November 20, 2007

The Conservation of Global Crop Genetic Resources In the Face of Climate Change

Summary Statement from a Bellagio Meeting Held on September 3-7, 2007

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Introduction

The release of the Intergovernmental Panel on Climate Change (IPCC) fourth report in 2007 confirms once again—with strong scientific consensus—that the global climate is changing, and that humans are both causing and will be damaged by this change. The ability of ecosystems to provide the most basic types of services to humans, such as food and water, will be affected by climate change throughout the world. A common assumption is that agricultural systems will shift in response to climate change over time to regions with suitable agro-climatic conditions, resulting in little net impact on global food supplies in the future. However, this assumption overlooks a critical set of conditions: *that crops will shift only with extensive genetic manipulation through breeding, and that these breeding efforts will require the continued collection, evaluation, deployment and conservation of diverse crop genetic material.*

In September 2007, a group of experts from the genetic conservation, climate science, agricultural development, and plant genetics and breeding communities met at the Rockefeller Foundation Conference Center in Bellagio, Italy, to initiate a discussion about the management of global crop genetic resources in the face of climate change. Our underlying focus was on global food security—defined here as the ability of all people at all times to have access to sufficient diets for a healthy and productive life. Much of the discussion therefore centered on malnourished populations, the majority of whom depend to some extent on agriculture for their livelihoods. In particular, we directed our attention toward two key regions of food insecurity: a) South Asia, where the largest number of chronically hungry people live despite impressive technological gains in agriculture during the past 40 years and widespread use of irrigation in some areas; and b) the African continent, where the incidence of hunger is greatest and where rainfed systems account for over 90% of crop production.

The primary contribution of the meeting entailed the integration and advancement of two main bodies of work:

1. Projections of regional climate changes and their potential impacts on:
    a. Future distributions of crops and their wild relatives, and
    b. Agricultural productivity in developing countries
2. Comprehensive assessments of the needs and constraints on crop genetic collections, characterization, conservation, and breeding for future food security.

The interdisciplinary nature of the meeting revealed new insights for all participants and novel approaches for research and prioritization across the board—thus highlighting the importance of cross-disciplinary efforts in addressing the future impacts of climate change.

This document is divided into two sections: a) a brief summary of the material presented at the meeting on climate projections, potential climate impacts on existing agricultural systems, and seed collections and evaluation; and b) our collective views on priorities and actions needed to conserve crop genetic resources into the long-run future and to evaluate these resources for use in breeding. The main target audience is the Global Crop Diversity Trust, whose mission is to ensure the conservation and availability of global crop diversity in perpetuity in gene banks throughout the world, including the Svalbard Global Seed Vault (Norway). Our hope is that many other audiences—including the Governing Body of the International Treaty on Plant Genetic Resources for Food and Agriculture, the FAO Commission on Genetic Resources for Food and Agriculture, national leaders, advanced research centers, and foundations and international agencies investing in agriculture and rural development—will also find the results of this meeting important and worth acting upon.

What do we know now?

In charting a course for the long-run conservation and utilization of crop genetic resources, the first task is to assemble existing information on climate change, crop response to climate change (including the response of their wild relatives), and the current state of crop collections and evaluation worldwide. Some of this information can be found in existing published literature and on the IPCC 4th Assessment report (AR4) web site.[1] The novelty of our approach lay in the information and methods generated specifically to address the long-run challenge of managing crop genetic resources and their use under conditions of climate change, taking into consideration the roles of uncertainty, regional variation, and alternative time periods of analysis as described below:

Projections of Future Climate Change

There is broad consensus among the some 20 global climate models (GCMs, also known as general circulation models) considered by the IPCC that climatic conditions are changing significantly at regional and global scales, and that the climate at the end of this century will be substantially warmer than that of the past century. There is widespread agreement on three points in particular:

a) *All regions will become warmer*;
b) *Soil moisture will decline* with higher temperatures and evapotranspiration in the sub-tropics, leading to sustained drought conditions in some areas and flooding in other areas where rainfall intensity increases but soil moisture decreases; and
c) *Sea level will rise* globally with thermal expansion of the oceans and glacial melt.

The latter will be most devastating for small island states, of course, and for countries such as Bangladesh that are low-lying and highly populated. Large areas of Bangladesh already flood on an annual basis and are likely to be submerged completely in the future, leading to a substantial loss of agricultural land area, even for deep water rice. Another important change for Asia pointed out at our meeting will be the melting of the Himalayan glaciers; these glaciers regulate the perennial flow in large rivers such as the Indus, Ganges, Brahmaputra, and Mekong, and are already receding faster than any other glacier system in the world. With glacial melting, the river systems are expected to experience higher seasonal flow and more flooding.

