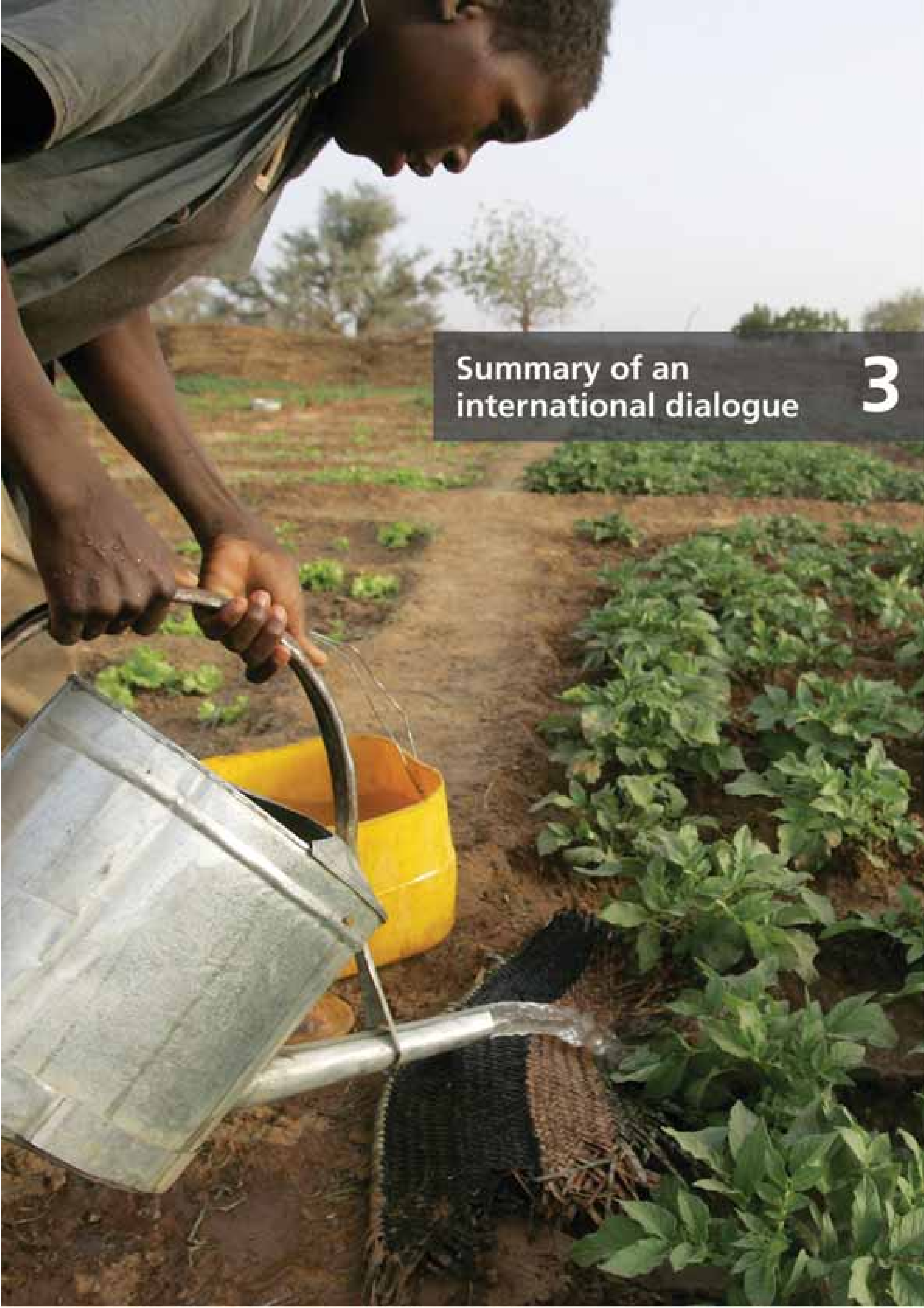

Summary of an international dialogue

3

EXECUTIVE SUMMARY

The availability of water is a challenge for all countries, but especially for those with scarce water resources and where the livelihoods of its people depend heavily on agriculture. The term 'biotechnology' includes a broad suite of tools that present varying degrees of technical sophistication and require different levels of capital input. A number of them can be used to mitigate water scarcity in agriculture, including a variety of plant biotechnologies, e.g. marker-assisted selection (MAS), and microbial biotechnologies, e.g. use of mycorrhizal fungi as a biofertilizer. Many examples of applications of biotechnology in developing countries were cited during this FAO e-mail conference. There was a general consensus that biotechnology has a valuable role to play in addressing the challenge of water scarcity in developing countries, although opinions differed on the relevance of different biotechnology tools. Despite much promising research and significant possibilities, the conference also indicated that many applications of biotechnology in this area have not yet met their full potential to deliver practical solutions to the end-user in developing countries.

