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COMMISSION ON GENETIC RESOURCES FOR FOOD AND AGRICULTURE

Item 9.1 of the Provisional Agenda

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BIOREMEDIATION AND NUTRIENT CYCLING SOIL MICROORGANISMS AND INVERTEBRATES

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I. INTRODUCTION

1. The Commission on Genetic Resources for Food and Agriculture (Commission), at its Seventeenth Regular Session, adopted its Work Plan for the Sustainable Use and Conservation of Microorganism and Invertebrate Genetic Resources for Food and Agriculture (Work Plan).[1] The Work Plan addresses microorganisms and invertebrates as functional groups and foresees that the two functional groups considered by the Commission at its Nineteenth Regular Session will be (i) soil microorganisms and invertebrates, with emphasis on bioremediation and nutrient cycling organisms and (ii) microorganisms of relevance to ruminant digestion.[2]

2. The Work Plan foresees that each functional group will be addressed on the basis of the following inputs: a summary of the status and trends of conservation, use and access and benefit-sharing, based on previous work of the Commission, existing literature and, as appropriate, an open survey that may also compile best practices with respect to their sustainable use and conservation; a mapping of regional and international organizations and other institutions most relevant for the functional group and the identification of strategic areas of possible collaboration; and an analysis of gaps and needs in the respective fields and opportunities for the Commission and its Members to address them.[3]

3. In response to the Work Plan, FAO commissioned the Austrian Institute of Technology, Vienna, to prepare a study on soil microorganisms and invertebrates relevant to bioremediation and soil nutrient cycling. A draft version of the study is presented in the document *Draft study on the sustainable use and conservation of soil microorganisms and invertebrates that contribute to bioremediation of agricultural pollutants and soil nutrient cycling*.[4]

4. The present document draws on the findings of the draft study to present an overview of the status of soil microorganisms and invertebrates that contribute to nutrient cycling and bioremediation and seeks the Commission's guidance on how work on this group of microorganisms and invertebrates should be advanced.

II. ROLES IN SOIL PROCESSES

5. Soil microorganisms and invertebrates are highly diverse and exist within complex communities that play vital roles in nutrient cycling and in maintaining soil structure. They are thus vital to food production. They provide a range of options for dealing with the contamination of soils with heavy metals and other pollutants (bioremediation). Their roles in the carbon cycle mean that they are vital to efforts to maintain and increase carbon sequestration in the soil. They contribute in various ways to "One Health", the approach that combines human, animal, plant and environmental health.

6. In line with the Work Plan, the draft study focuses particularly on the roles of soil microorganisms and invertebrates in nutrient cycling and bioremediation.

7. For healthy growth, plants require a wide range of macro- and micronutrients, specifically the elements carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, manganese, copper, zinc, molybdenum, boron and chlorine. They obtain carbon via photosynthesis and normally obtain other nutrients from the soil in which they grow.

8. In the case of the carbon cycle, dead organic material is transformed into soil organic matter by microbial and invertebrate decomposers. Carbon is naturally sequestered in the soil through the activity of photosynthesizers, soil-bioturbator invertebrates and oxalate producers.

9. The cycling, bioavailability and biomineralization of all macro- and micronutrients are connected to the biological activities of soil organisms. Key microbial functions include fixing nitrogen from the atmosphere and transforming it into plant-available forms and biomineralizing organic phosphorus into inorganic compounds.

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[1] CGRFA-17/19/Report, *Appendix E*.
[2] See CGRFA-19/23/9.2; CGRFA-19/23/9.2/Inf.1.
[3] CGRFA-17/19/Report, *Appendix E*, paragraph 7.
[4] CGRFA-19/23/9.1/Inf.1.

10. Various microorganisms can be actively recruited from the rhizosphere soil by plants to colonize their inner root tissues. This results in a metabolically profound plant–microbe relationship and is often crucial for plant development.

11. The mobility and availability of most metals in the soil depend on microbial processes. Numerous native soil bacteria contribute naturally to the reduction of toxicity levels by excreting exopolysaccharides that absorb heavy metals.

