CROP TRUST

PATRON: HRH, THE PRINCE OF WALES

SECURING CROP DIVERSITY

FOR SUSTAINABLE DEVELOPMENT, FOREVER

CROP TRUST PLEDGING CONFERENCE

APRIL 2016 WASHINGTON, D.C.

EXECUTIVE SUMMARY

1. Why is crop diversity important?

Crop diversity is the raw material for the development of new, improved varieties, which provide a range of important benefits to farmers and consumers. The importance of crop diversity in ensuring increased food quantity and quality can only continue to grow, given rising populations, changing consumer demands, pressures on land, resource constraints and global climate change.

▸ PAGE 4

2. Why do we need genebanks to conserve crop diversity?

The loss of crop diversity on farms has direct impacts not only for farming families, but also for the global agri-food system as a whole. Genebanks provide a safe, cheap means to secure crop diversity and ensure that scientists have ready, convenient access to all the diversity they need to improve crops, in the service of farmers and consumers. Today, there are about 7.4 million accessions conserved *ex situ* in over 1,750 collections worldwide. The large, mega-diverse collections managed by the CGIAR centers have a particularly important place among these, playing a key global role recognized by an international treaty.

▸ PAGE 6

3. What is the return on investment in genebanks?

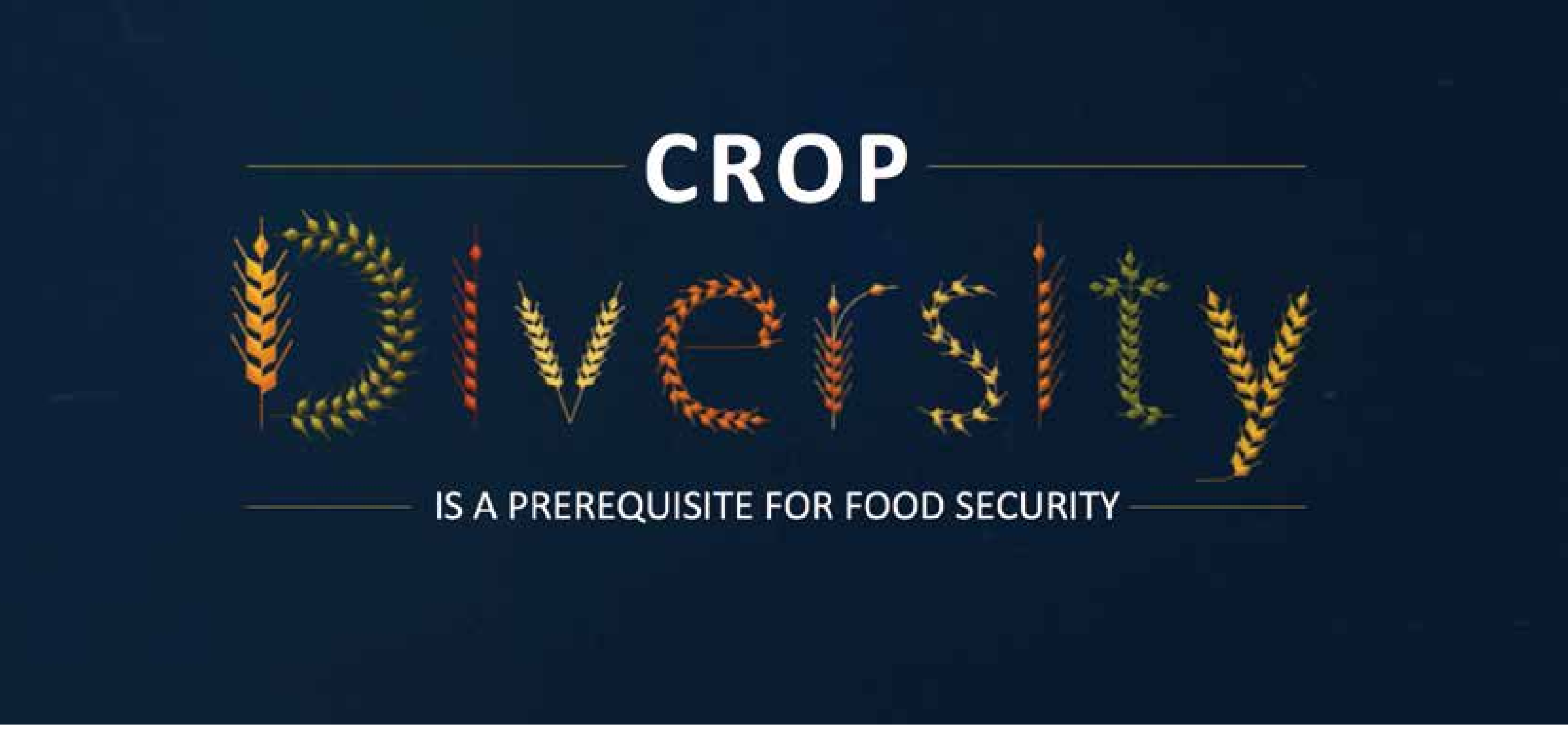
A large body of research has documented the high rates of return from the genetic improvement of crops for yield, yield stability, quality, nutritional composition, resource use efficiency and resistance to pests and diseases. Such crop improvement would not be possible without the crop diversity conserved in genebanks. Genebanks derive their economic value from their unique ability to provide, in a convenient and safe manner, the raw materials to improve food crops in the face of an uncertain future.

▸ PAGE 7

4. How can collections of crop diversity best be supported?

While the benefits of crop improvement have been significant, there has been under-investment in the conservation of crop diversity. Funding has been inconsistent because genebanks have long-term objectives and are remote from eventual development outcomes. The Global Crop Diversity Trust (Crop Trust) was established as an essential element of the funding strategy of the International Treaty on Plant Genetic Resources for Food and Agriculture to stabilize and guarantee funding for the most important genebanks in the world. Its endowment provides a technically and financially credible long-term solution to a long-term problem with global implications.

▸ PAGE 19



1. Why is crop diversity important?

Crop diversity is the foundation of agriculture, enabling it to evolve and adapt to meet the never-ending challenge of sustainably producing sufficient and nutritious food for an increasing population. For millennia, food plants have been domesticated, selected, exchanged, and improved by farmers in traditional ways, within traditional production systems (Plucknett et al., 2014). This process has been hugely accelerated and focused by scientific crop improvement, leading to such historic achievements as the Green Revolution and the steady rise in yields since then. Half of the increase in food production globally can be attributed to genetic improvement. The UN Food and Agriculture Organization (FAO, 2003) details a long list of other benefits from the development and release of improved varieties, which include a reduced need for environmentally harmful inputs such as pesticides; smaller fluctuations in yield; higher nutritional value of food crops; and increased resource-use efficiency on farms (of land, labor, etc.) that reduces the need to clear forests and cultivate on marginal areas.

Despite these undoubted achievements, much remains to be done. There are two billion people who are still malnourished, and of these about 749 million do not get enough calories (IFPRI, 2015). Meanwhile, yield gains are slowing down for some major food crops. Climate change has introduced additional, urgent challenges to farmers (Box 1). Today, modern tools and methods allow researchers to be ever more accurate and efficient in managing and manipulating genetic diversity. However, for breeders to continue delivering benefits, they require continued access to the raw materials of old.

Recognition of the significance of crop diversity to our future is perhaps most clearly epitomized by the agreement of a global treaty addressing the issue, the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), which came into force in 2004. This provides a legal structure for how crop diversity is conserved and made available for food and nutritional security. More recently, the UN Sustainable Development Goals have challenged the global community to eradicate hunger, and highlight the protection and use of crop diversity as an important means to that end in Targets 2.5 and 2.a:

- 2.5 By 2020, maintain the genetic diversity of seeds, cultivated plants and farmed and domesticated animals and their related wild species, including through soundly managed and diversified seed and plant banks at the national, regional and international levels, and promote access to and fair and equitable sharing of benefits arising from the utilization of genetic resources and associated traditional knowledge, as internationally agreed
- 2.a Increase investment, including through enhanced international cooperation, in rural infrastructure, agricultural research and extension services, technology development and plant and livestock gene banks in order to enhance agricultural productive capacity in developing countries, in particular least developed countries and landlocked developing countries, in accordance with their respective programmes of action.

