D2.1 - Specialized training programme on “water management, plant-soil interactions, alternative fertilizers”

[SECOND VERSION]

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Technical References

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Summary

The project SOILdarity has been designed to make a small contribution to the global effort of guaranteeing healthy and productive soils and supporting its fundamental ecosystem services. As a twinning exercise, SOILdarity will develop strategies to build on and strengthen the existing research and innovation capacities of the coordinator in several domains revolving around soil sciences. The short-term objective of the project is to successfully implement a methodological framework integrating knowledge transfer activities and partnership building efforts.

The whole project can be considered as a long-lasting capacity building action, likely to bear structuring and long-lasting benefits for the Coordinator.

SOILdarity's methodology is based on four pillars corresponding to four phases running highly interrelated actions, all equally important to deliver a comprehensive enhancement of the Coordinator's research profile and capabilities.

The phase called "Step up" deals with mechanisms of transferring relevant knowledge, research approaches, methodologies and updates generated by previous and ongoing work of the internationally leading research partners in the project to the Coordinator. It is implemented mainly through the specialized training modules, as well as soft skill training modules, including those reserved to young researchers.

This document particularly focuses on outlining the programme on the specialized training course on "water management, plant-soil interactions, alternative fertilizers". The programme includes the content of the courses and the individuals responsible for the sessions.

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Spelling Guidelines

Standardised British spelling should be used in the document. Generic terms are spelled in lower case, specific terms and proper names are spelled with initial capitals.

Disclaimer

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TABLE OF CONTENTS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No

1. Introduction

Research excellence, enhanced internationalization, and higher competitiveness together with the increase of national and international funding opportunities require improved research skills tools to increase performance indicators. MIGAL will coordinate the overall efforts to deliver two specialized intensive courses:

First year/ multi-module course on the "optimisation of the use of treated waste waters as a source for alternative fertilisers"	Phosphorous, a non-renewable resource, has been applied extensively in fields to increase crop yield, yet consequently has increased the potential of waterway eutrophication. Hence, there is an urgent need to develop an innovative method of P capturing, recycling and reuse that will sustain agricultural productivity while concurrently reducing the level of P discharge from and to agricultural settings. We will demonstrate the applicability of the widely produced by-products of drinking water utilities and desalinization plants known as Aluminum-based Water Treatment Residual (Al-WTR) and Iron-based Water Treatment Residual (Fe/WTR) respectively. Al- and Fe- WTR are known as an excellent P adsorbent and could be used to recover P from agricultural wastewaters; subsequently, it could be applied to the fields as a P fertilizer. We will show that Al-WTR and Fe-WTR behave as sinks and will adsorb inorganic P (Pi), along with organic P (Po), dissolved organic matter (DOM) and other constituents from agro-organic wastes. We will demonstrate that the sorption of multiple constituents generates an Al/Organic Composite (Al/O-WTR) and Fe/ Organic Composite (Fe/O-WTR) that will desorb Pi and Po more effectively in the field compared to Al-WTR and Fe- WTR. The workshop objectives are: 1) to develop a thorough understanding of the sorption mechanisms of Pi and Po onto the Al/O-WTR and Fe/O-WTR; and 2) to critically evaluate the performance of the composite WTRs as a fertilizer using selected plants grown in screen-houses and in test-fields.

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Second year/ multi-module course on “soil ecology in dry ecosystems”	Although hidden from the eye, it is becoming more and more clear, that the ecology of soil processes can have far reaching effects on the aboveground ecology of natural and agricultural habitats. The role of soil microbes in affecting forest health and crop yields is currently unravelling. The course will be made up of classroom lectures in which the role of soil microbes (with an emphasis on mycorrhiza and rhizobium) on forest ecology will be discussed. Each day will include a morning lecture followed by a field trip related to the taught material. Some of the topics that will be covered include nutrient cycling, the role of soil microbes in forest regeneration after disturbance, soil ecology and its effect on plant health, competitive interactions within the soil, plant soil feedback and their effect on plant community dynamics, soil microbes and invasive plant species.

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2. Training targets

Participation in the SOILdarity specialized training program will be open to students and researchers from FC.ID and CIÊNCIAS. A gender balance among the participants will be promoted and prioritized during the selection process.