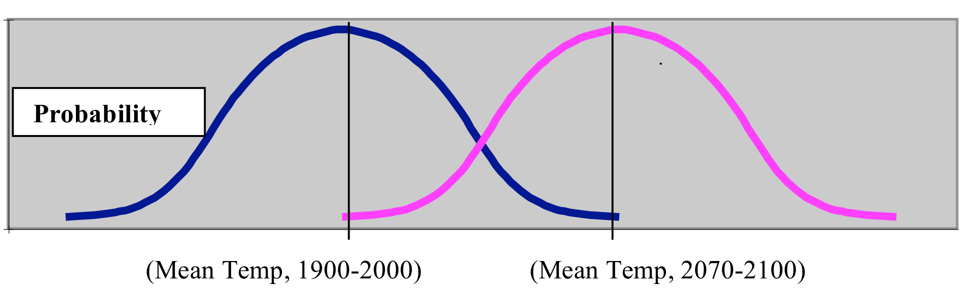
Projections of future precipitation patterns are far less certain. Most models project increased rainfall with warming in the maritime tropics and at high latitudes, and

[1] See http://www.ipcc.ch/

decreased rainfall over large land areas of the subtropics—that is, regions that are currently wet are expected to become wetter, and dry regions are expected to become drier. However, the annual cycles of rainfall are unclear from the GCMs. For the tropics as a whole, and especially for the monsoons, the location and pattern of rainfall is disputed among models. Presentations at our meeting showed that for the African continent, most GCMs predict warming and drying in the northern and southern countries, but the models currently depict large uncertainty regarding future rainfall levels and patterns in East, Central, and West Africa (including the Sahel). Variability in rainfall in these regions will continue to be linked to El Niño-Southern Oscillation (ENSO) patterns.

Many model projections cited in the literature focus on 2050, a "sweet spot" in climate projections when the projected climate is expected to lie out of the range of current natural variability, and when the uncertainty in the projected climate is not too high (especially relative to uncertainty at the end of the century) to say something meaningful. However, our group agreed that there is merit in focusing on shorter time scales; for example the period between now and 2030 when initial breeding investments will be needed to adapt to future climate change (as discussed in the following section). We also agreed that there is merit in focusing on much longer time scales—2070-2100 when the climate is expected to be dramatically different—in order to create a new vision for the future of global agriculture. For example, we asked the question: how should the genetic conservation and agricultural development communities think about future agricultural systems if the mean climate in 2100 is the same as the most extreme warm climates today (e.g., the upper tail of the climate distribution) as shown in Figure 1?

Figure 1: Illustration of observational vs. projected temperature range



A major result of our meeting was that actual projections from the GCMs show an even more serious situation than that depicted in Figure 1. Figure 2 shows summer average temperature distributions for modern day and future climate projections for several countries. Regardless of which country is selected, the general result is the same. In virtually all cases, *the future temperature distribution will be a whole scale warmer than the past temperature distribution; that is, the coolest summers in 2070-2100 are projected to be similar to or warmer than the warmest summers observed over the past century*.