BOX 1

Climate change and the future of crop diversity

Evidence of rising temperatures, changing seasonal patterns and increasing frequency of extreme weather events is growing. The consensus is that climate change will affect agricultural productivity worldwide. The adaptation of the agricultural sector will be crucial to ensure food security for a global population of nine billion people in 2050. Although climate change is one of the drivers of loss of biodiversity in general, crop diversity in particular is expected to play a significant role both in mitigating the adverse effects of, and adapting to, climate change. A report by FAO (2015) places crop diversity at the forefront of adaptation solutions. A key to achieving adaptation, according to Asfaw and Lipper (2012), is broadening the genetic base of crops. Simulation studies have demonstrated simple and feasible changes in farm practices that can have significant impacts on crop productivity, such as changing varieties and planting times to avoid drought and heat stress during dry periods. The continued availability and accessibility of both traditional and improved varieties is key to future improvements in crop productivity. For example, the “scuba” rice varieties released in India, Bangladesh, the Philippines, Indonesia, Myanmar, Lao PDR and Nepal, which are able to grow in flood-prone areas and withstand submergence under water for up to two weeks, were produced by the International Rice Research Institute (IRRI) through the introduction of a gene from an Indian landrace (Almendral, 2014; CGIAR Consortium, 2012; IRRI, 2015). Such conditions are expected to become much more common under even conservative climate change scenarios.

2. Why do we need genebanks to conserve crop diversity?

Crop diversity has its impacts in farmers' fields – in situ – and in the markets and supermarkets where consumers increasingly demand choice. A sweeping study of farm data in the U.S. confirms a narrowing of the number of crops grown in most parts of the country in the past three decades (Aguilar et al., 2015), as farmers specialize and intensify agricultural production. Similar processes are at work in other parts of the world, and are often characterized by a decrease not just in the number of crops grown, but also in the diversity within the range of varieties in the field. While change is inevitable in farming systems, as farmers experiment with and adopt new crops and varieties, this narrowing of crop diversity at both the species and genetic level has consequences for the productivity, stability and resilience of the global agri-food system (Khoury et al., 2014a).

Recognizing this, researchers have been assembling and managing *ex situ* collections of crop diversity in a systematic manner for over a century, securing hundreds of thousands of samples of traditional crop varieties and related wild species from a myriad of remote, dispersed locations into genebanks. Such genebank collections provide a means to make unique diversity available cheaply and effectively, for the long-term, so that it may be used by breeders in the future, returned to farmers and offered to consumers.

Without access to the diversity already stored in genebanks, the researcher trying to understand the diversity of a crop and the plant breeder embarking on an improvement program would have little alternative but to create their own collections from scratch. This would involve locating the diversity in farmers' fields or in the wild (assuming it is still there); negotiating with multiple countries, institutes and farmers for access; carrying out arduous fieldwork over several years; cleaning and health testing collected samples; and, if the process is not to be repeated, carefully documenting and conserving the resulting material so that it may be used again. For a single breeder, this process would be expensive and time-consuming, but perhaps manageable; for hundreds of independent breeders and researchers around the world, the cumulative cost would be prohibitive and the effort laughably inefficient. A study carried out by the National Bureau of Plant Genetic Resources in India determined that 250 rice samples can be collected during an exploration trip of about 15 to 20 days (Saxena et al., 2002). Theoretically, it would take at least 200 successful trips and over 10 years to gather 50,000 samples, and several more years to clean and multiply them for use. We know from a 2010 costing study (Hawtin et al., 2011) that to fully incorporate 50,000 samples of cultivated rice (wild rice would be considerably more expensive) into a genebank collection would cost USD 6 million, or USD 120 per accession, not including the costs of building the facility or of ongoing conservation thereafter. But, major collections of rice already exist, underpinning global rice production. The International Rice Research Institute (IRRI) conserves more than 100,000 different samples of rice in a cost-efficient manner, obviating the need and expense of having each rice breeder create their own collection of genetic resources.

Today, few countries lack a national genebank, and the value placed by governments on crop diversity is reflected in the dramatic increase in the number of collections and of the accessions they hold in the past 30 years. FAO documents that 7.4 million accessions (about 2 million of which are estimated to be unique) are now conserved *ex situ* in over 1,750 facilities worldwide (FAO, 2010). The work of such genebanks is vital to national efforts to conserve and use crop diversity, and makes invaluable contributions to regional and global germplasm exchange.

However, there are distinct advantages to the crop improvement and research community as a whole in also establishing large, mega-diverse, international *ex situ* collections. Housed in advanced facilities, under the care of specialist staff who are able to refine management protocols for particular crops and expeditiously distribute material worldwide to all types of users in a safe manner, such collections are a unique component of the global system for the conservation of crop diversity. The genebanks of the CGIAR centers, (including other international, regional, and national collections) have helped create a rational system, recognized by the International Treaty, in conserving and making available a significant proportion of the world's unique accessions of crop diversity.

The advantages of such centralization are especially obvious when considering the international distribution of crop diversity. For example, while wheat seed is one of the easiest to store, ensuring that the seed is free of karnal bunt (a dangerous fungal disease) demands professional disease indexing and strict adherence to health control measures at every step of the conservation process. Spreading potentially devastating diseases is a major risk associated with the exchange of crop diversity, especially in countries where phytosanitary controls may be inadequate.

3. What is the return on investment in genebanks?

While the value of crop diversity is not disputed, it has multiple components and can be complex to quantify. We focus here on two broad sources of economic value of crop diversity: use and option value. "Use value" refers to the ability of crop diversity to provide yield (including yield stability) and non-yield (e.g. nutritional, environmental) benefits. "Option value" is associated with retaining potentially valuable but unknown genes and traits within a crop diversity collection, which may be discovered and provide use value in the future. This category of value can be equated with the insurance provided by crop diversity against future unpredictable challenges, such as new pests and diseases and evolving market conditions.

The value of crop improvement

The monetary value of the current and past use of diversity to improve yield, nutrition and resistance to pests and diseases has been documented a number of times in the literature because it is the least complicated to calculate. Raitzer and Kelley (2008) provide a meta-analysis of the relative benefits and costs of CGIAR research investment, and find aggregate benefit-cost ratios ranging from 1.94 to 17.26. Table 1 presents estimated net benefits from various studies and robustly suggests that the CGIAR research programs have been a productive investment. Renkow and Byerlee (2010) confirm large returns from investment in CGIAR research programs, particularly on crop genetic improvement, which have had the most profound documented positive impacts globally.

Further, there have been a number of attempts to quantify the specific contribution to crop improvement of a particular subset of crop diversity: crop wild relatives. Table 2 gives examples of the economic value of genetic contributions from wild relatives to the improvement of a number of different crops. Table 3 provides examples of the range of valuable traits transferred from wild species to improved varieties of rice.

Table 1. "Plausible" aggregate benefit estimates by crop and geographical region

Commodities	Region	Reference	Total benefits (1990 USD million)
Barley	Global	Aw-Hassan et al., 2003	330
Beans	Global	Johnson, Pachico, & Wortmann, 2003	590
Cassava	Global	Johnson, Manyong, Dixon, & Pachico, 2003	230
Maize	Global	Morris, 2002	440
Wheat - spring bread	Global	Byerlee & Traxler, 1995	9,750
Wheat - spring bread	Global	P. Heisey, Lantican, & Dubin, 2002	880
Rice (IRRI)	Asia	Hossain et al., 2003	4,310
Rice (CIAT)	Latin America	Sanint & Wood, 1998	8,280
Rice (WARDA)	West Africa	Dalton & Guei, 2003	150

Source: Raitzer and Kelley (2008)

Table 2. Estimates of the economic value of genetic contributions of crop wild relatives

Crop	Region	Parameters	Reference	Annual value (2012 USD)
Wheat	Global	Annual benefits from disease resistance introgressed from wild wheat species	Witt, 1985	107 million
Tomato	Global	Annual contribution of genes from wild tomato species *Lycopersicon chmielewski*	Iltis, 1998	16 million
Coffee	Global	Annual economic value of wild coffee genetic resources	Hein & Gatzweiler, 2006	1.66 billion
Sunflower	Global	Annual contributions of the wild sunflower gene pool	Hunter & Heywood, 2011	273-392 million
Tomato	Global	Annual contributions of a wild tomato species providing a 2.4% increase in solids content	Hunter & Heywood, 2011	255 million
Multiple	US	Annual contributions of CWR to US economy from domestic and imported sources	Prescott-Allen & Prescott-Allen, 1986	712 million
Multiple	US	Annual contributions of CWR to US economy	Pimentel et al., 1997	28.61 billion
Multiple	Global	Annual contributions of CWR to world economy	Pimentel et al., 1997	164.5 billion
Multiple	Global	Annual value of increase in crop productivity because of CWR genetic contributions	NRC, 1991	1.686 billion
Multiple	Global	Current value of CWR genetic contributions	PwC, 2013	68 billion