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3. Intensive specialised training courses

3.1. Course on “Optimization of the use of treated waste waters as a source for alternative fertilizers”

Instructor

Prof. M. Iggy Litaor, Lab assistants Dr. Oren Reichman and Adi Zarka (M.Sc.)

Pre-requisites

General Chemistry, soil chemistry, Statistics

Impetus

Phosphorous, a non-renewable resource, has been applied extensively in farm fields and orchards to increase crop yield, yet consequently has increased the potential of waterway eutrophication. Hence, there is an urgent need to develop an innovative method of P capturing, recycling and reuse that will sustain agricultural productivity while concurrently reducing the level of P discharge from and to agricultural settings.

Course structure

The course has two basic modules. The first module consists of 10 meetings, 2 hours each, that will be taught via remote mode (Zoom and alike). The second module of 3 meetings, 8 hours each will be conducted in the laboratory by remote instruction or in person (MIGAL’s team will spend a week in University of Lisbon and supervise the lab experiments). The latter is preferable but hinges on the status of the C-virus pandemic.

Course Objectives

1. The students/participants will acquire fundamental understanding of the physicochemical characteristics of Al^{-} water treatment residue (Al-WTR) and its transformation into Al organic composite known as Al/O-WTR.
2. The students/participants will be able to quantify the P sorption on Al-WTR and evaluate the desorption capacity of Al/O-WTR and assess its suitability to become an alternative P fertilizer.

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Course outcomes

1. Students/Participants will understand the physicochemical processes responsible and controlling the loading of P onto Al-WTR.
2. Students/Participants will produce Al/O-WTR and will test its performance using selected crop.

Course assignments and grade

During the course the students/participants will be assigned to read technical and scientific papers. The grade will be based on a verbal presentation and assay (5 pages long) on certain topic selected by the student/participant with consultation with the course instructor.

Subject Matters

First lecture: **Introduction to P cycling** including eutrophication processes of water ways, expected global P scarcity and its influence on the green revolution, and a preliminary survey of methods of P removal from agro-industrial waste streams. These methods include biological such as enhanced biological P removal – EBPR, chemical treatment and physical treatment such as reverse osmosis and other membranes technologies.

Reading Assignment:

- Yang, et al., 2018. Global development of various emerged substrates utilized in constructed wetlands, Bioresour. Technol. 261: 441–452, https://doi.org/10.1016/j.biortech.2018.03.085.
- Huang, et al., 2017. Adsorptive removal of phosphate from water using mesoporous materials: a review, J. Environ. Manage. https://doi.org/10.1016/j.jenvman.2017.02.030.
- Karunanithi, et al., 2015. Phosphorus Recovery and Reuse from Waste Streams, Elsevier Ltd, 2015, https://doi.org/10.1016/bs.agron.2014.12.005.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No

Second lecture: **Physical and chemical characteristics of alum residue (Al-WTR)**.

Suggested reading:

- Bhatnagar, and Sillanpää, 2010. Utilization of agro-industrial and municipal waste materials as potential adsorbents for water treatment-a review, Chem. Eng. J. https://doi.org/10.1016/j.cej.2010.01.007.
- Wang, et al., 2014. Utilization of alum sludge for producing aluminum hydroxide and layered double hydroxide, Ceram. Int. 40 :15503–15514, https://doi.org/10.1016/j.ceramint.2014.07.012.

Third lecture: **Mechanism of adsorption capacity of Al-WTR**. Class discussion will cover the alum internal attributes such as particle size, surface functional groups, specific surface area, metal content and stability, as well as external conditions like solution pH, temperature, presence of competitors, dosage of sorbent, and initial phosphorous solution concentration.

Suggested reading:

- Yang, et al., 2006. Characteristics and mechanisms of phosphate adsorption on dewatered alum sludge, Sep. Purif. Technol. https://doi.org/10.1016/j.seppur.2006.01.013.
- Makris, et al., 2004. Phosphorus immobilization in micropores of drinking-water treatment residuals: implications for long-term stability, Environ. Sci. Technol. https://doi.org/10.1021/es049161j.

