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COMMISSION ON GENETIC RESOURCES FOR FOOD AND AGRICULTURE

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INTERGOVERNMENTAL TECHNICAL WORKING GROUP ON PLANT GENETIC RESOURCES FOR FOOD AND AGRICULTURE

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STATUS AND TRENDS IN THE CONSERVATION AND USE OF MICRO-ORGANISMS AND INVERTEBRATES IN RICE AND ROOT AND TUBER PRODUCTION SYSTEMS

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I. INTRODUCTION

1. At its Twelfth Regular Session, the Commission on Genetic Resources for Food and Agriculture (the Commission) emphasized the need for assessing the status and trends of micro-organisms relevant to food and agriculture. More specifically, the Commission requested FAO to prepare, together with relevant international organizations and scientific institutions, focused targeted assessments of the status and trends in the conservation and use of soil micro-organisms, biological control agents and plant pathogens, in particular of important crops, for presentation at its Fourteenth Regular Session.[1]

2. At its Thirteenth Regular Session, the Commission reiterated the need to continue to advance this work, and requested its Intergovernmental Technical Working Groups to review the relevant assessments within their fields of expertise.[2]

3. This document briefly introduces and summarizes the two studies that have been prepared in this context:

i) A review of the status and trends of invertebrate diversity in rice production systems. This study focuses on irrigated, rainfed lowland and upland rice production systems. Most of the analyses provided are based on data and information gathered in Asia.
ii) A second study, focusing on the state of knowledge and trends in the conservation and use of micro-organisms and invertebrates in cropping systems based on roots and tubers. The scope of this global study is limited to the major root and tuber crops, including cassava, potatoes, sweet potatoes, yams, cocoyams and aroids.

To the extent possible, both studies assess the diversity and abundance of the most relevant crop-associated organisms, focusing on soil organisms, biological control agents and pathogens. The complete version of the study on invertebrates in rice production systems is available as Background Study Paper 62.[3] The study related to root and tuber production systems is still in preparation due to time constraints. This document will be finalized for the Commission's Fourteenth Regular Session in April 2013.

II. BACKGROUND

4. Rice, roots and tubers are among the world's most important food crops. They are grown on all inhabited continents and are staple foods for more than half of the world's population. Asia is both the main producer of rice (90 percent of total world production) and of roots and tubers (40 percent). Levels of production and utilization of the different root and tuber crops vary significantly among regions and countries. While Europe accounts for approximately 80 percent of global potato production, China and Nigeria are the major producers of sweet potato and yam, respectively. In terms of consumption and utilization, the main roots and tubers in the different regions are: sweet potato for Asia, cassava in Sub-Saharan Africa and Latin America, and potato in the Near East and North Africa.

5. As world population grows and becomes increasingly urbanized, the demand for staple foods is also increasing. Rice demand in Asia is expected to grow by about 1 percent a year until 2025, while demand in West and Central Africa is currently growing at 6 percent a year. The demand for roots and tubers crops as sources of food, starch and feedstuffs, and as substrate for industry, is also steadily expanding, particularly in developing countries, where locally produced roots and tubers are often the main source of protein at reasonable cost.

6. The Green Revolution of the late 1960s led to a quantum leap in food production, bolstering world food security. World cereal production rose from 876 million tonnes in 1961 to more than 2.4 billion tonnes in 2010, an increase far in excess of population growth. However, the application of

[1] CGRFA-12/09/Report, paragraph 60.
[2] CGRFA-13/11/Report, paragraph 91.
[3] CGRFA Background Study Paper No. 62: Invertebrates in rice production systems: a status and trends review.

"Green Revolution production technologies", such as chemical fertilizer and synthetic pesticide, has in some cases severely depleted the natural resource base of agriculture and jeopardizes future productivity. Moreover, after 30 years of insecticide use in rice fields, there is no convincing evidence that farmers' yields have increased as a result.

7. With increasing pressures on land, water and labour resources, meeting the growing demand for staple foods such as rice and roots and tubers, while ensuring the sustainability of production systems, is a daunting task. The challenge facing policy makers is to find effective ways of scaling up sustainable agricultural practices and to prioritize sustainable crop production intensification, which aims at producing more from the same area of arable land, while conserving resources, reducing negative impacts on the environment and enhancing natural capital and the flow of ecosystem services.