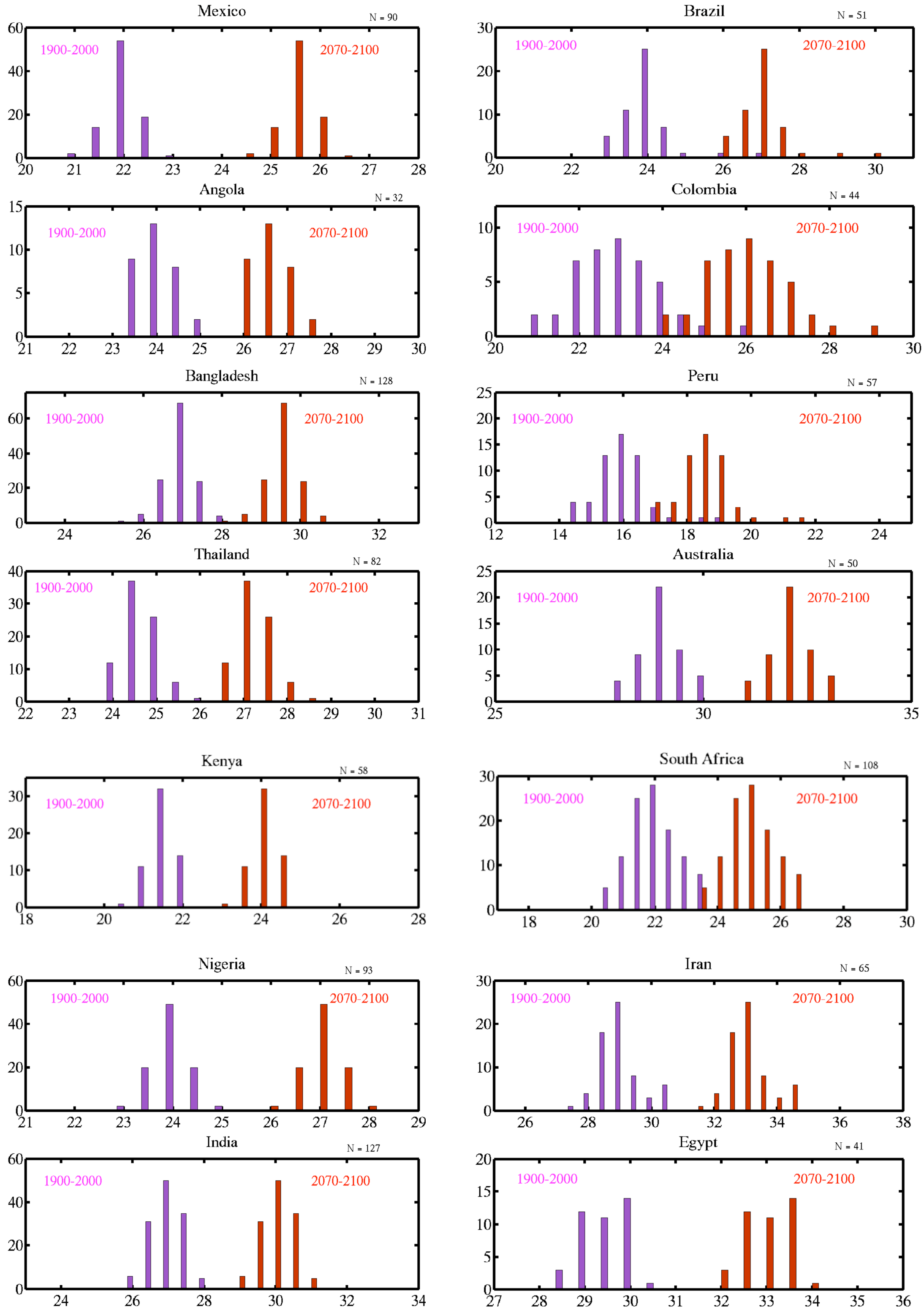
Projections of Future Impact on Agriculture

In order to promote agricultural adaptation in the face of such dramatic changes in climate, substantial breeding efforts will be required, which will depend on the collection, conservation and distribution of appropriate crop genetic material among plant breeders and other researchers. Breeding investments typically run in 12-20 year cycles from the time of problem identification to the time of varietal deployment at the farm and commercial levels. Between now and the end of the century, there will be several generations of breeding effort in programs overlapping in time. Our group concluded that assessing the potential impact of climate change on crop productivity in 2030 and identifying priorities for immediate collection and breeding is therefore an important first step in ensuring longer run adaptation.

An empirical model was presented at the meeting that compared the impacts of climate change in 2030 on the productivity of a wide variety of crops grown in developing regions where 95% of world's malnourished population currently live.[2] The analysis was based on a synthesis of what poor people eat and where the relevant crops are grown, observed relationships between historical production and climate variability, and projections of future climate (temperature and precipitation) changes during the main growing season in each region by 2030. A total of 94 crop-region combinations were