Fourth lecture: **Adsorption kinetic models**. Adsorption kinetic model is a graphical solution that describes the rate of retention or release of a solute from an aqueous environment to solid-phase interface (e.g., Alum) at a given adsorbents dose, temperature, flow rate and pH. During adsorption two main processes are involved; physical (physisorption) and/or chemical (chemisorption).

The Adsorption Challenge: If the goal is to capture and reuse the P from various agricultural waste streams then irreversible adsorption would be least preferred. The Practical Challenge: To reuse the P-containing alum as a form of quick or slow-release fertilizer to offset P-deficiency in soils

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No

and limit over-use of the natural reserves for this non-renewable resource as well as to avert eutrophication.

Suggested reading:

- Babatunde, and Zhao. 2010. Equilibrium and kinetic analysis of phosphorus adsorption from aqueous solution using waste alum sludge, J. Hazard. Mater. https://doi.org/10.1016/j.jhazmat.2010.08.102.
- Li, et al., 2016. Phosphate adsorption on metal oxides and metal hydroxides: a comparative review, Environ. Rev. https://doi.org/10.1139/er-2015-0080.

Fifth lecture: **Adsorption equilibrium isotherm models**. Equilibrium will be established between the amount of adsorbents and the amount of adsorbate in solution. The equilibrium relationship is described by adsorption isotherms. Common knowledge suggests that the optimum equilibration time for P adsorption on alum sludge is 24 h. The variations in the equilibration times are due to differences in experimental conditions that include alum sludge dose, initial P concentration, agitation, solution pH, temperature of reaction, and particle size distribution of the Al-WTR.

Suggested readings:

- Hou, et al., 2018. Phosphorus adsorption characteristics of alum sludge: adsorption capacity and the forms of phosphorus retained in alum sludge, Mater. Lett. 229: 31–35, https://doi.org/10.1016/j.matlet.2018.06.102.
- Maqbool, et al., 2016. Reuse of alum sludge for phosphorus removal from municipal wastewater, Desalin. Water Treat., https://doi.org/10.1080/19443994.2015.1055806.
- Zhao, et al., 2007. Reuse of aluminum based water treatment sludge to immobilize a wide range of phosphorus contamination: equilibrium study with different isotherm models, Sep. Sci. Technol. https://doi.org/10.1080/01496390701511531.

Sixth lecture: **Adsorption is highly dependent on pH** of the solution and the highest adsorption capacity mostly happens in acidic pH range of 4–5.5. This adsorption occurs in the pH range below the pH_{pzc} of alum sludge which is 7.5.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No

Selected Readings:

- Yang, et al., 2006. Characteristics and mechanisms of phosphate adsorption on dewatered alum sludge, Sep. Purif. Technol. https://doi.org/10.1016/j.seppur.2006.01.013.
- Liu, et al., 2018. Review of metal (hydr) oxide and other adsorptive materials for phosphate removal from water, J. Environ. Chem. Eng. https://doi.org/10.1016/j.jece.2018.08.008.

Seventh lecture: **P adsorption is more favoured by small/fine particle size ranges than with bigger sized particles**. Fine particles can significantly increase the intra-pore specific surface area and provide additional adsorption sites in the form of micropores, macropores and mesopores. Particle size of alum sludge can be manipulated to increase its efficacy as an adsorbent. The only difficulty is the lack of a standard size of particles that give the best adsorption which makes a unified comparison difficult.

Suggested readings:

- Lee, et al. 2015. Aluminum-based water treatment residue reuse for phosphorus removal, Water https://doi.org/10.3390/w7041480.
- Elkhatib et al., 2015. Green synthesis of nanoparticles by milling residues of water treatment, Environ. Chem. Lett. https://doi.org/10.1007/s10311-015-0506-6.

Eighth lecture: **Inconclusive results of retention time were reported in the literature**. Greatly depends on experimental conditions. If there is little P for adsorption surface adsorption will still prevail and rapidly for that matter, regardless of contact time, so long other factors are optimal such as the particle size of the alum sludge, the temperature, pH, agitation and presence of competing substances.