Among the different plant biotechnologies, MAS and genetic modification elicited most discussion. Although the general opinion of participants was that MAS had significant potential, some underlined the obstacles to its practical application in developing countries, such as the relatively high costs of breeding using molecular markers and the complexity of traits involved in drought resistance and water use efficiency in plants. For genetic modification, promising research results were reported but many participants expressed doubts about the role of genetically modified crops in helping developing countries to cope with water scarcity, referring to the kinds of obstacles also relevant to MAS (costs, complexity of the traits to be improved etc.) as well as to a number of additional concerns, such as intellectual property rights issues and potential environmental impacts.

To ensure that research initiatives to develop drought resistant crops are successful and that the resulting products actually reach the farmers, participants called for increased collaboration between researchers in different disciplines and for all relevant stakeholders to be involved in the design of solutions to the problems of water scarcity in agriculture. Research should not neglect dryland (non-irrigated) agriculture. The role of the Consultative Group on International Agricultural Research (CGIAR), a strategic partnership supporting the work of 15 international centres, in developing drought resistance crops was emphasized.

A positive outlook was foreseen for microbial biotechnologies in managing water scarcity. Participants described the potential of applying mycorrhizal fungi and certain bacteria as a biofertilizer to assist plants to cope with water stress, calling for greater research in this area. Several applications of biotechnology were reported as playing a useful role in treating wastewater, mainly on a small scale, involving the use of plants and microbes, so that it could be re-used for agricultural purposes. Participants also discussed the potential to design biotechnology-based wastewater treatment systems in such a way that they yield co-products (e.g. biogas) that could be used to generate income locally.

INTRODUCTION

The aim of this chapter is to provide a summary of the main arguments and issues discussed during the conference, based on the participants' messages. During the 4-week conference, a total of 78 messages were posted, each one numbered in order of posting. Specific references to messages posted, giving the participant's surname and message number, are provided here. All of the messages can be viewed at www.fao.org/biotech/logs/c14logs.htm. Note, in the Forum, participants are always assumed to be speaking on their own personal behalf and not on behalf of their employers, unless they state otherwise.

More than 400 people subscribed to the conference and the 78 messages were posted from 50 people living in 24 different countries; 75% of messages were from developing countries. Roughly 70% of messages came from people working in universities and in national or international research organizations, while the remainder came from people working as private consultants or in private companies, non-governmental organizations (NGOs), government ministries or UN organizations/projects.

Most participants directed their messages to the technical challenges associated with applying different biotechnology tools to address water scarcity in agriculture. Some discussed the application of biotechnology to develop drought tolerant crops, others with the aim to make more water available to crops through symbiotic associations with soil micro-organisms. A number of participants addressed the potential for biotechnology to treat wastewater for re-use in agriculture. Some participants addressed their remarks to the appropriateness of different biotechnology tools to confront the problem, in the context of other approaches or potential solutions. The challenge of delivering effective biotechnology-based solutions to the end-user in the field was discussed. Participants also addressed cross-sectoral issues, such as resource availability, constraints and international collaboration. Most of the discussion, however, centred on technical issues. There was considerable agreement among the participants that the suite of biotechnology tools currently available holds much promise to address the challenge of water scarcity in agriculture in developing countries, although opinions differed on the merits of individual biotechnologies.

Discussions in the conference are summarized here under three main subjects: applications of biotechnology to develop crops with improved drought resistance or water use efficiency; the use of mycorrhizal fungi and bacteria as a biofertilizer; and the use of biotechnology in wastewater treatment. The chapter concludes with information on participation as well as a list of names and countries of the people whose messages are referenced.

CROPS WITH INCREASED DROUGHT RESISTANCE OR WATER USE EFFICIENCY

Conference participants were acutely aware of the importance, as well as the challenges involved, in endeavouring to develop crops that are better able to cope with water scarcity in agriculture. For Murphy (71), the most serious threat to future food production will come from aridification, rather than temperature change, and the wise and selective application of our increased scientific knowledge of crop breeding and agronomy will "largely determine whether our agricultural systems can weather future episodes of widespread and prolonged aridity".

A number of different biotechnologies can be used to produce crops that are better able to cope with water scarcity in agriculture. Most discussion was dedicated to MAS and genetic modification with a few messages also dedicated to other crop biotechnologies. [Note, more detailed information on MAS can be found in a comprehensive book recently dedicated to this technology (FAO, 2007b)]. The issue of how to deliver real solutions to farmers was also considered as well as the role of the CGIAR.

