ACTIONr NEWSLETTER

Issue 4/ January 2025

ACTIONr

Research Action Network for Reducing Reactive Nitrogen Losses from Agricultural Ecosystems

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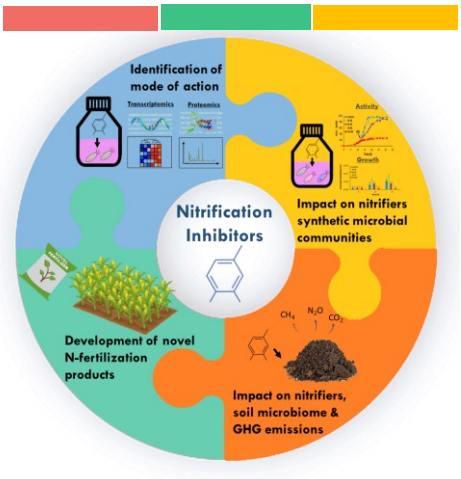
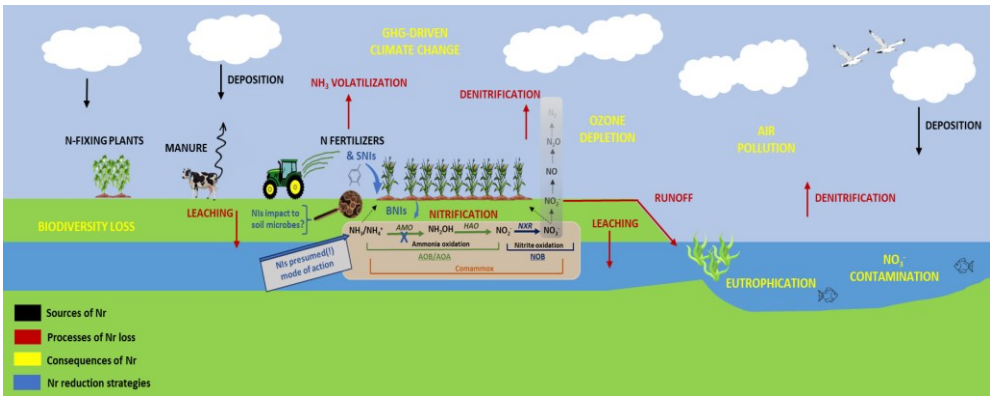


The ACTIONr project is exploring novel strategies to mitigate reactive nitrogen losses from agricultural ecosystems.

ABOUT ACTIONr

More than half of the nitrogen (N) fertilizer used in agriculture is lost as nitrate and N-oxides. A promising solution to increase N use efficiency (NUE) is the mitigation of reactive nitrogen (Nr) loss via nitrification inhibitors (NIs), synthetic and biological. Thessaly (Greece) is a suitable model for relevant research. However, local capacity is not yet fully explored. The EU-funded ACTIONr project will unravel the scientific excellence and innovation potential of the University of Thessaly (UTH) by establishing new tools and pathways to optimize NUE, decelerate the N cycle, and decrease the environmental footprint of Nr. To achieve this, UTH will twin with two internationally leading partners in the Ecogenomics (University of Vienna-UNIVIE) and Microbial Ecology (École Centrale de Lyon -ECL) of the soil N cycle.



THIS ISSUE

EDITORIAL

By Prof. **Dr. Dimitrios G. Karpouzas**

"How useful are nitrifiers in an ecotoxicological context?"

Nitrifiers is a broader functional group of microorganisms which collaborate to perform nitrification, the transformation of ammonium to nitrate. Nitrification is the most classic example of division of labor in the microbial world: ammonia oxidizing bacteria and archaea take on the first step and transform ammonia to nitrite, a substrate for nitrite oxidizing bacteria that transform it to nitrate. Since 2015 we know that nitrification could be also performed in a single cell by a group of bacteria called comammox (Daims et al., 2015).

Despite concerns about the acceleration of nitrification which contributes to climate change, through the enhanced production of highly potent greenhouse gases like nitrous oxide, and environmental pollution, through leaching of nitrates to groundwater, we still need to maintain soil nitrification rates to ensure nitrogen availability for plant growth and ecosystem functioning.