III. STATUS, TRENDS AND THREATS

12. Efforts to understand soil biodiversity have been greatly enhanced in recent years by the emergence of genomic approaches. The introduction of molecular tools has made it possible to detect the genetic fingerprint of any organism with high accuracy and at greater resolution. Modern genomic approaches focus on the variability of genes and functions rather than only on taxonomic richness. Specific ecological statistical models are used to infer whether a conservation intervention is needed for a given group of organisms.

13. Only a fraction of soil microbes have been taxonomically described. New technological advances, such as matrix assisted laser desorption ionization-time of flight (MALDI-TOF) mass spectrometry and high-throughput sequencing, allow microorganisms to be rapidly identified and quantified. However, because of the difficulty involved in species-level identification, knowledge of soil microbial taxonomy remains insufficient at times.

14. An estimated 80–90 percent of soil microorganisms cannot be cultured with current laboratory practices, despite the numerous efforts made to circumvent the limitations of classical cultivation strategies. Metagenome-based estimates have shown that phylogenetically novel, highly divergent uncultured microbes with unknown functions dominate the soil ecosystem. The status and trends of individual microbial species and even genera are therefore mainly unknown.

15. In the case of invertebrates, although populations can be successfully quantified and identified with cost-effective methods, scientific literature on the large-scale spatial distribution and temporal population dynamics of below-ground diversity is limited.

16. Land-use change and heavy use of agrochemicals in agriculture have been associated with a loss of functional and taxonomic soil biodiversity. The available evidence suggests that such losses have been massive. However, their worldwide extent has not been quantified.

17. The natural occurrence, diversity and functional richness of soil organisms in agricultural systems are threatened by the application of excessive amounts of chemical fertilizers and by the absence of regenerative soil-management practices. Appropriate policies and legislation on the protection of soil biodiversity are often lacking.

18. A lack of sufficient studies across different regions and production systems means that knowledge of the effects that particular agricultural practices have on soil biodiversity remains patchy. Broadly speaking, it appears that tillage and inappropriate irrigation practices can negatively affect the functions of the soil ecosystem. Pesticides have also been found to have disruptive effects on the soil microbiome, but results have been variable and in some cases the microbiome has proved able to adapt. Above-ground biodiversity influences below-ground biodiversity, and long-term crop monoculture has been found to negatively affect various components of soil biodiversity. The risks and benefits of potential treatments such as the addition of biochar to the soil and the use of phages remain unclear and require further research.

19. Non-native earthworm species that have been intentionally or unintentionally introduced are likely to have led to declines in native terrestrial worm diversity on several continents. While there are gaps in knowledge of their full impact, in some cases they have been found to affect ecological functions or to have major impacts on components of native biodiversity. Other invasive alien invertebrates and microorganisms have also been found to have severe effects on soil biodiversity.

20. The spread of antibiotic resistance genes (ARGs) among soil organisms is another concern. The main sources of ARGs in the soil are the application of animal manure as fertilizer and irrigation

with human wastewater. ARGs can persist for as long as two years in the soil after manure has been applied. The use of antibiotics in agriculture poses a major threat to native soil microbial biodiversity. Antibiotics and ARGs contribute to the development of multidrug-resistant bacterial strains in the environment.

21. Soil biodiversity is affected by changes in temperature and soil moisture content and is therefore vulnerable to the effects of climate change. However, precise impacts are difficult to predict based on currently available information. Impacts on the role of microorganisms in the carbon cycle may be substantial. Studies of the impact of temperature and precipitation on microorganisms involved in biological nitrogen fixation suggest that they could be strongly affected. Changes in the climate can also interact with other threats such as pollution with heavy metals or pesticides.

22. Experimental findings on the decline of particular microbial and invertebrate taxonomic groups as a result of changes in selected environmental factors or agricultural practices are available. However, the publications in question usually provide aggregated information on the abundance and species-richness of populations or functional groups. Species-specific temporal dynamics are less frequently reported.

23. Mathematical models can be used to understand complex ecological processes and predict how real soil ecosystems might change under particular conditions. Modelling the extinction of soil organisms is challenging because of the complexity of soil microhabitats, the variability of the organisms' body sizes and the large size of their populations. Moreover, as existing ecological concepts cannot be applied to microorganisms, soil biota extinction models are currently limited to experimental findings from artificial microcosms and cannot readily be scaled up or generalized.

