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The impact of possible climate changes on developing countries

The needs for plants tolerant to abiotic stresses

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Some authorities interpret measured increases in global temperatures as indicating an approaching major change in climate around the world although there is argument about both the extent and the origin of the phenomenon as well as its climatic implications. While in some quarters the carbon dioxide generated by human activities is regarded as the major driver of global temperature increases, others contest that view.

It is not our purpose here to take sides in this conflict of ideas but rather to explore the consequences of postulated climate change were they to occur to a serious degree. If the world's climate is not changing significantly, there is nothing special for us to write about under this heading. But suppose it is: what are likely to be the consequences for agriculture and for our food supplies, both in general and in detail?

In addition to the heating effect itself on biological systems, increasing global temperatures, should they occur, are likely to have significant impacts in the coming decades through changes in rainfall, wind speeds, reduced cover of snow, reduced incidence of frosts, length of growing season, and, perhaps, the timing of extreme and critical threshold events relative to crop development.[1] If some or all of these effects were indeed to occur we might expect major consequences for agriculture, fishing, and other aspects of our food supply.

One consequence, in particular, might well be a rise in seawater level which would have serious implications for countries whose lands are at elevations close to sea level. Among the regions most threatened by a rise in sea levels are the old deltas where agriculture first started, leading to loss of land and migration of the people living there to higher and safer lands. In Egypt, if the sea level were to rise 50 cm nearly 1800 km of the north coast and the Nile delta would be inundated by seawater with major effects on the lives of about 3.8 million people.[2] With climate change, the expected drought, salinity and floods would invariably have grave implications on crop production and, hence, on food security, possibly resulting in acute food shortages locally and even globally. Producing enough food for a rapidly growing population under extreme and changing weather conditions would be a major challenge, especially as there are few or no remaining redundant water resources and arable lands to be brought into use.[3]

In addition, the increase of atmospheric carbon dioxide concentration already with us is likely to be causing ocean acidification. Carbon dioxide dissolves in sea water to form the weak carbonic acid thus lowering the pH and affecting some marine organisms. Higher concentrations of carbon dioxide in the atmosphere will reduce the amount of nutrients such as zinc and iron in rice, wheat and legumes, with deleterious effects on people whose diets are based on these crops.[1] However, elevated atmospheric carbon dioxide levels is known in some cases to improve the efficiency of photosynthesis and so might increase some aspects of plant productivity.

Developing countries, particularly those in South Asia and sub-Saharan Africa, may well be hit the hardest as they will suffer the gravest consequences of these changes to their food production systems. Climate change, were it severe, might undermine the ability of developing countries to attain millennium development goals and achieve sustainable development. There is already an outspoken demand for increasing crop yields two-to 3-fold as populations continue to increase, again particularly in the developing countries.[4-6]

Agricultural systems can be vulnerable to climatic conditions, with small increases in temperature in some cases being very detrimental to productivity. Success in producing more food under worsening climatic conditions—and with a severely constrained natural resources base—hinges on enhanced efficiencies, that is, achieving more yield per unit of input. According to the Intergovernmental Panel on Climate Change (IPCC) an additional 40 to 170 million more people might be undernourished as a direct consequence of climate change.[7-9] The growing of diverse "smart" crop varieties capable of producing "more with less" requires the re-orientation of many aspects of crop production systems using plant breeding and the cultivation of the resulting high yielding, well adapted, input use-efficient, and resilient crop varieties constituting a major component of the interventions.[10]

The National Adaptation Plan (NAP) process was established in 2010 within the Cancun Adaptation Framework by the United Nations Framework Convention on Climate Change (UNFCCC). The developed plans are intended as a means for countries to reduce their vulnerability to the impacts of possible climate change by building adaptive capacity and resilience while facilitating the integration of climate change adaptation into development planning processes and strategies across all sectors and scales. They provide a critical process for countries to

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mainstream climate adaptation interventions across all relevant sectors and scales.[11,12] Linking adaptation strategies to planned development projects can safeguard development investments from climate change impacts and also result in significant cost savings. The development of new plant varieties with low water requirements, better water-use efficiency and the production of drought-tolerant varieties can help increase food production. If the worst happens, all this will be of critical importance in many countries in Africa in which agriculture directly employs nearly 80 percent of the population. Were they to occur, desertification and climate change would severely impact agriculture for the worse.

The negative impacts of climate change on crop production might include the risk of extinctions of important species, decreases in yields and/or quality of crops currently near climate thresholds, agricultural lands in drier areas affected by desertification and salinization, reductions in land suitable for cultivation, increased infections with pathogens, nematodes and insects, reduction in water availability, flora likely to become vulnerable, endangered or committed to extinction by the end of this century and a wider geographical spread of one or more major horticultural pests.[3,13]

There is no doubt that in such circumstances improving plant tolerance to abiotic stresses would continue to be a priority. Efforts to direct new research and the transfer of available technologies to overcome climate changes are highly relevant. Thus, water stress caused by drought is a major factor limiting plant growth and crop productivity worldwide, highlighting even under existing climatic conditions the need for improving drought tolerance in a wide range of present-day crops.

Conventional agriculture has impacted the environment significantly. Biotechnology can be used to reduce the environmental footprint of agriculture by allowing a significant reduction in pesticides, saving on fossil fuels, decreasing CO_2 emissions through reduced plowing regimes, and conserving soil and moisture by optimizing the practice of no till through application of herbicide tolerance.[1,6]

How to develop plants capable of mitigating climate change?