Ammonia oxidizers are the key microbial components of nitrification controlling the rate limiting step of this microbial process in soil. However, it is known since 1970s that ammonia oxidizing microorganisms are particularly sensitive to abiotic perturbations including stressors like pesticides (Domsch 1972). The sensitivity of ammonia oxidizers to pesticides has been verified since and their use as potential indicators of the toxicity of pesticides on soil microorganisms has been proposed (Karpouzas et al., 2022) since they have the credentials of an ideal bioindicator (i) they carry an important soil function (ii) they are sensitive to stressors and (iii) we have standardized tools like ISO methods (ISO17601-Estimation of abundance of selected microbial gene sequences by quantitative PCR from DNA directly extracted from soil; ISO15685 - Determination of potential nitrification and inhibition of nitrification – rapid test by ammonium oxidation) to measure their abundance and activity). The identification of such good microbial indicators for assessing the soil microbial ecotoxicity of pesticides is very relevant these days considering the well acknowledged limitations of the current testing methods for assessing the toxicity of pesticides on the soil microbiota (OECD 216 soil nitrogen mineralization) (Sweeney et al., 2024), and the decision made for reevaluating the pesticide risk assessment procedures for soil ecosystems.

So where are we regarding the implementation of ammonia oxidizers in pesticide risk assessment? A fair answer will be "still far", but what are the steps that have been taken and those that remain to be done. In this direction the EU project ARISTO (https://aristo.bio.uth.gr/) has been instrumental. First a tiered risk assessment procedure, in line with the ecotoxicological approaches taken in other trophic systems, has been proposed where ammonia oxidizing microorganisms, along with arbuscular mycorrhizal fungi, are central (Figure 1) (Karpouzas et al.,

Glossary

Abiotic perturbations:
Non-living environmental changes or stressors, such as the application of pesticides, that can impact microbial activity.

Bioindicator:
An organism or group of organisms used to assess the health of an environment or the impact of stressors like pesticides.

ISO methods:
Standardized methods developed by the International Organization for Standardization to measure specific processes, such as:

ISO 17601: Quantitative PCR estimation of microbial gene sequences in soil.

ISO 15685: A test for determining potential nitrification and its inhibition.

Pesticide Risk Assessment:
A process for evaluating the impact of pesticides on the environment, including soil ecosystems and microorganisms.

OECD 216 Soil Nitrogen Mineralization Test:
Current method for assessing the impact of pesticides on soil microbial activity by measuring nitrogen mineralization.

ARISTO:
An EU-funded project focusing on advancing pesticide risk assessment ecosystems, particularly involving ammonia oxidizers and other key microorganisms.

Arbuscular Mycorrhizal Fungi (AMF):
Fungi that form symbiotic relationships with plants, aiding nutrient uptake and often considered in ecological risk assessments.

2022). Like in all tiered systems we are testing the toxicity of pesticides against microbial indicator groups like ammonia oxidizers by gradually increasing the level of complexity. We start at Tier I with single species tests against soil-derived strains of ammonia oxidizing microorganisms covering as much as possible the phylogenetic and ecophysiological diversity of these organisms in soil. Depending on the outcome of the assessment in Tier I, we move to higher tiers that involve tests which assess the toxicity of pesticides on natural soil microbial assemblages of ammonia oxidizing microorganisms in soil microcosms/pots (Tier II) or field (Tier III).