III. MICRO-ORGANISMS AND INVERTEBRATES IN MAJOR CROP PRODUCTION SYSTEMS: STATE OF KNOWLEDGE AND TRENDS

8. Knowledge of the complexity and diversity of micro-organisms and invertebrates in major crop production systems is still limited. While those organisms clearly perform different and valuable functions that contribute to the delivery of essential ecosystem services, much remains to be understood: which organisms are present, what they do, and how they interact with each other and with their associated crop.

9. In rice fields and in root and tuber production systems, the contribution by micro-organisms and invertebrates to the delivery of regulating and supporting ecosystem services is particularly important. Through, *inter alia*, the decomposition of organic matter and their multiple roles in nutrient cycling, they maintain and promote soil health and fertility. As natural enemies of insect pests (or "biological control agents"), invertebrates, in particular, contribute significantly to the regulation of pests and diseases. In the absence of beneficial invertebrates, pest problems would be more severe, and successful crop production would be extremely difficult. However, there is evidence that beneficial invertebrates diversity in rice production systems is declining owing to the excessive use of synthetic pesticides.

Soil organisms

10. In general, the use of organic matter, mulch, manure and green manure, minimum tillage and less flooding, crop rotation, less pesticides and reasonable fertilization have a positive influence on soil organisms; conversely, monoculture, the over-use of pesticides, frequent and deep tillage, the burning of crop residues, and the fumigation, solarisation and compaction of soil have a negative influence on soil biota.

11. Organisms known as "ecosystem engineers" play a major role in creating, maintaining modifying and destroying the habitats that other species depend upon. By controlling the flow of energy and materials, they can profoundly affect the way an ecosystem functions. Ecosystem engineers include plants, animals and micro-organisms. In rice production systems, the dominant invertebrate ecosystem engineers are nematodes (roundworms), annelids (e.g. earthworms), arthropods (ants, termites) and molluscs. They affect soil properties positively and influence the availability of resources for other organisms, including micro-organisms and plants. However, how their impact on the soil modifies natural selection pressure on them and on other organisms has received little attention. Similarly, there has been no classification of ecosystem engineers by rice cultural type.

12. In root and tuber production systems, the bio-geographical distribution and the precise role of many soil organisms is still unknown, although the great diversity and abundance of microbial, plant and animal life in soil seems likely to influence ecosystem functions in various ways. Root crops have been associated with high diversity of arbuscular mycorrhizal fungi (AMF) with high colonization levels. Several studies have reported beneficial effects of AMF inoculation for micro-propagated root and tuber crops, including improved viability of potato plants during transfer from in vitro conditions, and increased potato and cassava yields and sizes. In vitro propagated yam is increasingly used to provide yam planting material to research centres, and increasingly to small- and large-scale

production systems in West Africa. AMF and Trichoderma are also believed to have great potential for use as organic fertilizer and biological control agents. However, intensive agricultural practices are known to lead to the loss of AMF.

13. Recently, Acidobacteria and Verrucomicrobia isolates were obtained from the rhizosphere of the potato. Knowledge of these two groups of micro-organisms and their roles in bio-geochemical cycles is limited, and both phyla are underrepresented in microbial culture collections. However, their abundance and diversity suggest their potentially great ecological importance. Environmental genomics has shown that Acidobacteria forms a coherent but highly diverse group with the capacity to utilize organic carbon. Acidobacteria are difficult to culture and only small quantities have been recovered from bulk soils.

Biological control agents

14. In the available literature, little information could be found on the diversity and abundance of natural enemies in the different rice and root and tuber production systems. In tropical irrigated rice, the invertebrate food web is highly complex. Most insect herbivores co-vary with the large complex of natural enemy species through a rich and intricate web of predators, parasitoids, parasites and detritivores that live in the plant canopy, on the water surface, in the paddy water, and on or in the water logged soil. Biological control in these food producing ecosystems involves many species, spans multiple trophic levels and acts along spatiotemporal gradients.

15. In 1996, a study of arthropod community structure dynamics in rice fields in north and central Java, revealed a very diverse natural enemy community in rice. Some 765 species of spiders and insects were catalogued, of which about 19 percent were detrivores and plankton feeders, 16.6 percent herbivores and 64.4 percent natural enemies (40 percent predators and 24.4 percent parasitoids). It became apparent that invertebrate species diversity is consistently lower in rice production systems that are under an intensive pesticide schedules than in traditional rice systems and in modern rice production systems where insecticide use is low.

