Food and Agriculture Organization of the United Nations

Soil Biodiversity: a nature-based solution?

Friday 22 May 2020

GSP Webinars

GLOBAL SOIL PARTNERSHIP

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The Webinar

In order to observe the International Day for Biological Diversity, on 22nd May 2020 the Global Soil Partnership (GSP) organized the Webinar "Soil Biodiversity: a nature-based solution?".

The webinar consisted of two keynote presentations and a presentation of the global status of soil biodiversity. This interactive webinar invited participants to react with comments and questions during the entire webinar through the chat and by answering polls presented after each speaker's presentation.

The webinar, which was attended by over 1318 participants from 146 countries, aimed to reconnect people with soil biodiversity. The webinar acted as an essential platform to raise awareness on the importance of soil biodiversity for achieving several global goals, including the ones related to food security and nutrition, human health, climate change adaptation and mitigation, land degradation neutrality, and ecosystem restoration. The webinar also gathered people with different expertise and allowed participants worldwide to exchange information and expand their networking opportunities.

Opening remarks – Ms. Maria Helena Semedo

Ms. Maria Helena Semedo, Deputy Director General Climate and Natural Resources, FAO, provided opening remarks. Ms. Semedo welcomed all participants addressing the celebration of the International Day for Biological Diversity. Ms. Semedo informed that the State of the World's Forest 2020 (SOFO) was launched in the morning, and one of the conclusions was the need to connect humans and nature. She highlighted the connections between healthy soils for healthy plants and resilient ecosystems. Ms. Semedo emphasized the importance of soil biodiversity and the remaining need to assess and better understand underground biodiversity, particularly microorganisms. She thanked the GSP for raising awareness and promoting the 2020-year campaign with the theme "Keep soil alive, protect soil biodiversity". Despite all changes in the international agenda due to Covid-19, the importance of nature is more than never crucial to deal with all challenges and to integrate better solutions for post-COVID19. Many of the responses are in nature, and the webinar is an excellent opportunity to discuss what soil biodiversity is and what kind of solutions are necessary to build a more sustainable world.

Opening address – His Excellency Mohammad Hossein Emadi

His Excellency Mohammad Hossein Emadi, Permanent Representative of the Islamic Republic of Iran to FAO, addressed the webinar highlighting the importance of this UN day and also how biodiversity is getting increasing attention. His Excellency recorded that he first studied soil's chemical and physical components, and then the biological aspects. Now the ecological view of soil is connecting all components and underlining the critical role of soil biodiversity. The potential role of soil goes beyond food production, and it is about guaranteeing the health of this planet. His Excellency also emphasized that the webinar is an excellent way to take advantage of the current challenges and difficult moments by connecting people and discussions.

Opening address – Mr. David Cooper

Mr. David Cooper, Deputy Executive Secretary of the Convention on Biological Diversity, thanked all for the celebration of the Biological Diversity Day and the work of FAO on the preparation of the Global Report of Soil Biodiversity. The Report will be very timely to the discussions on the next Global Biodiversity Framework during the upcoming CBD COP in 2021, to be held in China. In this currently challenging scenario, one health approach will be necessary, taking all the links between human health, biodiversity, and agricultural systems. Indeed, solutions are in nature, and soil biodiversity is a key answer to support all these factors.

Keynote presentation – Is soil biodiversity a nature-based solution? – Mr Wim van der Putten

Mr. Wim van der Putten from the Netherlands Institute of Ecology provided the first presentation. Mr. van der Putten highlighted that we are all benefiting from soils in different ways. Everything that we eat, drink, breath, clothes that we wear, also constructions, pass through soil biodiversity over and over again. Almost half of the SDGs are affected by soils. Therefore, soil biodiversity is a solution for sustainability, and we can learn from nature. For that, it is necessary to think beyond numbers (quantity of organisms and microorganisms) and to take into consideration that restoring soil biodiversity requires ecosystem management since it englobes numerous ecosystem services provided by soil biota.

Recent studies have shown the dramatic reduction of insects, but before that, studies in Europe already had signalized to the loss of soil biodiversity due to intensive agricultural practices. He brought to attention the example of recovering soil biodiversity in abandoned lands with several succession stages. For current agricultural lands, some responses to increasing soil biodiversity include reduced tillage, soil organic carbon increase, cover crops, and pesticide reduction. Mr. van der Putten explained that in order to maximize the intake of nutrients from plants, besides increasing soil biodiversity, it is necessary to have the right plant species and crops in the same soil system. Currently, several lines are being explored to help crops to make use of enhanced soil biodiversity. One line is about going back to wild crop relatives to understand how they make use of soil microbiomes and if those traits can be restored. The second line is to study wild plants species along successional gradients to understand how plants can be more productive in high-diversity soils.

Keynote presentation – Why should we care about soil biodiversity? Links to human-health and food security – Ms Daphne Miller

Ms. Daphne Miller from the Department of Family Medicine of the University of California provided the second presentation. Ms. Miller started showing how the ecosystem approach of microorganisms (virus and bacteria) in the human body is similar to the soil ecosystem. Moreover, the ecosystem approach is something new for treatments, and it is the type of solution that is, in general, needed. Pesticides and antibiotics, along with other intensive agricultural techniques (i.e. plowing, monoculture, livestock, and reduction of genetic variety), have caused biodiversity loss and resistance to external inputs. She presented several successful cases that are keeping soil covered, promoting plant diversification, integrating livestock, and causing minimal disturbance to the environment.

Oklahoma is an area in the USA that has had critical soil loss, and it is also a nutrient insecure area of the country, where the population has low nutritional intakes due to the limited access to fresh food, with high rates of obesity, diabetes and heart diseases. Farmers from Oklahoma are innovating by using a mix of edible cover

crops ("three sisters" style) to protect and nurture the soil while offering fresh food to the local community. Another example is the new study about the link between mental health and healthy soils. The discovery of a new medication from the isolation of soil bacteria (Mycobacterium vaccae) with immune-regulatory and stress release properties. The third example provided links between grazing, livestock, and benefits for human health. Some studies have shown that children raised on healthy dairy farms could have better responses from their immune system. Even urban areas that can reproduce those farms environment microbiome can benefit, for instance, with the reduction of asthma and immune modulation. Ms. Miller also highlighted the importance of the conservation of some wild and riparian areas in agricultural lands to prevent diseases spillover through those buffering interfaces with nature. To close, Ms. Miller showed amazing similarities between the layers, the system structure, and the functioning of our body system with the soil system.

Global Soil Biodiversity: Status, gaps and way forward – Ms Monica Kobayashi

Ms. Monica Kobayashi from the GSP Secretariat, FAO, provided the third presentation. Ms. Kobayashi recalled the importance of restoring the link between humans and soil biodiversity. She started by reminding all that the UN Decade on Biodiversity is coming to an end, but many successful milestones with regards to soil biodiversity were achieved. It includes the establishment of the GSP, the International Year of Soils, the launch of the European Commission Soil Biodiversity Atlas, the FAO Voluntary Guidelines for Sustainable Soil Management, and now, the preparation of the Global Report on Soil Biodiversity by FAO.

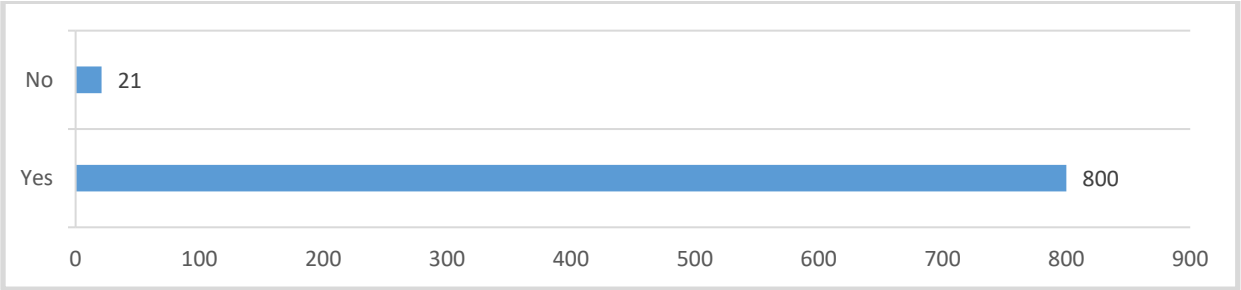
There is a significant momentum to raise awareness and leverage the importance of the belowground biodiversity through the GSP 2020 campaign “Keep soil alive, protect soil biodiversity” and the Global Symposium on Soil Biodiversity in February 2021. Additionally, soil biodiversity can play an important role in the next decade with the upcoming post-2020 Biodiversity Framework, the new Plan of Action for the International Initiative on Soil Biodiversity, the UN Decade on Ecosystems Restoration and supporting the achievements of all Sustainable Development Goals.

The FAO Soil Biodiversity Report, which will be released in December 2020, presents the soil biota (from megafauna to microorganisms), their interactions, the ecosystem functions and services provided by them and the connection with aboveground biodiversity. Ms. Kobayashi also highlighted some new findings, such as the global distribution of some soil organisms. Some key messages of the Report are the practical application of soil biodiversity, the status and the main threats, as well as some responses, which include new technological approaches. Also, the Report brings up the immense potential for the use of soil microorganisms' genetic resources in the food, pharmaceutical, bioremediation, and agricultural industries. The loss of soil biodiversity could limit our capacity to find sustainable solutions for human health as well. Finally, Ms. Kobayashi presented some recommendations and some remaining gaps of knowledge, implementation, and policies.

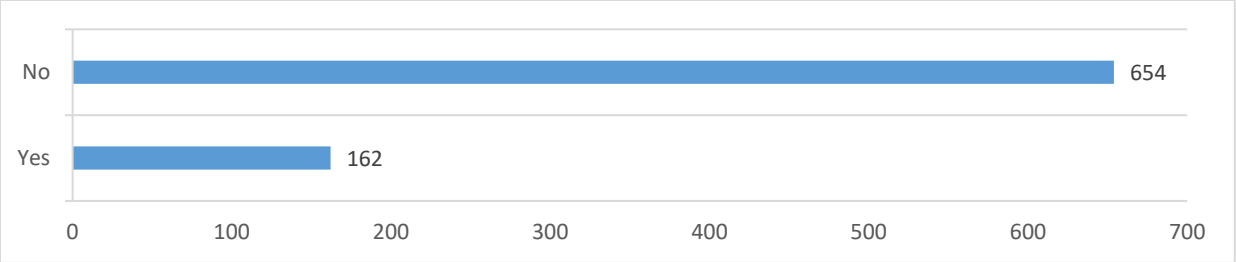
Interactive session – Poll results

After the presentations, an interactive session was implemented with six questions posed to the participants.