Marker-assisted selection

Prakash (72) highlighted that MAS had been successfully used in agriculture for many years and its key advantage was the shorter time taken to introduce desired traits. Boopathi (2) believed that MAS could increase the productivity of crops in fragile environments, but he also highlighted a number of challenges to its use, including those related to experimental design and statistical models used for quantitative trait locus (QTL) analysis, an issue also raised by Manneh (40). Gupta (14, 25) gave some assistance on this and drew attention to a number of computer programmes that can be used for QTL analysis. Kumar (18), however, cautioned that before using any software in this area, one should carefully examine the methodology employed.

Agbicodo (45) maintained that with MAS for yield under water stress, two main issues had to be considered. The first was to select a trait that could be measured with reasonable accuracy to first establish the linkage with specific molecular markers (where the trait could be grain yield and its components and/or a specific physiological or morphological trait). The second was to choose the kind of markers to be used for genotyping. Kumar (18, 23) reported on their work in India carried out on drought tolerance in pearl millet which had shown that terminal drought tolerance is the major factor for yield determination under drought-prone rainfed conditions of the semi-arid tropics. Lin (34) pointed to research showing, similarly, that the timing of drought had a significant impact on yield and commented that the division of drought according to time (pre-flowering, flowering and terminal drought), and its effects on yield components, highlights the complexity of breeding for drought resistance. He maintained that if, for a particular crop in a certain region, it is known that drought stress is most prevalent during a certain stage of crop development, then attention could be focused on QTL mapping for drought-related physiological traits at that stage of crop development.

Manneh (40) pointed out that significant genetic variation for drought tolerance at different developmental stages of rice had been reported by several researchers. He commented that although QTLs had been reported for some traits associated with drought tolerance (deep and thick roots, good osmotic adjustment etc.), not much success had been achieved in developing drought tolerant rice cultivars through MAS. He noted that many MAS research activities usually focus on introgressing a gene (or genes) for one trait at a time, even though the incidence of drought is highly unpredictable and the effects of drought stress on rice depend on the developmental stage at which the stress occurs, and so different gene complexes are involved. He therefore suggested that MAS for drought tolerance might require pyramiding appropriate alleles of different genes controlling traits that contribute to drought tolerance occurring at different developmental stages.

While comments about MAS were generally positive, Samanta (65) noted that high-tech molecular breeding is costly for developing countries and, instead, advocated that the existing genetic diversity for drought tolerance be evaluated by screening large numbers of genotypes under the specific environment where the variety would be cultivated. Gupta (78) agreed, suggesting that "expensive techniques of molecular biology should be used only when there is no substitute". Dulieu (55) doubted whether the large number of crop species used for human consumption in arid and semi-arid regions could be rapidly improved with the help of molecular mapping, considering that there is comparatively little financial support to achieve the goal by this means. He, supported by Boopathi (58), noted that plant breeding for drought resistance could also be carried out successfully without molecular markers and he proposed a rough strategy for crops where no molecular data existed that would allow the rapid selection of varieties able to survive and yield in water-limited conditions. In this context, Samanta (65) described the successful use of a local drought tolerant rice variety developed by traditional selection in West Bengal in India. Babu (48) argued that large-scale, field-based phenotyping under the target ecosystem for drought stress was critical for transferring drought tolerant lines to the farmer, and lamented the dearth of published literature in this area.

Rakotonjanahary (70) commented that while MAS tools have considerable potential to improve the efficiency of water use in crops, drought tolerance is a very complex trait and the application of MAS in developing countries has many bottlenecks, both technical and practical (costs, infrastructure required etc.). Ashton (67) argued that while advanced breeding techniques like MAS might offer some solutions, more readily affordable and available methods should be preferred.

Genetic modification

Prakash (72) reported that plant biotechnology had a good track-record in providing benefits to farmers in developing countries and that, even though most of the current genetically modified (GM) crops were developed by the private sector in industrialized countries, 90% of farmers using them were in developing countries. He also said that the private sector was actively developing technology to deliver drought tolerance in crops and, although not intended to result in crops grown under extreme desert conditions, their promising results led him to believe that this area should have some priority among technologies being developed to mitigate drought conditions in developing countries.