16. It also became clear that natural enemies of insect pests are not only confined to rice fields. Non-rice crops in the rice environment enhance biological control of rice pests by providing shelter and supplementary and/or alternate food for natural enemies. The varied flora in and around rice fields creates a favorable environment for many invertebrates. Predators such as crickets and many parasitoids live in the non-rice habitats and visit rice fields in search of prey or hosts, while many arthropods occupy different habitats within the paddy ecosystem in different phases of their life cycle. Non-rice vegetation therefore plays an important role in maintaining invertebrate species diversity and in biological control of pests in the rice ecosystem.

17. Crop rotation and crop mosaics in the rice environment also promoted increased biodiversity. Multiple crops grown at the same time or in rotation stimulate a multitude of soil organisms, which not only help to control soil-borne pathogens and weeds, but also improve soil structure. important reservoirs of natural enemies include non-rice crops such as cowpea, mung bean, maize, bell pepper, garlic, onion and soybean.

18. For thousands of years, biological control of rice pests has been sustained through the conservation of invertebrates in rice fields. This stable, traditional system of “natural biological control”, relying on the conservation of natural enemies, has been disrupted over the past 50 years by Green Revolution technologies, including the application of modern insecticides, the switch to rice monocultures and the use of entire-area or “clean” cultivation. After experiencing four decades of pest outbreaks beginning in the 1970s, and investigating several different approaches to pest control (particularly chemical control and plant resistance), researchers now realize that maintaining a natural faunal balance in rice ecosystems, through the conservation of natural enemies, is crucial in avoiding serious pest outbreaks.

19. For field crops of short duration, such as rice, the conservation of indigenous natural enemies is clearly the best strategy. Only two rather insignificant cases are known where the introduction of exotic parasitoids has resulted in relative success in controlling a rice pest. In 1928, populations of the rice leaf folder (*Marasmia exigua*) in the Fiji Islands were apparently reduced by the introduction of

Trathala flavoorbitalis (Cameron) (Ichneumonidae) from Hawaii. In the 1930s, three parasitoids introduced from Asia helped to reduce infestations of the rice striped stem borer, Chilo suppressalis, in Hawaii. Several other attempts to introduce exotic parasitoids to control indigenous rice insect pests in South and Southeast Asia were unsuccessful. Such interventions are costly, of uncertain effectiveness, and do not appear to be an economic proposition in annual crops such as rice.

20. In the 1970s, classical biological control approaches were used together with breeding to combat major pests of cassava. The predator wasp, *Anagyrus lopezi*, was introduced to control the mealybug, and research was conducted on the control of cassava greenmite using predatory mites (*Typhlodromalus aripo* and *T. manihoti*) and, later, an acaropathogenic fungus (*Neozygites tanajoae*) from Brazil.

21. The microbial population in the rhizosphere of root and tuber crops is different from that of populations found in other bulk soil and also varies with plant type. Saprophytes such as Trichoderma and biotrophs such as microrrhizae, which may also grow into the root hairs, provide plants with inherent resistance to certain diseases. The interaction of micro-organisms in the rhizosphere, such as that between rhizobacteria and pathogens as well as preditor-prey interactions, also contribute to disease control. Enhancing micro-organism abundance and diversity in the rhizosphere of tubers may also contribute to controlling potato tuber rots.

22. In some soils, natural disease suppression can also be achieved by antagonists such as Pseudomonas. *Pseudomanas putida*, which is antagonistic to the soil-borne fungal pathogen *Verticillium dahlia*, has been isolated from the rhizosphere of potatoes. Within the rhizosphere soil, Pseudomonas (*P. Chlororaphis*, *P. fluorescens*, *P. putida* and *P. syringae*) and Serratia (*S. grimesii*, *S. Plymuthica* and *S. proteamaculans*) antagonized *Prectobacterium carotovorum* (Formerly *Erwinia carotovorum*) and *Verticillium dahlia* .

Herbivores

23. A large complex of invertebrate herbivores is active in rice production systems. However, data on their diversity and abundance are not available for specific rice production environments, with the exception of upland rice. A detailed review of current literature is needed to provide more information. To date, a total of 527 species of herbivorous invertebrates have been recorded, of which 96 percent are insects and the balance are mainly crabs, snails, nematodes and mites.