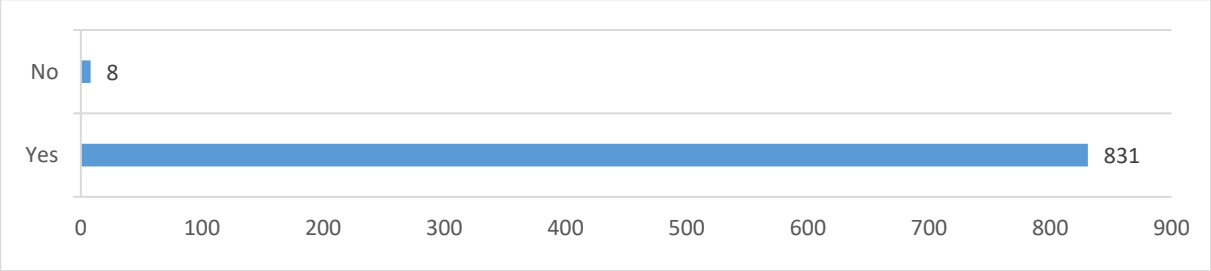
Question 1: Do you agree that soil biodiversity loss, caused by unsustainable human activities, is one of the main soil threats?



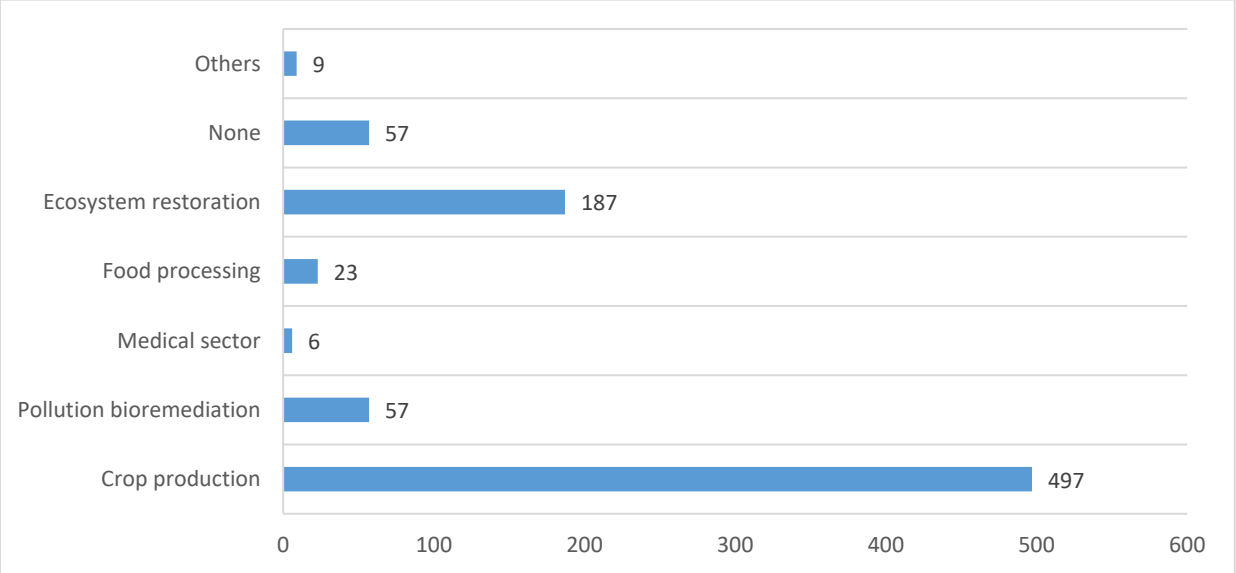
Question 2: Is data/information about soil biodiversity available and regularly surveyed in your country?



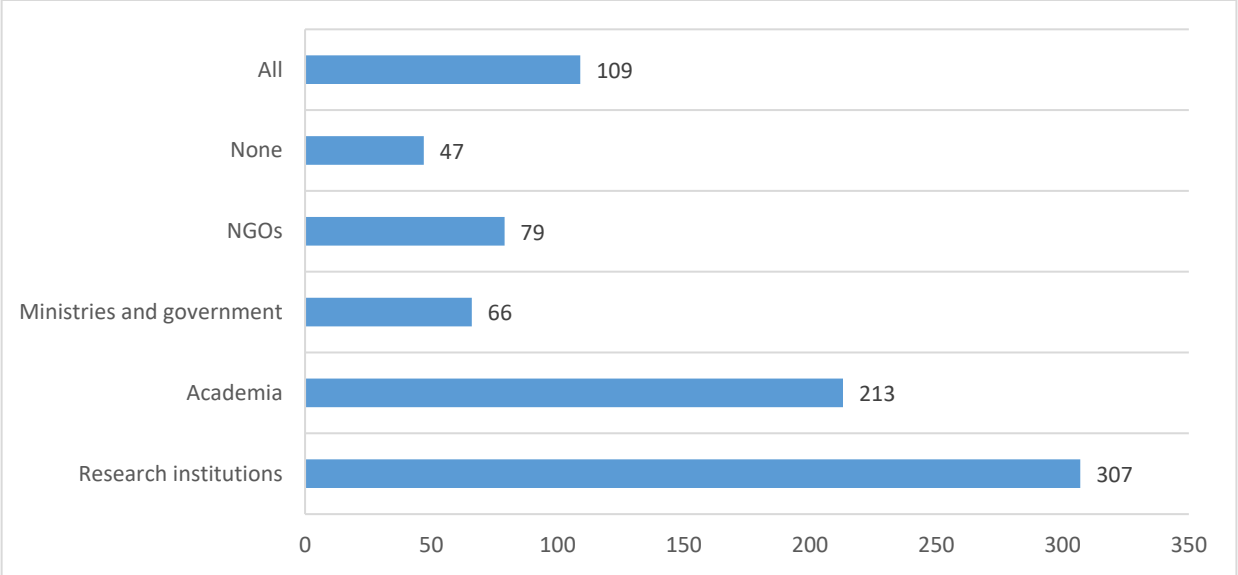
Question 3: Is there a need for capacity development on soil biodiversity?



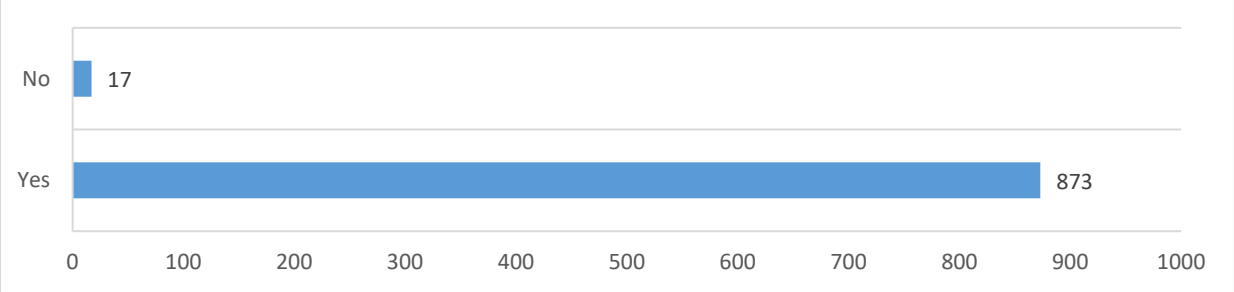
Question 4: What are the main applications of soil biodiversity in your country?



Question 5: In your country, who are the main actors addressing soil biodiversity?



Question 6: Do you consider soil biodiversity as a nature-based solution to global challenges such as human health, food production, climate change, soil pollution and land degradation?



Closing of the meeting – Mr. Eduardo Mansur

Mr. Eduardo Mansur, Director of FAO's Land and Water Division, thanked all attendees and panelists for their participation and for the opportunity to celebrate the International Day for Biological Diversity in a very productive way. Mr. Mansur briefly summarized the webinar by starting with the key messages of Ms. Semedo, in which she highlighted the crucial role of soil microorganisms. Then, he thanked His Excellency Mohammad Hossein Emadi for mentioning the role of mainstreaming soil biodiversity and Mr. Cooper, for highlighting the need to know more about soil biota. Mr. Mansur thanked Mr. van der Putter for his excellent presentation and specifically for mentioning what we do in belowground effects

aboveground, and consequently, this relationship is the challenge to produce food sustainably. He also thanked Ms. Miller for her incredible and timely presentation, where she showed clearly the relationship with human health and agriculture, by bringing many examples and translating science in a language that everyone can understand. Finally, Mr. Mansur thanked Ms. Kobayashi for giving “an appetizer” of the upcoming report on Soil Biodiversity prepared by FAO.

Annex 1 – Agenda, presentations and recordings

Agenda

Moderator: Mr. Ronald Vargas, GSP Secretary, FAO

15:00 - 15:05 | OPENING REMARKS - Ms. Maria Helena Semedo, FAO Deputy Director-General, Climate and Natural Resources, FAO

15:05 - 15:10 | OPENING ADDRESSES

- His Excellency Mohammad Hossein Emadi, Permanent Representative of the Islamic Republic of Iran to FAO
- Mr. David Cooper, Deputy Executive Secretary, Convention on Biological Diversity

15:10 - 15:20 | KEYNOTE PRESENTATION - Is soil biodiversity a nature-based solution? Mr Wim van der Putten, Netherlands Institute of Ecology, The Netherlands

15:20 - 15:30 | KEYNOTE PRESENTATION - Why should we care about soil biodiversity? Links to human-health and food security, Ms. Daphne Miller, Department of Family Medicine, University of California, USA

15:30 - 15:40 | Global Soil Biodiversity: Status, gaps and way forward Ms. Monica Kobayashi, FAO

15:40 - 15:55 | OPEN SESSION - Discussion

15:55 - 16:00 | CONCLUSION – Mr. Eduardo Mansur, Director, Land and Water Division, FAO

Presentations

- Is soil biodiversity a nature-based solution? Mr Wim van der Putten – Netherlands Institute of Ecology, The Netherlands

- Why should we care about soil biodiversity? Links to human-health and food security, Ms Daphne Miller – Department of Family Medicine, University of California, USA

- Global Soil Biodiversity: Status, gaps and way forward Ms Monica Kobayashi – FAO

Meeting recording

- LINK

Annex 2 – Questions & Answers

The answers provided here are the views of the speakers and FAO/GSP experts do not express directly that of FAO/GSP.