Participants discussed the technical feasibility of using genetic modification to create crops with enhanced drought tolerance. Venkateswarlu (42) reported on their ongoing research in India to produce GM crops with enhanced tolerance to abiotic stresses, where genes responsible for osmotic adjustment had been introduced successfully to sorghum and where similar work had been initiated on blackgram and greengram. Mundembe (44) was encouraged by the message of Venkateswarlu (42) and highlighted the ability of 'resurrection plants' (discussed in chapter 2) to tolerate near-total water loss in their vegetative tissues and revive to full physiological activity on re-hydration. He expressed the hope that it would be possible to develop crops with some of these traits. Lin (50) added that several groups worldwide were working on resurrection plants and drew attention to the work of one such group on *Xerophyta viscosa*, a native of Southern Africa, where several genes of interest had been isolated and transformation of maize plants was underway, inserting the ALDRXV4 gene, which in model plants conferred significant tolerance to severe osmotic and salt stresses.

In light of the discussion on MAS, which highlighted the complexity of the genetics of drought tolerance or water use efficiency, Kumar (23) raised a query about transgenic plants developed with a single gene, questioning how one such gene, like the erecta gene (also discussed in chapter 2), could exert control over the entire physiological process of water use efficiency or the pathway of genes involved. Murphy (73) also cited the promising research results on the erecta gene, isolated in the model plant *Arabidopsis*, but argued that although this approach merits further attention, many other genes might be involved in a practical field situation.

Murphy (73) commented that although much mention had been made of the potential of genetic modification to improve drought tolerance in crops in developing countries, limited knowledge of stress-associated metabolism in plants still constituted a significant handicap to this in practice. He also argued that it is often the combination of different stresses that negatively impacts crop performance, and because the co-presence of several stresses is the norm in the field, "the success of a molecular approach to stress remediation in crops will require a broader and more holistic approach than we have seen hitherto". To support this, he drew a comparison with salt tolerance (an osmotic stress, closely related to drought stress) and noted that attempts to improve salt tolerance through genetic modification (or conventional breeding) had so far met with very limited success, largely due to the complexity of the trait. Similarly, El-Tayeb (57) argued that GM crops for drought tolerance and other environmental stresses are not likely to be available in the foreseeable future because of their complexity and "our extremely limited knowledge of biological systems and how genetic/metabolic functions operate".

Several participants argued that alternatives to genetic modification should be used. Seshadri (54) was concerned about developing GM drought tolerant crops, arguing that they were just causing greater problems for the agricultural community, and proposed instead a list of 13 alternative technologies and strategies such as the use of biofertilizers, mulching and use of crop species that demand less water. Oehler (56) agreed, arguing that genetic modification was an extremely expensive means to deal with water scarcity, and she too advocated use of alternative solutions. Dulieu (63) also agreed with Seshadri (54), raising, among others, concerns about ownership of the genetic resources by the international corporations and about transgene flow. Ferry (64) also agreed, arguing that many better alternatives exist and that "genetic modification to introduce genes to improve drought resistance seems to me much more another hype for the biotechnology sector to get funds". Varghese (66) supported Oehler (56), highlighting in particular concerns about the safety of GM crops. Ashton (67) agreed with Seshadri (54) and said genetic modification was a "questionable option" in this case, given his appraisal of its costs and benefits. Okoli (69), echoing Muralidharan (60), advocated use of proven traditional biotechnologies rather than putting "the major share of the strategies on modern biotechnology and expect miracles to happen". Murphy (71, 73) argued that the present methods of genetic modification were still too primitive to contribute significantly, mainly because traits such as drought tolerance are highly complex and regulated by many genes, but maintained that non-GMO biotechnologies such as MAS could be useful. Echoing concerns also raised by Nasar (1) and El-Tayeb (57), Murphy (71) added that a drawback of most transgenic technologies is their ownership by the private sector, which can limit public-good applications. On the other hand, Prakash (72) noted that plant biotechnology is just one of many approaches to address water scarcity, and said that different approaches should be considered as complimentary, rather than as alternatives.

Other crop biotechnologies

Murphy (73) noted that another option to introduce drought tolerance was to use wide crossing and tissue culture methods, for example, to cross drought tolerant pearl millet with one of the other high-yielding cereal crop species, to create a new drought tolerant, high-yielding hybrid species. He pointed to the success of a similar strategy in creating the new rye/wheat hybrid species, triticale. Liu (28) also highlighted the success of the hybrid New Rice for Africa (NERICA), developed using embryo rescue and anther culture techniques, which "produces more than 50% more grain than current varieties when cultivated in traditional rainfed systems without fertiliser". Dulieu (55) raised the issue of mutation breeding, noting that the available pool of genetic variability can be enlarged by mutagenesis, and low cost screening can be applied to identify plants with desirable traits. Rakotonjanahary (70) supported this and reported on their work on mutation breeding in Madagascar to generate drought resistant lines in rice, groundnut and bambara nut. Shanker (68) argued that genomics tools had already provided a wealth of data and better understanding of the changes in cellular metabolism that are induced by abiotic stresses, although fewer results had been forthcoming with respect to the functioning of the whole plant. Combined with tools such as bioinformatics, allele mining and proteomics, he saw that "it will be possible to rationally manipulate and optimize tolerance traits for improved crop productivity well into the twenty-first century".