Agriculture may face a massive challenge because of climate change. We would need new tools to help us to adapt: geographic information systems and remote sensing, simulation modeling, genetic engineering, nanotechnology, techniques to harvest renewable energy and new techniques to desalinize sea water. If the threats materialize, water stress caused by drought and salinity will be the most important abiotic factor limiting plant growth and crop productivity. There is an urgent need for enhancing osmotic stress tolerance in crops grown under such conditions to avoid present and future disasters.[2,14,15]

"The current levels of adaptation and mitigation efforts are insufficient so we need to act with urgency to address the aftermath of powerful floods, typhoons, droughts and other extreme weather events," says Koko Warner, lead author of the study and the head of the Environmental Migration, Social Vulnerability and Adaptation Section at UNU-EHS. The UN Framework Convention on Climate Change (UNFCCC) already includes provisions and processes to deal with and support adaptation, but not damage beyond adaptation.[16,17]

Plants respond to drought by the activation of genes involved in the perception of drought stress and in the transmission of the stress signal. There are two mechanisms for such responses: the first is the activation of genes encoding proteins to protect the cells from the effects of desiccation. These genes include some that govern the accumulation of compatible solutes, passive transport across membranes, energy-requiring water transport systems, and protection and stabilization of cell structures from desiccation and damage by reactive oxygen species. The second mechanism involves genes activated by drought which express regulatory proteins to regulate further the transduction of the stress signal and modulate gene expression. At least four independent stress-responsive genetic regulatory pathways are known to exist in plants. Two of them are dependent on the hormone ABA, the others ABA-independent. These pathways are also implicated in the perception and response to additional stress factors, including cold, high temperature and salinity.[2,3]

Conventional breeding requires the identification of genetic variability to drought among crop varieties, or among sexually compatible species, and introducing this tolerance into lines with suitable agronomic characteristics.[3]

The development of crop varieties with increased tolerance to drought, both by conventional breeding methods and by genetic engineering, is also an important strategy to meet global food demands with less water.

The existence of high genetic diversity with positive responses to abiotic stress in genetic resources could open new opportunities for understanding the physiological and genetic mechanisms involved in plant response to different stresses and so provide tools for molecular screening and genetic engineering applications in crop improvement for increased abiotic stress tolerance.[2,3]

Microsatellite-based markers are the most promising analysis for the structural characterization of the collection germ plasm in different crops. They are also valuable for studying the genetic and physical maps and are used in marker-assisted breeding for improving the efficiency of breeding for abiotic stress. Improved crop varieties showing superior agronomic and quality traits are the direct consequences of plant breeding.[2,18] Quantitative trait loci (QTL) analysis is an important component of crop improvement strategy for dry areas. Identifying the correlation between DNA markers and agronomic traits will allow plant breeders and geneticists to hasten the development of pure lines from the crosses as compared with conventional pedigree or bulk methods.[3,19]

Although conventional breeding for drought tolerance has had some success, it is a slow process limited by the availability of suitable genes for breeding. Marker-assisted selection, supported by the tools of genomics and the other -omics and information technology platforms permits high throughput evaluations of breeding materials.

On the other hand, the development of adverse environment-tolerant crops by genetic engineering requires the identification of key genetic determinants underlying stress tolerance in plants and introducing such genes into crops. Drought triggers a wide array of physiological responses in plants and affects the activity of a large number of genes: gene expression experiments have identified several hundred genes which are either induced or repressed during drought.

The introduction of several stress-inducible genes into plants by genetic engineering has resulted in the transgenic constructs exhibiting increased tolerance to drought, heat, cold and salinity stresses.

The first biotech maize hybrids with a degree of drought tolerance were commercialized in 2013 in the USA and the first tropical biotech drought-tolerant maize is expected by about 2017 in sub-Saharan Africa. Drought tolerance is anticipated to have a major impact on more sustainable cropping systems worldwide, particularly in developing countries where drought will likely be more prevalent and severe than industrial countries.[20,21]

Biotech crops can contribute significantly both to sustainability and for the mitigation of the formidable challenges associated with possible climate change and global warming: the potential for the future is enormous. In addition, biotechnology can help to increase productivity and income significantly and hence serve as an engine of rural economic growth contributing to the alleviation of poverty for the world's small and resource-poor farmers.[20,21]

Genetic transformation and the resulting GM crops are increasingly cultivated around the world; the technology holds promise and countries need capacity building in order, at the very least, to make decisions as to its adoption based on evidence rather than emotion and political convenience.

Nanotechnology, too, is likely to have wide applications in agriculture, opening enormous new opportunities such as the fabrication of nano-sensors for protecting food from pathogens and pests, identification and control of insect pests and pathogens, new tools for molecular and cell biology (including more efficient techniques for gene delivery for genetic engineering), and molecular nano-machines and devices. The use of nanotechnology in agriculture has begun, and will continue to develop with significant effects on different areas of agriculture and the food industry. We hope that nanotechnology will in the future be able to help plants to cope with whatever devastating environmental changes may occur globally or locally.[2,22]

Other emerging biotechnologies such as zinc finger nuclease, oligonucleotide-directed mutagenesis, transgenesis, and cisgenesis, RNA-dependent DNA methylation, grafting onto GM stock, reverse breeding, agro-infiltration and synthetic genomics, while still requiring further refinements to varying degrees, will also become important in the very near future. Countries will increasingly require support in navigating the IPR regimes that govern access to these technologies and the regulatory issues pertaining to their adoptions. As massive numbers of new breeding materials are generated through pre-breeding, MAS must be complemented by phenomics in order that reliable predictions of the breeding values can be made.[3]

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