Soil

1. Is it really sustainable to create new soils in the desert regions? Some people even speak about soil salinization phenomenon following desert soils cultivation. what are your opinions about this?
   There are proven experiences (in China for instance) that you can habilitate desert soils and bring them into production. However, that requires investment and a medium term process. Soil salinization is inherent to this ecosystem, but if you follow sustainable practices, then you can address it.

2. What are available solutions to fight soil acidification and its negative effects to soil biodiversity, especially which are applicable in the protected areas?
   The acidification of ecosystems is a natural process that is driven by the metabolic activity of soil organisms and plants, and it is also linked to the accumulation of soil organic matter. However, this acidification occurs across decades, centuries, millennia or even millions of years and the abundance and diversity of soil communities follows ecosystem development, what I assume that will be the case of Protected Areas.

3. Is there a role for biochar in soil biodiversity?
   There are some studies showing that biochar can increase the abundance and diversity of plant beneficial bacterial and fungal taxa. Additionally, biochar may also improve remediation and biophysical conditions of the contaminated soil environments, which could benefit soil biodiversity.

4. Have you better investigated the relationships between soil biodiversity, soil self-organization and peodiversity?
   There are few studies on the relationship between pedodiversity and soil biodiversity. However, many studies have shown that different soil types as well as different soil horizons house different assemblages of soil organisms.

5. Any suggestion for a soil scientist to involve soil biodiversity issues ?

There are many ways to be involved with soil biodiversity issues. One way is to work on the important gaps of knowledge, for instance, the relation of soil pedodiversity and soil biodiversity. Another way is supporting the implementation of sustainable management of soils, which should take into consideration biological indicators. Also, to consider soil biodiversity and soil health in soil rehabilitation plans, remediation, urban plans, etc.

Ecosystems and soil biota

1. Do you have any quantitative information on extinction of soil biodiversity in any part of the world?

   No, only in some places, but in general, the more intensive the land use, the more biodiversity will be threatened.

   Tsiafouli, MA, Thébault, E, Sgardelis, S, De Ruiter, PC, Van der Putten, WH, Birkhofer, K, Hemerik, L, De Vries, FT, Bardgett, RD, Brady, M, Bjornlund, L, Bracht Jörgensen, H, Christensen, S, D' Hertfelt, T, Hotes, S, Hol, WHG, Frouz, J, Liiri, M, Mortimer, SR, Setälä, H, Stary, J, Tzanopoulos, J, Uteseny, C, Wolters, V and Hedlund, K. 2015. Intensive agriculture reduces soil biodiversity across Europe. Global Change Biology 21:973-985.

2. In tropical lands the number of nematodes are expected to be more but the nature 2019 data tells opposite. What may be the reason?
   a. Huge agriculture practices.
   b. Use of chemicals
   c. Insufficient screening of the soil

   Tropical land has limited amount of soil organic matter (unless a peat area). Soil organic matter enhances bacteria (and fungi) which are food for nematodes.

3. Thank you for the presentation! Can you define what you mean to strengthening the soil network? Are we talking functionally, or about niche expansions? Are there high priority interactions?

   Explaining this question would take quite a while; best to read this paper: Morriën, E., Hannula, E.E., Snoek, L.B., Helmsing, N., Zweers, H., de Hollander, M., Bouffaud, M- Buée, M, Dimmers, W, Duyts, H, Geisen, S, Girlanda, M,

Griffiths, RI, Bracht Jòrgensen, H, Jensen, J, Plassart, P, Schmelz, RM, Schmidt, O, Thomson, BC, Tisserant, E, Uroz, S, Winding, A, Bailey, M, Bonkowski, M, Faber, J, Martin, F, Lemanceau, P, de Boer, W, van Veen, JA, van der Putten, WH 2017. Composition of soil biodiversity networks, functional changes in nutrient dynamics, and consequences for vegetation succession. Nature Communications |8:14349 | DOI: 10.1038/ncomms14349 |www.nature.com/naturecommunications

4. Can we integrate soil classification map with soil bio-diversity map?
   Yes, and indeed this should be done. ISRIC is interested in doing so.

5. I would like to know if there is any attempt to raise biodiversity atlas for Africa?
   The European Commission produced both, the Global Soil Biodiversity Atlas https://ec.europa.eu/jrc/en/publication/global-soil-biodiversity-atlas and the European atlas of soil biodiversity https://op.europa.eu/en/publication-detail/-/publication/7161b2a1-f862-4c90-9100-557a62ecb908.
   I am not sure about the Atlas for Africa, but the assessment of soil biodiversity in all regions of the world is a task that need to be done in a near future.

6. Onderzoekjes naar bodemleven maakt dat de verschillende bodems en bodemgebruik verschillende "ecosystemen" aan bodemleven heeft. Is er informatie te vinden welke bodemorganismen horen bij welke bodem en bodemgebruik. Als ik bijvoorbeeld een beukenbos en een ooibos wil onderzoeken op bodemleven. Wat voor bodemdieren hoor ik dan waar te vinden onder de goede omstandigheden.
   This question is about whether we already have reference soil biodiversity information for various types of ecosystems. Unfortunately, this is what we do not have yet. We know how a forest differs from grassland or agricultural land, but within these types of ecosystems, far less is known about the difference between e.g. a riverine forest and a beech forest, or e.g. between conventional and organic agriculture.

7. More how much function instead of how much taxa? That's it?
   In general, more taxa will lead to more functioning, unless taxa perform the same function.

8. We make more a focus on diversity than abundance are they following the same trend?
   Both diversity and abundance are relevant. For instance, a better understanding of the distribution and abundance of soil communities in different soil habitats will improve the accuracy of predictions of global biogeochemical models and, potentially the future climate models. Another example is the abundance of mutualistic soil microbiota like arbuscular mycorrhizal fungi and nitrogen fixing bacteria. Their diversity and abundance can help farmers to reduce costs and their dependence on chemical nitrogen fertilizer.

9. In short its more important to know who is interacting with who? rather to investigate who is there?
   We need both. We have been studying organisms and microorganism in isolation, but there is still a huge number of microorganisms to be identified (it is estimated that we know only 1% of them). There is a lack of taxonomists worldwide. Taxonomy is not only critical to the future of soil biodiversity research, but also to raise awareness about biodiversity collapse. Currently, technologies such as metagenomics is a promising approach to simultaneously study all DNA-based information in soils, including all groups of soil organisms and functional gene information. This technology allows us to study the metagenome (or collective genome) and explore the complex microbial communities.

10. Why are soils from polar regions are so rich in nematodes?
    Because those soils contain a lot of organic material, which provides food for bacteria and fungi, which Is food for nematodes. See: *van den Hoogen, J., Geisen, S., et al. (2019). Soil nematode abundance and functional group composition at a global scale. Nature, 572(7768), 194-198. https://doi.org/10.1038/s41586-019-1418-6*

11. How do we study species interaction in Soil?
    By changing the species composition in soil, e.g. by inoculation or partial sterilization.

12. How do you come up with such huge estimates of soil biodiversity compared to plant diversity or animal diversity?
    To some extent the comparison depends on scale: one square meter of land can contain 30-70 wild plant species, whereas one hand full of soil already contains 5000 taxa ('species') of microbes. Soil biodiversity estimates are based on the paper (end references therein):
    Bardgett RD and Van der Putten WH 2014. Soil biodiversity and ecosystem functioning. Nature 515:505-511.

13. What method should I use for study soil biodiversity, mainly focused on Arthropods?
    This depends on the study organisms. Carabid beetles can be collected by pitfall traps: (*Dedov, I., Stoyanov, I.L., Penev, L., Harvey, J.A., Van der Putten, W.H. and Bezemer, T.M. (2006). Long-term effects of sowing high or low diverse seed mixtures on plant and gastropod diversity. Acta Oecologia 30: 173-181.*). Collembola and mites can be collected by placing soil samples under heating lamps, and earthworms by pooring soap water on the soil or electricity (Morrien et al 2017 https://www.nature.com/articles/ncomms14349)

14. There are some assumptions recently that the next depot of viruses dangerous to humans will be the Amazon forests. Can the soil be considered such a depot and how this can be mitigated or avoided? Can you comment these assumptions regarding the Amazon soil biodiversity. Thank you.
    In general, soil contains human pathogens. See https://microbiologysociety.org/publication/past-issues/soil/article/the-ecology-of-soil-borne-human-diseases.html Soil also contains viruses. Whether human viruses can be contained in soil is not well known to my knowledge, but for that please ask a virologist. But in general, it is believed that soil biodiversity will control pathogens and that soil disturbance will reduce that control. Whether this is specific for Amazonia cannot be said, but as in the Amazon a lot of the forest is cleared and soils are used for agriculture, which is a soil disturbing activity, it is well imaginable that (human) disease incidence may go up.

15. Is there any data of soil biodiversity in every different characteristic of soil around the world?
    No, not of all soil biodiversity in all parts of the World, but there are increasing numbers of papers on bacteria (Fierer), (mycorrhizal) fungi (Tedersoo 2014 Science), nematodes (van den Hoogen et al. 2019 Nature). The current global soil biodiversity assessment that is in preparation will provide an overview of what is known, but good world-covering data for all soil biodiversity are currently lacking.

16. Is there any study on the extent to which microbes can mitigate abiotic stress like soil salinity, drought etc.? As abiotic stress related yield loss is major concern now a days.
    Scientists agree that diverse soil microbiome is tied to the reduction of abiotic stress. For instance, many studies show that Mycorrhizas in general (AMF is one category) can alleviate both biotic and abiotic stresses since them can contribute to restoring degraded lands and ecosystems via artificial inoculation, while they improve the access of plants to nutrients. They also can regulate abiotic and biotic stresses to plants such as drought, salinity stress, heavy metal phyto-accumulation and protection against pathogens

Ecosystem services

1. How much is the attention given to microorganism's application for soil health and ecosystem services in the developing world?
   Some developing countries have been investing considerably in research on soil microorganisms, which indirectly is related to soil health and ecosystem services. For instance, studies on the mutualism of soil microbiota (for example arbuscular mycorrhizal fungi and nitrogen fixing bacteria) and crops. However, the majority of countries have reported that the lack of resources, knowledge and capacity have been a barrier to further implement activities related to the sustainable use and conservation of soil biodiversity, including soil microorganisms.

