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MEETING REPORT

The Future of Science: Food and Water for Life

Throughout the world, an estimated one billion people lack access to clean fresh water, and almost as many suffer from hunger and malnourishment. At the other end of the food spectrum, millions of people suffer disease and ill health associated with overconsumption and poor-quality nutrition. For the first time in modern history, average life expectancies in developed nations such as the United States are projected to decline in the next generation as a result of conditions associated with poor nutrition, including obesity, diabetes, and cardiovascular disease. The potential of science to address these global issues was examined at the Fourth World Conference on The Future of Science, September 24–27 in Venice, Italy. The theme of the conference was ''Food and Water for Life'' (www.thefutureofscience.org). Speakers and conference attendees included scientists from many disciplines as well as politicians, economists, and social scientists, all united by their interests in exploring solutions to some of the most pressing problems facing humanity. Plant Science has a central role in addressing many of these issues, especially those related to food and agriculture. Plant scientists who spoke on how research in their area can help secure adequate food and improved nutrition for the world in the 21st century included Dirk Inzé (Ghent University, Belgium), Jonathan Jones (Sainsbury Laboratory, UK), Cathie Martin (John Innes Centre, UK), Ingo Potrykus (Golden Rice Board and Swiss Federal Institute of Technology, Switzerland), David Tilman (University of Minnesota), and Chiara Tonelli (University of Milan, Italy). This report offers a brief summary of and commentary on issues discussed, focusing on topics directly related to plant science.

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FOOD FOR THE FUTURE

Some people believe that there is already enough food produced to feed the world, and the problem of food security is principally one of distribution, not production. They argue that our primary focus should be on improving food distribution globally and reducing waste in developed countries, rather than increasing crop yields. However, this notion ignores a number of key facts that indicate that further increases in crop yields are essential. First, causes of and problems associated with inadequate food distribution in developing nations have been recognized for more than 50 years but remain unresolved due to multiple political and socioeconomic factors. Consequently, arguments that focus purely on resolving distribution problems are unlikely to be effective in meeting the challenges of food security over the next 50 years. Second, consumption of grain has outpaced production for years, with the result that world grain stocks have fallen annually for the last 10 years and are now at the lowest level (55 d) since 1960 (Brown, 2008). Third, the global population is projected to increase by at least another 50% to 9 to 10 billion in the next 50 years. It is calculated that feeding this population will require increases in food production of 120 to 170%—the larger figure being required if all nations were to attain the current diets and caloric intake that developed nations enjoy today. In addition, food scarcity and hunger are prevalent in areas that have the lowest grain production and the lowest crop yields, such as sub-Saharan Africa and the Indian subcontinent. Enhancing crop production in these areas therefore could help to supply food where it is needed and help to improve incomes for local farmers, widely recognized to be two key factors in ensuring food security and lifting people out of poverty (United Nations Food and Agriculture Organization, 2006).

Increased food production could be accomplished by increasing the amount of arable land or increasing crop yields per unit of land. The potential for new arable land is severely limited worldwide, and many nations have declining areas of arable land due to water shortages, soil erosion, and desertification. Global climate change is expected to further exacerbate these problems. Indeed, a recent report suggests that climate changes this century are likely to cause major disruptions to global agriculture unless new heat- and drought-tolerant crop varieties and more efficient irrigation systems are developed (Battisti and Naylor, 2009). Plant scientists and others therefore see a critical need for a ''second green revolution'' involving the development of not only higher yielding crop varieties per se, but higher yielding varieties that will be adapted to local, nonoptimal conditions s uch as those in sub-Saharan Africa and the Indian subcontinent in particular.

Furthermore, rising living standards have increased meat consumption, so that grain crops increasingly go for animal consumption and are no longer available for people. Average meat consumption in the United States is 120 kg/year per capita (more than three times the world average), and many regions in developing countries are experiencing a substantial shift from cereals to meat and eggs. On average, the production of 1 kg of meat requires 4 to 8 kg of cereals. The consequent increase in demand for maize and coarse grains for animal feed will have a significant impact on agricultural land. Nutrition and health experts at the conference unanimously considered today's consumption of meat by developed countries to be in considerable excess and called for a drastic shift to healthier and more sustainable dietary habits.