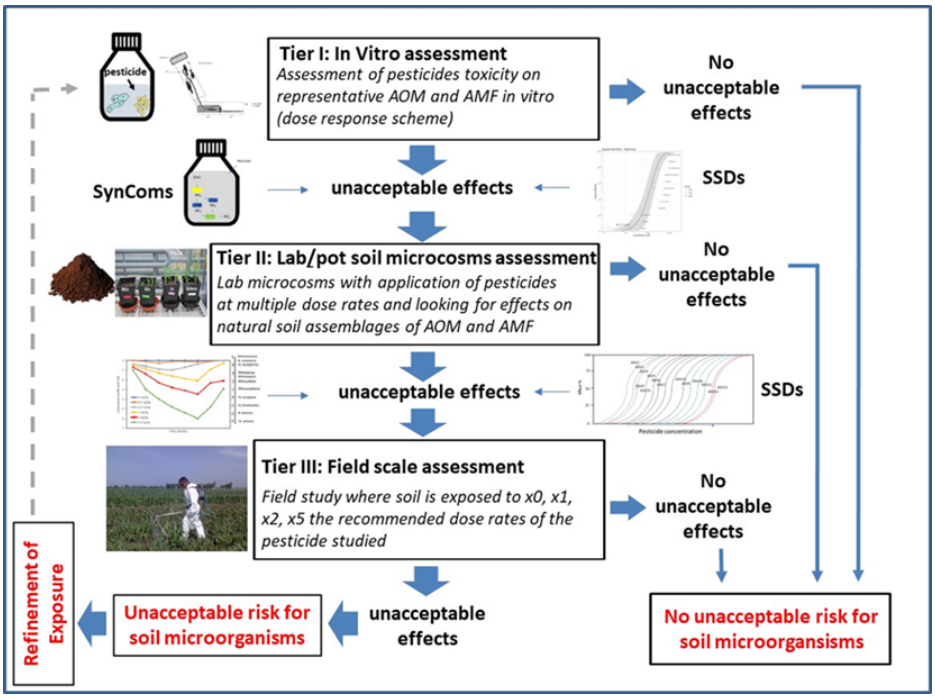


Figure 1. *A tiered risk assessment proposal or assessing the soil microbial toxicity of pesticides where ammonia oxidizing microorganisms (AOM) are central. The three tiers of testing are showing along with intermediate tests or approaches that could be used as refinement of Tier I (SSDs from single species tests or SynComs of nitrifiers) and Tier II (SSDs and Principal Response Curves from amplicon sequencing data).*

So where do we stand now regarding the implementation of this Tiered approach? We have now completed the first standardization steps of the single species tests with ammonia oxidizers through a tedious procedure that led to the identification of the most ecotoxicologically relevant and sensitive species of ammonia oxidizing bacteria and archaea that could be used in those tests. Furthermore, we have miniaturized the procedure in the form of a fast-track testing system which allows the calculation of EC50 values for a number of molecules in a single run of a 96-well plate. *What is the next step?* Establishment of an ISO standard that will enable the use of these single species tests as a Tier I tool. *Is there any room for improvement and refinement at Tier I?* Plenty I would say. A consistent criticism of single species tests is their limited ecological relevance regarding the breadth of organisms exposed and the mode of exposure. The use of synthetic communities (SynComs) of nitrifiers could enhance the ecological relevance of Tier I tests. Now bipartite and tripartite SynComs including ammonia-oxidizing bacteria, ammonia oxidizing archaea and nitrite oxidizing bacteria

Glossary

Tiered Risk Assessment:
A systematic approach to evaluate pesticide toxicity by gradually increasing the complexity of testing environments, from controlled lab tests to real-world field conditions.

Phylogenetic diversity:
The variety of evolutionary lineages within a group of organisms, such as ammonia-oxidizing microorganisms.

Ecophysiological diversity:
Variations in the functional and environmental adaptations of organisms within a group.

Species Sensitivity Distributions (SSDs):
Statistical models used to estimate the variation in sensitivity of different species to a toxic substance, such as pesticides.

Principal Response Curves (PRCs):
Statistical tools used to analyze changes in microbial community composition over time, often derived from amplicon sequencing data.

Single Species Tests:
Laboratory tests that assess the toxicity of a substance on an individual microbial species, such as ammonia-oxidizing bacteria or archaea.

EC50:
The concentration of a substance that reduces a biological function (e.g., nitrification) by 50%, used as a measure of toxicity.

***Synthetic Communities (SynComs)*:**
Artificially assembled microbial communities, such as combinations of ammonia-oxidizing bacteria, archaea, and nitrite-oxidizing bacteria, used to enhance ecological relevance in testing.

have been established and first tests are on the way to check their potential use in an ecotoxicological context.