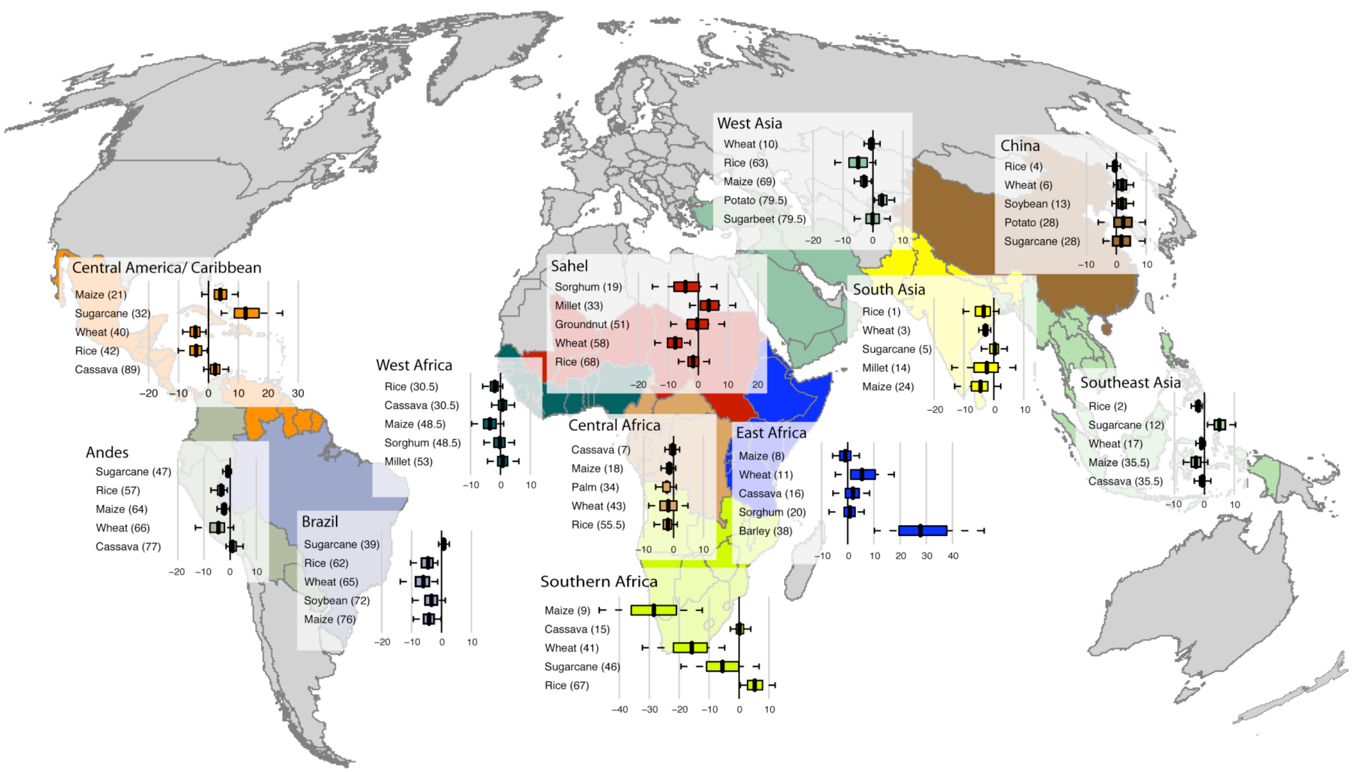
[2] See David Lobell, Marshall Burke et al. (2007). "Prioritizing climate change adaptation needs for food security in 2030". Paper prepared for the Bellagio meeting (September 3-7, 2007), currently under review for publication. Contact lead author at: lobell2@llnl.gov.

Figure 2: Distributions of observed average (summer) growing season temperature for 20th century (purple), and climate model projections for 2070-2100 (red) (y=probability, x=degrees C) (Taken from D. Battisti.)



evaluated, ranging from the most important global crop—rice in South Asia—to groundnuts in East Africa, which are less important on a global basis but still significant regionally. The results for the top five crops in each region are summarized in Figure 3.

Figure 3: Projected impacts of climate change by 2030 for the three most important crops in each region. Boxes represent the 25th to 75th percentile of model projections, whiskers represent the 5th to 95th percentiles, and the dark line represents the median projection. Numbers in parenthesis are the overall rank of the crop/region in terms of importance to global food security. (Taken from D. Lobell et al.)



The results show that South Asia and Southern Africa are two "hunger hotspots" that are likely to face the most serious impacts from climate change. The crop with the single largest potential impact is maize in Southern Africa; this crop is the most important source of calories for the poor in this region and is projected to suffer losses of 30% by 2030. In South Asia, where roughly one-third of the world's malnourished live, several key crops—including wheat, rice, rapeseed, millet, and maize—have more than a 75% chance of incurring losses from climate change. The potential impact of climate change on agricultural productivity remains highly uncertain in other "hunger hotspots", such as West, Central, and East Africa, where the quality of data is generally too poor for reliable evaluation. The use of these results for setting investment priorities depends importantly on one's risk attitude; for example, whether one cares more about crops for which there is a 95% chance of production losses greater than zero (e.g., Southeast Asian rice, South Asia wheat, and Southern African maize) or crops for which there is a 5% chance of production losses greater than 10% (e.g., South Asia millet, Sahel sorghum and also Southern African maize).

Results from a set of crop models from India were also presented for rice and wheat. These models reflected the interactive effects of projected changes in temperature, precipitation, elevated carbon, and other variables influenced by increased greenhouse gas concentrations. As illustrated in Figure 4, the models show a narrowing of the yield gap in recent decades as farmers' yields rose toward the biophysical potential yields (left panel); they also show that a projected decline in the biophysical potential of crops resulting from climate change may lead to a wider yield gap in the future despite genetic gains (right panel). The net production effects of these models are consistent with the direction of change noted in Figure 3 and raise serious concerns for the future state of hunger in South Asia.