IV. CONSERVATION AND SUSTAINABLE USE

24. There is an urgent need for action to address the above-described threats to soil biodiversity and to devise strategies for the management of soil biodiversity that account for the need to promote sustainable food production in combination with a variety of other ecosystem services while also reducing the harmful effects of agricultural practices.

25. Successful conservation of soil organisms requires a combination of *in situ* and *ex situ* approaches. As discussed above, agricultural management practices often pose a threat to soil biodiversity. Various techniques have, however, proven capable of reversing losses and helping to conserve native soil organisms. These include maintaining soil cover (e.g. using mulch or cover crops), permaculture, use of tree crops and agroforestry (including silvopasture), diversified crop rotations, use of indigenous crops, interseeding and reduced pesticide use, although outcomes vary with the particular combination of practices and environmental conditions.

26. Traditional management practices that benefit soil biodiversity are often overlooked. Many such practices could disappear before their efficiency can be evaluated.

27. Composting has been used for centuries to turn waste into fertilizer with the help of microorganisms and invertebrates. Use of compost in agriculture has been shown to provide long-term benefits for soil nutrient content, carbon-sequestration potential and soil biodiversity, even if data on its effects on the latter are limited to date.

28. Fostering more widespread and more rapid adoption of sustainable soil-management practices requires better cooperation between farmers and land managers and researchers, engineers and legislators. Active involvement of farmers has been promoted through approaches such as farmer-managed natural regeneration, a regenerative form of agroforestry that has achieved successes in the Sahel.

29. Soil microorganism and invertebrate conservation needs to be supported by appropriate guidelines that include well-defined key soil parameters, information on important indicator organisms, and carefully chosen quality standards that allow comparative assessment.

30. *In situ* soil biodiversity protection in some cases needs to be complemented with soil regeneration programmes, involving, among other measures, the reintroduction of depleted or locally extinct soil organisms from *ex situ* collections.

31. Where conservation efforts focus on individual species, invertebrates and particularly microorganisms tend to be neglected because of their “invisibility”, lack of appreciation of their importance and their absence from listings such as the International Union for Conservation of Nature’s Red List of Threatened Species.

32. Most studies of soil biodiversity loss to date have focused on the effects of single threats rather than on the multiple threats operating simultaneously, and hence they do not provide sufficient information to allow effective planning of management interventions.

33. The diversity of soil organisms varies around the world, with different locations having been found to be hotspots of community dissimilarity, species richness or the supply of ecosystem services, each potentially requiring a different set of interventions to ensure their conservation. Only a small proportion of these hotspots are currently protected. Some parts of the world are particularly lacking in data on soil biodiversity, making it difficult to plan effective interventions to promote their conservation and sustainable use.

34. Assessing the need for conservation and other management interventions requires good-quality ecological data. However, collecting such data, particularly long-term population data, can be time-consuming and costly. Because of inadequate data on the distribution and ecology of the target species, it is often impossible to transfer conservation models and applications to other areas. Using models to predict ecosystem changes under future environmental conditions and to support sustainable management requires standardization of data collection, laboratory protocols, data analysis and modelling.

35. Lack of data means that some conservation planning is done using proxies such as data on surrogate species that serve as indicators for the desired objective. Indicators of ecosystem or soil health such as soil organic carbon content and water retention can also be used. Developing statistical ecological models that can optimize multiple conservation- and productivity-related objectives is challenging. Surrogate-based optimization approaches can provide management frameworks with acceptable prediction accuracies that are highly adaptable to different parameters and types of spatial and temporal data.

Culture collections

36. Microbial culture collections serve as hubs of soil microorganism identification and conservation and as sources of microorganisms for research and use. The most comprehensive catalogue of culture collections and database of recognized microorganisms is available via the webpage of the World Federation of Culture Collections,[5] which provides information on 768 culture collections from 76 countries. The World Data Centre for Microorganisms[6] database is a directory of worldwide collections that provides information on over 3 million microorganisms and cell lines across 831 culture collections from 78 countries. Some collections are at risk of being lost because of a lack of funding, including for staff, or because of natural disasters, and action is needed to ensure that they are preserved for the future.