Suggested readings:

- Mohammed and Rashid, P removal from wastewater using oven dried alum sludge, Int. J. Chem. Eng. (2012), https://doi.org/10.1155/2012/125296.
- Makris, et al., 2005. Relative efficacy of a drinking-water treatment residual and alum in reducing phosphorus release from poultry litter, Commun. Soil Sci. Plant Anal. https://doi.org/10.1080/00103620500303574.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No

- Bai, et al., 2014. Reuse of drinking water treatment residuals in a continuous stirred tank reactor for phosphate removal from urban wastewater, Environ. Technol. (United Kingdom) https://doi.org/10.1080/09593330.2014.920050.

Ninth lecture: **Competitive Ions**. Conclusively, nitrates and chlorides are weaker competitors whilst carbonates and fluorides are stronger competitors than phosphates for aluminum. Sulfates have a larger ionic radius than chlorides and nitrates so they strongly compete with P on the positively charged Al ion.

Suggested readings:

- Yang, et al., 2006. Characteristics and mechanisms of phosphate adsorption on dewatered alum sludge, Sep. Purif. Technol. https://doi.org/10.1016/j.seppur.2006.01.013.
- Liu, et al., 2016. Evaluation of natural organic matter release from alum sludge reuse in wastewater treatment and its role in P adsorption, Chem. Eng. J. https://doi.org/10.1016/j.cej.2016.05.019.
- Li, et al., 2016. Enhancing phosphate adsorption by Mg/Al layered double hydroxide functionalized biochar with different Mg/Al ratios, Sci. Total Environ. 559: 121–199, https://doi.org/10.1016/j.scitotenv.2016.03.151.

Tenth lecture: **Dosage of adsorbent**. Most studies have found that P adsorption increases as dosage of alum is increased but these upper limit dosages are different because of other experimental factors such as particle size distribution, contact time, initial P concentrations, shaking duration, speed and/or intensity. Therefore, there is need for an optimization study to determine the optimum dosage of alum sludge-based adsorbent, of a particular optimum particle size, Al content and form, to be used to achieve effective and efficient phosphate adsorption from aqueous solution.

Suggested readings:

- Hou, et al., 2018. Phosphorus adsorption characteristics of alum sludge: adsorption capacity and the forms of phosphorus retained in alum sludge, Mater. Lett. 229 (2018) 31–35, https://doi.org/10.1016/j.matlet.2018.06.102.

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Eleventh lecture: **Desorption, regeneration and recovery**. The objectives of desorption/regeneration exercises are to recover the adsorbent or adsorbate depending on their market demand (desorption), restore the adsorbent back to its initial properties for effective reuse (regeneration) and so, reduce the overall process cost of the adsorption process. The bound phosphate ions cannot be easily recovered from alum sludge for other environmentally sustainable uses such as source of phosphorous-based fertilizer. However, Al-WTR composited with organic matter prior to P adsorption resulted in a significantly greater release of P from the cowshed wastewater amended-alum sludge than alum sludge alone (yielding concentrations of 31.8 and 0.2 mg soluble reactive P/kg solid, respectively). Organic matter probably inhibited the formation of strong binding of phosphates to the adsorption sites making them easily desorbed.

Suggested readings:

- Devi, and Saroha 2017. Utilization of sludge-based adsorbents for the removal of various pollutants: a review, Sci. Total Environ. 578:16–33, https://doi.org/10.1016/j.scitotenv.2016.10.220
- Zhao and Zhao 2009. Investigation of phosphorus desorption from P-saturated alum sludge used as a substrate in constructed wetland, Sep. Purif. Technol. https://doi.org/10.1016/j.seppur.2008.11.020.
- Zohar, et al., 2017. Innovative approach for recycling phosphorous from agro-wastewaters using water treatment residuals (WTR), Chemosphere https://doi.org/10.1016/j.chemosphere.2016.10.041.

The next 2 meetings will be dedicated to laboratory experiments to facilitate hands-on experience based on the theory provided in the on-line lectures. The experiments will be conducted at University of Lisbon.