Source: Tyack and Dempewolf (2015)

Table 3. Examples of CWR traits transfer to rice *(Oryza sativa)*

CWR	Traits
O. australiensis	Resistance to: bacterial blight, brown planthopper
O. brachyantha	Bacterial blight resistance
O. glaberrima	Nutritional and grain quality improvement, acidity, iron, and aluminium toxicity tolerance, resistance to nematodes
O. glumaepatula	Cytoplasmic male sterility, yield improvement
O. grandiglumis	Improved grain quality
O. longistaminata	Drought resistance, yield improvement, resistance to: grassy stunt virus, bacterial blight, yellow stem borer
O. minuta	Improved agronomic traits, resistance to: bacterial blight, blast, brown planthopper, white-backed planthopper
O. nivara	Cytoplasmic male sterility, resistance to: bacterial blight, grassy stunt virus, leaf-folder, tungro, yellow stem borer
O. officinalis	Resistance to: bacterial blight, brown planthopper, grassy stunt virus, white-backed plant-hopper
O. perennis	Cytoplasmic male sterility
O. ridleyi	High acidic-sulphate content soil tolerance
O. rufipogon	Aluminium toxicity tolerance, cytoplasmic male sterility, drought resistance, yield improvement, acid sulphate soil tolerance, cold tolerance, resistance to: bacterial blight, brown planthopper, grassy stunt virus, leaf-folder, rice stripe necrosis virus, soil-borne diseases, tungro, white-backed planthopper, yellow stem borer
O. sativa f. spontanea	Cytoplasmic male sterility
O. latifolia	Resistance to: bacterial blight, yellow stem borer
Zizania latifolia	Improved grain quality, resistance to: blast, sheath blight

Source: Maxted and Kell (2009)

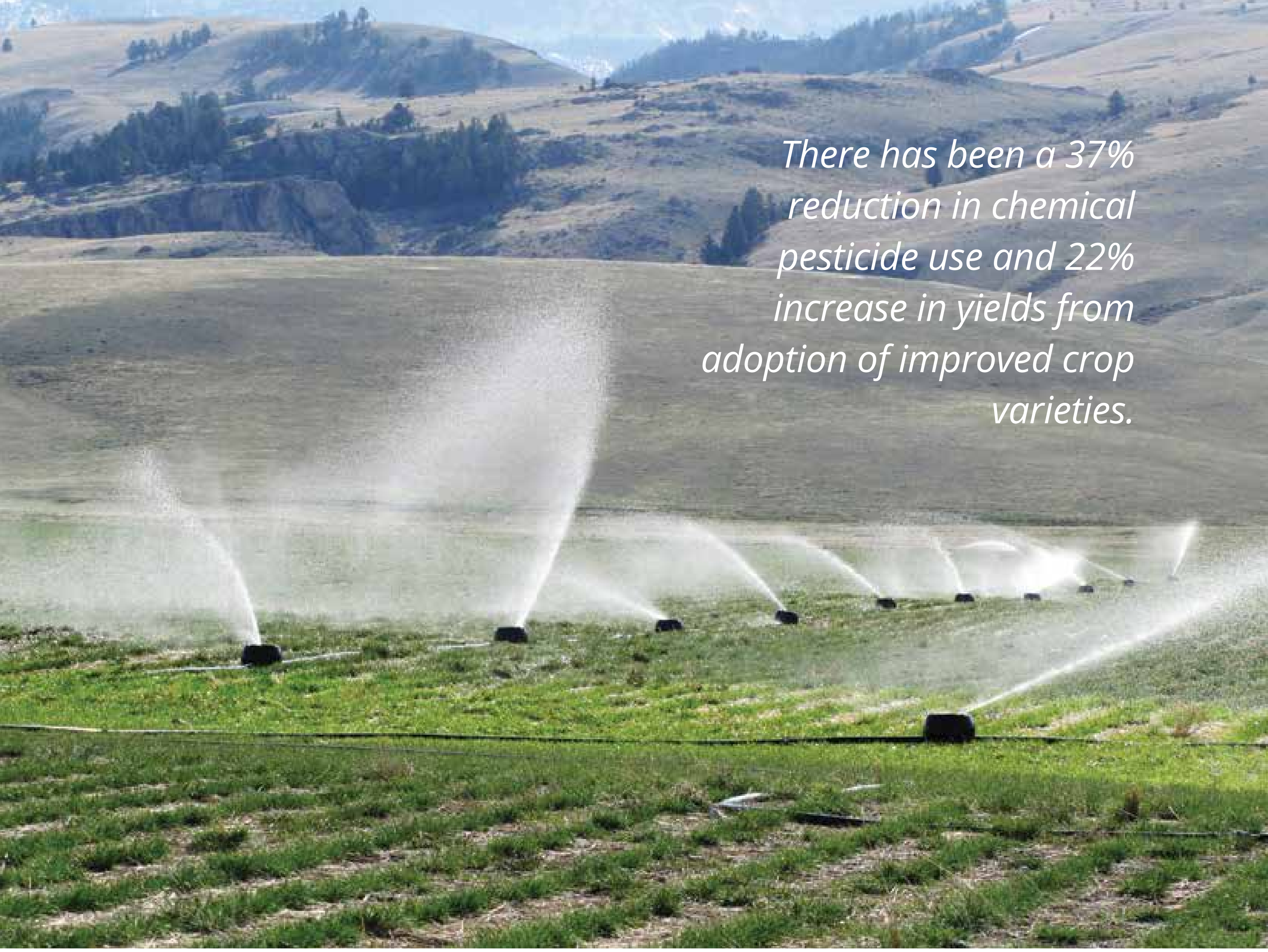
Yield stability

Crop improvement has contributed not only to the level of crop yields, but also to their stability. Yield stability is especially critical for farmers in vulnerable, marginal situations (FAO, 2015; Harvey et al., 2014; Heisey and Rubenstein, 2015). Gollin (2006) finds declining yield variability of maize and wheat in developing countries, as measured by the coefficient of variation around trends over the past 40 years. The result is strongly associated with the spread of improved varieties, even after controlling for increased use of irrigation and other inputs. The annual value of benefits from improved yield stability are estimated at USD 149 million for maize and USD 143 million for wheat, which exceed the total annual spending on breeding research on these crops. Other studies put values on long-standing efforts in breeding for disease and pest resistance. Marasas et al. (2004) estimate that CIMMYT's work on maintaining leaf rust resistance has generated USD 5.4 billion (in 1990 dollars), at a benefit-cost ratio of 27:1. Dubin and Brennan (2009) put the global benefits of resistance to all types of wheat rusts between USD 600 million and USD 2 billion per year (in 2006 dollars). More importantly, agricultural systems globally have largely avoided major crop failures, in part because more frequent turnover of varieties has brought new sources of resistance (Renkow and Byerlee, 2010).

Nutrition enhancement

The majority of poor households rely on staple crops for their nutrient, and not just calorie, needs. This recognition necessitates an increased emphasis on the nutrient content of high-yielding varieties of cereals, pulses, roots, and tubers. HarvestPlus (2014) highlights the condition of "hidden hunger," whereby more than two billion people in the world do not get enough essential vitamins and minerals – such as vitamin A, zinc, and iron – because more nutritious foods are too expensive or simply unavailable. Through biofortification, the CGIAR and its partners have developed new varieties of staple food crops that contain higher amounts of key nutrients. The focus on biofortification of staple crops is advantageous because such crops can reach marginal communities often missed in public nutrition interventions. Moreover, biofortification is cost-effective, as it requires one up-front investment, and is sustainable, because consumers eat staple foods on a regular basis.