Figure 4: Impact of climate change on future opportunities for increasing wheat production in India. Left hand panel=yield gap over time (1960-2000); Right hand panel=yield gap with increasing temperature (0-5 degrees C above average in 1960-2000). (Taken from P. Aggarwal)

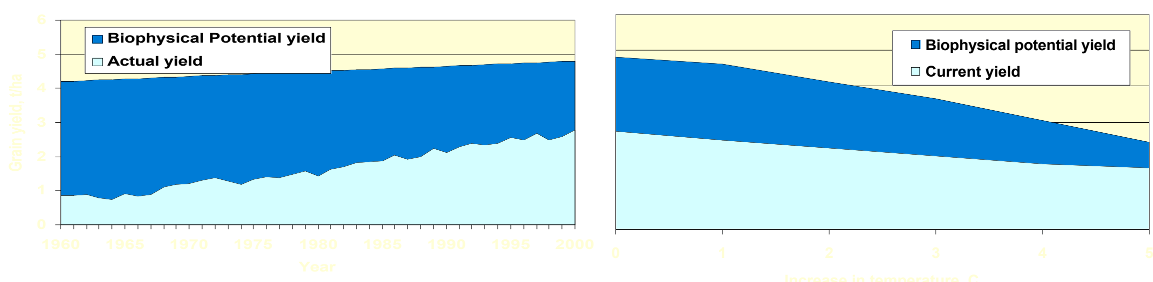


Figure 4 underscores the challenges of breeding for climate change—particularly for extreme changes in temperature as illustrated in Figure 2. Participants at our meeting presented and discussed ongoing breeding efforts in wheat, rice, sorghum, millets, pigeon pea, and sweet potato. These discussions emphasized four broad sets of relationships that have been observed and measured in the field in several regions:

a. Connections between temperature increases and reductions in the length of the growing season (time to maturity)
b. Connections between temperature and precipitation changes on pest, disease, and weed populations;
c. Differences in drought tolerance among crops, with sorghum and millets outperforming wheat and maize; and
d. Interactions of multiple phenotypic changes in response to elevated greenhouse gas concentrations.

We concluded that, in general, the understanding of abiotic interactions is better than biotic interactions (pest/pathogens) in the context of climate variability and climate change. The meeting also highlighted the fact that plant biologists typically work on one trait at a time (e.g., aspects of drought tolerance). With simultaneous changes in temperature, precipitation, CO_2 fertilization, and pest/pathogen dynamics, the breeding challenge will be enormous. Integrated research will be needed in the broader field of crop improvement and in assessments of the production chain from geneticists to consumers. Basic research on individual traits will be necessary but not sufficient for crop adaptation to climate change. Useful traits will need to be "stacked" if new varieties are to be successful in adapting to the multivariate changes predicted by the models.

Crop Collection and Evaluation

Our discussions on climate change and climate impacts—even by 2030—generated a sense of urgency for genetic conservation and breeding investments to enhance future crop adaptation. But we pondered the question: are the available crop genetic resources and the associated information adequate for such breeding efforts? Important information on the current state of crop collections was presented, as follows.

There are about 150 different crops traded in the world market, only 35 of which are covered within the International Treaty on Plant Genetic Resources for Food and Agriculture—a treaty that sets a multilateral legal framework for facilitated exchange of genetic resources across borders.[3] There are also thousands of crops/species that are consumed and traded locally but do not enter the world trading system; much of the genetic diversity for these crops is not stored in gene banks. Finally, there are over one billion people living in families that are self-provisioning in the seeds they plant each year, and who serve as the *in situ* conservers of abundant crop genetic diversity for both traded and non-traded crops.

The need for *ex situ* storage of diverse crop genetic material is thus becoming increasingly urgent in the face of rapid changes in land use and climate worldwide, and potential displacements of landraces and improved crop varieties. There are roughly 1400 gene banks around the world that contain some 6 million accessions (samples) of crop genetic resources, 1.5 million of which are thought to be distinct or unique. The size of gene banks varies substantially; for example, the Chinese national gene bank holds about a half million accessions, while national banks in some other parts of the world hold only a few thousand, and institutional collections may consist of as few as one or two accessions. The typical size of crop gene bank collections is 650 accessions. There are three general types of seed collections: a) those operated internationally in the public trust by the Consultative Group on International Agricultural Research (CGIAR) (72% of the world's crop diversity); b) those operated by national governments (15% of the world's crop diversity); and c) those operated and controlled by private entities (14% of the world's crop seed collections). These collections include domesticated crops, landraces that have been selected over time by farmers, and wild relatives. Wild relatives, a rich source of diversity and adaptive traits for extreme abiotic conditions and pests and diseases, comprise a relatively small share of most collections, particularly in government and private seed banks.

How much of the world's crop genetic material has actually been collected and is now being conserved *ex situ*? It is thought that 95% of the genetic diversity of the world's major cereal crops—rice, wheat, and maize—has been collected. For cassava, one of the world's most important root crops, only 35% of genetic diversity is thought to have been collected. It is interesting to note that only 16 crops have 5000 samples or

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[3] The International Treaty on Plant Genetic Resources was adopted by the United Nations in 2001 and has been ratified by more than 115 countries around the world. The 35 crops covered under the treaty are the focus of the Global Crop Diversity Trust's activities and also of the discussions at this meeting. See Appendix 1.

more in gene banks, and many locally important crops, such as African leafy vegetables, have no significant genetic collections at all. Moreover, the characterization of existing genetic material remains a huge hurdle for many gene banks, especially for minor crops. In other words, many of the "books" in these "libraries" have not yet been opened, much less read.