Additional Literature (optional reading)

- Zohar, I., M. S. Massey, J.A. Ippolito, and M. I. Litaor. 2018. Phosphorus Sorption Characteristics in Aluminum-Based Water Treatment Residuals Reacted with Dairy Wastewater, Part I: Isotherms, XRD, and SEM-EDS Analysis Journal Environmental Quality. doi:10.2134/jeq2017.10.0405

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- Massey, M.S., I. Zohar, J.A. Ippolito, and M.I. Litaor. 2018. Phosphorus sorption to aluminum-based water treatment residuals reacted with dairy wastewater, Part II: X-ray adsorption spectroscopy. Journal Environmental. Quality. doi:10.2134/ jeq2017.10.0407.
- Litaor, M.I., S. Schechter, I. Zohar, M.S. Massey, J. A. Ippolito. 2019. Making Phosphorus Fertilizer from Dairy Wastewater with Al Water Treatment Residuals. Soil Science Society of America Journal. doi:10.2136/sssaj2018.07.0278
- Banet, T., M.S. Massey, I. Zohar, M. Iggy Litaor, J.A. Ippolito. 2020. Assessing modified aluminum-based water treatment residuals as plant-available phosphorus source. Chemosphere, 247, https://doi.org/10.1016/j.chemosphere.2020.125949.
- Zohar, I., J.A. Ippolito, and M. I. Litaor. 2020. Phosphorus pools in Al and Fe-based water treatment residuals (WTRs) following mixing with agro-wastewater - a sequential extraction study. Environmental Technology & Innovation, 18, https://doi.org/10.1016/j.eti.2020.100654.
- Banet, T., Massey, M.S., Zohar, I., Litaor, M.I. and Ippolito, J.A. 2020. Phosphorus removal from swine wastewater using aluminum-based water treatment residuals. Resources, Conservation and Recycling: X,6, 100039. https://doi.org/10.1016/j.rcrx.2020.100039.

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3.2 Second Course on "Soil ecology in dry ecosystems"

Instructor

Course coordinators: Dr. Eric Palevsky, Agricultural Research Organization, Newe Yaar Research Center, (Israel). Prof. Cristina Cruz, Faculdade de Ciências da Universidade de Lisboa (Portugal)

Pre-requisites

English proficiency, General Biology, Agronomy, Ecology, or consult with instructor.

Impetus

Soils are home to more than 25% of the earth's total biodiversity and supports life on land and water, nutrient cycling and retention, food production, pollution remediation, and climate regulation. Accumulating evidence demonstrates that multiple sustainability goals can be simultaneously addressed when soil biota are put at the centre of land management assessments; this is because the activity and interactions of soil organisms are intimately tied to multiple processes that ecosystems and society rely on. However, we are in need of a more integrated view of the global changes and pressures that threaten soil biodiversity, and actions to conserve soil biodiversity and advance sustainability goals especially in dry ecosystems. This course puts together experts in crucial soil functions and functional groups and aims to highlight the latest empirical evidence from soil biological research, showcasing tangible actions in dry ecosystems for a sustainable future.

Course structure

The course has two basic modules. The first module consists of 10 meetings, 2 hours each, that will be taught via remote mode (Zoom and alike). The second module of 3 meetings, 8 hours each will be conducted in the laboratory by remote instruction or in person (MIGAL's team will spend a week in University of Lisbon and supervise the lab experiments). The latter is preferable but hinges on the status of the C-virus pandemic.

Course Objectives

1. The students/participants will acquire fundamental understanding of the soil ecology characteristic of the dry ecosystems and will be able to identify soil as a regenerative element of ecological sustainability.

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2. The students/participants will be able to recognise and use biological indicators of soil health.

Course outcomes

1. Students/Participants will understand the theoretical principles and the practical application of state-of-the-art tools with the potential to understand and support soil management.
2. Students/Participants will identify knowledge and technical gaps in soil ecology knowledge.

Course assignments and grade

During the course the students/participants will be assigned to read technical and scientific papers. The grade will be based on a verbal presentation and assay (5 pages long) on certain topic selected by the student/participant with consultation with the course instructor.

Subject Matters

First lecture: **Systems Biology in Ecology & Agriculture**.

Expert: ***Shiri Freilich*** is a researcher at the Newe Yaar Research Center (NYRC), the northern campus of the Agricultural Research Organization (ARO), Israel. Her research aims at harnessing microbial function for the service of ecology & agriculture through the educated design of communities.