A study by Gannon et al. (2014) in Zambia found significant increases in total body stores of vitamin A for groups that received biofortified orange maize. In Mozambique, Low et al. (2007) showed significantly increased intake of vitamin A among young children in households receiving orange-fleshed sweet potatoes combined with extension advice on nutrition. A follow-up study by Jones and de Brauw (2015) found evidence of reduced duration of diarrhea through agricultural interventions that promoted the consumption of orange-fleshed sweet potato. In 2013, the first zinc-rich rice variety "BRRI dhan 62", developed from zinc-rich parental germplasm produced at IRRI and advanced by the Bangladesh Rice Research Institute with support from HarvestPlus, was released in Bangladesh. In Ethiopia, Ghana, India, Mexico and Nicaragua, quality protein maize (QPM), a pioneering technology developed by the International Maize and Wheat Improvement Centre (CIMMYT), is now being widely promoted in response to the problem of putting affordable protein within the reach and means of smallholder farmers. While impact studies have not considered aggregate adoption and long run use, this type of work is likely to accelerate with the scaling up of biofortification research by CGIAR and partners (Renkow and Byerlee, 2010).



Environmental impact

Crop genetic improvement has also resulted in increases in resource-use efficiency in farms, minimizing adverse pressures on the environment. While the early varieties of the Green Revolution were input intensive, there has been a shift towards improved varieties that require less pesticide, fertilizer, water, labor, and indeed, land. Genetic improvement of crops under resource-scarce conditions will be an important avenue to improve food security given increasing population demands and changing climate conditions (Hall and Richards, 2013). Studies by Byerlee et al. (2014) and Villoria et al. (2014) show net saving of land due to agricultural innovations and that technology-driven intensification at a global level minimizes expansion of agriculture into marginal lands. Crop genetic improvement also provides opportunity to identify and select for physiological and morphological traits that increase the efficiency of water use and yield under water-limited conditions (Ito et al., 1999; Richards et al., 2002). For example, IRRI scientists have identified several key regions of the rice genome associated with drought tolerance and improved grain yield under drought conditions (Kumar et al., 2014). Drought-tolerant varieties released in India, the Philippines and Nepal show promising yield advantages of 0.8-1.2 tons per hectare over drought-susceptible ones (IRRI, 2015).

A meta-analysis by Klümper and Qaim (2014) covering 147 publications finds 37% reduction in chemical pesticide use and 22% increase in yields from adoption of improved crop varieties. Together, the yield gains and cost savings have resulted in a 68% increase in farm profits. At IRRI's rice research farms in the Philippines, insecticide use has been reduced by 96% between 1993 and 2008 (Hamilton, 2008). In a similar vein, nitrogen-fertilizer efficiency of maize in the U.S. has increased by 36% in the past 21 years due to public sector research and extension (Tilman et al., 2002).

Option value

Option value is associated with the unknowable future role of crop diversity as a source of valuable genes and traits that have yet to be discovered. A large collection of crop diversity has high option value as insurance against future, unanticipated challenges, such as new pests and diseases, changing environments and evolving consumer needs. Given the progress in genomics as a tool for mining germplasm collections and identifying adaptation traits of crops and wild relatives to abiotic and biotic stress factors, the availability of plant genetic resources to breeders and researchers in the future has become more important than ever.

Smale and Hanson (2010) show that the option value of large collections of crop diversity is greatest when the chances of finding a specific trait are slim but the economic return on discovery is significant, or when the trait of interest is found in a tiny part of the genepool, such as a subset of landraces or crop wild relatives from a particular geographic location. The availability of large amounts of characterization and evaluation data is a particular added value of large international collections, facilitating the identification of traits needed by the user. For example, using CIMMYT's data on germplasm search costs and areas planted to wheat susceptible to Russian wheat aphid, Gollin et al. (2000) simulate various scenarios depending on the time lag from discovery of resistant material to farm-level adoption and estimate net benefits ranging from USD 1.2 to USD 166 million. For soybeans, Zohrabian et al. (2003) calculate a benefit-cost ratio for investing in an additional accession to prevent losses from a single pest in the range of 36 to 61. This confirms that the expected marginal benefit from exploring an additional unimproved genebank accession for breeding resistant varieties more than covers the costs of acquiring and conserving such collections.

Option value is also highest when genebanks maintain material that is held nowhere else. Much of the material in the international collections was collected decades ago, before the modernization of agriculture around the world. We know that some of that diversity can no longer be found in the field. Perhaps most importantly, the value of collections is influenced by the geographic origin of the material. This point is crucial because the genetic diversity within a crop is richest in its center of origin. Multiple crops have centers of origin concentrated in a relatively small number of specific geographical areas worldwide. Coupled with the globalization of agriculture and food systems, this has resulted in all countries being interdependent for crop diversity. Such interdependence is a key reason why large international genebanks have particularly high option value (Box 2).

Dr. Denise Costich, Head of the Maize Germplasm Collection, CIMMYT, Mexico ▼

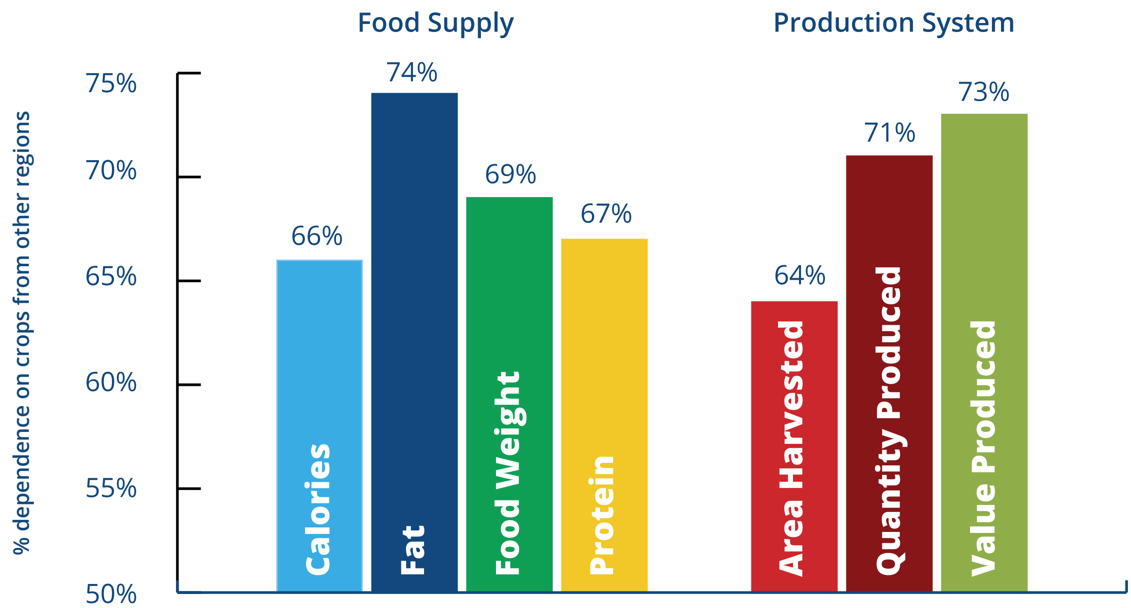
The genebank at the International Rice Research Institute in the Philippines. ▲

Isolating the contribution of genebanks

Few studies have succeeded in attributing a dollar value to the specific contribution made by genebanks to crop improvement. The difficulty of this task leads Smale (2006) to conclude that the economic benefits of using crop diversity in breeding can probably not be calculated with accuracy, but are so great that they certainly far outweigh the costs (Box 3) of long-term conservation and maintenance in genebanks. A study commissioned by CGIAR's Standing Panel on Impact Assessment estimates that a total of about USD 800 million (in 2002 dollars) was spent by CGIAR on germplasm collecting, conservation, characterizing and evaluation (GCCCE) activities in the years from 1970 to 2010 (Robinson and Srinivasan, 2013). What has been made clear in recent studies is that the availability of diverse germplasm for evaluation in multiple environments plays a key role in the success of crop improvement programs. A 2012 study of rice varietal releases, for example, reveals that 100% of IRRI rice varieties and 90% of rice varieties released by national programs had at least one IRRI genebank accession in their pedigrees (CGIAR, 2013). Similarly, Johnson et al. (2003a) show that nearly 60% of the 411 bean varieties released since 1976 contain materials from the genebank of the International Center for Tropical Agriculture (CIAT). A significant share of the impact of CGIAR research and breeding can plausibly be attributed to the international genebanks. The results from detailed case studies – rice in Asia (Box 4), the cassava Kasetsart 50 (KU 50) in Thailand (Box 5), and the potato Cooperation 88 in China (Box 6) – suggest that the benefits accrued from the adoption of a few improved varieties alone would together pay for CGIAR's 40-year investment in GCCCE activities.