24. The literature indicates that herbivore diversity in Asia is twice that found in Africa, South and Central America and the Caribbean, and is nine times greater than that of the United States of America and Europe. This might be explained by the vast extent of Asia’s rice areas, in a variety of climates and floral regions, and by the greater number of rice cultural types grown. The fact that more intensive studies have been conducted in Asia than in the other regions could also be a factor.

Effects of human induced activities on crop-associated organism diversity

25. The excessive use of insecticides and nitrogen fertilizer is known to cause the loss of beneficial invertebrate abundance and diversity, leading serious outbreaks of plant hoppers and other pests, and to greater disease susceptibility of rice plants. Insecticides kill invertebrates indiscriminately, both in the crop canopy and in paddy water. Farmers in major rice producing countries are overusing nitrogen at an increasing rate[4] and several countries are known to be exceeding the insecticide application limit.[5] Both the average application of nitrogen fertilizer and of insecticide could be used as indicators of the stability and the health status of a production system and to determine areas at high risk of invertebrate diversity loss and plant hopper outbreaks.

26. FAO and IRRI have been promoting sound pest management practices since the 1980s, through intensive farmer field schools and “farmer participatory research”. Such programmes have

[4] Use of nitrogen fertilizer >100 kg N/ha

[5] From the insecticide use pattern and the history of plant hopper outbreaks, it appears that three or more applications per season reduce invertebrate diversity and pest regulatory services sufficiently to trigger plant hopper outbreaks.

contributed to correcting farmers' misperceptions about the need to control pests with insecticide. They have also encouraged countries such as India, the Philippines and Indonesia to develop national Integrated Pest Management (IPM) policies. In Indonesia, a policy shift in the mid-1980s in favour of IPM led to the banning of 57 pesticides in rice and a reduction in pesticide imports of two-thirds. However, despite several large-scale IPM training schemes for farmers conducted for more than two decades, insecticide misuse and the overuse of nitrogen fertilizer is increasing. In most Asian countries pesticides are being sold using fast moving customer goods (FMCG) marketing strategies. The marketing of pesticides is driven by aggressive advertising which uses emotional appeals to conquer Asian rice farmers. The developed world has regulations to curb and limit the misuse of pesticides, but these are absent in most Asian countries.

27. Crop varietal diversity also plays an important role in minimizing the risk against insect pest and disease outbreaks: if one variety succumbs to a pest outbreak, farmers can still produce food using other varieties. However, studies have yet to investigate the effects of crop varietal diversity on the diversity and abundance of rice invertebrates.

IV. MAIN KNOWLEDGE GAPS AND POSSIBLE FUTURE RESEARCH

28. A major research effort is needed to assess the importance of micro-organism and invertebrate diversity and abundance in the delivery of supporting and regulating ecosystem services, in both rice and root and tuber farming systems. This will facilitate the conservation and optimal use of micro-organisms and invertebrates to the benefit of stable, healthy and sustainable production systems.

29. The abundance, the diversity and the functions of micro-organisms and invertebrates are only partially understood in tropical irrigated rice environments. Similar research in sub-tropical irrigated rice environments of Asia and in major rice-growing areas in Africa and Latin America is still lacking. Extensive research work is needed to identify soil organisms, biological control agents and pathogens that are associated with the various root and tuber crops. In particular, the symbiotic relationships between soil organisms and the different crop varieties need to be fully understood, in light of the potential contribution of these organisms in pest and disease control.

30. In any research on biodiversity, accurate and reliable taxonomic identification is essential. Taxonomic expertise and facilities are virtually absent in most major rice producing countries. In the future, taxonomists could make a valuable contribution to biodiversity research through remote microscopy connectivity.

31. Irrigated rice accounts for some 24 to 30 percent of the world's total freshwater withdrawals. With increasing shortages of irrigation water and global warming, aerobic rice cropping and rice cropping under wet and dry conditions are likely to increase. However, little is known about the diversity, abundance and the functions of crop-associated organisms under such cropping conditions. To prepare for future challenges, knowledge in this area needs to be strengthened. Analysing rice cropping systems where rice is already grown under alternate wet and dry conditions, such as in the Zanghe Irrigation System in the Yangtze River Basin of China, would be a good starting point for building up such knowledge.