The major crops have received highest priority in collections and breeding, and are now adapted to a wide range of agro-environments. Maize, in particular, is grown all over the world. Minor crops, such as yams, finger millet, and pigeon pea, have smaller collections and over the years have acquired less breeding attention (due primarily to lesser demand). They are more limited in their geographic range, in part perhaps because of more limited scientific attention. The diversity of vegetatively propagated crops is especially difficult and expensive to store; as a consequence, collections tend to be small and vulnerable. The combination of relatively small accessions and minimal numbers of breeders for minor crops bodes poorly for their future adaptation to climate change.

The group agreed that for all species, the collection and conservation of wild relatives is a particularly large challenge in terms of expertise, access, and expense. Wild relatives should play a key role in crop genetic improvement under conditions of climate change, because they are generally more diverse and have responded to all sorts of evolutionary forces over time. They are thus expected to contain a wealth of adaptive traits. But unfortunately they remain a relatively low priority in collection due to financial and political impediments. Additionally, and for the moment, there is also some understandable resistance to their use by many breeders as such wild forms contain a large number of undesirable traits that must be eliminated in the final commercial variety.[4] This constraint is likely to diminish as more refined biotechnological tools are integrated with breeding in future crop improvement efforts, which could result in more precise insertion of genomic segments from the wild into improved germplasm. The use of crop wild relatives in breeding programs requires large investments of time, effort, and expertise.

[4] There are many important examples of the use of wild relatives in crop improvement despite the resistance within the crop genetics community.

In Situ Distribution of Wild Crop Relatives

Much of our discussion focused on the importance of wild relatives for collections and breeding. A key question was therefore raised: what is the vulnerability of *in situ* wild relatives to climate change? Studies presented at the meeting on current and future species richness for wild crop relatives painted a grim picture. For example, maps of the distribution of wild peanut species in South America, cowpea species in Africa, and wild potato species in Central and South America suggested that:

a) Most of the species studied are expected to lose over half of their range area by the middle of this century due to climate change;

b) *All of the species will likely move up in elevation, and some will shift in latitude; and*

c) *An estimated 16-22% of the wild species studied are expected to go extinct.*

These results highlight the need for more collection efforts in the short run before diversity is lost. Participants at the meeting noted that even today, the diversity of wild relatives of key agricultural species in the world's "Centers of Origin" is being lost to changes in land use and other forces. Unfortunately, most accessions have not been fully geo-referenced, so mapping the origin of existing *ex situ* material in gene banks is imprecise at best. We concluded that more work is needed to geo-reference existing collections of wild relatives (and indeed collections in general), improve the quality of existing data in gene banks, and make these data widely available to the international community in order to support ongoing efforts to model wild species distribution and change over time.

If wild relatives are threatened because of climate change, the same must be said, though more so, of the remaining uncollected farmers' varieties (landraces) still found largely in the fields of small and subsistence farmers in developing countries. An estimated 1+ billion rural households are thought to be self-provisioning in terms of seed supply. The loss of these varieties to climate change will not only deprive the world and future generations of an immense source of diversity, it will doubtless result in extreme hardship to some of the poorest of the poor as their varieties steadily lose their productivity and resilience. Absent suitable replacement varieties for such fragile economic and environmental settings, substantially increased food insecurity could result.

Priorities and Actions

The cross-disciplinary exchange of ideas enabled our group to move to new ground in terms of setting priorities and actions for future conservation and utilization of crop genetic resources. The process also led to surprise and even a sense of shock among individual members of the group. Participants outside of the climate science community were shocked by the projections of climate change beyond 2050, and especially by 2100. Participants outside of the genetic conservation community were surprised to learn that many "books" in the "library" of ex situ collections had not been opened or read—and in fact that the library itself was woefully short of books. Participants outside of the genetics and plant breeding fields were surprised to learn that the genetic resources from wild relatives were not widely used in genetic manipulation. Everyone was shocked by the potential impacts of climate change on crop productivity in certain locations, such as southern Africa and South Asia, and on wild relatives and local landraces.

With all these surprises in mind, the group asked the question: given the mandate of the Global Crop Diversity Trust to conserve the world's crop genetic material in perpetuity through a global gene bank system, which crops, regions, and traits should be the focus of its activities in light of expected climate impacts? What mechanisms should be used to enhance the characterization of this material for breeding purposes? And what role should international funding and conservation organizations play in promoting crop adaptation to climate change? As we discussed these questions, we raised several more questions in the process. Our conclusions are grouped below as collection challenges, breeding challenges, and education challenges.