2. Is any microbial operation which provide soil good health as well as production?
   Microorganisms provide us many ecosystems services that results in soil health and consequently can be related to soil productivity. For instance, nitrogen fixing

bacteria associate with legume roots fix large amounts of nitrogen that are of pivotal importance for plant productivity.

3. How can we determine ecosystem services from Soil biodiversity? is there any good study?
   There are many studies on soil biodiversity and ecosystem services. Please see this recent article:
   Soil Biodiversity Integrates Solutions for a Sustainable Future (2020) Elizabeth M. Bach, Kelly S. Ramirez, Tandra D. Fraser and Diana H. Wall

4. What do you mean with "soil biodiversity application"?
   What I meant was the application of genetic resources in some industries (like pharmaceutical, agricultural and food industries) and the current use of ecosystems functions and services provided by soil biodiversity (like soil formation, nutrients cycle, pest control, etc.) that we have taken for granted.

5. I am wondering about the question of "appliance" of soil biodiversity. It is not applied as per se, but more "used for benefits", isn't it?
   Yes, exactly. As per the above question, is the application in some industries and the use of the benefits arising from the functions and services provided by soil biodiversity.

Human health

1. How does biodiversity contribute to infection prevention?
   It depends on the situation but much of the time species diversity has a dilution effects and crowds out the emergence of one destructive pathogen. Of course, this is not always the case and occasional diversity can have an amplifying effect. Like everything in agriculture and health, context and community dynamics are very important. Here is a great article to read https://www.pnas.org/content/115/31/7979

2. Is the knowledge of soil biodiversity having impact on mental health and immune modulation already used in medicine?
   Only in the use of probiotics. There are some doctors that are promoting the use of soil-based probiotics but **NO clinical evidence to support this approach**!

3. How Soil biodiversity and pharmaceuticals are linked?

   Soil microorganisms has an immense potential for pharmaceutical industry because historically the discovery of numerous new drugs and vaccines comes from soil organisms. From well-known antibiotics like penicillin, to bleomycin using for treating cancer and amphotericin for fungal infections and therapeutic measures for treating and controlling diseases. Please see also above.

4. In the context of agriculture: testing microbial community structure is still not a reality as it changes in the sampled soil. This applies to large number of sampling where freezing sample is not possible. Is there any research going on this?
   That is correct, many different methodologies and debate about gold standard. For example, 16sRNA misses viruses altogether and they likely play a critical role in soil health. I will let the soil microbiologists weigh in here.

5. What is the situation of research about viruses used as antibiotics, previously developed in former Soviet Union?
   Yes, these are called bacteriophages, or viruses that attack bacteria. These have been known to exist for over a century but for a variety of reasons (most of them having to do with patents and profit) antibiotics were promoted instead and considered the “wonder drugs”. Now that we have come to the end of the road with antibiotics, phages are getting a second look. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3442826/

6. We’re hearing a lot from the biodiversity / environmental sector about soil biodiversity being a potential “nature-based solution” for human health. But if this approach is going to actually have a meaningful and sustained benefit for human health, we need the health sector to embrace the idea and to take a role in related policy development and implementation. How do we achieve this? How do we get the health sector to engage on the topic of soil?

   I agree that there is a problematic gap here, one that I have dedicated my career to trying to bridge. I would love for the FAO to take a lead by advancing work on human health in tandem with planetary health and involving more people from

the health professions at high levels within the organization. One concrete example would be the High Level Panel of Experts on Nutrition and Food Security http://www.fao.org/fileadmin/templates/cfs/HLPE/HLPE_Steering_Committee_2019_2021.pdf
There is only one person with human health expertise on this panel (nutrition) and all the rest are from agriculture. More representation and collaboration is needed at a high level for this change to happen.
Similarly, FAO has embraced agroecology (which is great) but shouldn't Health (planetary and human) be one of the TEN key elements?
Finally, interdisciplinary work should be a priority within education programs. For example, technical advisors in agriculture could be co-educated with community health workers.

7. Not done with undies but done with cloth. Culturally cannot do with undies
   Of course—as long as it is 100% cotton. In US Fruit-of-the-Looms are the iconic litmus test.

8. How did they promote the suppression of bacteria with the bacteriophages?
   I included an article above. Bacteria and viruses co evolve together and these viruses are essentially very specialized bacteria hunters.

Drivers of loss

1. In our state Assam, India the Brahmaputra River Valley is very fertile. Every year we are affected by flood for 4-6 months, due to soil erosion. The government is applying various methodology to curb soil erosion, but still not able to manage soil erosion. How can soil erosion be managed in the flood plain like Brahmaputra river?
   Controlling this type of phenomena is not simple but feasible and requires a long term strategy and efforts. The key is to ensure that the soil erodibility of upstream soils is reduced considerable. Sustainable soil management practices together with bio-mechanical control measures is the key to avoid that the plain is flooded every year. In some countries though, land users from flood plains are happy with yearly small flooding as that brings new fertile soils, so it is a trade-off.

2. We are losing big portions of our soil biodiversity by flooding each year, are there actions taken against this?

   There are actions possible, but often, flooding is caused by increased extreme weather events in combination with poor management of upstream regions (loss of water holding capacity of soil, over-intensification of land, canalization of rivers). Currently, that actions that are possible are not being taken adequately. This is a combination of politics, innocence, and unwillingness as short-term interests of humans weigh more heavily than long-term sustainability. In any case the Sustainable Development Goals of the United Nations also include this issue.

3. How will be the trend of microorganisms in case of forest soils in depth wise?

   Soil biodiversity is highest in the upper layers (perhaps not in the very top layer that may dry out) and declines with depth. Most diversity will be found in the layer where plant roots are present.

4. How or what happened to soil biodiversity after incidents of fires (bush/forest fires) and floods. how can we expedite rehabilitation of soil biodiversity?
   There are different opinions about the real impact of fires on belowground ecosystems and their functionality because it depends on the ecosystem and the frequency of fires. After fire, during recolonization (which can be quick due to the large volumes of unburnt dead wood), there is an overall shift from bacteria-driven towards fungi-driven community. Many soil organisms such as protist and invertebrates decreased and depending on the frequency of fires, they may never recover. Recent studies show that boreal forest ecosystems recovery of macroinvertebrate diversity and functional structure may require up to 75 years depending on the fire intensity and ecoregion.

5. Have you any article about the effects on soil biodiversity of deforestation and conversion of soil in agricultural system?

   Deforestation can alter the structure of soil communities and decrease species richness (including natural predators and pollinators) and leading to homogenization. Consequently, the area will have a reduction of ecosystem resilience due to organism's imbalance, which can favor pests and diseases outbreaks. Soil predators such as spiders and predatory insects consistently

decreases following deforestation, these benefited organisms are often plant pests that can harm crops or existing forests.

Please see some references below:

Crowther, T. W., Maynard, D. S., Leff, J. W., Oldfield, E. E., McCulley, R. L., Fierer, N., and Bradford, M. A. (2014). Predicting the responsiveness of soil biodiversity to deforestation: a cross-biome study. Global change biology, 20(9), 2983-2994.

Franco, André L.C., Bruno W. Sobral, Artur L.C. Silva, and Diana H. Wall. 2019. "Amazonian Deforestation and Soil Biodiversity." Conservation Biology 33 (January): 590–600. https://doi.org/10.1111/cobi.13234.

Kroeger, M. E., Delmont, T., Eren, A. M., Meyer, K. M., Guo, J., Khan, K., ... and Tiedje, J. M. (2018). New biological insights into how deforestation in amazonia affects soil microbial communities using metagenomics and metagenome-assembled genomes. Frontiers in microbiology, 9, 1635

6. In certain circumstances, we are in a dilemma, especially in poor societies who utilize soil and ecosystem generally considered un-responsible, such as forest cutting, max tillage etc. However they have no choices to do that due to their needs. We have to wise on this, not just to blame them. What can we do about this?

   Ideally, one response to this issue is to increase in a sustainable way the productivity of the current agricultural lands to avoid expansion to natural areas. Additionally, reduction of food losses and waste also plays an important role. Increasing diets with local varieties and diversifying food production like urban agricultural, hydroponics, and others could help to alleviate the stress on the natural lands.

IAS

1. How does invasive species affect soil biodiversity?

   The introduction of all kind of invasive alien species has had a negative impact on the above ground biodiversity and on the native soil biodiversity. The effects of invasive species in soil biodiversity vary depending on the specie trophic position (pathogens, herbivores, predators, etc.). Many invasive soil species are related to agricultural pests. Certain species are introduced as biocontrol agents. Another example is the introduction of non-native earthworms (which

are ecosystem engineers), but their invasions can cause cascading effects that impact plant communities, forest, carbon sequestration and wildlife.

2. What are effective measures to present the income of invasive species during traveling?

   Countries have adopted measures to prevent and control the introduction and spread of invasive alien species through trade, travel and transportation. Please see the CBD website for more information on the current measures: https://www.cbd.int/idb/2009/about/cbd/

3. Since the UN asked FAO to do a soil biodiversity assessment which is now in progress, what is FAOs take on invasive species versus soil biodiversity?

   As per the answer above, many invasive soil species are related to agricultural pests. Certain species are introduced as biocontrol agents. Another example is the introduction of non-native earthworms (which are ecosystem engineers), but their invasions can cause cascading effects that impact plant communities, forest, carbon sequestration and wildlife. So before introducing a specie, it is very important to have a risk assessment for biocontrol, for instance.

4. Are you referring to soil borne disease like Fusarium Pathogen? Do you mean to control the pathogen use increases soil biodiversity?

   Fusarium is a soil borne disease and a soil with rich diversity of organisms and microorganisms can be more resilient. Different components of soil biota regulate the system and help to control, prevent and suppress outbreaks. For example, the abundance of pathogen suppressive microorganisms is significantly greater in a diverse crop rotation compared to monocultures. Another example is the use of nematodes as a biocontrol agent.

5. What could be the possible reasons for reduced number of pathogens with dense networking after prolonged period of abandonment?

   One possible reason is that after a long period of abandonment, natural regeneration can achieve an ecosystem equilibrium and stabilized food web.