32. The adoption of an IPM policy in Indonesia in the mid 1980s saved the Indonesian government more than US$100 million per year in pesticide imports. A recent study of Vietnam's "Three Reductions, Three Grains" programme, aimed at motivating farmers to reduce seed rates, fertilizer rates and pesticide applications, estimated a saving of US$57 per ha. Studies quantifying the contribution of micro-organism and invertebrate diversity to the livelihoods of farmers through, for example, reduced health-related costs, could contribute to further promoting sound pest management practices.

33. Private seed companies claim that hybrid rice increases yields by 15 to 20 percent over inbred varieties. However, farmers of hybrid rice apply much higher rates of nitrogen fertilizer and insecticide than those of inbred high yielding varieties. A cost-benefit analysis of hybrid rice production at farmer, consumer and environment levels could demonstrate whether the replacement of inbred by hybrid varieties is truly beneficial.

34. In root and tuber production systems, in particular, the control of soil-borne diseases, nutrient availability to plants and soil structure formation could be enhanced through the application of inoculants. Genetic markers facilitate the study of inoculants in the soil and molecular techniques are useful in studying the genetic potential in microbial cells for adapting to the prevailing conditions in bulk soil and the rhizosphere. However, for the successful application of inoculants in root and tuber production systems, greater knowledge of their ecology is needed.

35. Large-scale irrigation, crop intensification, the narrowing of genetic diversity and the misuse of chemical inputs, have all contributed to weakening “natural” pest regulatory service found in traditional crop production systems, and led upsurges of secondary pests and widespread pest and disease outbreaks. These conditions can and should be reversed to make local crop production environments less favourable to pests and more favourable to pests’ natural enemies. That can be achieved by re-establishing strong linkages between pests and their natural enemies through ‘ecological engineering’.

36. Ecological engineering is a new approach that aims at maximizing natural biological control and reducing unnecessary insecticide applications. The main principle of this approach is that any modification of the environment should be based on ecological principles. Ecological engineering is a particularly useful conceptual framework for arthropod pest management through habitat manipulation, such as planting nectar-rich flowering plants (e.g. sesame) on rice bunds to attract parasitoids. Ecological engineering contributes to the conservation of natural enemies by offering shelter and supplementary and/or complementary food. Future research on insect pest management in rice, and also in other crops, should take such approaches into consideration.

37. FAO is supporting in Cambodia and Lao PDR the development of a licensing and inspection system for the pesticide retail sector. The outcomes of this project could help to strengthen similar systems in other countries in Asia and elsewhere. FAO is also developing various specifications and guidelines to assist countries in the implementation of the International Code of Conduct on Distribution and Use of Pesticides. FAO’s Regional Office for Asia and the Pacific has developed five operational guidelines to promote regulatory pesticide management among member countries of the Association of Southeast Asian Nations. This has lead to the preparation of country action plans to enhance regulatory management of pesticides in the subregion.

38. At present, data on the possible responses of micro-organism and invertebrate communities to global warming are limited. However, studies do indicate flexibility inherent within species, including those of the micro-organism and invertebrate communities. Some researchers speculate that higher temperatures are likely to shorten the life cycles of pests, enabling an additional generation to occur in a crop season and increasing the risk of crop loss. However, higher temperatures may also shorten the duration of crop growth, counter balancing their effect on pest life cycles. Because species do not encounter global warming in isolation, community-level or ecosystem-level responses to the changes should be investigated.

V. GUIDANCE SOUGHT

39. The Working Group may wish to recommend that the Commission:

a) Welcome the studies, *Invertebrates in rice production systems: a status and trends review*, and, *The conservation and use of micro-organisms and invertebrates in integrated root and tuber production systems: state of knowledge, trends and future prospects*;

b) Reiterate the importance of microbial and invertebrate diversity for sustainable crop production and for food and nutrition security, particularly in the light of global environmental and health challenges.

c) Request FAO to:
   i) undertake similar studies for other major food crops, such as wheat and maize with a special emphasis on good agricultural practices favouring delivery of ecosystem services by beneficial micro-organisms and invertebrates, upon the availability of funds; and
   ii) address the contribution of micro-organisms and invertebrates to the delivery of ecosystem services for food and agriculture in *The State of the World's Biodiversity for Food and Agriculture*, when relevant.