FOOD FROM SUSTAINABLE AGRICULTURE AND TRANSGENIC CROPS

There is a growing realization among all sectors of society that nations must adopt sustainable agricultural and industrial practices to realize the goal of providing fresh water, a healthy diet, and adequate living standards, not only in the short term, but also into the distant future. The need to develop higher-yielding crop varieties that will be adapted to local conditions and conducive to sustainable agriculture, and remain high yielding in the absence of irrigation and large inputs of petrochemicals (fertilizer and pesticides), is an exceptionally tall order, especially in the short time frame available. Many plant scientists believe that the use of modern biotechnology, molecular breeding techniques, and genetic engineering of crop species can contribute significantly to achieving these goals. Nevertheless, a number of conference attendees from different disciplines expressed skepticism about genetic engineering (transgenesis) of crops, echoing the general fear and distrust of this technology that is prevalent across Europe and the UK, particularly with respect to its close associations with multinational businesses and globalization.

Arguments against the use of genetically engineered (transgenic) crops and foods appear to be shifting, albeit slowly, from the idea that such foods might be unhealthy or unsafe for individuals or for the environment. First, there is no evidence that transgenic foods are fundamentally unsafe for human consumption. Although it might be possible to create unhealthy foods using transgenic technology (for example, foods that contain an allergenic or toxic compound), food safety regulations are in place to prevent this from happening (currently these regulations are far more stringent than for nontransgenic foods). More importantly, the use of modern biotechnology could lead to the production of foods that are more nutritious and healthy for individuals. For example, Cathie Martin spoke on the potential of plant science to improve preventative medicine to combat chronic disease. She is involved in research to develop transgenic crops with enhanced nutritional content that will supply additional phytonutrients known to combat disease, such as polyphenols, which have been shown to reduce the risk of cardiovascular disease and cancer. Such foods could benefit consumers in both developing and developed countries.

Secondly, it is becoming increasingly apparent that the environmental benefits of transgenic crops outweigh any potential environmental risks. Jonathan Jones addressed issues related to the use of biotechnology to develop more disease-resistant crop varieties. This is an area where transgenic crops can have a major impact on environmental protection and the development of sustainable agriculture. As noted by Jones, ''controlling plant disease with genetics will allow us to move away from controlling it with chemistry.'' Namely, the use of transgenic crops that are genetically modified to resist disease can lead to significant reductions in the use of chemical pesticides, reducing negative impacts on the environment as well as creating a healthier environment for farm workers, and can lower significantly the energy demands of agriculture.

Current arguments against the use of transgenic crops focus on the notion that this technology is fundamentally ''against nature'' and should therefore be avoided and/or that it is designed to benefit large multinational corporations at the expense of the small farmer. The claim that genetic engineering is against nature can be answered by realizing that molecular breeding is no different from traditional breeding in this respect, and all crops plants are the result of genetic engineering. Modern molecular breeding techniques are more precise, broader in scope, and allow for much faster development of new varieties than traditional breeding. The notion that transgenic crops are designed to benefit large multinational corporations at the expense of the small farmer is pervasive, and many people mistakenly view biotechnology as an anathema to sustainable farming and to small farmers. Multinational companies, such as Monsanto, certainly have a large stake in biotechnology. Furthermore, the development of transgenic crops is expensive and seemingly out of reach of small farmers, especially in impoverished areas of the world. However, there is no fundamental reason that biotechnology cannot be used to benefit small farmers and enhance sustainable agriculture; far from contradictory, the merging of genetic engineering and organic farming offers our best shot at truly sustainable agriculture (Ronald and Adamchak, 2008).

Genetically engineered crops in combination with organic techniques have already helped farmers in less developed countries and have been used to reduce the adverse environmental effects of farming and enable farmers to produce and sell more food locally. For example, when small-scale papaya farmers in Hawaii were confronted with a devastating viral disease, transgenic papaya was the most appropriate approach to restore the industry (funded by nonprofit sources and distributed free to growers). There are no conventional or organic methods to control the disease. Indeed, the difficulties in getting regulatory approval for the cultivation and sales of genetically modified crops are probably the most important reasons why they remain largely the preserve of the multinationals. One option would be to free biotechnology from excessive regulation, allowing its application, case by case, to enhance the nutritional quality and productivity of crops, particularly in unfavorable growing environments.

Ingo Potrykus argued persuasively that, instead of working to prevent the use of transgenic crops, a key role for nongovernmental organizations should be to help ensure that improved crops and other benefits from biotechnology reach the small farmers and impoverished areas that need them the most. Potrykus related the story behind ''Golden Rice,'' which he helped to develop. Golden Rice has been genetically modified to produce high levels of provitamin A, and its widespread use could make a significant

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contribution to combating vitamin A deficiency in developing countries. Potrykus is involved in efforts to introduce Golden Rice and other beneficial transgenic crops to developing countries via international research centers, free of costs and restrictions on property rights.