How about tier II testing? The current OECD 216 test used in pesticide risk assessment is considered as a Tier II assay, and despite its limitations, it is expected to be maintained but not in its current form. It has been already proposed to be performed in a dose – dependent scheme allowing the derivation of EC_{50} values. In addition, data produced by ARISTO have shown that this test suffers from limited sensitivity and the use of higher resolution, standardized molecular methods like q-PCR could identify effects that were overlooked by the classic scheme (Pedrinho et al., 2024).

Another obvious question that becomes apparent is *how we could use the wealth of high-resolution microbiome data obtained from amplicon sequencing to determine the toxicity of pesticides on the soil microbiota*? As soil microbial ecotoxicologists we could borrow tools from aquatic ecotoxicology to exploit these data and calculate relevant ecotoxicity thresholds. Species sensitivity distributions could be used in multiple ways to provide Hazard Concentrations 5% for risk assessment, either using data from single species tests with ammonia oxidizers (as it is done in the aquatic ecotoxicology, Posthuma et al., 2019), or with amplicon sequencing data obtained by soils studies that have considered a multiple dose treatment scenario. Alternative approaches like the Threshold Indicator Taxa Analysis (TITAN) (Baker and King 2013) or the principal response curves (Jurburg et al., 2017) could be also considered in this context to provide ecologically and ecotoxicologically relevant threshold values. A main obstacle in the route towards uptake of such methods in the regulatory framework is the lack of standardization in the analysis of amplicon sequencing data, and it might take long to achieve it.

I would close this editorial with a few bullet points to where we should focus our research on the use of nitrifiers in soil microbial ecotoxicology in the future

• Verify the role of single species tests and the OECD-216 tests as Tier I and Tier II tests respectively

• Optimize refinement methods for testing the ecotoxicity of pesticides on nitifiers (e.g. improve SynComs complexity to make them more ecologically relevant for improved Tier I testing)

• Verify the potential of species sensitivity distribution and other advanced biometric methods to be applied in soil microbial ecotoxicology

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Glossary

Hazard Concentrations 5% (HC_5):
The concentration of a substance predicted to adversely affect 5% of species in a community, used as a benchmark in risk assessment.

Threshold Indicator Taxa Analysis (TITAN):
A method for identifying and quantifying changes in specific taxa in response to environmental stressors, such as pesticides.

Soil Microbial Ecotoxicology:
The study of the effects of toxic substances, such as pesticides, on soil microbial communities and their functions.

Biometric Methods:
Advanced statistical and analytical techniques, such as SSDs and PRCs, used to evaluate ecological and toxicological data.

Dimitrios G. Karpouzas *is the coordinator of ACTIONr, Prof. in Environmental Microbiology and Biotechnology and the Head of the Department of Biochemistry and Biotechnology, at the University of Thessaly, Greece.*

ORCiD

Hugo Ribeiro holds a PhD in Biomedical Sciences (Biogeochemistry) from the Biomedical Sciences Institute Abel Salazar (ICBAS), University of Porto (Portugal). He has contributed to numerous Portuguese and international research projects at CIIMAR (Portugal), focusing on nitrogen cycling, the effects of pollutants such as heavy metals and petroleum hydrocarbons, and optimizing nitrogen removal in wastewater treatment systems. Currently, Hugo is a postdoctoral researcher at the Department of Biochemistry and Biotechnology, University of Thessaly, Greece. His research focus on identifying and evaluating biological nitrification inhibitors.

"I have always been fascinated by the intricate balance of nitrogen cycling and the pivotal role that microbial communities and environmental factors play in its regulation"

INTERVIEWING RESEARCHERS OF ACTIONr

Hugo, please give a summary of your current research activity.

My current research focuses on the discovery and evaluation of biological nitrification inhibitors (BNIs) derived from natural compounds, such as triterpenes, and their potential to mitigate nitrogen losses in agricultural ecosystems. I am developing protocols to grow plants and extract bioactive compounds, testing their effectiveness in inhibiting nitrification and reducing greenhouse gas emissions. My work bridges fundamental research with practical applications, aiming to improve nitrogen use efficiency while minimizing the environmental impacts of agricultural practices.

What triggered your interest to contribute this research work?