37. A number of different *ex situ* conservation technologies can be employed, depending on the objectives. Long-term conservation methods include cryoconservation, underwater storage and lyophilization. In the case of some organisms, conservation in the most viable form requires soil- and substrate-based maintenance, occasionally together with the organism’s symbiotic partner, for example in the case of arbuscular mycorrhizal fungi (AMF). Although some require high-energy equipment, long-term conservation techniques have many advantages and are used in most culture collections.

[5] https://wfcc.info
[6] https://www.wdcm.org

38. Constraints faced by microbial culture collections include shortages of trained personnel and cutting-edge technologies for high-throughput cultivation, whole microbiome cultivation and propagation of currently uncultivable organisms. There is also often a lack of coordination between collections.

Use of cultured and transplanted organisms

39. Biofertilizers are formulated agricultural products that contain cultured and selected microorganisms that can increase the availability of soil nutrients. Beneficial bacteria that have plant growth-promoting traits or nitrogen-fixing abilities and are widely used in biofertilizers include those from the genera *Rhizobium*, *Azotobacter* and *Azospirillum*. There are also numerous products on the market containing AMF. However, the viability and the reliability of many of these inoculants remain questionable, as they often fail to become established in field conditions. Studies of the benefits of microbial inoculants have mostly been conducted under greenhouse conditions.

40. Microbial inoculants could pose a threat to native soil organisms. Although most studies to date have found such impacts to be limited, more research is required. The effects of biopesticides on soil biodiversity also need to be better investigated.

41. Use of earthworms in composting is widespread and they are widely available for purchase for this purpose. Nematode products for soil applications can be found on the biological pest-control market in the form of capsules or dried cultures. Species of entomopathogenic nematodes are commonly used in the management of agricultural pests and are mass produced via incubation in bioreactors.

42. Selective breeding of soil invertebrates is not common. Promising results have been obtained at the research level for characteristics such as biomass, maturation time, cocoon production rate and hatching success in the earthworm *Eisenia fetida*. Attempts to selectively breed soil nematodes for improved attraction to a root signal, desiccation tolerance and selective host-finding have shown that manipulating key traits can be effective if the heritability of the selected trait is high enough or if beneficial traits are stabilized in inbred lines.

43. The use of whole microbiomes (or microbial consortia) rather than single species or species mixes as biostimulants, biofertilizers and biopesticides in agriculture is emerging as a novel approach. They sometimes prove more effective than single species, possibly because of the effects of complementarities. Some successes have been achieved with the reintroduction of native AMF communities and whole soil microbiomes to promote the regeneration of native vegetation.

44. Because of their complex nature, plant-associated microbiome applications involve a number of challenges, including those related to regulatory approval, which currently requires strain-identification in microbial products, something that is not possible for a microbiome product that contains hundreds of thousands of microorganisms. There is a need to unify or standardize research protocols for the study of the soil microbiome and to improve interdisciplinary links between microbiome research communities (human, environmental, plant and animal).

Use in bioremediation

45. Several technologies can be used to remediate sites contaminated with heavy metals. The traditional approach of using physico-chemical methods can be expensive and may involve dangerous radiation or chemicals. Bioremediation is a safe, low-cost and relatively eco-friendly alternative that is particularly suited for removing low concentrations of pollutants. The term bioremediation refers to *in situ* biological treatment that uses soil microorganisms and is primarily used to degrade organic contaminants, including petroleum hydrocarbons, solvents and pesticides, and to transform species of trace elements to reduce their availability.

46. Bioremediation via biosorption (sorption with biological material) allows heavy-metal decontamination without the generation of toxic sludge or secondary pollutants. It can be done with both living and dead microbial biomass. The use of dead cells has the advantage that they can be easily stored in powdered form and hence do not need to be maintained under the specific growth conditions

needed by living microorganisms. While bioaccumulation (accumulation of the pollutant in the organism) is an active process that depends on microbial metabolism and is partially reversible, biosorption is a metabolism-independent, reversable process that does not require much energy input or ideal respiratory environments. Another method of bioremediation is to use organisms that can transform the toxic forms of a pollutant into non-toxic and less-mobile forms.