Pesticides & Fertilizers

1. Is there a well developed protocol to produce bio based fertilizers and pesticides?

   Not to our knowledge

2. Can there be an initiative on 'Pesticide Code of Conduct' for countries like 'Fertilizer code of Conduct'?
   The FAO Code of Conduct on Pesticide Management was approved by the FAO Conference in June 2013. The International Code of Conduct on Pesticide Management is the framework on pesticide management for all public and private entities engaged in, or associated with, production, regulation and management of pesticides. The Code provides standards of conduct serves as a point of reference in relation to sound pesticide life cycle management practices, in particular for government authorities and the pesticide industry. (http://www.fao.org/agriculture/crops/thematic-sitemap/theme/pests/code/en/)

3. Chemical pesticides have a catastrophic impact on the soil biodiversity so how we can consider that in pesticides registrations?
   The FAO Pesticide Registration Toolkit is a decision-support system for pesticide registration in developing countries. It will assist registrars in the evaluation and authorization of pesticides. The Toolkit can best be considered as a web-based registration handbook intended for day-to-day use by pesticide registrars. Registration staff can use the Toolkit to support several of their regular tasks, including: finding data requirements, evaluating technical aspects of the registration dossier, choosing an appropriate pesticide registration strategy and procedures, reviewing risk mitigation measures and getting advice on decision making.

   The Toolkit also links to many pesticide-specific information sources such as registrations in other countries, scientific reviews, hazard classifications, labels, MRLs and pesticide properties. (http://www.fao.org/pesticide-registration-toolkit/en/).

   FAO has constituted a working group on soils to discuss the evaluation of pesticide risks to soil organisms, biodiversity and ecological functions. The working group was asked to provide advice to FAO on appropriate approaches, methods and models for risk assessment of pesticides to soil organisms, which can be used by registration authorities with limited resources. A large number

of proposals were made by the working group and these recommendations will be incorporated into the Toolkit.

4. Does FAO plan to support governments to provide the correct types of subsidies – not to pesticides and chemicals, but as compensation for the partial loss in yield in the first 1-2 years that arises from the switch from chemical-based monocropping to organic, multi-cropping, permaculture, etc?
   There is no a direct plan as such. However, under the initiative RECSOIL, we aim to provide technical support and financial incentives to farmers for implementing good practices, mainly focused on soil organic carbon sequestration. The reduce use of such inputs is imminent under those practices.

5. Other than pesticide pollution mentioned above, there are now bits and pieces of millions of chemicals compounds found their way into soils and destroying soil biodiversity. Is there any action by the GSP secretariat or FAO, etc. against this?
   The Global Soil Partnership initiated its work on soil pollution in 2018 with the organization of the Global Symposium on Soil Pollution, in May 2018 (http://www.fao.org/about/meetings/global-symposium-on-soil-pollution/en/). As a result of the Symposium discussions, the outcome document Be the solution to Soil pollution (http://www.fao.org/3/ca0362en/CA0362EN.pdf) was launched with a series of recommendations that define the FAO/GSP agenda for action on soil pollution aspects. The GSP has established two multidisciplinary working groups, composed by experts from all around the world, to work on the preparation of technical manuals and guidelines for the full cycle of soil pollution, from the assessment, mapping, monitoring and reporting to risk assessment and remediation and management of polluted soils (http://www.fao.org/global-soil-partnership/intergovernmental-technical-panel-soils/gsop18-implementation/en/).

   In order to increase policymakers and other stakeholders' awareness on the sources of soil pollution, the type of contaminants and their impact on the environment, human health and food safety and security, the FAO/GSP is preparing a Global Assessment of Soil Pollution, in close cooperation with UN

Environment and World Health Organization. The report will provide state-of-the-art scientific knowledge and key recommendations for governments to take to prevent, control, manage and remediate, when feasible, soil pollution. The Global Assessment report is to be launched in February 2021.

Further activities on the field will follow, as the GSP aims to translate the existing scientific knowledge into action on the ground to tackle this hidden but threatening problem.

6. We already lost a big portion of soil biodiversity due to unregulated and overuse of pesticides mostly in developing countries, now does UNEP & other related agencies get the opportunity of the COVID time to stop this overuse and misuse?
   FAO and UNEP, through the Global Environmental Fund (GEF), have been working on judicious and responsible use of pesticides for decades. Many projects have been implemented on cleaning-up polluted soils with obsolete pesticides and other persistent organic pollutants (https://www.thegef.org/topics/persistent-organic-pollutants). Many efforts are also in place to control the use and marketing of obsolete and highly hazardous pesticides (http://www.fao.org/agriculture/crops/obsolete-pesticides/fao-program/en/).

   During and after the COVID pandemic, many countries are facing food shortages due to closed borders and restrictions on transport and movement of agricultural labour, which means they will have to rely on local food production. If not properly managed, this new pressure on local soils could affect soil health and limit the provision of ecosystem services now and in the future, which is why the Intergovernmental Technical Panel on Soil and the GSP Secretariat urgently call on governments to immediately and sustainably implement the principles of the World Soil Charter and the Voluntary Guidelines for Sustainable Soil Management to ensure food security without compromising the health of their national soil resource.

7. Poultry waste are harming to soil Biological Diversity.
   In general, bringing back organic matter and manure to soil is good, as it promotes circularity. The problem starts when there is an excess of waste

dumped on the soil. So, wise use is crucial. What is wise use will depend on soil type, climate, and other local conditions.

8. As per literatures Rhizosphere can decrease the pH up to 2 unit . could decrease pH of rhizosphere can help to increase phosphorus efficiency specially in vertisols that is rich P in Ca-P form? Sometimes it is observed vertisols do not response to P application specially in pulse crops.
   In those cases, one could also consider crops that make use of arbuscular mycorrhizal fungi, as those fungi will help to get the P out of the soil.

9. Lot of conservation agriculture uses herbicides. how does herbicides affect soil health?
   There are many gaps of knowledge regarding the impact of pesticides on non-target soil organisms. Some studies have shown that herbicides can have a negative impact on some soil organisms like cyanobacteria, which will affect soil health.
   Other studies show isolated effects of glyphosate on enzyme activity but no general effect of glyphosate on soil microorganisms. FAO has published this Global Assessment of the impact of plant protection products on soil functions and soil ecosystems: http://www.fao.org/3/i8168en/I8168EN.pdf

10. How can we increase soil diversity, in condition where famers are still more interested in synthetic pesticides that can threaten the diversity of soil organism?

    Microbial biological control agents employed for commercial plant protection act through multiple modes of pest-host interference mechanisms, such as via nutrient or space competition (e.g. Fusarium oxysporum) that can modulate the growth conditions for the pathogen or pest; via antibiosis to interference in a pathogen with production of volatile or non-volatile substances, such as enzymes or other metabolites that can kill or inhibit growth of another organism (e.g. antibiotics).

    Please see FAO has published this Global Assessment of the impact of plant protection products on soil functions and soil ecosystems. It includes sustainable soil management and plant protection products.

http://www.fao.org/3/i8168en/I8168EN.pdf

11. Climate Change and farmers intervention to combat climate change to enhance their crop productivity by applying modern farming techniques is affecting the soil quality in developing states. Improper and unscientific use of fertilizers and pesticides is also polluting the water and soil quality. How it can be managed??

    Please see FAO has published this Global Assessment of the impact of plant protection products on soil functions and soil ecosystems. It includes sustainable soil management and plant protection products.

    http://www.fao.org/3/i8168en/I8168EN.pdf & the Voluntary Guidelines for Sustainable Soil Management http://www.fao.org/3/a-bl813e.pdf

12. I just wonder how soil biodiversity affect ecosystem services. Is there any impact of these chemical fertilizers to Soil Biodiversity? If there, how can we improve the soil health?

    The misuse of fertilizers may have a negative impact on soil biodiversity, which could affect the long-term agricultural productivity and sustainability. Synthetic fertilization may have a negative impact on microbial communities and fauna. Excess fertilizer applications typically reduce the abundance of mutualistic soil biota, which enables increase in pathogenic microbiota. For instance, nitrogen fertilization can greatly increase the populations of soil mite predators and reduce microbial biomass, arbuscular mycorrhizal fungal (AMF) and faunal diversity. Pollution of nitrogen and Sulphur acidify soil can favors saprotrophic groups. Heavy Nitrogen pollution may alter the balance among taxonomic and functional groups and ecosystem nutrient cycling. One way to improve soil health related to soil fertility is supporting mutualistic soil microbiota like arbuscular mycorrhizal fungi and nitrogen fixing bacteria. Their diversity and abundance can help farmers to reduce costs and their dependence on chemical nitrogen fertilizer.

13. Anyone who has published a paper (s) on the impacts of Sulphur and Micro-nutrients (especially ZINC) fertilization on soil microbiota?

    Please see some:

Alloway, B. J. 2008. Zinc in Soils and Crop Nutrition. International Zinc Association and International Fertilizer Industry Association, Brussles, Belgium and Paris, France.

Hopkin, A. S. P., and M. H. Martin. 1982. The Distribution of Zinc , Cadmium , Lead and Copper within the Woodlouse Oniscus asellus (Crustacea , Isopoda). Oecologia 54:227–232.

Climate change

1. Apologies for late arrival and am likely re-asking previous question, but isn't the key issue that of the need to combine soil biodiversity with viable income earning opportunities for local communities to ensure that their wellbeing and GHG reductions intersect? And if so, how likely is that at the scale that would be required for soil to be a viable GHG sink?

   The key is that all land users (small farmers to industrial farming) could implement Good practices like those suggested in the Voluntary Guidelines for Sustainable Soil Management. Small farmers require technical support and some financial incentives to implement those good practices. There are successful experiences that demonstrated this is feasible.

2. How strong are the Climate Change effects on soil biodiversity?

   Climate will have different potential effects on soil biodiversity, depending on the ecosystem. Alterations to ecosystem processes linked to organic matter will impact the diversity and composition of soil biota. Losses on aboveground biodiversity will also impact. The impact also depends on the organism, for example, in some areas climate change may have dramatic impacts on soil biodiversity and its functions from earthworm invasion. But it is difficult to generalize the impact since other microorganisms may have different behaviors, like fungal diversity may respond to climate change because some of them have shown certain degree of resilience.

3. What is the relationship between soil biodiversity and climate change?

   Soils comprise the largest carbon stocks on earth. Keeping and enhancing carbon in soil is necessary for soil biodiversity survival, climate change mitigation and for agriculture productivity. The role of soil biodiversity in addressing global climate change cannot be understated: the soil community's activities can either

contribute to the emission of greenhouse gasses or to absorbing carbon into soils from the atmosphere. Carbon is either fixed or released from soils, depending the activity of the soil organisms and driven by soil conditions. Carbon is fixed into soils through the transformation of plant and animal detritus, and also some bacteria and archaea can fix carbon by using atmospheric CO2 as their energy source.