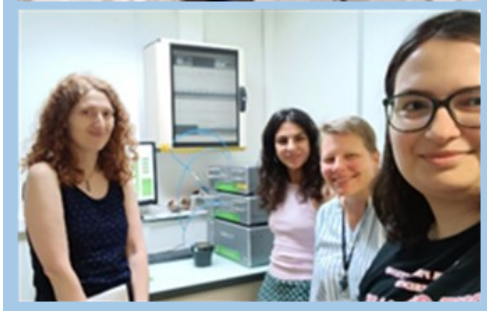
I have always been fascinated by the intricate balance of nitrogen cycling and the pivotal role that microbial communities and environmental factors play in its regulation. The environmental consequences of nitrogen losses, such as nitrate leaching and nitrous oxide emissions, present urgent challenges. Investigating plant-derived compounds as sustainable alternatives to synthetic inhibitors offers a unique and promising way to address these issues. This research enables me to apply my background in biogeochemistry and microbial ecology while exploring innovative strategies that align with global sustainability goals. Moreover, the opportunity to collaborate with international experts and engage with interdisciplinary research has been a major driver for my involvement in the ACTIONr project.

Can you describe in a few words your work highlights?

Since joining this research group, I have developed and standardized protocols for cultivating various plant species under controlled conditions and extracting potential BNIs from their root exudates and tissues. I have also conducted experiments to evaluate the inhibitory effects of natural compounds, particularly triterpenoids, on nitrifying microbes such as ammonia-oxidizing bacteria and archaea. A key highlight has been collaborating with international partners to predict the potential inhibition of specific compounds using mathematical models based on their chemical structure, allowing us to hypothesize their modes of action. These efforts have deepened our understanding of how BNIs influence nitrogen cycling and their potential applications in sustainable agriculture.

What about your upcoming steps in this research project?

The next steps involve scaling up plant-based extraction protocols to enhance the yield and purity of BNIs and conducting *in vitro* experiments to evaluate their effects on nitrification pathways under controlled conditions. I also plan to refine the chemical characterization of these compounds through advanced analytical techniques, such as GC-MS, in collaboration with international partners. To expand the scope of this research, I aim to incorporate advanced omics approaches to investigate the genetic and metabolic responses of nitrifying microorganisms exposed to BNIs. These steps will provide a comprehensive understanding of the feasibility and scalability of using plant-derived BNIs in real-world agricultural systems, contributing to the development of sustainable nitrogen management strategies.



A remarkable training experience leaded by the masters in Environmental Microbial Genomics of the École Centrale de Lyon.

Mind-stimulating presentations with compelling content by UTH members Professor Dr. Dimitris Karpouzas, Assistant Professor Dr. Evangelia Papadopoulou and PhD student Dimitris Dalkidis, along with ECL members Professor Graeme Nicol and Principal Investigator Christina Hazard, to the 19th International Symposium on Microbial Ecology (ISME19), held in Cape Town, South Africa, 18 - 23 August 2024.

LATEST NEWS OF ACTIONr NETWORK

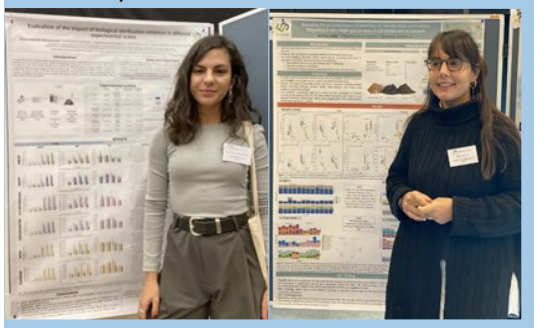
New educative training visit through ACTIONr project

Along a hot summer in Greece, the third fascinating training visit was accomplished by ACTIONr dedicated UTH staff members, at the prestigious École Centrale de Lyon (ECL) as a host spot! Under this, Assistant Professor Dr. Evangelia Papadopoulou and PhD student Paraskevi Amanatidou went into a thrilling experience of a two-week hands-on practice-training in frontline technologies and topics, like Stable Isotope Probing (SIP) for microbial ecology and GHG analysis. They had the opportunity to work alongside the specialist in Environmental Microbial Genomics Group at Laboratoire Ampère, joined also by ACTIONr PhD student Valia Moutzourelli from UTH, who was doing her secondment at ECL. Grateful acknowledgments to the experts Professor Graeme Nicol and Principal Investigator Christina Hazard for their guidance and skillset support throughout this unique engagement.