Delivering practical solutions to the farmers

To develop new successful varieties in this technically difficult area, participants said that researchers needed to collaborate across disciplines (e.g. Dulieu, 55; Murphy, 71; Prakash, 72). Krishna (35) suggested that in breeding crop varieties to grow in water-limited conditions, a major thrust should be directed to the development of varieties with high water-use efficiency, either through conventional breeding or with the aid of molecular techniques. She advised that in taking this approach, "a multi-disciplinary team consisting of molecular biologists, plant physiologists, geneticists, plant breeders and agronomists can deliver the product in a much more effective way than solely by the molecular biologists/breeders". Similarly, Nicolay (41) warned that a lack of cooperation between plant breeders and biotechnologists would lead to missed opportunities.

To develop new varieties, across-country collaboration and within-country capacity building may also be important. Primo (12) pointed that out in a small country such as hers, the Federated States of Micronesia, there might not be sufficient science and technology expertise to do the research in-country so partnerships and technology transfer would be crucial. Omari (22) and Rivasplata Maldonado (49) also underlined the importance of building the capacity of scientists in developing countries to take advantage of biotechnologies that can assist with water scarcity.

However, the successful development of drought tolerant varieties by good research initiatives is not the final goal in itself. After they have been developed, they should be used, but in practice there may be problems in reaching the farmers (Lin, 62). For example, Paul (17) wrote "India can boast of a highly technical and extensive agricultural research system with accomplished scientists and managers. But, somehow or other, the gains of research and development are not percolating down to the people in general". Ultimately, as pointed out by Shanker (68), the value of any genes or pathways for drought tolerance in crops can only be judged by their eventual performance in the field. The topic of how to ensure that results from the research laboratory lead to practical implementation in the field was also discussed in the conference.

Nicolay (41) emphasized that the bottom-line should be the delivery of sustainable and widely accepted services, products and approaches, and added that all relevant stakeholders should participate in the design of solutions. Referring to discussions in Conferences 8 and 12 of the Forum (FAO, 2006a), on the role of biotechnology in the agricultural research agenda and on public participation in decision-making regarding GMOs respectively, he suggested that if stakeholders such as farmers, consumers and local politicians were not involved in developing solutions to water scarcity in agriculture then they might not be implemented in practice. In a similar vein, Tchouaffé (47) commented that community leaders, local authorities and NGOs each had an important role to play in technology transfer and he stressed the importance of encompassing all stakeholders and establishing partnerships between public and private sectors to develop solutions that would be "efficient and economically viable, but also socially acceptable". In designing solutions, Nicolay (41) advocated using an holistic approach that, he argued, would help to close the gap between science, research and development on one side and "a rather confused society dealing with highly complex but existential issues" on the other. Sahoo (46), furthermore, asked "how can biotechnology be made popular among the farmers in developing countries where they are still guided by traditional customs and norms?" and cautioned that without addressing this issue, the success of an external agency introducing biotechnology-based solutions was doubtful.

Nicolay (61), returning to the question of how biotechnologies could best be implemented for practical solutions, emphasized that biotechnology could best play a role if it is accepted that it is only a part of the solution, and that institutions and the people involved constituted another part. Lin (62) highlighted the need to involve the private sector, arguing that public-private partnerships are a vital means to ensure that improved varieties will reach farmers who need them. Prakash (72) supported Nicolay (41, 61) and Lin (62), urging that once solutions have been identified, there is a need for stakeholders to form partnerships to evaluate them for different local contexts and to ensure that they are accessible, affordable and appropriately used.

Which kinds of farmers should be targeted by this research? Krishna (3) felt that dryland farmers were being unduly neglected. She argued that biotechnologies, such as MAS, were being used extensively in improving water use efficiency in irrigated or commercial crops, albeit without major success so far, but that greater attention should be given to dryland agriculture. The importance of focusing on dryland agriculture was also highlighted by Varghese (66) and Di Ciero (4), who mentioned in particular the small, poor farmers in the northeast of her country, Brazil. Several participants also highlighted the importance of a number of non-biotechnology approaches, such as mulching, to save water in dryland agriculture (e.g. Peter, 5; Tchouaffé, 6; Sangaré, 11; Paul, 17; Achakzai, 26; Liu, 28; Okoli, 69).