Dirk Inzé spoke about the vast potential and necessity of plant biotechnology to contribute toward boosting sustainable crop production, given that crop productivity globally needs to be at least doubled to alleviate hunger and feed 9 billion people by 2050. The first step will be to work toward avoiding loss of production. Water scarcity represents a major threat to agriculture and is the single most common cause of severe food shortages in developing countries. Even in the most productive agricultural regions, short periods of water deficiency are responsible for considerable reductions in seed and biomass yields every year. More than 70% of the globally available fresh water is used in agriculture to sustain crop production. To cope with the detrimental effects of climate changes on crop yield and to fulfill the growing demand for food production, it is imperative to develop new crops with higher performance under water scarcity, which are able to consume less water and to maintain high efficiency.

As underlined by Dirk Inzé and Chiara Tonelli, the traditional approach of growing and crossing varieties and evaluating how the progeny vary in their ability to deal with stress has limited potential for increasing crop production in areas with suboptimal water availability, whereas plant biotechnology offers the greatest innovation potential. A promising strategy consists first in the identification of the master regulatory genes involved in plant water use and in plant drought tolerance. Transcription factors that naturally act as master regulators of cellular processes are excellent candidates for modifying complex traits, and transcription factor-based technologies are likely to be a prominent part of the next generation of successful biotechnology crops. Chiara Tonelli reported the successful modification of a transcription factor involved in stomatal activity as an attractive approach to reduce the water requirements of crops and to enhance productivity in water scarcity conditions.

The more people understand about both traditional and modern biotechnological plant breeding methods, the more they realize that the use of biotechnology and transgenic crops can play a valuable, sometimes essential, role in our quest to provide healthy nutritious food for the world and achieve sustainable agriculture on a global scale. Plant scientists therefore have a significant role to play in public education as well as agricultural research and development.

FOOD FOR AFRICA

Africa is home to many of the world's most hungry and impoverished citizens. Although the developed world speaks of the need for a ''second green revolution,'' it is widely recognized that the first green revolution of the 20th century bypassed Africa almost entirely. The high-yielding varieties of wheat, maize, and rice of the green revolution were not successfully introduced to African agriculture, mainly because they require large inputs of fertilizer and pesticides to realize their high-yield potential, and most African nations have lacked the infrastructure necessary to grow these varieties on a large scale. Two schools of thought for improving agriculture in Africa today (not necessarily mutually exclusive) were evident at the conference: one that seeks to find ways to apply the lessons of the first green revolution, and the other that believes the answers lie in a second green revolution. In the first instance, it appears obvious to many that African agriculture could benefit greatly by increased application of fertilizer. Reasons for this include not only the complete lack of fertilizer use in many areas of Africa, but also evidence that soil nitrogen is being depleted in the majority of African nations (Henao and Baanante, 2006). However, it is widely recognized that the first green revolution was accompanied by an increased number of environmental problems attendant with vast inputs of fertilizer and chemical pesticides. In addition, it is expected that climate change will lead to reduced water availability and increased incidences of prolonged drought throughout sub-Saharan Africa and will further exacerbate problems with soil fertility. Therefore, success with a second green revolution and the development of high-yielding, drought-tolerant, and disease-resistant varieties adapted to local conditions, accompanied by improvements in the efficient use of fertilizer and sustainable agricultural techniques, may be critical.

It is also recognized that there is an urgent need for training and education of scientists within developing nations and for technology transfer to strengthen regional scientific institutions and laboratories. Tilahun Yilma (University of California, Davis, CA) spoke about his efforts in creating and distributing vaccines for rinderpest and other animal diseases. The first large-scale rinderpest eradication program in Africa, which took place in the 1960s and 70s, succeeded in vaccinating 124 million cattle, but ultimately failed to make significant headway against the disease, mainly because the program failed to transfer technology for sustainable disease control to affected countries. Yilma formed the International Laboratory of Molecular Biology for Tropical Disease Agents, whose goal is not only to train scientists from developing countries, but also to strengthen regional laboratories throughout Africa in virology and molecular biology. Similar programs are urgently needed in all areas of agricultural and economic development in Africa.

FOOD VERSUS FUEL

There is ongoing debate in many scientific circles as well as mainstream media over how to avoid problems of food security associated with growing crops for biofuels instead of food. David Tilman noted that expanding the production of food-based biofuels, such as maize, inevitably will either take away land from food crops or require new land. There is growing interest in the development of ''second-generation'' biofuel feedstocks, which will have improved characteristics for biofuel production and are not used in food production, such as perennial grasses and woody species, cellulosic waste, and algae.