Beyond the research programs on crop improvement, CGIAR has also been instrumental in helping to rebuild agricultural systems in at least 47 developing countries affected by conflicts and natural disasters across Asia, Africa and Latin America, through the restoration of crop diversity (Varma and Winslow, 2005). The economic value of such contributions has not been estimated, but this is a clear additional benefit beyond the contribution of crop diversity to improvement programs. Recently, Moeller and Stannard (2013) document the assistance given to countries in Asia after the 2004 tsunami, which drew attention to salinity problems in paddy rice cultivation. The International Potato Center (CIP) has been working for many years with the communities of the Parque de la Papa in Peru to restore lost ancestral potato varieties (CIP, 2012). The cultural importance of such interventions is impossible to value in dollar terms.

Figure 1. Global degree of dependence



Source: Khoury et al. (2014)

BOX 2

Global interdependence in genetic resources

Global interdependence supports the rationale for considering crop diversity as a global public good and offers a strong argument for a more comprehensive participation of countries in the Multilateral System of Access and Benefit-Sharing of the International Treaty (Halewood et al., 2013). Khoury et al. (2014b) provide a dynamic estimation of countries' interdependence in crop diversity from 1961 to 2009. They find that countries strongly depend on crops whose genetic diversity originates from foreign regions (Figure 1), both in their food supply (with an average 66% dependence on foreign crops for calories, 67% for protein, 74% for fat and 69% for food weight across countries worldwide) and production systems (71% for production quantity, 64% for harvested area and 73% for production value). Dependence on foreign crops is highest in countries that are geographically isolated or located at a great distance from the primary regions of diversity of major staple crops, such as Australia and New Zealand, the Indian Ocean islands, the Caribbean, South America, North America, southern Africa and northern Europe. While these countries are generally in temperate climates, some continental tropical regions, such as Central Africa, also have very high levels of dependence. Moreover, the dependence on crops that originated in other regions has increased over time. Countries with the greatest increases in dependence over the past 50 years were located in Africa; West, South, Southeast and East Asia; Central America and Mexico; and Andean and tropical South America.

Galluzzi et al. (2015) analyzed international movements of crop diversity facilitated by the genebanks of seven CGIAR centers from 1985 to 2009. This study also showed strong global interdependence, with dozens of countries both contributing to, and benefiting from, the international genebanks. Similarly, Halewood et al. (2013) show that both developed and developing countries are net recipients of crop diversity, receiving more diversity than they contribute to others through the international genebanks. The top sources of crop diversity are developing countries in important centers of crop origin. However, many top recipients are also developing countries in centers of origin or diversity of crops. Institutional problems often beset local agricultural systems, which have deterred enhanced use and availability of plant genetic resources. Further, in both developed and developing nations, the main recipients of CGIAR germplasm are public institutions, including national agricultural research centers, national genebanks and universities. The analysis also found differences in the types of materials provided by certain countries. Developed countries contribute a proportionally higher share of advanced materials, on which some formal research, pre-breeding or other form of improvement has been conducted, although they provide an overall lower quantity of materials compared to developing countries. In the end, the studies confirm that no country is self-sufficient for the crop diversity needed in agricultural production.

BOX 3

Costs of genebanks

The operational costs of a number of international genebanks have been studied in detail by Hawtin et al. (2011), Koo et al. (2003) and Pardey et al. (2001), among others. The costs of operation may be kept as low as USD 1 per accession if a genebank undertakes only the minimum activity required to keep seeds in a cold room or freezer. However, other important costs must be considered, such as health testing, disease cleaning, information management and characterization. Horna et al. (2010) establish that the reproductive biology of the crop is the major determinant of the scale of the costs, varying widely between outcrossing and self-pollinated species and between seed and vegetatively propagated crops.

The most recent costing study (Hawtin et al., 2011) estimates per-accession annual operating costs (not including capital costs) at USD 3 for wheat, compared to USD 33 for tropical forages, with an overall average of USD 12 for seed accessions. Clonal crops are substantially more expensive to conserve and distribute because of the labor-intensive nature of field and in vitro conservation; the average per accession cost is at least ten times higher than for seed crops. A rational duplication of conserved samples must also be considered for breeding and research institutes in different countries to have ready access to popular material (Hodgkin et al., 1992; van Treuren et al., 2010).

Considering the scale of the cost of conserving 7.4 million accessions worldwide, while improving the coverage of numerous genepools, especially with regard to crop wild relatives which contain considerable amounts of untapped genetic diversity, the rationalization of conservation efforts should be a global priority (Engels and Visser, 2003; FAO, 2010).

"Ex situ collections remain the best and most cost-efficient way to study, store, document, share, pass on, and make available the widest possible crop diversity to the widest possible audience of users, researchers, and breeders." (Lusty et al., 2014)

Ms. Marie Haga, Executive Director of the Crop Trust, and Dr. David Ellis, Genebank Manager of the International Potato Collection, inside the potato genebank in Peru. ▼

BOX 4

IRRI and rice in Asia

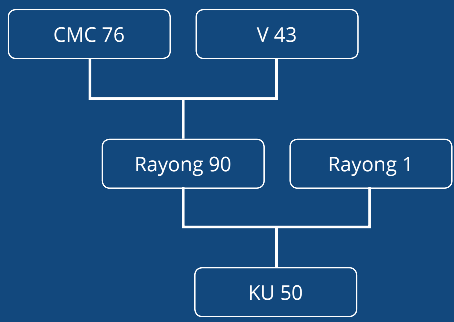
As the staple food for more than 3.5 billion people worldwide, rice is one of the best documented crops. In Asia, where many people eat rice two or three times a day, rice contributes 30% to 70% of calorie intake. Future crop failures due to extreme weather events or pest and disease outbreaks could spell disaster for millions. Evenson and Gollin (1997) trace the genealogies of rice varieties released by national programs and IRRI from 1965 to 1990. They estimate the value of a landrace added to the IRRI genebank to be as high as USD 50 million (in 1990 dollars), and an addition of 1,000 catalogued accessions to be associated with the release of 5.8 additional varieties, which would generate a present value income stream of USD 325 million (in 1990 dollars), assuming a delay of 10 years and a 10% discount rate.

BOX 5

CIAT and cassava in Thailand and Vietnam

Kasetsart 50 (KU 50) is a high-yielding cassava variety developed through collaboration between CIAT (Centro Internacional de Agricultura Tropical), the Department of Agriculture of Thailand, and Kasetsart University in Thailand. KU 50 is currently grown on over one million hectares in Thailand and Vietnam and has also been adopted in Indonesia and Cambodia. It was developed to escape the poor yields associated with the narrow genetic base of established cassava varieties in Thailand. KU 50 has also been successfully used as a parent in crosses that have produced several hybrid cultivars that are currently being adopted in Southeast Asia.

Figure 2. The pedigree of KU 50



KU 50's pedigree represents a selection from hybrid seed produced from a cross between Rayong 1 and Rayong 90, the latter of which was the product of a cross between CMC 76 and V 43 (Figure 2). CMC 76, which represents a key parent in the pedigree of KU 50, came from the CIAT genebank (collected in Venezuela in 1967) and was selected by CIAT cassava breeders during the evaluation of genebank accessions. Extensive programs of evaluation and selection conducted over thirty years at many sites in Colombia and Thailand led to the eventual development of KU 50 and other high-yielding hybrid cassava varieties.

It is estimated that the aggregate economic benefits accruing from adoption of KU 50 exceed USD 44 million in Thailand (released in 1992) and USD 53 million in Vietnam (released in 1995) (at adoption levels of 60% and 75%, respectively). Moreover, KU 50 has had a substantial impact on poverty alleviation in Thailand and Vietnam through the producer surpluses accruing to cassava growers. It is suggested that such an impact would have been very difficult to achieve without the use of cassava germplasm conserved in the CIAT genebank in Colombia. No other institute would have been able to provide breeding programs with such a broad range of cassava genetic diversity or with the particular CMC 76 accession.