Role of the CGIAR

Abdel-Mawgood (37) highlighted the role that international research centres can play in providing help to developing countries to develop their own crops that are tolerant to abiotic stresses, urging that they should play a more substantial role in making breeding materials and genetic constructs readily available for researchers in developing countries. Lin (62) pointed out that the CGIAR has 22 mandated crops, where increased drought resistance is a breeding goal in all of them, and that for most of these crops, sources of enhanced drought tolerance had been identified, and several varieties had been released for evaluation by researchers and farmers. Some examples of this kind of research carried out at two of the CGIAR centres, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the Africa Rice Center (WARDA), were provided by Kumar (18, 23) and Manneh (40) respectively. Lin (62) added, however, that a bottleneck exists in getting the released varieties to the farmers, because the CGIAR centres have no mandate to produce basic or certified seed for distribution, and state actors in many countries are unable to provide these services effectively. Murphy (71) advised that the scarce resources of organizations such as the CGIAR should be focused on the proven approaches of conventional breeding, supplemented by all available modern technologies, providing the latter are both appropriate and cost-effective for the crop or region in question.

USE OF MYCORRHIZAL FUNGI AND BACTERIA IN WATER-LIMITED CONDITIONS

Mycorrhizal fungi and bacteria can be applied as a biofertilizer with the aim of increasing growth and improving water uptake. Several participants raised this issue as one effective way that biotechnology might be applied to improve the efficiency of water use in agriculture (e.g. Krishna, 36; Venkateswarlu, 42; Nasar, 76), and there was a general call for greater research in this area. For example, Ashton (67) felt that the use of microbial inoculants in the soil was "perhaps one of the most exciting possibilities offered by microbiology towards reducing drought impacts on plants" but cautioned that this, like other solutions, cannot be analysed in isolation. Benefits, however, are not guaranteed, and participants reported that technical challenges to their use as a biofertilizer persist. Questions were also raised about access to the technology for farmers in developing countries.

Nasar (1) said that their results of farmer-participatory experiments over several years in India had shown that the use of microbial fertilizers in combination with organic compost reduced the amount of irrigation water required; lowered the amount of diseases and pests; improved crop productivity and quality; and improved the water-holding capacity of the soil. Lin (10) similarly highlighted various studies on the effectiveness of mycorrhizal fungi as a biofertilizer. Oehler (8) noted from her study of the literature that ectomycorrhizae are often involved in acquiring water and nutrients from microenvironments in the soil that are unaccessible to plant roots because of physical or chemical restrictions. She argued, however, that the inoculation of plants with desired strains was difficult and resource-intensive. Regarding the challenge of inoculation, Venkateswarlu (53) pointed out that the cropping systems could be organized in such a way that one of the crops in the sequence might be highly mycorrhizal dependent, so that naturally the mycorrhizal fungal population in the field would increase substantially without any inoculation.

Some participants raised the point that the efficiency of water uptake by plants aided by mycorrhizal fungi can be enhanced in the presence of other organisms and agents. For example, Krishna (36) noted that the application of mycorrhizal fungi can help increase the efficiency of water use, "especially when applied together with other beneficial micro-organisms such as Rhizobium, plant growth promoting rhizobacteria and phosphate solubilising bacteria or when combined with cheap sources of phosphorus such as rock phosphate".

Edema (43) was cautious, stating that a lot more work needed to be done to confirm the value of mycorrhizal fungi as a biofertilizer in helping developing countries to cope with water scarcity, indicating that some scientific studies had shown that, alone, they were not as efficient as believed. Gupta (14) acknowledged that a lot of research had been undertaken or was underway on the use of mycorrhizal fungi, but wondered whether there were examples of large-scale commercial use of this technology by farmers in the field. Morris (51) felt that the technology was being used more and more by larger commercial farmers with access to relatively short production distribution chains but noted the challenge of transferring the benefits to small farmers in rural areas in developing countries as many inoculant products have a relatively short shelf life or require stringent storage conditions that are often unavailable in these areas. He hoped that with advances in production and packaging it might be possible to increase the shelf life and tolerance of these products to sub-optimal storage conditions. As Venkateswarlu (53) summed it up: "ultimately, we need simple low cost approaches based on microbes, which farmers in developing countries can adopt."