The Collection Challenge

The background information presented on future climate change and climate impacts on agriculture led us to debate several new questions in our priority setting exercise:

- Should efforts be directed at collecting and conserving crop species expected to experience the greatest negative impact or the least negative impact in the future? Is the goal to preserve existing cropping systems or to transition toward crops more likely to tolerate climate change in a particular region? That is, should we be focusing on obstacles or opportunities?

- Will national seed banks as currently configured become less important in the future as climate ranges for crops change? Will material currently stored in national banks be more useful in other countries, and less useful to their current holders in the future? Are national gene banks over-valued, and will international seed collections become increasingly valuable?
- Given limited resources, will some triage in conservation efforts be needed? Should efforts be placed on minor crops such as sorghum, millets, and yams (which have relatively small collections or collection centers and are grown in regional niches) instead of maize (which has large public and private collections and is grown globally)? Or vice versa?
- Should efforts be directed at conserving crops consumed by the largest number of people? The largest number of poor people? Or the largest concentrations of poor people—those subject to the highest rates of poverty? How are these numbers and rates expected to change in the future?
- Should the focus of collection activities be at the extremes of genetic diversity given the magnitude of climate change expected by the end of the century? Should the collection of wild relatives, with their vast genetic variation, be given priority? Should collection activities be geared toward the expected climate in 2030, 2050, or 2100?

Although these questions seem somewhat daunting, the group managed to narrow down an approach for moving forward. First, we agreed to recommend an initial focus on the following crops for collection and conservation: rice, wheat, maize, sorghum, millets, groundnut, rapeseed, cowpea, pigeon pea, lentil and cassava. We noted, however, that certain other crops such as sweet potatoes, potato, bananas, and grass pea (*Lathyrus*) might also have a legitimate claim on collection, deployment, and conservation. This list represents crops most likely to be affected by climate change; crops most widely consumed by the poor; crops with high nutritional qualities for the poor; and "safety crops" that can tolerate climate fluctuations. Most, but not all, of these crops are listed within the International Treaty (Appendix 1).

In addition to focusing on this set of crops, the participants agreed that the traits of interest be targeted on responses to:

- Temperature (length of growing season, flowering, sterility, protein content)
- Precipitation (drought and flood tolerance, as well as the timing and quantity of rainfall in general)
- Pest and pathogens, including those associated with post-harvest losses

With these crops and traits in mind, we agreed to examine regions where the climate is already extreme and which might represent expected future climates. We also agreed that the following two elements should be an integral part of any collection strategy to prepare for climate change adaptations:

1. **The design and implementation of trait collections as opposed to crop collections**. The goal is not simply to fill gaps in crop genetic resource collections—that has been the rationale for gene bank collections for quite some time. The goal can become more focused. How can the crop genetic resources community ensure that the appropriate traits are captured within the genetic material of a wide variety of crops to promote successful breeding for climate change? Gene sources for valuable traits can be used within species and across species. The latter does not necessarily imply the indiscriminate use of GMOs; the concepts of homologous series and synteny can be used to identify useful traits within families for breeding purposes.[5]
2. **The collection of genetic resources at the extreme ends of diversity**. Given the expected magnitude of climate change in 2100, we agreed that the international community needs to be thinking outside of the box and conserving a wider range of genetic diversity before it is lost forever. In order to accomplish this goal, there will need to be a better understanding of a) wild relatives and their distributions; b) landraces and their distributions; c) climate sensitivity of

[5] The "Law of Homologous Series in Variation" is a concept invented by Vavilov, stating that a trait found in one plant species is likely to be found in other similar species or genera. The related concept of synteny emerged during the biotechnology era and shows that genes conferring such traits can be found in the same location on the chromosomes of species within families.

different species (wild and cultivated); and d) genetic material currently in the gene banks. The skills needed to accomplish these overlapping objectives include taxonomy (for identification of wild relatives), species distribution and performance modeling (for mapping wild relatives and landraces), genetic tools for evaluation, and climate impact analysis. Needless to say, searching at the extremes will be no easy feat.