4. Can increase in soil biodiversity act as negative feedback on climate change considering increase in soil respiration?

   The soil community's activities can either contribute to the emission of greenhouse gasses or to absorbing carbon into soils from the atmosphere. Carbon is either fixed or released from soils, depending the activity of the soil organisms and driven by soil conditions. Carbon is fixed into soils through the transformation of plant and animal detritus, and also some bacteria and archaea can fix carbon by using atmospheric CO2 as their energy source.

Pollution

1. Main Challenge for soil Biodiversity is Plastic and polybags. Is FAO working on something similar?

   Plastics and microplastics are indeed among the main challenges for soil biodiversity. Agriculture is an important source of plastics in soils and also for water bodies. This is why FAO has established an inter-departmental working group on agro-plastics to try to collect data on the life cycle of agro-plastics, their effects on ecosystems and to propose solutions or alternatives to the practices and materials most harmful to the environment and human health. This working group has recently been established and it is working on a FAO strategy on plastics. Follow the activities of the GSP regularly to be aware of the latest developments of this working group.

2. I will work on soil biodiversity in metal-contaminated soils, can anyone recommend me a group studying this topic??

   The GSP is creating a database of soil-related research centres and programmes and a directory of soil scientists and other related stakeholders under its Pillar 3. We would be pleased to learn more about your areas of research work and to connect you to our already extensive network of experts in soil pollution and

soil biodiversity. Please do not hesitate to contact the GSP Secretariat for further information at GSP-Secretariat@fao.org.

3. kindly share some insights into Soil biodiversity in heavy metal affected soils w.r.t coal mine affected Soil.

   Mites and other soil arthropods have been used as bioindicators of soil contamination by toxins. AMF contribute to soil remediation thanks to their partnerships with plant (phytoremediation). But as fungi accumulate heavy metals from the polluted environment, mites feeding on fungi accumulate metals too (due to the food web). High soil diversity is expected to fasten soil remediation and in former industrial sites, bacteria and fungi within soil can actively degrade chemical pollutants in soil like diesel and tolerate and chelate heavy metals to reverse degradation.

   Soil microorganisms play a pivotal role in the degradation of chemical pesticides as well. The objective of all soil remediation methods should not only focus on removing the contaminants from the soil, but also to improve soil health. Some methods result in a strong adverse impact on soil functioning and on soil biodiversity. For instance, physicochemical soil remediation technologies designed to clean up contaminated soils (e.g. excavation, containment, soil washing, and incineration). Some remediation methods can even be more damaging to the integrity of the soil system than the contaminants themselves. Some contaminated sites, particularly metalliferous mining sites, can harbour a unique biodiversity of, for instance, metallophytes and metal tolerant microorganisms that must be preserved for its intrinsic and utilitarian value.

4. Are there plastic eating bacteria from the soil?

   Recently, Germany researchers have found a strain of soil bacterium (Pseudomonas putida) that can produce enzymes to digest polyurethanes thus making it biodegradable. The bacterium found in the soil surrounding a heap of plastic waste was feeding on polyurethane diol.

Technology

1. To all speakers, do you think if it would be possible to organize training programs for delivering novel or recent technologies and bioinformatical approaches used in the arenas of soil-plant microbiome interactions, as well as soil/plant

microbiome, giving a little priority to the researchers and PHD students from the countries lacking of know-how and data in terms of soil biodiversity ?
This is the intention we have in the GSP, as we are currently developing EduSOILS which will be a free educational platform where there will be training courses for all areas related to sustainable soil management.

2. Can you suggest some methods to delimit the soil interactions? I am profoundly interested in developing a method ("omics") to define functional responses, at different organismal levels?

   This is indeed also a subject being worked on in my (Wim v.d.P.) group (see https://www.nature.com/articles/ncomms14349) and a collaboration with Swiss and Spanish colleagues (https://www.nature.com/articles/s41467-018-06105-4) . For the concept of ecosystem coupling, I would suggest contacting Dr. Raul Ochoa in Cadiz: https://rochoahueso.wordpress.com/ and for the network analysis Dr. Elly Morriën at University of Amsterdam: https://www.uva.nl/profiel/m/o/w.e.morrien/w.e.morrien.html

3. How can we exploit the unculturable microbiota in the soil to increase soil bio-diversity?

   Indeed, unculturable cannot be studied experimentally, which is a problem. What you may do is study treatment effects on sequenced community composition and compare the full community composition with that of the sequenced culturable. That would be an indirect way.

   How can companies providing smart (digital) farming solutions can participate in addressing the soil biodiversity challenge?

   There is a great potential to use soil biodiversity information to smart farming solutions. For instance, microbiome-based precision farming, in which predictive models could assess the performance of an inoculant strain or provide forecast which crop and soil management practices will be the best. The development of monitoring tools is important to recording changes in soil biodiversity and establishing databases to link diversity with soil functions and artificial intelligence, for instance, has great potential to understand the interaction between the organisms and through the processing capacity of complex

information from multiple databases. Another example is precision agriculture with the use of satellite, aerial and ground images.

4. Is digital agriculture going to improve the soil biodiversity? Ahmad Mahdavi from Iran.

   There is a big potential to digital agriculture to support soil biodiversity, for instance, in term of assessment and monitoring. Please see some examples above.

5. Do you think that in the developing countries like India the introduction modern farming technology over traditional farming techniques is affecting the soil quality??

   This depend on what modern farming technology has been applied. However, despite the kind of technology, it is very important to take into consideration traditional knowledge and traditional farming techniques that have been successfully implemented for ages. Ideally, all those new advances in terms of technology should work together with best practices and help to disseminate them.

Indicators and Monitoring

1. Importance of biodiversity in general and soil biodiversity particularly seems not to be well understood by smallholders Farmers in Africa. It's Something abstract. Interested by Tools, training materials that can be used to explain this importance to Farmers. How can we identify, map biodiversity in fields?

   See e.g. a citizen science project on soil animals: https://nioo.knaw.nl/en/calendar/soil-animal-days-2020 . More can be read on the website in Dutch; perhaps google translate can help.

2. When we will have actionable, aligned and peer reviewed COMMON metrics on biodiversity and soil biodiversity that we can use to prioritize individual efforts and to along common approaches with governments and all stakeholders along the value chain?

   I'm afraid that many who promise such a metrics may not deliver on a short term. Moreover, the question is whether that is the best way to go. Another option is to start from management practices that have demonstrated positive effects on

soil (and aboveground) biodiversity and then steer on those actions, rather than trying to measure the effects.

3. Is there any significant progress on soil quality "micro" indicators, suitable for quick "on site" soil testing?

   Just google on site DNA barcoding and nanopore sequencing and you will see that companies are offering this technique, which is also under further development. But, for the testing, one would also need proper reference soils. So, the techniques are being offered, but a lot will depend on their cost-effectiveness and proper references. There are also other possibilities; see answer to question above.

4. Are there consensus biological indicators defined yet?

   Work on biological indicators for soil biodiversity, soil health, etc. has been done and is being done, however, to date there is no simple, convenient and reliable/representative tool available (in spite of what is promised, every method has its specific drawbacks).

5. What is the role of soil insect as an indicator of soil quality?

   See answer above; every species group (bacteria, fungi, nematodes, etc.) has been proposed as an indicator group. Thus far, nematodes have been shown to be quite informative, but, as mentioned above, there is not one single indicator group that addresses all issues.

Soil transplantation, restoration

1. For intensive agricultural lands, where the chance for restoration is very little (almost not time to restore, e.g. Bangladesh), in that case, what would be the possible way to restore soil biodiversity?
   It would be important to identify the drivers of loss to work on them and identify best practices. For for instance, completely eroded soil or agricultural land, adding soil organic matter (composted plant material) will help. In the case of erosion, that should be stopped, and then replanting the soil with the native vegetation. In the case of agriculture, reduce soil tillage, and provide a variety of crops in rotation. The less the soil will be disturbed, the better. Also inoculating the soil with 1-5% of soil from a site with ample soil biodiversity (or soil from a target site for restoration) will help.

2. What is the main challenging to restore and main the Soils Biodiversity and soil health in sustainable way?
   The first challenge is to avoid the drivers of loss. Then I would say to change the soil management practices and adopt more soil biodiversity-friendly ones. One of the big challenges is the bioproducts available that sometimes cannot be so efficient as current chemical ones, making difficult the transition.
3. what do you suggest as solutions for restoring soil health, apart sustainable management of forests?
   It would be important to identify the drivers of loss to work on them and identify best practices. For instance, completely eroded soil or agricultural land, adding soil organic matter (composted plant material) will help. In the case of erosion, that should be stopped, and then replanting the soil with the native vegetation. In the case of agriculture, reduce soil tillage, and provide a variety of crops in rotation. The less the soil will be disturbed, the better. Also inoculating the soil with 1-5% of soil from a site with ample soil biodiversity (or soil from a target site for restoration) will help.
4. How can I possibly enhance soil biodiversity in semi-arid and arid regions of Zimbabwe?
   Depends on where you start from: completely eroded soil or agricultural land. In both cases adding soil organic matter (composted plant material) will help, but also ensuring ample water. In the case of erosion, that should be stopped, and then replanting the soil with the native vegetation. In the case of agriculture, reduce soil tillage, and provide a variety of crops in rotation. The less the soil will be disturbed, the better. Also inoculating the soil with 1-5% of soil from a site with ample soil biodiversity (or soil from a target site for restoration) will help.
5. Most of agricultural soils in Indonesia has been degraded and has low SB (sick soils). How to restore the SB (soil health) in a changing climate
   It would be important to identify the drivers of loss to work on them and identify best practices. For for instance, completely eroded soil or agricultural land, adding soil organic matter (composted plant material) will help. In the case of erosion, that should be stopped, and then replanting the soil with the native vegetation. In the case of agriculture, reduce soil tillage, and provide a variety of crops in rotation. The less the soil will be disturbed, the better. Also

inoculating the soil with 1-5% of soil from a site with ample soil biodiversity (or soil from a target site for restoration) will help.

6. What are the breakthrough technologies for enhancing or restoring soil microbial biodiversity in arid soil having low carbon and low nitrogen with poor water holding capacity. Dr Ummed Singh, Jodhpur, Rajasthan, India

   Soil transplantation in combination with removing the factors that are causing erosion. See *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.*

7. What is the AVG time to recover all microorganism relations after abandon an agriculture area?
   Some 10-20 years

   Zhang, K., Cheng, X., Shu, X., Liu, Y., Zhang, Q. 2018. Linking soil bacterial and fungal communities to vegetation succession following agricultural abandonment. Plant and Soil, 431(1-2), 19-36.