Richardson (59) suggested that application of 'compost tea' (high in bacteria and fungi) had shown remarkable improvement on expansive grey clay soils, increasing friability, water intake, and productivity of many species of perennial grasses. He cautioned, however, that if the soil is degraded by erosion or poor management, several applications over several seasons may be necessary before the system becomes self-maintaining. Morris (51) reported that inoculation of crop roots with selected strains of *Trichoderma harzianum*, a fungus commercially produced as a biocontrol agent, can result in significantly larger root systems, many more root hairs and thereby more efficient nutrient and water uptake. Venkateswarlu (53) stated that although soil micro-organisms are generally known to be involved in nutrient transformation, their role in improving the fitness of plants in stress situations is now coming to light. Venkateswarlu (42) reported on their ongoing work on isolating rhizosphere micro-organisms that can improve soil aggregation when inoculated into the root zone, where they form a biofilm around the roots and significantly influence the water relations of the plant when subjected to water stress.

Gueye (16) discussed the role of rhizobia bacteria and argued that a lot of research supports the view that nodulation and nitrogen fixation activity in nodules were depressed in plants under drought conditions, but that no effect of water stress had been observed in plants inoculated with selected rhizobial strains. He added that nodulation and nitrogen fixation under water stress conditions depend not only on the plant species, but also on the selected rhizobial strains, and that suitable strains for use as inoculants are available in most microbiological resource centres devoted to rhizobial culture collections, in Brazil, Kenya and Senegal. He concluded that agricultural biotechnology should be focused on selection of specific rhizobial strains to maximize the process of biological nitrogen fixation to sustain agriculture in arid and semi-arid zones. Bhattacharyya (19) reported on the successful dual inoculation of pea plants with rhizobia and mycorrhizal fungi in desert soil in India.

BIOTECHNOLOGY IN WASTEWATER TREATMENT

Participants highlighted that an important way in which farmers cope with water scarcity in developing countries is the recycling of wastewater. The treatment of wastewater before use, although this in itself presents significant challenges, is crucial for human health and environmental considerations. This issue was raised early in the conference. Several applications of biotechnology were noted to have a useful role to play in wastewater treatment, including the use of plants and microbes.

Lin (9) drew attention to two ways in which biotechnology can contribute to improved water treatment - the development of biosensors for the detection of heavy metals, herbicides and other contaminants in water, and the development of biofilters to remove contaminants, such as heavy metals, from water. He reported that biofilters had been developed using the dry matter of the Azolla fern (a free-floating aquatic fern well-known for its capacity to absorb heavy metals) and that research was ongoing to use cyanobacteria (also known to be capable of absorbing heavy metals) in biofilters. Arora (20) agreed with Lin (9) and reported that her institute in India was working on using Azolla and algae for the removal of heavy metals, as well as nitrogen and phosphorus, to render wastewater safe for re-use in agriculture.

Okoli (27) supported such initiatives and reported on their research on indigenous plants in south east Nigeria to develop a simple method of bio-based treatment for wastewater, so that it would be suitable for livestock to drink. Both he and Van Milligen (24) mentioned use of the moringa tree for phytoremediation purposes and Bett (38) described the positive results from her project in Kenya using crushed seeds of the moringa tree to purify rainwater for household use. Rao (39), similarly, described the use of ground seeds of the tree *Strychnos potatorum* in rural Andhra Pradesh, India, to flocculate suspended matter, but noted that although these seeds, and seeds or wood paste of the moringa tree, can be used to clarify small amounts of water for domestic use, they are impractical for use on a larger scale. Similarly, Agarwal (52), while noting that small-scale farmers would like to treat wastewater and use it for their crops, was doubtful whether it would be possible for anything other than limited application, such as small kitchen gardens for growing vegetables.

Rivasplata Maldonado (49) noted that there were serious risks associated with use of wastewater without treatment. Omari (22) noted that the use of untreated water in Ghana to water vegetables was on the increase and argued that there was therefore an "urgent need to consider putting structures in place to treat wastewater used for irrigation purposes". She warned, however, that if not treated properly, use of wastewater could compromise water safety as the microbiological safety of treated wastewater was also a major concern. She called for more research on the biology of treated wastewater and the appropriate biotechnology tools that could eliminate harmful pathogens it might contain.