The Breeding Challenge

With a focus on the collection of genetic material for traits and at the extreme ends of the diversity scale, we unveiled a major constraint on linking collections to breeding in the future. Crop breeders are typically rewarded for the creation of new and improved varieties that are used widely by farmers and accepted by consumers. Creating these varieties requires time, focus, and money. Breeders are evaluated on the number of varieties developed, released, and deployed over a given time period; the incremental gain reflected in these varieties; and their eventual economic success. They are not typically rewarded on a single variety over an unlimited breeding period unless the variety is exceptional and has lasting success. Based on this incentive structure, most breeders work with a generally limited segment of the core genetic collection available to them—the segment of genetic diversity that has sufficient variation and has performed well in the past. Breeders are generally reluctant to explore the genetic material in wild relatives, because the wild relatives contain too much random genetic information (having evolved in response to multiple forces in the wild) for efficient identification and isolation of traits. Yet the genetic material at the extreme ends of landrace diversity and within wild populations is likely to be essential for successful breeding in the face of global climate change. Moreover, this diversity—which is so important to future adaptation to climate change—may itself fall prey to climate change. For example, temperature tolerance in a wild relative may be lost because the wild relative may not be able to cope with a change in water availability, both a product of climate change.

As a result of the mismatch between breeders' incentives and the potential value of genetic material in wild relatives and the extreme ends of landrace diversity, we placed strategic priority on the initiation of programs for:

3. **Pre-breeding as a public good**. Pre-breeding would entail the evaluation of genetic material at the extreme, using available and conventional tools that remain powerful (e.g., cytogenetics). Such an effort would require substantial time and resources. Given that an increasing share of crop genetic material used for breeding is being privatized, it is essential that genetic resources be maintained in the public domain, i.e., under the terms of the International Treaty, for pre-breeding efforts, and that the results be publicly available to the global community of breeders. Gene banks have an important role to play in pre-breeding, particularly given breeders' reluctance to explore crop wild relatives.

The Education challenge

Meeting the collection and breeding goals described above creates new educational challenges and opportunities for involving the international community in efforts to conserve and utilize crop diversity effectively for the benefit of humankind. Substantial scientific talent exists in advanced research institutes, including universities, which could be mobilized to augment the efforts at the CG Centers and the National Agricultural Agencies. It may appear that the majority of researchers in these advanced laboratories are more focused on their next set of publications than on contributing to improvements in the welfare of the poor. But they also may not be informed of what exactly is at stake or how to benefit from the enormous potential gains in this field. Our final strategic priority was thus:

4. **Informing key players of the need for the conservation of crop genetic resources in the face of climate change**. These groups include:
   - The Governing Body of the International Treaty on Plant Genetic Resources
   - The FAO Commission on Genetic Resources for Food and Agriculture
   - National leaders
   - Advanced scientific research institutions, and
   - The international development and philanthropic communities

The four priority actions outlined above—creating trait-based collection strategies, collecting material at the extreme ends of genetic diversity, establishing pre-breeding as a public good, and educating key players about the importance of conserving genetic resources in the face of climate change—require immediate attention by the international policy and science communities.

> *If the policy and science communities are not brought together on this issue, the ability of agricultural systems to adapt to climate change will be limited. Sadly, the first and greatest losers in such an outcome are likely to be the world's poorest populations*.

Appendix 1. Food crops covered under the International Treaty on Plant Genetic Resources

Crop	Genus
Breadfruit	*Artocarpus*
Asparagus	*Asparagus*
Oat	*Avena*
Beet	*Beta*
Brassica complex	*Brassica* et al. Genera included are: *Brassica, Armoracia, Barbarea, Camelina, Crambe, Diplotaxis, Eruca, Isatis, Lepidium, Raphanobrassica, Raphanus, Rorippa*, and *Sinapis*. This comprises oilseed and vegetable crops such as cabbage, rapeseed, mustard, cress, rocket, radish, and turnip. The species *Lepidium meyenii* (maca) is excluded.
Pigeon Pea	*Cajanus*
Chickpea	*Cicer*
Citrus	*Citrus*
Coconut	*Cocos*
Major aroids	*Colocasia, Xanthosoma* Major aroids include taro, cocoyam, dasheen and tannia.
Carrot	*Daucus*
Yams	*Dioscorea*
Finger Millet	*Eleusine*
Strawberry	*Fragaria*
Sunflower	*Helianthus*
Barley	*Hordeum*
Sweet Potato	*Ipomoea*
Grass pea	*Lathyrus*
Lentil	*Lens*
Apple	*Malus*
Cassava	*Manihot Manihot esculenta* only.
Banana / Plantain	*Musa* Except *Musa textilis*.
Rice	*Oryza*
Pearl Millet	*Pennisetum*
Beans	*Phaseolus* Except *Phaseolus polyanthus*.
Pea	*Pisum*
Rye	*Secale*
Potato	*Solanum* Section tuberosa included, except *Solanum phureja*.
Eggplant	*Solanum* Section melongena included.
Sorghum	*Sorghum*
Triticale	*Triticosecale*
Wheat	*Triticum* et al. Including *Agropyron, Elymus,* and *Secale*.
Faba Bean / Vetch	*Vicia*
Cowpea et al.	*Vigna*
Maize	*Zea* Excluding *Zea perennis, Zea diploperennis*, and *Zea luxurians*.