47. Earthworms have been found to be able to reduce the concentrations of various heavy metals in the soil. Combined use of earthworms and microorganisms has shown promise.

48. While it is possible to stimulate the native microbial and invertebrate communities already present in the soil in order to promote the degradation of a specific local contaminant (biostimulation), the more common approach is to isolate specific microbial strains from the contaminated site and cultivate them in the laboratory for subsequent use in soil inoculation campaigns (bioaugmentation).

49. The ideal way to obtain good microbial candidates for bioremediation is to collect on-site samples and isolate heavy-metal resistant strains with the specific genetic toolset needed to transform the polluting agent. The introduction of bioengineered or non-native microorganisms into the soil is questionable, even at contaminated sites, although they offer a fast and easy way of treating sewage sludge or sewage water in closed systems where sterilization or termination of the organisms is possible before the bioremediated material is used in the field. All bioremediation involving the use of live organisms should be subject to a proper evaluation of possible risks to human or animal health or to the local ecosystem.

50. Aside from heavy metals, microorganisms can also be used to bioremediate soils polluted with various pesticide residues. However, information on the extent to which such approaches are used in practice is limited.

51. Many of the microorganisms and earthworms added to the soil to reduce the bioaccumulation or bioavailability of toxic substances can also simultaneously increase plant growth, soil fertility and nutrient availability.

V. POLICY AND LEGAL FRAMEWORKS

52. At global level, the Conference of the Parties (COP) to the Convention on Biological Diversity (CBD) decided in 2002 to establish the International Initiative for the Conservation and Sustainable Use of Soil Biodiversity[7] under its Programme of Work on Agricultural Biodiversity. FAO and other relevant organizations were invited to facilitate and coordinate this initiative.[8] The COP adopted a framework for action for the initiative in 2006.[9] In 2022, the 15th meeting of the COP endorsed a new plan of action for the initiative, covering the period 2020 to 2030.[10] The document *Progress Report on the implementation of the International Initiative for the Conservation and Sustainable Use of Soil Biodiversity*[11] provides an update on activities under the initiative. The 15th meeting of the COP to the CBD requested a strategic review and analysis of the CBD's programmes of work in the context of the Kunming-Montreal Global Biodiversity Framework to facilitate its implementation, and the preparation of draft updates of these programmes of work for consideration by the 16th meeting of the COP.[12] Also, at global scale, the Framework for Action on Biodiversity for Food and Agriculture[13] makes a number of specific references to soil biodiversity and soil health.

53. At the national level, a majority of countries include some soil-related measures in their national biodiversity strategy and action plans (NBSAPs). However, few have measures specifically focused on soil biodiversity. In their national reports to the CBD, countries have referred to difficulties

[7] Decision VI/5.
[8] Decision VI/5.
[9] UNEP/CBD/COP/DEC/VIII/23.
[10] CBD/COP/DEC/15/28.
[11] CGRFA-19/23/9.1/Inf.2.
[12] CBD/COP/DEC/15/4, paragraph 9.
[13] CGRFA-18/21/Report, *Appendix C*.

in identifying and understanding soil biodiversity and to a lack of expertise and tools in this field. Data for assessing the impacts of national policies are often lacking.

54. Overall, few countries have put in place effective policy and legal frameworks for the sustainable use and conservation of soil biodiversity, and those that have are largely restricted to the developed regions of the world. However, examples of countries adopting soil biodiversity-related policy measures can be found in all regions of the world.

55. International exchanges of soil microorganisms and invertebrates are affected by legal frameworks related both to access and benefit-sharing and to sanitary and phytosanitary protection. Quarantine measures serve to protect native soil biodiversity from threats associated with disease and alien invasive species.

VI. NETWORKS AND COOPERATION

56. A large number of global and regional networks contribute to the management of soil biodiversity. Prominent among these is the Global Soil Partnership (GSP).[14] The GSP is a globally recognized mechanism established in 2012 with the mission of positioning soils in the global agenda and promoting sustainable soil management. The GSP, which is hosted by FAO, works to improve soil governance with the aim of guaranteeing productive soils that contribute to food security, climate change adaptation and mitigation, and sustainable development for all.[15]

57. The International Network on Soil Biodiversity (NETSOB)[16] was established in December 2021 to promote the sustainable use and conservation of soil biodiversity and to bring together relevant experts and existing initiatives to contribute to the implementation of the Global Soil Biodiversity Observatory (GLOSOB).