Source: Robinson & Srinivasan (2013)

▼ *A farmer collects cassava roots.*

C88 potato variety growing in Yunnan, China. ▲

BOX 6

CIP and potato in China

Cooperation 88 (C88) is a high yielding potato variety developed by the Chinese national agricultural research system and CIP to improve late blight resistance in potato adapted to sub-tropical highlands. It is grown on about 400,000 hectares in five provinces of southwestern China, where it has replaced Mira, a variety of German origin which has become increasingly susceptible to late blight and viruses. Late blight, a fungal pathogen, is considered the most serious threat to potato production, accounting for more than USD 1 billion each year in lost production and costs of control.

Breeders from CIP and Yunnan Normal University jointly evaluated the germplasm for the maternal parent of C88, while the male parent was derived from potato crosses made in the Philippines. The potato seed was evaluated in China, and after five years of trials and selection, clone #88 was identified as a high-yielding and late blight resistant variant which was adapted to longer day growing conditions. The variety was named Cooperation 88 and launched in 1996. A large part of this genebank material was collected in the center of origin of potato in the South American Andes, and thus provided the unique possibility to substantially broaden the genetic basis of potato in China.

It is estimated that the economic benefits accruing from C88 in China at the level of adoption in 2010 were USD 350 million, and will increase to USD 465 million per year if farm-level adoption increases to 600,000 hectares. More than half of the economic benefits are estimated to accrue to the poor (between USD 192 and USD 256 million). Moreover, C88 has stimulated growth in the potato processing industry because of its suitability for both table and chipping purposes. Such benefits would not have been possible without the use of germplasm conserved in the genebank at CIP.

Source: Robinson and Srinivasan (2013)

4. How can collections of crop diversity best be supported?

Developing the international *ex situ* collections of the CGIAR centers, including the skills to manage, study, and make available their contents, has made a major contribution to crop improvement around the world. However, because genebanks have long-term objectives and are remote from development outcomes, this has not always been recognized, and funding levels have been inconsistent and unpredictable. At the same time, Article 15 of the International Treaty commits the CGIAR centers to making material in the international genebanks they manage available for the long term under the Multilateral System (Halewood et al., 2013). The Crop Trust was established in 2004 as an independent international organization with the aim of guaranteeing stable, predictable and perpetual funding for the long-term conservation of crop diversity through the mechanism of an endowment fund. This is recognized as an essential element of the funding strategy of the International Treaty (Box 7). A variety of external audits and reviews confirm that the Crop Trust has the necessary systems and capacities in place for sound technical and financial management (Box 8).

Through a partnership with the CGIAR Consortium Office called the Genebanks CGIAR Research Program (Genebanks CRP), funding from which complements the endowment contribution, the Crop Trust ensures that the genebanks of CGIAR are performing at agreed high standards and have the capacity to sustain essential operations for the long-term future (Crop Trust, 2015a). The commitment to stable, predictable and perpetual funding is necessary because collections will require constant management into the distant future, and disruptions or shortfalls in funding create not just inefficiencies, but also backlogs that can leave crop diversity at risk of permanent loss. This work is "a vital safeguard against hunger" (The Economist, 2015).

Since the Genebanks CRP started in 2012, the international genebanks have distributed more than 300,000 accessions to users in 120 countries; regenerated more than 200,000 accessions; sub-cultured more than 100,000 tissue-culture samples; and acquired more than 30,000 new accessions. Aside from the individual achievements of the centers, the collaboration between the CGIAR genebanks over many years has brought about a number of globally significant outcomes, including:

- The use of the Svalbard Global Seed Vault as a fail-safe seed storage facility, built to stand the test of time and the challenges of natural and man-made disasters. The importance of the Vault was brought into sharp relief in September 2015 by the decision of the International Center for Agricultural Research in the Dry Areas (ICARDA) genebank to retrieve its safety duplicates from the Arctic in order to re-establish its collection in Morocco, given the inaccessibility of its former facility in Aleppo, Syria (Conlon, 2015).
- The development of the global online portal Genesys (www.genesys-pgr.org). This is fast becoming the main window through which users may access accession-level information not just from individual genebanks, but across genebanks, on genepools as a whole.
- The launch of DivSeek (www.divseek.org), an initiative that aims to enable breeders and researchers to leverage modern biotechnologies and bioinformatics to more effectively mobilize plant genetic variation in the service of crop improvement.
- The establishment of a quality management system tailored specifically to genebanks, based on a history of developing and sharing best practices, protocols and guidelines.

The Genebanks CRP provides a centralized mechanism by which the activities of 11 CGIAR centers managing 850,000 accessions in 35 crop and tree collections are financed and monitored through the use of common performance targets, regular online reporting and a rigorous external review processes. In the past, genebanks competed poorly for funding within research programs, and numerous routine genebank activities were chronically under-resourced. Through the Crop Trust, the Genebanks CRP has not only secured adequate funding for the essential operations of the genebanks, but is also allowing the Centers to make strategic investments in optimizing operations. The Crop Trust provides a long-term solution that is technically and financially credible to an urgent problem that, though often overlooked, is eminently soluble.

BOX 7

Supporting the global system of *ex situ* conservation

Under the United Nations Sustainable Development Goals, governments have reaffirmed their commitment to the conservation of plant genetic resources for food and agriculture as an essential component of global food security. The mission of the Crop Trust is to contribute to the *ex situ* conservation of crop diversity by helping to build a rational and cost-effective Global System -- a worldwide community linking the international genebanks, national and regional genebanks, and researchers, breeders and other users, with transparent common quality standards, performance targets and monitoring and reporting systems.

The Crop Trust was also established to fund such a system, focusing on crop collections that are of global significance, accessible under the Multilateral System, and conserved in institutions that are committed to making collections available in the long term, following the Fund Disbursement Strategy. A practical methodology to identify and engage with such collections has been adopted by the Executive Board in March 2015 (Crop Trust, 2015b).

> *'It is essential – and not only desirable – that such a global system for ex situ conservation be rational and cost-effective. A rational system is one in which the key actors have clearly defined roles, and coordinate in order to provide the services that are most needed and that they are best placed to provide. A cost-effective system is one in which efforts are not unnecessarily duplicated, beyond the duplication required for the long-term safety and security of collected material.'*
> *Crop Trust's Strategic Work Plan 2014-2024*

By 2018, the Crop Trust aims to raise an endowment of USD 850 million to provide long-term funding for the conservation of priority collections of crop diversity held in international and national genebanks around the world. Of this, USD 500 million will support the international collections under Article 15 of the ITPGRFA, and USD 250 million will support the conservation of key national collections of 25 of those crops listed in Annex 1 of the ITPGRFA which are most important to production in Least Developed Countries. The remaining USD 100 million will support the long-term operation of the Svalbard Global Seed Vault and fund Secretariat operations for the management of the endowment and long-term partnership agreements with genebanks, including convening and facilitating crop communities. Supporting the Global System would benefit all genebanks -- in terms of improved standards and quality management systems, access to the global portal of accession-level data (Genesys), and advanced bioinformatics tools (DivSeek), whether or not they are funded by the endowment.

BOX 8

Financial transparency and efficiency of the Crop Trust

In 2015, the Crop Trust worked with various auditors who undertook reviews of its projects and activities, including PricewaterhouseCoopers (PwC), KfW and the Norwegian Agency for Development Cooperation (NORAD). Overall, the audits confirmed that the Crop Trust has the necessary systems and capacities in place for the sound financial management of the endowment fund and bilateral projects. Further audits to be conducted by CGIAR Internal Audit and the CGIAR Fund Office Independent Evaluation Arrangement (IEA) are planned for late 2015 and 2016.

The Crop Trust also conducted financial reviews of its largest partner in one of its major projects, the Royal Botanic Gardens, Kew, UK, as well as CGIAR center genebanks, in order to understand and monitor expenditures. In the process, it introduced new measures for greater transparency and accountability. In addition, the Crop Trust welcomed the opportunity to provide donors with detailed operating expenditure analysis, as requested.