Tilman and colleagues have argued that expanding the production of food-based biofuel crops to newly cleared land would release large amounts of carbon dioxide to the atmosphere, which would negate their use to offset carbon emissions (Fargione et al., 2008). Instead, Tilman argued for the possibility of using land abandoned by agriculture to plant high-diversity mixtures of native grasses and legumes, which have the potential for use as biofuels as well as creating net stores of carbon to combat climate change. For example, the United States has nearly 37 million acres of retired agricultural land enrolled in the U.S. Conservation Reserve Program, under which farmers are paid to retire highly erodible and other environmentally sensitive cropland and pasture. Growing maize or other food crops in monoculture for biofuels could compromise goals of conserving and improving the soil, water, and wildlife resources on these reserve lands. By contrast, the use of diverse mixtures of native grasses and legumes on land already degraded by agriculture might have conservation and wildlife benefits as well as benefits for carbon storage and biofuels production, and importantly, would not require the clearing of additional land and the concomitant loss of biodiversity and massive release of greenhouse gases. It is clear that proponents of biofuels need to work closely with plant scientists, ecologists, and conservation biologists to ensure that growing plants for biofuels does not create as many problems as it solves.

FOOD FOR THOUGHT

Several meeting attendees raised the question of whether increasing food production would push population growth, leading to a global population beyond the earth's carrying capacity and exacerbating global problems of poverty, starvation, and ecological destruction. This is essentially a Malthusian prediction about population growth: increases in productivity will stimulate further population growth, which eventually will outstrip the carrying capacity, resulting in a population crash (from famine, poverty, disease, war, etc.). In a similar vein, Ehrlich (1968) predicted that hundreds of millions would die from the effects of overpopulation in the 1970s and argued for compulsory birth regulation. There are those who continue to maintain that these predictions ultimately will come to pass: they argue that Malthus and Ehrlich were mistaken only with their predictions of the time involved. Are we then ill-advised to work toward increasing crop productivity and food production? In an extreme example of this type of thinking, Garrett Hardin (Hardin, 1974) went so far as to argue that we must employ ''lifeboat ethics'' and not engage in helping the poor in order to save the world from environmental ruin.

There are at least three very strong arguments against these ideas. First, analyses of food availability and productivity compared with population growth trends have shown unequivocally that improving living standards leads to lower birth rates and stabilizing trends in population growth. Conversely, the nations with the highest rates of birth and population growth are those with the highest rates of poverty and starvation. There is good evidence that increasing food production in developing countries, concomitant with improving incomes, standards of living, and education (particularly for women), leads to declining birth rates and stabilizing population dynamics. Accordingly, the primary goal of the United Nations Millenium Development Goals Report (United Nations Department of Economic and Social Affairs, 2008) is to eradicate extreme hunger and poverty by working to obtain maximum crop yields and raise income. And for many whose principal form of income is agriculture, raising income depends primarily on maximizing crop yields.

Second, future population estimates (not to mention existing populations) are not based on assumptions of increased food production. The reality is that we must find ways to lift ~1 billion people out of poverty today, and in addition, provide adequate food and water for 9 to 10 billion in 2050 and beyond. With world grain stocks declining, accepting the premise that increasing food production will lead to overpopulation would likely condemn billions to starvation and is morally unacceptable.

Finally, Hardin's ''harsh ethics,'' which makes the claim that condemning the poor to starvation is necessary to ensure the survival of some, presupposes that the human population has already reached or exceeded the earth's carrying capacity. This assumption is likely to be deeply flawed, as it fails to acknowledge the human potential for innovation and problem-solving. David Tilman reminded us of the words of the Greek philosopher Plato that necessity is the mother of invention; humans have faced and solved many critical problems throughout history and will continue to do so, motivated by necessity. Many who attended The Future of Science conference came away with a renewed commitment to the idea that innovation in science and technology can and will provide solutions to the world's biggest challenges out to 2050 and beyond. Humans tend to look for easy solutions and often attempt to reduce problems to simple ''either-or'' answers. It is likely that the challenge of providing adequate food and water for the growing world population in an ecologically sustainable manner while dealing with and attempting to mitigate adverse effects of climate change will require complex, multifaceted solutions. The scientific community can further help by educating the world's citizens to comprehend and be more comfortable with complex solutions. The focus of science should be on creating more with less, producing more food while assuring

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sustainability in the management of natural resources and using all appropriate scientific methods.

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