   Morriën, E., Hannula, E.E., Snoek, L.B., Helmsing, N., Zweers, H., de Hollander, M., Bouffaud, M- Buée, M, Dimmers, W, Duyts, H, Geisen, S, Girlanda, M, Griffiths, RI, Bracht Jὸrgensen, H, Jensen, J, Plassart, P, Schmelz, RM, Schmidt, O, Thomson, BC, Tisserant, E, Uroz, S, Winding, A, Bailey, M, Bonkowski, M, Faber, J, Martin, F, Lemanceau, P, de Boer, W, van Veen, JA, van der Putten, WH 2017. Composition of soil biodiversity networks, functional changes in nutrient dynamics, and consequences for vegetation succession. Nature Communications |8:14349 | DOI: 10.1038/ncomms14349 |www.nature.com/naturecommunications

8. Land with two transplanted paddy land, how soil biodiversity retains?
   Minimal tillage, organic matter addition and diversification of crops.

9. Do we need different strategies drawn out (and how different) when trying to rehabilitate soils under perennial crop cultivation as opposed to annual crop systems?
   Here soil tillage is already minimal, and the perennial crops provide more organic matter to the soil, so, perennial agriculture may already be a good tool

to rehabilitate soils. There is one risk, which is that the perennial crops develop soil-borne pathogens, or that harvesting leads to soil compaction.

10. What constitutes a slow growing plant? And as a follow up, in agriculture would application of this principle be a mixed-cropping system?

    Fast growing plants are the weedy plant species that grow in crop fields and are named weeds; when agricultural land is abandoned these are the first species to appear. These are often annual plant species, but they may also be perennials. A slow growing plant is a (wild) plant species that comes in later and replaces the fast-growing plant species in due time. Usually, these are perennial plant species. Second question: this would indeed be possible, for example by having slow growing plant species as understory plants in orchards, but perhaps also in crop fields as intercropping plants. The species choice needs to be carefully examined, so that the slow growing plants do not negatively affect the crop plants, directly or indirectly.

11. Are there any quantitative studies that have estimated the potential recovery of soil biodiversity in managed forests? Many studies consider either agricultural lands or grasslands, very few have addressed these issues in forest ecosystems.

    Although forest ecosystems cover about 30% of the Earth's land surface and they are habitat for a highly diverse soil biodiversity, the soil communities are still poorly studied. This is one of the gaps that need to be tackled.

12. How about the soils in dumpsites, what processes can we integrate to rehabilitate the soil there?

    In addition to decomposing vegetal detritus, many soil bacteria can transform different types of contaminants such as saturated and aromatic hydrocarbons (e.g. oil, synthetic chemicals and pesticides). For instance, soil bacteria and fungi can help reduce petroleum hydrocarbons after a spill by up to 85%. Therefore, soil biodiversity can support the biological remediation of dumpsites as well as mining sites, and consequently support the rehabilitation of degraded soils, if it is the case.

Crops

1. Can you give a small example as to how a particular crop species to help extract nutrients?

   Every crop species extracts nutrients from soil. If you want to extract many nutrients, do not grow species like corn, which like high amounts of nutrients, but rather slower growing grasses, that can better exploit scarce nutrients.

2. The link between soils and plant breeding is very important. How much is the nutrient uptake ability taken into account in commodity crop breeding programmes?

   I think that most current breeding programs more and more select for crops that are not limited by nutrients and water. There may be breeders doing so, but there is a lot of scope to breed for taking up nutrients under limiting conditions, such as is also done for breeding for salt tolerance.

3. How can we enhance soil biodiversity when the dominant agriculture system is still the monocrop?

   One solution would be keeping some natural vegetation or restoring patches of natural and semi-natural habitats on farms.

4. Given that matching a crop to a soil still seems to promote the use of monocultures, would you say there's a link between soil biodiversity and crop diversity? and if so would the ideal model increase both components?

   It is indeed thought that crop biodiversity enhances soil biodiversity. In general, growing more crops will also help to grow crops that are ‘good’ for soil (enhancing soil organic matter, extensive root system), which will also enhance soil biodiversity.

5. How Much monoculture affect soil biodiversity?

   Monocultures tend to decrease the diversity of above- and belowground biodiversity, consequently limiting the presence of beneficial bacteria, fungi and insects. Large-scale monocultures reduce soil biodiversity because they increase the quantity of specific soil bacteria and fungi and the higher trophic level organisms that they attract, facilitating the spread and expression of soil-borne diseases.

6. Do you think that genetic engineering should be used to ensure a sufficient amount of agricultural plant species that can handle the soils, rich in biodiversity? Thank you!

   The question will be what to engineer in the crops and how? So, first we need to know what traits we should incorporate in crops, then seeing whether these traits are present in the crops, and if not, then develop strategies to get those traits in the crops.

7. Are there examples of crops that have been successfully adapted to high biodiversity soils? and how does their productivity compare to that of conventional cropping systems?

   Most 'big' crops, such as potato, cereals, sugar beet are not well adapted to high diversity soils; later succession species, such as almonds, and olives and classic orchard trees are better examples. Or traditional species rich grasslands. But currently, those systems are less productive. Perhaps that perennial crops would do better.

8. How do cover crops help in enlisting biodiversity compared to other crops like corn, rice…?

   Cover crops provide food and ground cover to the soil organisms when there is no crop growing.

9. What are the species of edible cover crops? is there any information of their relative performance?

   Some food crops can be grown as cover crops, such as winter wheat, winter barley, and winter rye. Other cover crops, such as crucifers, or grasses, can be fed to animals, however, that goes at the expense of the cover crops providing food to soil organisms. Some cover crops, such as grasses, may be mown once for feed and then continued to be grown as food for the soil.

10. What is part of intensification? Is that nitrogen use, ploughing, parcel surface?

    All these factors contribute to intensification.

11. How could we improve soil biodiversity while intensification of agricultural production continuously increases particularly in tropical countries?

This is indeed a dilemma: intensification results into loss of soil biodiversity. Minimal tillage and enhancing the level of soil organic matter will be crucial.

12. Should we 'feed' the soil first? Not the plant. In term of marginal land, should we enrich the soil or create the plant that is tolerant to marginal land?

    First question: if you feed the soil with organic matter, this will automatically mean that the soil will feed the plant. Second question: The question is whether marginal land is needed for food production, wood production or for whatever region, or whether the marginal land can be better left natural. The best is to improve the land, when needed, by growing the proper plant species. In any case, without improving the land, no crops will grow, unless those are the same species that currently inhabit the marginal land.

13. Is it a solution only when until its ready to be applied and so deliver positive change?

    Every solution needs to be tested and refined in practice, so, better start doing this as soon as possible to obtain experience and further improve.

14. Healthy food depends on healthy soils & soil biodiversity (SB). Climate change and intensive agriculture has affected the SB severely and livelihood of smallholder farmer. How to accelerate the restoring of the SB, particularly in tropical country.

    I defer to soil experts but apply the 4 tenets of soil health https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/mgnt/

    Less disturbance (tillage, 'cides, synthetic fertilizers), Keep living roots in the ground, Diversify plants, Keep the soil covered

15. How grazing is helping in maintaining soil health? Because grazing will promote soil erosion.

    Grazing at low density might help. Indeed, overgrazing is leading to catastrophe.

16. In the context of agriculture, as the science of producing food, should we just spare the land for the sake of high biological diversity or it should be in tandem with food production? or we should adopt sustainable soil management practices that helps to improve biodiversity and hence improved soil health for improved production and productivity?

There is a long debate on land sparing vs land sharing, but it depends on each case. Therefore, I totally agree with you that the most important thing is about sustainable soil management practices, which includes monitoring soil health and consequently, adapting measures to increase, in a sustainable way, crop/livestock productivity.

17. Zero tillage is good for soil it seems, does it have any relation with soil microorganisms?

    Reduced tillage can enhance earthworm (and other organisms) abundance and diversity. Therefore, it can contribute to the increase of organic matter in agricultural soils, the increase of microbial biomass, and as per consequence, the improvement of soil health and crops productivity.

18. How does irrigation system help in soil biodiversity?

    If irrigation enhances plant growth, that also enhances organic matter inputs into the soil, which is then for the soil organisms.

19. Why do plants grow slower on a high-biodiversity soil?

    Because the soil organisms compete with plants for nutrients, for example nitrogen. Also, nutrients become 'locked' in the soil organic matter. So, under those conditions, plants need special 'tricks' to provide their own nutrients. For example, nitrogen fixation and mycorrhizal fungi for phosphorus uptake.

20. Is continuous wet land cultivation hampering soil biodiversity?

    Wet land will contain only few fungi, and relatively many bacteria. Some soil organisms, such a nematode, may do well under wet conditions, but bigger soil organisms, such as micro-arthropods, many insect larvae, and earthworms may be reduced as well.

21. Is there any correlation between soil biodiversity and agricultural productivity?

    Soil biodiversity can change the soil through their biological activity and an increase in soil biodiversity is positively linked to an increase in soil function, including an increase in plant growth, resistance to pathogen invasion and higher nutrient use efficiency. Soil biodiversity can also improve soil structure with positive repercussions for soil water and nutrient holding capacity. They contribute to nutrients cycle and to transform complex chemical forms into

simple molecules or compounds that can be absorbed by plants, providing feedback to plant productivity and re-growth. The relationship between roots and soil biodiversity enables plants to capture essential minerals.

22. How to mechanism of interaction between soil fauna and microorganisms i.e. arbuscula mycorrhiza in increasing plant growth.

Symbiosis with roots help plants to acquire more quantity of nutrients in an efficient way. For instance, Mycorrhizal fungi form symbiotic help the majority of plants to acquire nutrients such as phosphorus and nitrogen. Nitrogen fixing bacteria associate with legume roots fix large amounts of nitrogen that are of pivotal importance for plant productivity in a wide range of ecosystems across the World. Mutualistic soil microbiota (i.e. arbuscular mycorrhizal fungi, nitrogen fixing bacteria) are key components of soil biodiversity as their diversity and abundance can minimize cost and dependence on chemical nitrogen fertilizer in agriculture, enhance soil fertility and environmental sustainability (air, soil water) including reducing greenhouse gas emissions from the energy intensive manufacture of nitrogen fertilizer.