ACTIONr participation to ISME19 conference

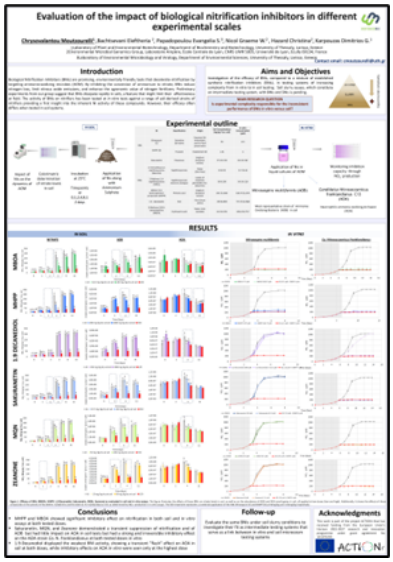
The ACTIONr consortium supported an outstanding participation in the *19th International Symposium on Microbial Ecology (ISME19)*, held from August 18 to 23, 2024, in the beautiful city of Cape Town, in South Africa. UTH team shared inspiring posters, showcasing the discussion-triggering open field of potentially novel nitrification inhibitors and their impact on soil ammonia and nitrite oxidizers, as a promising avenue to mitigate nitrogen losses and greenhouse gas emissions. The indeed exceptional work of the PhD student Dimitris Dalkidis, coming out in partnership with the University of Vienna, provided preliminary insights into the potential modes of action of synthetic and biological nitrification inhibitors, exploring their effects on the transcriptome and proteome of soil ammonia oxidizers.

Intriguing poster presentations performed by PhD student and ACTIONr member Valia Moutzourelli and PhD student Maria Kolovou, to the 4th International Conference on Microbial Ecotoxicology, carried out in Gothenburg, Sweden, 12 – 14 Nov. 2024.



A bunch of new knowledge and research produced along the passing year along with the new goals for the coming year was displayed by the established members of ACTIONr consortium, in Vienna.

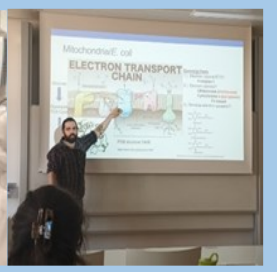
ACTIONr participation to EcotoxicoMic 4rth conference

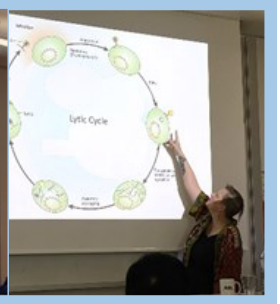


ACTIONr robust attendance, represented by PhD student Valia Moutzourelli as first author, delivered valuable insights to the 4th International Conference on Microbial Ecotoxicology, carried out from November 12 to 14, 2024, in Gothenburg, Sweden. Her poster presentation spotlighted potential impacts of biological nitrification inhibitors over different experimental scales, from soil microcosms to soil microbial strains individually cultured, offering innovative perspectives over the efficacy of BNIs. She was accompanied by the PhD student Maria Kolovou, dedicated member of the broader ACTIONr Team, who also presented her poster on the potential impact of pesticides over soil and single nitrifier species. They both supplied the conference with mind-expanding findings on state-of-the-art topics towards the field of microbial ecotoxicology.

ACTIONr annual meeting in striking Vienna

After a full of work year, here we are again! The second annual meeting of ACTIONr consortium was achieved throughout a stormy weather, on 15-16 of September 2024 at the Department of Biology, of the startling University of Vienna and under the hostness of Professor Christa Schleper's group. This second year's meeting started enriched with two new scientist entries, the PostDoc Researchers Dr. Elena Papadopoulou from UTH and Dr. Eleftheria Bachtsevani from ECL, who introduced themselves to the ACTIONr community. Despite the cold outside, under a warm gathering, the devoted scientists and the PhD students of the project presented their latest, noteworthy and insightful research results and the innovation and dissemination activities obtained until then. It was an indeed astonishing assemblage that provided a valuable opportunity to review the project's progress, share key findings and plan the next steps for the coming year, since more and more research advance comes out. We had, finally, the pleasure to refresh our mind and enjoy some interesting talks by dinning all together! Can't wait for our next research team reunion!





