employed at INRA since 1981. His interests include development of mycorrhizal symbioses, fungal evolution, comparative genomics, and fungal ecology. His research focuses on understanding how fungi drive forest ecosystems through their roles in important soil processes including decomposition and nutrient turnover as well as carbon sequestration. Much of his research has concentrated on ectomycorrhizal fungi, which form symbiotic associations with the roots of forest trees. He is currently Director of the Cluster of Excellence ARBRE. In 2012, he was awarded the INRA Laurel Wreath for Excellence. He is member of the French Academy of Agriculture.

Recent papers

- Martin *et al.* 2016. Unearthing the ectomycorrhizal symbiosis. *Nature Review Microbiology*, in press.
- Peter, Kohler *et al.* 2016. Ectomycorrhizal ecology is imprinted in the genome of the dominant symbiotic fungus *Cenococcum geophilum*. *Nature Communications*, in press.
- Kohler *et al.* 2015. Convergent losses of decay mechanisms and rapid turnover of symbiosis genes in mycorrhizal mutualists. *Nature Genetics*, 47, 410-415.
- Floudas *et al.* 2012. The Paleozoic origin of enzymatic lignin decomposition reconstructed from 31 fungal genomes. *Science*, 336, 1715-1719.
- Martin *et al.* 2010. Perigord black truffle genome uncovers evolutionary origins and mechanisms of symbiosis. *Nature*, 464, 1033-1038

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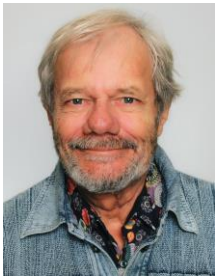

Dominique Job, membre de l'Académie d'agriculture de France (section des Sciences de la vie), modérateur lors des présentations/discussions durant le présent colloque, est directeur de recherche émérite au CNRS. Il s'est d'abord intéressé à l'étude physico-chimique des peroxydases végétales, en particulier en lien avec le métabolisme de l'auxine, phytohormone régulant la croissance des plantes. Puis il a abordé l'étude de l'expression des gènes de plantes supérieures, principalement par la caractérisation biochimique et fonctionnelle des différentes ARN polymérases nucléaires. Par la suite, il a développé des recherches sur le métabolisme spécifique des plantes (vitamines, acides aminée essentiels), tant au plan fondamental que pour le développement de nouveaux herbicides. Enfin, il a contribué à l'essor de la génomique végétale et s'est consacré à l'étude du protéome des plantes.

Recent papers

- Dieryckx *et al.* 2015. Beyond plant defense: insights on the potential of salicylic and methylsalicylic acid to contain growth of the phytopathogen *Botrytis cinerea*. *Frontiers In Plant Science* 6, 859.
- Poncet *et al.* 2015. The *Amborella* vacuolar processing enzyme family. *Frontiers In Plant* Sciences 6, 618.
- Galland *et al.* 2014. Dynamic proteomics emphasizes the importance of selective mRNA translation and protein turnover during *Arabidopsis* seed germination. *Molecular & Cellular Proteomics* 13, 252-268.
- Albert *et al.* 2013. The *Amborella* genome and the evolution of flowering plants. *Science*, 342, 1241089.
- Agrawal *et al.* 2013. A decade of plant proteomics and mass spectrometry: Translation of technical advancements to food security and safety issues. *Mass Spectrometry Reviews*, 32, 335-365.

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Daniel Tessier, Ingénieur géologue, Docteur d'État ès sciences (sciences physiques de la terre ; Paris 7) est Directeur de recherche honoraire de l'INRA où il a dirigé l'unité de Science du sol de Versailles. Il est également Membre de l'Académie d'Agriculture de France où il exerce la fonction de secrétaire de la section Interactions milieux-êtres vivants.
Ses domaines d'expertise concernent l'organisation et les propriétés des sols, et le rôle des sols dans l'environnement et pour la production agricole.
Il est auteur de nombreux articles scientifiques, rapports et ouvrages sur la physique du sol en relation avec l'établissement de la vie tellurique.
Il a exercé de nombreuses fonctions de coordination de la recherche, notamment en tant que Président de l'Association Française pour l'Etude du Sol.
Il est très activement impliqué dans la formation des professeurs du secondaire en sciences de la vie et de la terre.

Recent papers

- Rheinheimer dos Santos D., Cambier P., Mallmann F.J.K., Labanowski J., Lamy I., Tessier D., Van Oort F. 2013. Prospective modelling with Hydrus-2D of 50 years Zn and Pb movement in low and moderately metal contaminated agricultural soils. *Journal of Contaminant Hydrology*, 145, 54-66.
- Tessier D., Van Oort F. 2013. Organisations pédologiques à l'échelle des minéraux argileux. Les Sols et leurs Structures Chapitre 11. Versailles (FRA) : Editions Quae (Synthèses), 157-172.
- Calegari A., Tiecher T., Hargrove W.L., Ralisch R., Tessier D., De Tourdonnet S., Guimaraes M.d.F., dos Santos D.R. 2013. Long-term effect of different soil management systems and winter crops on soil acidity and vertical distribution of nutrients in a Brazilian Oxisol. *Soil and Tillage Research*, 133, 32-39.
- Mallmann F.J.K., Rheinheimer D.D.S., Labanowski J., Cambier P., Lamy I., Santanna M.A., Tessier D., Van Oort F. 2012. Using a two site-reactive model for simulating one century changes of Zn and Pb concentration profiles in soils affected by metallurgical fallout. *Environmental Pollution*, 162, 294-302.
- Chaplain V., Défossez P., Delarue G., Roger-Estrade J., Dexter A.R., Richard G., Tessier D. 2011. Impact of lime and mineral fertilizers on soil stability for soil pHs. *Geoderma*, 167-168, 360-368.

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Launch of the Global Soil Biodiversity Atlas in France

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