23. Are you familiar with win sector and is there research on crop adaptation on biodiversity soils in wine?

For wine, the soil microbiome plays a central role in soil fertility and crop health, both in viticulture (e.g.) and enology (e.g. in fermentation and flavor). Italy reported some studies on soil biodiversity and vineyards.

Zarraonaindia I, Owens SM, Weisenhorn P, West K, Hampton-Marcell J, Lax S, Bokulich NA, Mills DA, Martin G, Taghavi S, Lelie D van der, Gilbert JA. 2015. The soil microbiome influences grapevine-associated microbiota. mBio 6: e02527-14, DOI: 10.1128/mBio.02527-14

Belda, I., Ruiz, J., Alastruey-Izquierdo, A., Navascués, E., Marquina, D., and Santos, A. (2016). Unraveling the enzymatic basis of wine "flavorome": a phylo-functional study of wine related yeast species. Front. Microbiol. 7:12. doi: 10.3389/fmicb.2016.00012

Belda, I., Ruiz, J., Esteban-Fernández, A., Navascués, E., Marquina, D., Santos, A., et al. (2017). Microbial contribution to wine aroma and its intended use for wine quality improvement. Molecules 22, E189. doi: 10.3390/molecules22020189

Best practices

1. There is a huge opportunity loss in the amount of garbage not segregated in cities and just dumped in landfills where they spread all sorts of diseases to those living around the area – this is a composting opportunity lost, and all of that waste rotting in landfills could be used to generate compost for farmers living in the rural areas. Is there anyone who is doing the logistics of mass waste management from urban settings and composting this "waste" in farmlands? If so please could you reach out with contacts?

   There are many successful experiences about composting and big/small processing factories, including community based companies that process organic residues and transform into organic fertilizer. Our manual for composting could help you out: http://www.fao.org/3/a-i3388e.pdf

2. Half of the Netherlands was underwater. How did the soil change from dried sea land to cultivable land? How did the biodiversity changed?
   Main effect: more fungi, earthworms, moles, but also more soil-borne pathogens (fungi, bacteria, and plant parasitic nematodes).

3. How can soil diversity can be maintained in country like India?
   Providing ample soil organic matter, minimal tillage, prevention of drought, prevention of soil contamination and excessive use of chemical crop protection.

4. Regarding the breeding, how far breeding project targeted the best varieties that well interact with soil microorganism? in term of plant growth nor plant defend system.

   This is currently rarely done, so breeding programs should start focusing on this aspect

5. Small farms with diversified intensive vegetable farms and livestock grazing often self-boast about how they are managing soil health and biodiversity. How do regenerative agricultural practices relate to soil biodiversity?

   All types of agriculture that can support soil biodiversity and restore ecosystem functions and services, including regenerative agriculture, are important.

Techniques that promote the conservation and restoration of farming soils can contribute to above and belowground biodiversity.

6. How does conservation agriculture affect soil biodiversity? Are there any studies on this?

   All types of agriculture that can support soil biodiversity and restore ecosystem functions and services, including conservation agriculture, are important. Please see some references used in the Repor:

   Kleijn, D., Rundlöf, M., Scheper, J., Smith, H.G., Tscharntke, T., 2011. Does conservation on farmland contribute to halting the biodiversity decline? Trends in Ecology and Evolution 26, 474-481.

   Zhu Z., Chang L., Li J., Liu J., Feng L. and Wu D. (2018) Interactions between earthworms and mesofauna affect CO2 and N2O emissions from soils under long-term conservation tillage. Geoderma 332: 153-160.

7. what about permaculture?

   All types of agriculture that can support soil biodiversity and restore ecosystem functions and services, including permaculture, are important.

8. In addition to ploughing, how does the compaction by heavy machinery for ploughing etc. affect soils?

   Compaction could impact soil structure and increase the risks of erosion, and consequently, contribute to soil carbon loss and biological diversity changes.

9. Here in Bolivia, there is a great agroecological movement, as in other countries. Therefore, the use of soil-related microorganisms has been promoted. However, its medium and long-term effect discourages farmers. What can be done when income is more important?

   The results arising from agro-ecological practices sometimes can be perceived as long when compared to intensive agriculture practices. One reason is because the performance of some bioproducts (such as biofertilizers and biopesticides) under field conditions are still lower when compared with current chemical products. However, the long-run benefits (soil health and other the minimization of soil threats) provided by the agro-ecological practices as well as

by the soil biota need to be taken into consideration for the profitability and future productivity of those agricultural areas.

Hydroponics and Urban agriculture

1. What is your opinion of Hydroponics plant production, Is good for soil biodiversity or otherwise?
   No, hydroponic plant production does not help soil biodiversity, unfortunately.

2. Recently we are seeing news on practicing growing plant without soils i.e, hydroponic plant as soil become infertile day by day and in the urban area soil is limited. So, is this soil based nature solution could cope up with modernization.?

   The future of food systems will count on many different solutions that will be complementary. This mosaic could include farms, urban agriculture, hydroponic and any other kind of sustainable food production that contribute to achieve the main societal goals, such as feed the increasing population with nutritious food and at the same time, conserving biodiversity.

3. It was mentioned that fungi are health ambassadors. I assume you were referring to mycorrhizal fungi. And what do you say about the well-being and stability of urban ecosystems? where are these fungi known to be eliminated, and the main role in urban ecosystem is taken by mold fungi?

   Urban agriculture can have a high degree of biodiversity and offer many ecosystem services. http://w3.biosci.utexas.edu/jha/wp-content/uploads/Lin-Philpott-Jha-2015-future-urban-agriculture-BA-Ecology.pdf

Mainstreaming

1. There is a lot of momentum to maintain the status quo industrial agricultural system. What do you think are the prospects of change? How quickly might things change? And what can we do to help that change happen?

   Part of the answer is in your question. Society has the power to change the status quo of industrial systems. We can help thought many ways, and one important contribution is raising awareness about the need to have more sustainable agricultural and food systems. In our society, information is key. I believe that

the change has started already, but it takes time because we are talking about a transformative change of our society to become more sustainable in all aspects.

2. How about establishment an international working group bringing knowledge and experience on synthetic ecology studies opening new insights for understanding of plant-soil microbiomes to design model communities in the future?

   The Global Soil Biodiversity Initiative (GSBI) could be one option. It was designed to create a global collaboration of scientists, all with the goals of informing the public, promoting this information into environmental policy, and overall creating a platform for the current and future sustainability of soils.

   Please see https://www.globalsoilbiodiversity.org/

3. Observation after the excellent presentation and opening remarks: Systems-thinking to, systemic application of the problem analysis and solution analysis seems desired. Are we, as a community, there yet? Are we looking at issues systemically? Are we incorporating the "unusual suspects" and potential blind spots such as socio-economic, institutional political economy influences in our diagnosis and solution propositions to improve soil biodiversity?

   I think we have a lot more to do in our combined disciplines.

4. How do you think global networks and international collaborative approaches are needed to ask cross-continental scale questions in soil biodiversity?

   It would be important to do the same sort of soil sampling and soil biodiversity analysis at many places worldwide, at the same time. That would require many people that will be trained to do so and sending the samples to a number of experts who determine soil biodiversity. The funding will be the main limitation. Perhaps the EU and similar organizations in other continents, or international organizations, such as the World Bank?

5. How is soil biodiversity reflected in the EU Biodiversity Strategy for 2030?

   Very poorly; greening of agriculture should promote soil biodiversity, however, most EU documents on biodiversity, habitat directive, etc. make little mentioning of soil, let alone soil biodiversity. However, we are now working on this. See also https://easac.eu/publications/details/opportunities-for-soil-sustainability-in-europe/

6. Do you think that the recent F2F strategy presented yesterday by EC Commission could contribute to improve biodiversity? Is there other strategies put in place around the world?

   Farm to Fork should be made more circular: from farm to fork and back to farm would have shown the awareness that food chains should not be linear, but circular, so that organic matter will be brought back to the soil.

7. Why this issue is the focus of an international accord?

   Soil biodiversity has been part of the Convention on biological diversity since the beginning. It is focus of an international accord because it is a cross cutting issue that goes from agriculture lands to protected areas. Soil biodiversity is key in sustaining life on this planet and delivering multiple ecosystem services.

Economic Value and financial mechanisms

1. Can we put an economic value, price on soil biodiversity? Can we estimate the "Cost of Inaction" similar to climate?

   Different approaches exist to attribute monetary values to changes in soil biodiversity, depending on the type of value. Pascual et al., (2015) offers a framework based on the Total Economic Value of soil biodiversity. But it is very complex to put an economic value, since we are talking about different biomes worldwide, with a myriad of organisms and each one performing multiple ecosystems services. For instance, only for earthworms, Bullock et al. (2008) suggest that earthworms add 723 million euros per year to livestock production in Ireland; adding the equivalent value for food crops could raise the total value of earthworms to over 1 billion euros. Bailey et al. (1999) estimated the value of earthworms for soil structuring service at £0.48 per kilogram of earthworms under reduced tillage. In 1997, Pimentel has estimated that bioremediation of pollutants has an estimated global economic value of 120 billion USD yr

   Please see: Pascual, U., Termansen, M., Hedlund, K., Brussaard, L., Faber, J. H., Foudi, S., et al., 2015. On the value of soil biodiversity and ecosystem services. Ecosystem Services 15: 11-18.

   Bullock, C., Kretsch, C., & Candon,, E. 2008. The Economic and Social Aspects of Biodiversity - Benefits and Costs of Biodiversity in Ireland. The Stationary Office, Government of Ireland, 195pp

Bailey, A. P., Rehman, T., Park, J., Keatinge, J. D. H., & Tranter, R. B., 1999. Towards a method for the economic evaluation of environmental indicators for UK integrated arable farming systems. Agriculture, Ecosystems and Environment, 72, 145-158.

Pimentel, D., Wilson, C., McCullum, C., Huang, R., Dwen, P., Flack, J. et al. (1997). Economic and Environmental Benefits of Biodiversity. BioScience, 47(11): 747-757. doi:10.2307/1313097

2. What are the current barriers to investment in this sector?

   The use of commercial beneficial soil microorganisms is a continuously growing market. One example is the bioproducts. But one barrier for further investment could be knowledge gap. Currently, many microbial biofertilizers, biopesticides and other related products show great effects when tested under laboratory and greenhouse conditions but fail to produce reproducible results under field conditions.