The Svalbard Global Seed Vault in Spitsbergen, Norway. ▼

BIBLIOGRAPHY

- Aguilar, J., Gramig, G., Hendrickson, J., Archer, D., Forcella, F., Liebig, M., 2015. Crop species diversity changes in the United States: 1978–2012. PLoS ONE 10. doi:10.1371/journal.pone.0136580
- Almendral, A., 2014. Scientists develop "scuba rice" that can stand up to climate change. Next City, March 14.
- Asfaw, S., Lipper, L., 2012. Economics of plant genetic resource management for adaptation to climate change: A review of selected literature (No. 12-02). ESA Working Paper. Food and Agriculture Organization of the United Nations.
- Aw-Hassan, A., Shideed, K., Ceccarelli, S., Erskine, W., Grando, S., Tutwiler, R., 2003. The impact of international and national investment in barley germplasm improvement in the developing countries, in: Crop Variety Improvement and Its Effect on Productivity: The Impact of International Agricultural Research. CABI Publishing.
- Byerlee, D., Stevenson, J., Villoria, N., 2014. Does intensification slow crop land expansion or encourage deforestation? Glob. Food Secur. 3, 92–98. doi:10.1016/j.gfs.2014.04.001
- Byerlee, D., Traxler, G., 1995. National and international wheat improvement research in the post-Green Revolution period: Evolution and impacts. Am. J. Agric. Econ. 77, 268–278. doi:10.2307/1243537
- CGIAR, 2013. Genebanks: Investing in Biodiversity for Future Generations. CGIAR Consortium, Partnership and Stakeholder Engagement.
- CGIAR Consortium, 2012. Scuba Rice: The Makings of a Runaway Success Story.
- CIP, 2012. New Advances in Repatriation and Conservation of Native Potatoes. International Potato Center.
- Conlon, K., 2015. Syria's civil war prompts first "Doomsday Vault" withdrawal. CNN, September 25.
- Crop Trust, 2015a. Genebank Program: Preproposal. Global Crop Diversity Trust.
- Crop Trust. 2015b. Rationale and approach for the identification of globally significant crop collections in national genebanks and provision of support by the Crop Trust. Global Crop Diversity Trust.
- Dalton, T.J., Guei, R.G., 2003. Ecological diversity and rice varietal improvement in West Africa, in: Crop Variety Improvement and Its Effect on Productivity: The Impact of International Agricultural Research. CABI Publishing.
- Dubin, H.J., Brennan, J.P., 2009. Combating stem and leaf rust of wheat: Historical perspective, impacts, and lessons learned. IFPRI Discussion Paper No. 00910. International Food Policy Research Institute.
- Engels, J.M.M., Visser, L. (Eds.), 2003. A Guide to Effective Management of Germplasm Collections. IPGRI Handbooks for Genebanks. International Plant Genetic Resources Institute, IFPRI, and CABI Publishing.
- Evenson, R., Gollin, D., 1997. Genetic resources, international organizations, and improvement in rice varieties. Econ. Dev. Cult. Change 45, 471–500. doi:10.1086/452288
- FAO, 2015. Coping with Climate Change: The Roles of Genetic Resources for Food and Agriculture. Food and Agriculture Organization of the United Nations.
- FAO, 2010. The Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture. Food and Agriculture Organization of the United Nations.
- FAO, 2003. World Agriculture: Towards 2015/2030. Food and Agriculture Organization of the United Nations.
- Galluzzi, G., Halewood, M., Noriega, I.L., Vernooy, R., 2015. Twenty five years of international exchanges of plant genetic resources facilitated by the CGIAR genebanks: A case study on international interdependence. Research Study No. 9. The International Treaty on Plant Genetic Resources for Food and Agriculture.
- Gannon, B., Kaliwile, C., Arscott, S.A., Schmaelzle, S., Chileshe, J., Kalungwana, N., Mosonda, M., Pixley, K., Masi, C., Tanumihardjo, S.A., 2014. Biofortified orange maize is as efficacious as a vitamin A supplement in Zambian children even in the presence of high liver reserves of vitamin A: A community-based, randomized placebo-controlled trial. Am. J. Clin. Nutr. doi:10.3945/ajcn.114.087379
- Gollin, D., 2006. Impacts of International Research on Intertemporal Yield Stability in Wheat and Maize: An Economic Assessment. International Maize and Wheat Improvement Center.
- Gollin, D., Smale, M., Skovmand, B., 2000. Searching an *ex situ* collection of wheat genetic resources. Am. J. Agric. Econ. 82, 812–827. doi:10.1111/0002-9092.00083
- Halewood, M., Noriega, I.L., Louafi, S. (Eds.), 2013. Crop Genetic Resources as a Global Commons: Challenges in International Law and Governance. Bioversity International.
- Hall, A.J., Richards, R.A., 2013. Prognosis for genetic improvement of yield potential and water-limited yield of major grain crops. Crop Yield Gap Anal. – Ration. Methods Appl. 143, 18–33. doi:10.1016/j.fcr.2012.05.014
- Hamilton, H.S., 2008. The pesticide paradox. Rice Today 7(1), 32–33.
- HarvestPlus, 2014. Going Global: 2014 Annual Report.
- Harvey, C., Rakotobe, Z.L., Ra, N., Dave, R., Razafimahatratra, H., Rabarijohn, R.H., Rajaofara, H., MacKinnon, J., 2014. Extreme vulnerability of smallholder farmers to agricultural risks and climate change in Madagascar. Philos. Trans. R. Soc. Lond. B Biol. Sci. 369. doi:10.1098/rstb.2013.0089
- Hawtin, G., Shands, H., MacNeil, G., 2011. The cost to the CGIAR centers of maintaining and distributing germplasm: Proposal to the Fund Council for financial support to the CGIAR Center genebanks. Consortium Board of Trustees.
- Hein, L., Gatzweiler, F., 2006. The economic value of coffee (Coffea arabica) genetic resources. Ecol. Econ. 60, 176–185. doi:10.1016/j.ecolecon.2005.11.022
- Heisey, P., Lantican, M., Dubin, H.J., 2002. Impacts of International Wheat Breeding Research in Developing Countries 1966-97. International Maize and Wheat Improvement Center.
- Heisey, P.W., Rubenstein, K.D., 2015. Using crop genetic resources to help agriculture adapt to climate change: Economics and policy. Economic Information Bulletin No. 139. Economic Research Service/USDA.
- Hodgkin, T., Adham, Y.J., Powell, K.S., 1992. A preliminary survey of wild Triticum and Aegilops species in the world's genebanks. Hereditas 116, 155–162. doi:10.1111/j.1601-5223.1992.tb00221.x
- Horna, D., Debouck, D., Dumet, D., Smale, M., Hanson, J., Payne, T., Sackville-Hamilton, R., Sanchez, I., Upadhyaya, H.D., van den Houwe, I., 2010. Cost effectiveness of germplasm collections in the CG system, in: Evaluating Cost-Effectiveness of Collection Management: Ex-Situ Conservation of Plant Genetic Resources in the CG System. Consultative Group on International Agricultural Research.
- Hossain, M., Gollin, D., Cabanilla, V., Cabrera, E., Johnson, N., Khush, G.S., Mclaren G., 2003. International research and genetic improvement in rice: Evidence from Asia and Latin America, in: Crop Variety Improvement and Its Effect on Productivity: The Impact of International Agricultural Research. CABI Publishing.
- Hunter, D., Heywood, V., 2011. Crop Wild Relatives: A Manual of In Situ Conservation. Bioversity International.
- IFPRI, 2015. Global Nutrition Report 2015: Actions and Accountability to Advance Nutrition and Sustainable Development. International Food Policy Research Institute.
- Iltis, H., 1988. Serendipity in the exploration of biodiversity: What good are weedy tomatoes?, in: Biodiversity. National Academies Press.
- IRRI, 2015. Climate-Change Ready Rice. International Rice Research Institute.