Reading Assignment:

- Xu, X., Zarecki, R., Medina, S., Ofaim, S., Liu, X., Chen, C., Hu, S., Brom, D., Gat, D., Porob, S., Eizenberg, H., Ronen, Z., Jiang, J., Freilich, S., 2019. Modeling microbial communities from atrazine contaminated soils promotes the development of biostimulation solutions. The ISME journal 13, 494.
- Zhimo, V.Y., Kumar, A., Biasi, A., Salim, S., Feygenberg, O., Toamy, M.A., Abdelfattaah, A., Medina, S., Freilich, S., Wisniewski, M., Droby, S., 2021. Compositional shifts in the strawberry fruit microbiome in response to near-harvest application of *Metschnikowia fructicola*, a yeast biocontrol agent. Postharvest biology and technology 175, 111469.

Second lecture: **The S cycle in the rhizosphere**. Adding perspectives and new players.

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Expert: ***Margarida Santana*** is a Researcher at the Faculdade de Ciências da Universidade de Lisboa (Portugal). Her research focuses on plant-bacteria associations, namely on the effect of soil thermophilic bacteria on C, S, and N cycling and on soil nutrient availability.

Suggested reading:

- Santana, Carvalho, Melo, Araújo, Cruz, 2020. Unveiling the hidden interaction between thermophiles and plant crops: wheat and soil thermophilic bacteria, Journal of Plant Interactions, 15:1, 127-138, DOI: 10.1080/17429145.2020.1766585

Third lecture: **Entomopathogenic fungi for the control of below and above ground soil pests**.

Expert: ***Dana Ment*** is a Researcher at the Volcani Institute, ARO. Her research focuses on arthropod pathogen from various perspectives and is primarily directed towards understanding the basic interaction between the pathogen and its invertebrate host.

Suggested reading:

- Ment, D., Kokiçi, H., de Lillo, E., 2020a. Preventative Approach to microbial control of Capnodis tenebrionis by soil application of Metarhizium brunneum and Beauveria bassiana. Insects 11, 319.
- Ment, D., Raman, S., Gal, S., Ezra, D., Palevsky, E., 2020b. Interactions of Metarhizium brunneum-7 with phytophagous mites following different application strategies. Insects 11, 333, 1-15.

Fourth lecture: **Transcriptomic-metabolomic profiling of soil fungi for soil health determination.**

Expert: ***Idan Perelman*** is a Researcher at MIGAL, Israel. His research focuses on Determination of altering fertilization regimes and soil type impact on mycorrhizal symbiosis

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No

Suggested reading:

- Attias, N., Danai, O., Abitbol, T., Tarazi, E., Ezov, N., Pereman, I., Grobman, Y.J., 2020. Mycelium bio-composites in industrial design and architecture: Comparative review and experimental analysis. Journal of Cleaner Production 246, 119037.
- Attias, N., Danai, O., Tarazi, E., Pereman, I., Grobman, Y.J., 2019. Implementing bio-design tools to develop mycelium-based products. The Design Journal 22, 1647-1657.

Fifth lecture: **Drivers of microbiome predator communities in soils and the resulting change in their function**

Expert: ***Stefan Geisen*** is a researcher at the Laboratory of Nematology, Wageningen University & Research, the Netherlands. His research focuses on the interactions of microbiome predators (protists and nematodes) with their bacterial and fungal prey.

Suggested reading:

- Wilschut, R.A., Geisen, S., 2020. Nematodes as Drivers of Plant Performance in Natural Systems. Trends in plant science.
- Xiong, W., Li, R., Guo, S., Karlsson, I., Jiao, Z., Xun, W., Kowalchuk, G.A., Shen, Q., Geisen, S., 2019. Microbial amendments alter protist communities within the soil microbiome. Soil Biology and Biochemistry 135, 379-382.

Sixth lecture: **Soil predatory mites as biocontrol agents and members of the soil food web.**

Expert: ***Eric Palevsky*** is a researcher at NYRC, ARO, Israel. His research focuses on identification and conservation of predatory mites for sustainable pest control.