VII. CAPACITY IN RESEARCH AND EDUCATION

58. In recent decades, a shortage of trained taxonomists and curators has created a “taxonomic impediment” in the field of soil microbiology, i.e. a lack of capacity to update information on some taxa and misidentified species and to deal with the large amounts of taxonomic data being added to databases. However, there has been a boom in the number of research papers, reviews, books, emerging journals, special issues, conferences and scientific networks addressing soil-related topics.

59. Citizen-science programmes can make important contributions to the collection of soil-related data, including on species distributions, with the help of volunteer data collectors. Several successful initiatives have been established, but only in a limited number of countries.

60. Fostering visibility and awareness of soil biodiversity requires public outreach. Promoting the uptake of improved management practices requires training and education for farmers and landowners. Various actions have been taken, including the development of educational websites and inclusion of training on soil-related topics in the work of farmer field schools. However, only a limited number of NBSAPs include specific plans to educate farmers and other stakeholders on soil management practices or to support multidisciplinary research networks targeting soil biodiversity conservation.

VIII. GAPS, NEEDS AND POTENTIAL ACTIONS

61. Major gaps in knowledge of the microorganisms and invertebrates involved in the various soil-nutrient cycles remain to be filled, including on how they are affected by agricultural management practices, their roles in potential alternatives to conventional phosphorus fertilization, their roles in carbon sequestration, the links between their roles in nitrogen fixation and their roles in methane production, and how they are affected by ARGs. There is a need for improved microbial gene databases and novel methods for predicting and quantifying microbial functions.

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[14] https://www.fao.org/global-soil-partnership/en

[15] See CGRFA-19/23/9.1/Inf.2.

[16] https://www.fao.org/global-soil-partnership/netsob/en

62. Improving bioremediation requires better understanding of the interactions between bacteria, fungi and invertebrates. Particular attention needs to be given to the roles of invertebrates in the bioremediation of heavy metals and pesticides, to improving *in situ* bioremediation methods, to bioremediation of multiple contaminants and to the identification of bioindicator organisms.

63. Maps and databases containing information on the status and trends of soil biodiversity and of threats such as invasive organisms and soil contamination need to be updated and expanded, potentially through the use of new technologies such as remote sensing, drones and robots.

64. Attention needs to be paid to improving the effectiveness of microbial products such as biofertilizers under field conditions, to avoiding non-target effects on native biodiversity and soil functions, and to investigating the potential benefits of using microbial consortia rather than single strains. There is a need to determine what constitutes a "healthy" soil and how this can be measured in different environments.

65. There also is a need to better communicate research results, such as those related to the benefits of soil biodiversity and sustainable agricultural practices, to farmers and the wider public and to better involve stakeholders in research, dissemination and development activities.

66. Improving the conservation of soil microorganisms and invertebrates will require better knowledge of their status (baseline surveys and frequent monitoring over the long term), better information sharing, efforts to overcome the neglect of these organisms in conservation planning, and identification of ways of incentivizing agricultural practices that benefit them. Conservation programmes for indigenous crops and trees and their associated indigenous microbiota and invertebrates are needed.

67. To strengthen *ex situ* conservation, but also to improve understanding of microbial functions, there is a need to develop protocols and high-throughput technologies that can bring "uncultivable" groups and whole microbiomes into cultivation. There is also a need to centralize the deposition of microbial strains. Shortages of funding and trained personnel are currently big constraints to *ex situ* conservation. Establishing collections that specialize in the cultivation of overlooked soil organisms or organisms that are hard to breed or cultivate under laboratory conditions is crucial.

68. There is a need to develop better methods for restoring soils in heavily disturbed areas such as those degraded by unsustainable agricultural practices. This will require holistic understanding of the interrelationships between plants, invertebrates, protozoa, bacteria, fungi, viruses and connected soil functions. Microbiomes rather than single organisms or limited groups of organisms need to be targeted. Lost soil organisms could potentially be obtained from *ex situ* collections and reintroduced.