A magnificent accumulation of knowledge was provided at the first ACTIONr Summer School, 16-21 September 2024, at the stunning University of Vienna (Archaea Biology and Ecogenomics Unit) incorporating lectures and practicals guided by internationally expert scientists.

First ACTIONr Summer School was carried out successfully in Vienna

What an experience for all the PhD Students, PostDoc and other Researchers that participated at the first ACTIONr Summer School, held from 16 to 20 September 2024 and organized by Prof. Christa Schleper's team! Participants from across Europe were able to explore the crucial roles that microbes play in methane and nitrous oxide, non-CO2 greenhouse gas production, while also examining how climate change affects these processes. Under the groundbreaking accommodations of the Department of Functional and Evolutionary Biology at the University of Vienna, they attended hands-on sessions and extraordinaire lectures led by top researchers, including Profs. Lisa Stein, Graeme Nicol, Dimitrios Karpouzas, Stephan Glatzel, and many more. All instructors, participants and speakers composed together a gorgeous academic environment, making this event an enchanting experience, while much more credits are attributed to Prof. Christa Schleper, Dr. Melina Kerou, Dr. Logan Hodgskiss, and Mag. Nathalia Jandl for their wonderful hospitality and flawless organization!

Mission accomplished: a six-month PhD Secondment at École Centrale de Lyon came to an end for Valia Moutzourelli. She grabbed the chance to delve more in the activity of nitrification inhibitors on the soil microbial world and explore new approaches regarding her soil experiments.

Exploring the Microbial Frontier: Shots from a Successful Secondment within the ACTIONr project

A full experience secondment was successfully fulfilled on July 2024 for our skilled PhD student Valia Moutzourelli (UTH), at the famed École Centrale de Lyon (ECL). Valia, under the support and supervision of Prof. Nicole Graeme and Dr. Christina Hazard, received tentative and in-depth training in Stable Isotope Probing (SIP) with labeled O_{18} water in soil microcosms. During this long-term visit, she optimized existing protocols to meet the requirements of her soil experiments. It was a real challenge for her, where she also tested a range of solvents for BNIs' application in soil, aiming to select the one with minimum impact on the conditions under which SIP carries out. Interestingly, in the framework of ACTIONr project, a new experimental concept set up was introduced, focusing on an upgraded approach of the efficacy of BNIs through an enriched experimental scale, from *in vitro* assays to slurry and in soil experiments. Fully recharged and more qualified, she returned to UTH to expand her knowledge and provide more findings for her PhD research! Until her next secondment there, Valia salutes Lyon with a big "Au revoir"!

Memorable activities engaging the scientific and the fascinating part of ACTIONr dissemination, under the grand event of ACTIONr Open Day, on 21st Nov. 2024.