- Ito, O., O'Toole, J., Hardy, B., 1999. Genetic Improvement of Rice for Water-limited Environments. International Rice Research Institute.
- Johnson, Manyong, V.M., Dixon, A.G.O., Pachico, D., 2003a. The impact of IARC genetic improvement programmes on cassava, in: Crop Variety Improvement and Its Effect on Productivity: The Impact of International Agricultural Research. CABI Publishing.
- Johnson, N.L., Pachico, D., Voysest, O., 2003b. The distribution of benefits from public international germplasm banks: The case of beans in Latin America. Returns Invest. Plant Genet. Resour. Conserv. Crop Improv. Res. 29, 277–286. doi:10.1016/S0169-5150(03)00055-0
- Johnson, N.L., Pachico, D., Wortmann, C.S., 2003c. The impact of CIAT's genetic improvement research on beans, in: Crop Variety Improvement and Its Effect on Productivity: The Impact of International Agricultural Research. CABI Publishing.
- Jones, K.M., de Brauw, A., 2015. Using agriculture to improve child health: Promoting orange sweet potatoes reduces diarrhea. World Dev. 74, 15–24. doi:10.1016/j.worlddev.2015.04.007
- Khoury, C.K., Bjorkman, A.D., Dempewolf, H., Ramirez-Villegas, J., Guarino, L., Jarvis, A., Rieseberg, L.H., Struik, P.C., 2014a. Increasing homogeneity in global food supplies and the implications for food security. Proc. Natl. Acad. Sci. 111, 4001–4006. doi:10.1073/pnas.1313490111
- Khoury, C., Achicanoy, H., Bjorkman, A., Navarro-Racines, C., Guarino, L., Flores-Palacios, X., Engels, J., Wiersema, J., Dempewolf, H., Ramírez-Villegas, J., Castañeda-Álvarez, N., Fowler, C., Jarvis, A., Rieseberg, L., Struik, P., 2014b. Estimation of countries' interdependence in plant genetic resources provisioning national food supplies and production systems. Research Study N. 8. International Treaty on Plant Genetic Resources for Food and Agriculture.
- Klümper, W., Qaim, M., 2014. A meta-analysis of the impacts of genetically modified crops. PLoS ONE 9.
- Koo, B., Pardey, P.G., Wright, B.D., 2003. The economic costs of conserving genetic resources at the CGIAR centers. Agric. Econ. 29, 287–297. doi:10.1111/j.1574-0862.2003.tb00165.x
- Kumar, A., Dixit, S., Ram, T., Yadaw, R.B., Mishra, K.K., Mandal, N.P., 2014. Breeding high-yielding drought-tolerant rice: genetic variations and conventional and molecular approaches. J. Exp. Bot. doi:10.1093/jxb/eru363
- Low, J., Arimond, M., Osman, N., Cunguara, B., Zano, F., Tschirley, D., 2007. A food-based approach introducing orange-fleshed sweet potatoes increased vitamin A intake and serum retinol concentrations in young children in Mozambique. J. Nutr. 137.
- Lusty, C., Guarino, L., Toll, J., Lainoff, B., 2014. Genebanks: Past, present, and optimistic future, in: Encyclopedia of Agriculture and Food Systems. Elsevier.
- Marasas, C.N., Smale, M., Singh, R.P., 2004. The economic impact in developing countries of leaf rust resistance breeding in CIMMYT-related spring bread wheat. Economics Program Paper No. 04-01. International Maize and Wheat Improvement Center.
- Maxted, N., Kell, S., 2009. Establishment of a global network for the in situ conservation of crop wild relatives: Status and needs. Background Study Paper No. 39. Commission on Genetic Resources for Food And Agriculture, Food and Agriculture Organization of the United Nations.
- Moeller, N.I., Stannard, C., 2013. Identifying Benefit Flows: Studies on the Potential Monetary and Non-Monetary Benefits Arising from the International Treaty on Plant Genetic Resources for Food and Agriculture. Food and Agriculture Organization of the United Nations.
- Morris, M., 2002. Impacts of International Maize Breeding Research in Developing Countries 1966-98. International Maize and Wheat Improvement Center.
- NRC, 1991. Managing Global Genetic Resources: The US National Plant Germplasm System. National Research Council, National Academy Press.
- Pardey, P., Koo, B., Wright, B., van Dusen, M.E., Skovmand, B., Taba, S., 2001. Costing the conservation of genetic resources: CIMMYT's *ex situ* maize and wheat collection. Crop Sci. 41, 1286–1299.
- Pimentel, D., Wilson, C., McCullum, C., Huang, R., Dwen, P., Flack, J., Tran, Q., Saltman, T., Cliff, B., 1997. Economic and environmental benefits of biodiversity. BioScience 47, 747–757. doi:10.2307/1313097
- Plucknett, D., Smith, N., Williams, J.T., Anishetty, N.M., 2014. Gene Banks and the World's Food. Princeton University Press.
- Prescott-Allen, C., Prescott-Allen, R., 1986. The First Resource: Wild Species in the North American Economy. Yale University Press.
- PwC, 2013. Kew's Millenium Seed Bank: Valuation Analysis of Crop Wild Relatives. PricewaterhouseCoopers LLP.
- Raitzer, D.A., Kelley, T.G., 2008. Benefit–cost meta-analysis of investment in the International Agricultural Research Centers of the CGIAR. Agric. Syst. 96, 108–123. doi:10.1016/j.agsy.2007.06.004
- Renkow, M., Byerlee, D., 2010. The impacts of CGIAR research: A review of recent evidence. Food Policy 35, 391–402. doi:10.1016/j.foodpol.2010.04.006
- Richards, R.A., Rebetzke, G.J., Condon, A.G., van Herwaarden, A.F., 2002. Breeding opportunities for increasing the efficiency of water use and crop yield in temperate cereals. Crop Sci. 42, 111–121. doi:10.2135/cropsci2002.1110
- Robinson, J., Srinivasan, C., 2013. Case-Studies on the Impact of Germplasm Collection, Conservation, Characterization and Evaluation (GCCCE) in the CGIAR. CGIAR Standing Panel on Impact Assessment.
- Sanint, L.R., Wood, S., 1998. Impact of rice research in Latin America and the Caribbean during the past three decades, in: Impact of Rice Research. International Rice Research Institute.
- Saxena, S., Chandak, V., Ghosh, S., Sinha, R., Jain, N., Gupta, A., 2002. Cost of conservation of agrobiodiversity. Report No. 2002-05-03. Indian Institute of Management.
- Smale, M. (Ed.), 2006. Valuing Crop Biodiversity: On-Farm Genetic Resources and Economic Change. CABI Publishing.
- Smale, M., Hanson, J., 2010. Assessing the Impact of CGIAR Investments in Germplasm Collection, Conservation, Characterization and Evaluation: The Scope of the Literature. CGIAR Standing Panel on Impact Assessment.
- The Economist, 2015. Growing pains: Storing wild seeds will save harvests—and lives. The Economist, 12 September
- Tilman, D., Cassman, K.G., Matson, P.A., Naylor, R., Polasky, S., 2002. Agricultural sustainability and intensive production practices. Nature 418, 671–677. doi:10.1038/nature01014
- Tyack, N., Dempewolf, H., 2015. The economics of crop wild relatives under climate change, in: Crop Wild Relatives and Climate Change. Wiley-Blackwell.
- van Treuren, R., Kemp, H., Ernsting, G., Jongejans, B., Houtman, H., Visser, L., 2010. Microsatellite genotyping of apple (Malus × domestica Borkh.) genetic resources in the Netherlands: Application in collection management and variety identification. Genet. Resour. Crop Evol. 57, 853–865. doi:10.1007/s10722-009-9525-0
- Varma, S., Winslow, M., 2005. Healing Wounds: How the International Centers of the CGIAR Help Rebuild Agriculture in Countries Affected by Conflicts and Natural Disasters. Consultative Group on International Agricultural Research.
- Villoria, N.B., Byerlee, D., Stevenson, J., 2014. The effects of agricultural technological progress on deforestation: What do we really know? Appl. Econ. Perspect. Policy. doi:10.1093/aepp/ppu005
- Witt, S., 1985. Biotechnology and genetic diversity. Briefbook No. 2. California Agricultural Lands Project.
- Zohrabian, A., Traxler, G., Caudill, S., Smale, M., 2003. Valuing plant genetic resources: An economic model of utilization of the U.S. National Crop Germplasm Collection. Am. J. Agric. Econ. 85, 429–436.

- Photos: CIAT (p. 10 and 17), Lori Iverson / USFWS (p. 11), Luis Salazar, Crop Trust (p.12 and 15), Getty Images (p. 2, 5 and 16), CIP (p. 18) and Crop Trust (p. 8, 13, and 21).

CROP TRUST
PLEDGING CONFERENCE

CITATION

Crop Trust. 2015. Securing crop diversity for sustainable development. Global Crop Diversity Trust. Bonn, Germany.

The Crop Trust acknowledges the following people in the preparation of this report:

Content:

Nelissa Jamora
Luigi Guarino
Charlotte Lusty

with

Marie Haga
Michael Koch
Renata Christen
Janet Muir

Lay-out and editing:

Brian Lainoff
Luis Salazar
Cierra Martin
Paul Cox
Epic Agency

+49 228 85427 122
+49 228 85427 144

www.croptrust.org
info@croptrust.org

Platz der Vereinten Nationen 7
53113 Bonn, Germany