69. There is a need to improve some regulations relevant to the management of soil biodiversity. For instance the requirement for strain-level registration potentially hinders the introduction of products containing multiple microbes into agricultural use. Rules for the import of invertebrates may also need to be reviewed. Other requirements include improving quality control of the viability of microbial products. There is a need to closely involve scientists and curators of culture collections in policymaking.

70. Areas requiring strategic, multidisciplinary, international collaboration include the following:

- development of strategies for better public and stakeholder outreach and communication, including information materials on soil organisms and their use;
- facilitation of interdisciplinary and international research and partnerships on topics related to soil biodiversity;
- transfer of knowledge between the agricultural, academic, industrial and policymaking sectors to improve products, relevant legislation and funding schemes for research;
- coordination of research, and development of protocols defining the concept of a "healthy" soil microbiome and for commonly used laboratory and analysis techniques; and
- harmonization of soil biodiversity-relevant monitoring programmes, networks, initiatives and databases.

71. Potential actions to improve the conservation and sustainable use of soil microorganisms and invertebrates could include the following.

- Guidelines and standard operation procedures for the definition of "healthy soils" need to be elaborated and used in comparative assessments of soil biodiversity. These guidelines and procedures need to include well-defined key soil parameters, which include biological parameters such as microbial/invertebrate taxa indicating soil health, and carefully chosen quality standards.
- There is a need to develop consensus on: (a) the most important soil functions; (b) parameters for inclusion in assessments of the effects that new agricultural methods have on soils; (c) key soil biodiversity parameters; and (d) unified sampling, laboratory and analysis procedures for soil-biodiversity.
- Recommendations on ideal soil conditions and on best practices and interventions in soil management in agriculture should be based on long-term observations made under a range of different environmental conditions and geographical regions.
- The uptake of promising agricultural practices that are beneficial to soil biodiversity conservation needs to be supported by improving evaluation of their applicability and their ease of implementation and should consider potential undesired effects.
- The functionality, standardization and maintenance of databases of soil-health parameters and soil-biodiversity characteristics at regional scales need to be improved.
- Addressing the complex problems facing soil protection in agricultural systems requires scientific approaches that are interdisciplinary and involve a range of specialists, including environmental chemists, biologists, agronomists and taxonomists.
- More and better coordination is needed among the numerous research activities and scientific networks working on the sustainable use and conservation of soil microorganisms and invertebrates.
- Raising awareness and building capacities in soil biodiversity conservation through the education and involvement of producers, as well as better dissemination and public outreach, are essential.
- Already existing *ex situ* and *in situ* conservation initiatives need to be better coordinated and should also address the cultivation and conservation needs of understudied groups of soil organisms.
- Short-term and long-term goals for the conservation and sustainable use of soil organisms need to be identified and a priority list established among them.

IX. GUIDANCE SOUGHT

72. The Commission may wish to:

(i) take note of and provide comments on the draft study;

(ii) recommend that the study be finalized, disseminated and brought to the attention of the GSP and the CBD;

(iii) respond to the findings and recommendations of the study and consider follow-up actions to ensure that the Commission and its Members continue to strengthen their work on soil microorganisms and invertebrates, with emphasis on bioremediation and nutrient cycling organisms;

(iv) recommend that FAO take the findings of the study into consideration in its work in fields relevant to the management of soil microorganisms and invertebrates, as appropriate;

(v) invite Members to promote the sustainable use and conservation of soil microorganisms and invertebrates and ensure they are given due consideration in local, national, regional and international policies and policy-development processes;

(vi) encourage relevant stakeholders, including scientific institutions, to collaborate on sustainable use and conservation of soil microorganisms and invertebrates, especially on capacity development in developing countries and countries with economies in transition;

(vii) invite Members and stakeholders to intensify research on soil microorganisms and invertebrates, in particular on conservation and cultivation methods and on the effects that agricultural practices have on soils, and to strengthen soil biodiversity assessment and monitoring programmes; and

(viii) request the Secretariat to collaborate with relevant experts in the drafting of specific recommendations on soil microorganisms and invertebrates for further consideration by the Commission at its next Session.