ACTIONr Open Day - A Celebration of Innovation and Collaboration

We are so proud for ACTIONr Open Day, such a gripping event and a milestone for this project that we had the honour to coordinate and attain on November 21st of 2024, in Larissa, Greece, spanning multiple locations, from the Laboratory of Plants and Environmental Biotechnology of UTH and Karavanas elementary School, to Joist Innovation Park and finally to the Mparaki of Mylos. The day began when ACTIONr opened its doors with a team of UTH researchers spreading around to share the daily routine and innovation part of ACTIONr under the full-equipped facilities of the Department of Biochemistry and Biotechnology, in UTH, Larissa and at the pretty-organized elementary Karavanas School. At UTH, six researchers led by Prof. Dimitris Karpouzas were implicated in displaying the nitrification field of research to high school students, invited to come in touch, be informed and get familiar with relevant laboratory's common assays on *in vitro* cultivated soil microorganisms and directly on soil. At Karavanas elementary school, Assistant Prof. Evangelia Papadopoulou surrounded by 5 more researchers, made everything moving to the rhythm of Nitrogen Cycle process! Through a unique entertaining experience, the little students there joined a marvellous presentation of Nitrogen Cycle, along with mind-broadening Nitrogen-related crosswords and drawings and the unforgettable N-races game, available to play on table and on floor form. In the evening, a comprehensive workshop was held at Joist Innovation Park throughout an interactive environment, with conversations stimulated by the extraordinary presentations of the academicians Prof. Christa Schleper from UNIVIE, Prof. Graeme Nicol from ECL and Prof. Dimitris Karpouzas from UTH and the Senior Researchers Dr. Fotini Giannakopoulou from Hellenic Fertilizers' Association (SPEL) and Dr. Michalis Omirou from Agricultural Research Institute of Lefkosia, Cyprus. At the end of the day, the workshop followed an open gathering at Mparaki of Mylos, where everybody was able to have a good time in enjoyfull beer talks with the ACTIONr consortium scientists, under a warm habitat of relaxed discussions. Special credits to the organizers of such a momentous, undoubtably unforgettable event embracing the celebration of innovation, creativity, and connection by ACTIONr!

FORTHCOMING CONFERENCES AND EVENTS

9th ICoN Conference and adjacent ACTIONr Workshop

Get ready for ICoN9! The 9th International Conference on Nitrification and Related Processes (ICoN9), where the heart of nitrification beats, is planned to be held on June 22 to 26, 2025, at the Department of Biogeochemistry, Max Planck Institute for Marine Microbiology (MPIMM), in Bremen, Germany. Bringing together worldwide known academicians, investigators and students at all level, this highly anticipated conference will shed again light on nitrification and related processes in the nitrogen cycle, giving the floor to keynote presentations to share novel scientific discoveries of the global biogeochemical nitrogen cycle. Of course, key members of the ACTIONr consortium will be in attendance, strongly involved in pioneering topics that will be regarded throughout the conference, encompassing oceanic and terrestrial biogeochemistry, microbial physiology, biochemistry, structural biology and climate change. An adjacent ACTIONr Workshop will follow on Friday, June 27th, offering a unique opportunity to explore and engage with the latest research and methodologies developed within the ACTIONr consortium. Don't miss it out!

9th International Conference on Nitrification and Related Processes & adjacent ACTIONr workshop

Max Planck Institute for Marine Microbiology (MPIMM), Bremen, Germany

22- 27 June 2025

Max Planck Institute for Marine Microbiology

Website

https://www.mpi-bremen.de/en/ICoN9-Conference.html

Second ACTIONr Summer School in Greece

The highly anticipated Second ACTIONr Summer School is set to take place in the stunning Paou Monastery of Pelion, Greece, in May 2025. This unique event promises to be an extraordinary gathering, bringing together researchers, students, and experts from around the world to share their knowledge and expertise in soil biochemistry, microbial ecology, and innovative agricultural practices. The picturesque location of the Paou Monastery will provide the perfect backdrop for a week of learning, networking, and collaboration. This year, the summer school will offer an exciting mix of lectures, hands-on workshops, and group discussions focused on Biological Nitrification Inhibitors, microbial interactions, and cutting-edge research in agricultural and ecological sciences. The tentative program includes a rich array of topics, ranging from phage therapy and metabolomic analysis to genomic and proteomic practicals, providing attendees with a comprehensive understanding of the latest advancements in these areas. This summer school will be a valuable opportunity for participants to enhance their skills, exchange ideas, and advance their research in areas critical to improving agricultural sustainability and tackling global environmental challenges. The event will also provide a chance to network with leading scientists, engage in productive discussions, and explore collaborative research possibilities.

The Second ACTIONr Summer School offers an immersive experience in the fields of soil biochemistry and microbial ecology. Held in the scenic Paou Monastery in Pelion, Greece, this event combines theoretical lectures with hands-on workshops. Participants will explore Biological Nitrification Inhibitors, microbial interactions, and advanced techniques such as phage therapy, metabolomics, and genomics, all while engaging with leading experts and fostering global collaboration.

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