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Suggested reading:

- Azevedo, L.H., Moreira, M.F.P., Pereira, G.G., Borges, V., de Moraes, G.J., Inomoto, M.M., Vicente, M., de Siqueira Pinto, M., Peres, L.P., Rueda-Ramírez, D., Carta, L., Meyer, S.L.F., Mowery, J., Bauchan, G.R., Ochoa, R., Palevsky, E., 2020. Combined releases of predatory mites and provisioning of free-living nematodes for the biological control of root-knot nematodes on 'Micro Tom tomato'. Biological Control 146, https://doi.org/10.1016/j.biocontrol.2020.104280.
- Young, M.R., Moraza, M.L., Ueckermann, E., Heylen, D., Baardsen, L.F., Lima-Barbero, J.F., Gal, S., Gavish-Regev, E., Gottlieb, Y., Roy, L., Recht, E., El Adouzi, M., Palevsky, E., 2019. Linking morphological and molecular taxonomy for the identification of poultry house, soil, and nest dwelling mites in the Western Palearctic. Scientific Reports 9, 5784.

Seventh lecture: **Resistance–recovery trade-off of soil microbial communities under altered rain regimes**: An experimental test across European agroecosystems.

Expert: ***José Paulo Sousa*** is a member of several European Workgroups responsible for the elaboration of test guidelines with soil invertebrates, published by ISO and OECD. Besides doing active research is also involved in consulting involving both prospective (for Portuguese paper industry and Shell Thiogro) and retrospective risk assessment (for PETROBRÁS) activities.

Suggested reading:

- Piton et al., 2020. Resistance-recovery trade-off of soil microbial communities under altered rain regimes: an experimental test across European agroecosystems. Journal of Applied Ecology. https://doi.org/10.1111/1365-2664.13774

Eighth lecture: **Effects of fertilizers and root stock on above ground pests.**

Expert: ***Liora Shaltiel*** is a researcher at MIGAL, Israel. Her research focuses on creating a sustainable agricultural interface by reducing hazardous pesticides and chemical fertilizer use.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No

Suggested reading:

- Shaltiel-Harpaz, L., Kedoshim, R., Openhiem, D., Stern, R., Coll, M., 2010. Effect of host plant makeup through nitrogen fertilization and growth regulators on the pear psylla population. Israel Journal of Plant Sciences 58, 149-156.
- Shaltiel-Harpaz, L., Gerchman, Y., Ibdah, M., Kedoshim, R., Rachmany, D., Hatib, K., Bar-Ya'akov, I., Soroker, V., Holland, D., 2018. Grafting on resistant interstocks reduces scion susceptibility to pear psylla, Cacopsylla bidens. Pest Management Science 74, 617-626.

Ninth lecture: **Effects of beneficial endophytic fungi on above ground pests**.

Expert: ***Maria Pappas*** is a Prof. at the Democratic University of Thrace in Greece. Her research focuses on ecology of arthropods and plant-herbivore interactions.

Suggested readings:

- Pappas, M.L., Liapoura, M., Papantoniou, D., Avramidou, M., Kavroulakis, N., Weinhold, A., Broufas, G.D., Papadopoulou, K.K., 2018. The beneficial endophytic fungus Fusarium solani strain K alters tomato responses against spider mites to the benefit of the plant. Frontiers in Plant Science 9, 1603-1603.

Tenth lecture: **Soil microbes and invasive plant species**.

Expert: ***Pedro Antunes*** is Associate Professor, Research Chair in Invasive Species Biology at Algoma University, Ontario, Canada. His research interests include soil microbial ecology; the roles of soil biota in plant communities; biology and ecology of mycorrhizal symbioses and invasive plant species management.

Suggested readings:

- Fahey, Koyama, Antunes, Dunfield, Flory 2020. Plant communities mediate the interactive effects of invasion and drought on soil microbial communities. ISME Journal, 2020, 14(6), pp. 1396–1409. http://10.1111.16676.

The next 2 meetings will be dedicated to laboratory experiments to facilitate hands-on experience based on the theory provided in the on-line lectures. The experiments will be conducted at the University of Lisbon.

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4. Time frame and venue

The courses will be taught in Lisbon (or theoretical online classes) and will be given during the period between month 10 and 23 (June 2021 – July 2022). Based on the logistic needs of the training, FC.ID will recommend suitable facilities in Lisbon that can accommodate various organisational set-ups and dynamics.

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