Nasar (1, 75), like Sharma (32), pointed out that arsenic contamination of the groundwater-irrigation water-soil-crop-animal-human continuum was a major concern. Nasar (75) noted that a number of weedy flowering and non-flowering plant species, crop varieties and cyanobacteria that absorb high levels of arsenic had been recorded and they were working to identify location-specific hyperaccumulators in West Bengal, India, for use in bioremediation of contaminated soils. He was, however, aware of the problems associated with this technology, such as the need for appropriate disposal after-use of the hyperaccumulating organisms, or the filtrates where arsenic filters have been used, to prevent toxic arsenic returning to the ecosystem. He was hopeful about the prospects of using genetic modification to develop organisms that could sequester heavy metals, but advised that at present the focus of developing countries ought to be on non-GMO options. Edema (43) said that biotechnology is playing, and will continue to play, a role in the efficient management of water resources in general and wastewater treatment in particular. Regarding removal of heavy metals from water, he noted that "there are many organisms that are able to degrade toxic materials and the application of biotechnology to improve their efficiencies holds a very promising future for water resources management and agricultural biotechnology".

Some participants highlighted the potential to design biotechnology-based wastewater treatment systems in such a way that they also yield co-products, such as oils, fertiliser and biogas, leading to the development of business opportunities. Van Milligen (24) pointed out that specifically crafted algae and other species can extract nutrients from polluted water, and not only clean it significantly, but also provide fuel, feed or fertiliser as a result. Rivasplata Maldonado (49) commented that anaerobic biotechnology can be applied in developing countries, since anaerobic wastewater treatments systems are relatively cheap and easy to handle. She remarked that upflow anaerobic sludge blanket reactors can help to reduce the organic load; are well adapted to tropical weather; do not require large amounts of energy; and generate biogas (that can be used e.g. for heating or cooking). The sludge produced can be used for re-inoculation or as fertiliser and the treated wastewater can be used to irrigate crops. She suggested that these co-products could be used to generate an income locally.

Omari (22) pointed to successes in the Netherlands in developing a bio-based water treatment system for vegetable processing facilities that had reportedly reduced water use by 50%, and in Germany, where an enzyme-based system for de-gumming of vegetable oil during purification after extraction had reportedly reduced water use by 92% and waste sludge by 88%. She urged developing countries to take advantage of these biotechnologies to address the challenge of water scarcity.

PARTICIPATION

The conference ran for four weeks, from 5 March to 1 April 2007. There were 431 subscribers to the conference, of whom 50 (i.e. 12%) submitted at least one message. There were 78 messages in total, of which 75% were posted by participants living in developing countries. Contribution to the conference came from all over the world, with 47% from Asia, 24% from Africa, 18% from Europe, 8% from North America and one message each coming from Latin America and the Caribbean and from Oceania. Contributions came from 24 countries, the greatest number from India, followed by France, the United States and Nigeria. The greatest proportion of messages came from people working in universities (42%), followed by those in research centres, including CGIAR centres (28%); in private companies or NGOs (8% each); and people working as private consultants (6%), for government ministries (4%) and UN organizations/projects (4%).

Name and country of participants with referenced messages (all can be read at www.fao.org/biotech/logs/c14logs.htm):

Abdel-Mawgood, Ahmed. Saudi Arabia
Achakzai, A.K.K. Pakistan
Agarwal, J.H. India
Agbicodo, Eugene. Nigeria
Arora, Anju. India
Ashton, Glenn. South Africa
Babu, R. Chandra. India
Bett, Bosibori. Kenya
Bhattacharyya, A.K. India
Boopathi, N. Manikanda. India
Di Ciero, Luciana. Brazil
Dulieu, Hubert. France
Edema, Mojisola. Nigeria
El-Tayeb, Ossama. Egypt
Ferry, Michel. Spain
Gueye, Mamadou. Senegal
Gupta, P.K. India
Krishna, Janaki. India
Kumar, P. Sathish. India
Lin, Edo. France
Liu, Junguo. Switzerland
Manneh, Baboucarr. Benin
Morris, Mike. South Africa
Mundembe, Richard. Zimbabwe
Muralidharan, E.M. India
Murphy, Denis. United Kingdom
Nasar, S.K.T. India
Nicolay, Gian. Ethiopia
Oehler, Friderike. Italy
Okoli, Charles. Nigeria
Omari, Rose. Ghana
Paul, D.K. India
Peter, K.V. India
Prakash, C.S. United States
Primo, Heidi. Micronesia
Rakotonjanahary, Xavier. Madagascar
Rao, Kameswara. India
Richardson, Dick. United States
Rivasplata Maldonado, Heidy. Canada
Sahoo, Sarbeswara. India
Samanta, S.K. India
Sangaré, M. Burkina Faso
Seshadri, S. India
Shanker, Arun. India
Sharma, H.S. India
Tchouaffé, Norbert. Cameroon
Van Milligen, Cornelius. United States
Varghese, Shiney. United States
Venkateswarlu, B. India